An Roinn Sláinte
Department of Health

Irish National Early Warning System

National Clinical Guideline No. 1 (Version 2)

Annex 1: Clinical & cost effectiveness of NEWS, A systematic review update

National Patient Safety Office
Oifig Náisiúnta um Shábháilteacht Othar

NATIONAL CLINICAL EFFECTIVENESS COMMITTEE

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CICER Collaboration in Ireland for Clinical Effectiveness Reviews

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Clinical and Cost-effectiveness of the National Early Warning System (NEWS): a Systematic Review Update

The Irish National Early Warning System (NEWS) National Clinical Guideline No. 1

August 2019

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About HRB-CICER

In 2016, the Department of Health requested the Health Research Board (HRB) to fund a dedicated multidisciplinary research group to support the activities of the Ministerial appointed National Clinical Effectiveness Committee (NCEC). Called HRB-CICER (Collaboration in Ireland for Clinical Effectiveness Reviews), a five-year contract (2017 to 2022) was awarded following a competitive process to the Health Information and Quality Authority (HIQA). The HRB-CICER team comprises a dedicated multidisciplinary research team (including expertise in health economics, qualitative and quantitative research methods and epidemiology) supported by staff from the Health Technology Assessment (HTA) team in HIQA and the HRB Centre for Primary Care Research at the Royal College of Surgeons in Ireland (RCSI), as well as national and international clinical and methodological experts.

Guideline development groups submit clinical guidelines for appraisal and endorsement by the NCEC as National Clinical Guidelines. HRB-CICER provides independent scientific support to guideline development groups tailored according to their specific needs. The main role of the HRB-CICER team is to undertake systematic reviews of the clinical effectiveness and cost-effectiveness of interventions included in the guidelines and to estimate the budget impact of implementing the guidelines. Additional support can be provided by HRB-CICER to guideline development groups including; providing tailored training sessions and working closely with the guideline development groups to develop clinical questions and search strategies; performing systematic reviews of international clinical guidelines; supporting the assessment of their suitability for adaption to Ireland and assisting in the development of evidence-based recommendations.

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List of abbreviations

ABCDE	Airway, Breathing, Circulation, Disability, and Exposure
AGREE	Appraisal of Guidelines for Research and Evaluation
ALERT	Acute Life Threatening Early Recognition and Treatment
AMSTAR	A Measurement Tool to Assess Systematic Reviews
ASSIA	Applied Social Sciences Index and Abstracts
AUC	Area under the receiver operating curve
AVPU	Alert, Voice, Pain, Unconscious
BP	Blood Pressure
CADTH	Canadian Agency for Drugs and Technologies in Health
CASP	Critical Appraisal Skills Programme
CBA	Controlled Before and After Study
CCCT	Communication, Collaboration and Critical Thinking Quality Patient Outcomes Survey Tool
CERQual	Confidence in the Evidence from Reviews of Qualitative research
CHEC-list	The Consensus Health Economic Criteria - list
CI	Confidence Interval
CINAHL	Cumulative Index to Nursing and Allied Health Literature
COPD	Chronic Obstructive Pulmonary Disorder
CREWS	Chronic Respiratory Early Warning System
DNR	Do Not Resuscitate
ED	Emergency Department
eMEWS	Electronic Modified Early Warning System
EMBASE	Exerptamedica Database
EMEWS	Emergency Medicine Early Warning System
ENTREQ	Enhancing transparency in reporting the synthesis of qualitative research
EWS	Early Warning System
FIRST^{2}ACT	Feedback Incorporating Review and Simulation Techniques to Act on Clinical Trends
GDG	Guideline Development Group
GIN	Guidelines International Network
HCP	Health Care Professional
HDI	Human Development Index
HDU	High Dependency Unit
HIQA	Health Information and Quality Authority
HMIC	Health Management Information Center
HR	Heart Rate
HRB	Health Research Board
HRB-CICER	Health Research Board Collaboration in Ireland for Clinical Effectiveness Reviews
HSE	Health Service Executive
HTA	Health Technology Assessment
HYE	Health Years Gained

IMEWS	Irish Maternity Early Warning System
ISBAR	Identify, Situation, Background, Assessment, Request
ICER	Incremental Cost Effectiveness Ratio
ICU	Intensive Care Unit
ISPOR	International Society for Pharmacoeconomics and Outcomes Research
ITS	Interrupted Time Series design
LOS	Length of Stay
LYG	Life Years Gained
MCQ	Multiple Choice Questionnaire
MEDLINE	Medical Literature Analysis and Retrieval System Online
MET	Medical Emergency Team
MEWS	Modified Early Warning System
NCEC	National Clinical Effectiveness Committee
NCG	National Clinical Guideline
NEWS	National Early Warning Score
NICE	National Institute for Health and Clinical Excellence
nRCT	Non Randomised Controlled Trial
PDSA	Plan, Do, Study, Act Framework
PEWS	Paediatric Early Warning System
PICOS	Population Intervention Comparison Outcome Study Design
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	Prospective Register for Systematic Reviews Database
QALY	Quality Adjusted Life Years
QIP	Quality Improvement Project
QUADAS	Quality Assessment of Diagnostic Accuracy
RAPIDS	Rescuing a Patient in Deteriorating Situations
RCSI	Royal College of Surgeons in Ireland
RCT	Randomised Controlled Trials
RR	Respiratory Rate
RRR	Relative Risk Reduction
RRT	Rapid Response Team
SAE	Serious Adverse Event
SBAR	Situation, Background, Assessment and Recommendation
SD	Standard Deviation
SOF	Summary of Findings
SpO_2	Oxygen saturation
UCC	University College Cork
VIEWS	VitalPAC Early Warning Score

Executive Summary

Background and objectives

The National Early Warning System (NEWS) is a bedside tool used for monitoring the condition of adult (non-pregnant) patients in acute health care settings, to facilitate the timely identification of physiological deterioration and prevent adverse patient outcomes including death. The NEWS facilitates the timely assessment of, and response to the deterioration of acutely ill patients by classifying the severity of a patient's illness, providing prompts and structured communications tools to escalate care following a definitive escalation plan and appropriate response model. Detection is achieved through the use of a colour-coded observation chart and the routine measurement of patient's vital signs (blood pressure, pulse, respirations etc.). With the NEWS, each vital sign is allocated a numerical score from 0 to 3, plotted on a colour coded observation chart (a score of '0' represents the least risk and a score of '3' represents the highest risk), the scores are then combined to give the patient's NEWS score. If a patient's aggregate score exceeds the pre-defined NEWS thresholds, an escalation of care should be initiated.

The NEWS was the first National Clinical Effectiveness Committee (NCEC) National Clinical Guideline (NCG No. 1) introduced in 2013.[1] It was subsequently updated to include additional practical guidance specific to sepsis management in 2014. An updated systematic search of the clinical and cost-effectiveness literature specific to early warning systems (EWSs) in adult patients was completed in 2015 by a team from University College Cork (UCC).[2]

The aim of this current systematic review was to systematically search the literature to inform the update of NCG No 1 based on six specific review questions. Four questions were included in the previous review. There were two new questions, one focussed on modified EWSs for use in specific sub-populations, and a qualitative question exploring why health care professionals fail to escalate as per the NEWS protocol.

Methods

A systematic review of the published and grey literature was conducted in February 2018 using a comprehensive list of search terms based on the specific population, intervention, comparison and outcome (PICO) approach for each of the review's six questions. The search included 11 electronic databases, five grey literature databases and over 30 websites relevant to clinical guidelines. Two review team members screened the titles and abstracts in EndNote Reference Manager applying pre-defined inclusion exclusion criteria as well as the full texts of any potentially eligible studies. Data extraction and quality appraisal using various tools dependent on study design was also conducted by two review team members. The certainty of the evidence overall was assessed using the GRADE approach. The findings for each of the six review questions are presented in a narrative summary:

Review questions:

*Q1: What EWSs and or track and trigger systems are currently in use? [**Chapter 4**]*

Q2: How effective are the different EWSs in terms of improving key patient outcomes?

*A: Effectiveness of EWSs (the afferent limb) [**Chapter 5, Chapter 6**]*

*B: Predictive ability of EWSs [**Chapter 7**]*

*C: Effectiveness of emergency response systems (the efferent limb) [**Chapter 8**]*

*Q3: What education programmes have been established to train healthcare professionals (HCPs) relating to the implementation of EWSs or track and trigger systems and how effective are these? [**Chapter 9**]*

*Q4: What are the findings from the economic literature on cost-effectiveness, cost impact and resources involved with the implementation of EWSs or track and trigger systems? [**Chapter 10**]*

*Q5: Are modified EWSs (e.g. CREWS) more effective than the NEWS in specific adult sub-populations? [**Chapter 11**]*

*Q6: Why do HCPs fail to escalate as per the NEWS escalation protocol? [**Chapter 12**]*

Results

Systematic search summary:

From 335 full texts assessed for eligibility, 154 studies were included in the review overall (n=123 studies for Q1, n=26 for Q2a n=68 for Q2b, n=32 for Q2c, n=23 for Q3, n=3 for Q4, n=4 for Q5 and n=18 for Q6). Note that some studies were included in more than one review question.

Q1: Descriptive overview of early warning systems (EWSs) currently in use in adult non-pregnant populations:

In total, 123 studies conducted across 22 different countries were eligible for inclusion in this descriptive overview of EWSs. The EWSs varied with 47 different named EWSs included (e.g. the NEWS, ViEWS, etc.), 13 unnamed EWSs, 23 studies which only include a single criterion for activating the emergency response system and two studies which did not provide details on the EWS included. The number and type of vital sign parameters included varied with some EWSs having as little as two and one algorithm-based EWS including 398 parameters. The majority of the 123 studies included electronic rather than paper-based EWSs, however in 44 studies it was not reported or it was not clear. Importantly, the majority of the 123 studies did not report how often parameters were measured (n=83) which can effect performance of an EWS, and where they did, it varied from study to study. There were 71 studies which included one or more EWSs which consisted of aggregated scores from vital signs where the weighting of these varied from study to study. The large number of EWSs in the literature varied in many ways, making it difficult to compare the systems.

Q2: The effectiveness of early warning systems currently in use in adult non-pregnant populations:

A: Effectiveness of EWSs (the afferent limb – recognition and escalation)

Twenty-one studies in total investigated the effectiveness of EWSs (afferent limb) interventions. Of these, 13 studies (three RCTs, one nRCT, one ITS study and eight observational studies) included the primary outcome mortality. Of the 13 studies, six studies including 244,340 patients, found no reduction in mortality rates; one study reported an increase in mortality; and seven studies reported a decrease in mortality as a result of use of the EWSs. Seven studies (no RCTs identified) including 89,767 patients reported on cardiac arrests. Of the seven studies four showed no change in the occurrence of cardiac arrest, while three studies showed a significant reduction in cardiac arrest rates as a result of use of the EWSs. In terms of length of stay (LOS), four out of the five studies (three RCTs, two observational studies) including 24,146 patients in total, showed no change in mean or median LOS as a result of EWSs. For the fourth primary outcome, ICU transfers or admission rates, the findings were mixed. Ten studies (three RCTs, one nRCT, one ITS study and five observational studies), including 79,893 patients reported this outcome. Of these, three studies showed an improvement in ICU transfers or admission rates; six studies showed no change; and one study reported a worsening in rates. The certainty of the evidence was graded as *very low* overall across the primary outcomes.

B: Predictive ability of EWSs

In total, 68 studies measured the predictive ability of EWSs for a range of outcomes including mortality, cardiac arrest, LOS and ICU transfers or admission. Thirty-three studies examined predictive ability for mortality in 1,732,733 patients. AUCs ranged from 0.52 (Shock Index EWS) to 0.97 (NEWS EWS minus temperature). For cardiac arrest, 15 studies including 1,605,574 patients in total compared the predictive ability of different EWSs. AUCs ranged from 0.48 (MEWS) to 0.88 (newly developed 17-item cardiac arrest model including vital signs and laboratory results). One study including 752 patients reported LOS and the

AUC was 0.70 (for the Simple Clinical Score EWS). Twenty studies including 1,435,957 patients reported on predictive ability for ICU transfers or admission. AUCs ranged from 0.62 (SOFA) to 0.89 (MEWS with blood lactate added). The certainty of the evidence was graded as *very low* overall across the primary outcomes.

Five studies focussed on the effectiveness of different paper based EWSs chart designs on specific outcomes including response time (of study participants to recognise physiological deterioration) and accuracy (of documentation and recognition of deterioration). These studies looked at different components of EWSs chart design and found that even where a significant effect was reported (in particular for response time), the difference was not clinically significant. The included studies were of poor quality.

C: Effectiveness of emergency response systems (the efferent limb - response)

There were 32 studies which investigated the effectiveness of emergency response systems (efferent limb) on mortality, cardiac arrest, LOS and ICU transfer or admission. Twenty-five studies including 2,617,122 patients investigated the effect of various emergency response systems on mortality. Fourteen out of the 25 studies showed a significant effect on mortality after the emergency response system was introduced (13 showed a reduction and one showed an increase in mortality). However, 11 studies showed no change in mortality rates as a result of the emergency response system. Eighteen studies including 1,878,003 patients examined the effectiveness of EWSs on cardiac arrest. Twelve out the 18 studies showed a significant reduction in cardiac arrests while six studies showed no change as a result of the emergency response systems. LOS was included in seven studies with a total of 576,504 patients. Four out of seven studies found no reduction in the LOS and three out of seven reported a significant reduction in mean or median LOS as a result of the emergency response system. Fourteen studies including 1,284,311 patients examined the effectiveness of EWSs on ICU transfer or admission. Five studies showed a significant effect on ICU transfers or admissions (two showed a reduction and three showed an increase in ICU

transfers or admissions). The certainty of the evidence overall was deemed to be *very low* for these review primary outcomes.

Q3: The effectiveness of early warning system-based educational interventions in use in adult non-pregnant populations:

Twenty-three studies investigated the effectiveness of EWS-based educational interventions to improve the detection of physiological deterioration in adult (non-pregnant) patients. These included seven RCTs, one non randomised control trial, fourteen before-and-after studies, and one interrupted time series study. Evidence from the review suggests that at least in the short term educational interventions (including mannequin- or virtual-based simulation, validated programmes such as COMPASS® or FIRST^{2}ACT, or hospital specific programmes) succeed in increasing health care staff (predominantly nursing staff) knowledge (eight studies with 755 participants), clinical performance and self-confidence to recognise and manage a deteriorating patient (ten studies with 789 participants). The evidence also shows improvements in the documentation of vital signs and the use of EWSs post-educational intervention, but was mixed for the effect on patient outcomes including ICU admission, length of stay and cardiac arrest. Communication (through the use of standardised tools such as ISBAR, SBAR and ABCDE) between nurses and doctors in relaying a deteriorating patient and escalation improved post-training in the majority of the 23 studies in the short term at least (i.e. immediately post-intervention). The certainty of the evidence however was graded *very low* overall for the review's primary outcomes.

Q4: The cost-effectiveness of early warning system-based interventions in use in adult non-pregnant populations:

Three studies investigated the cost-effectiveness of EWSs interventions, which included one health technology assessment (HTA) on the implementation of an electronic NEWS, one budget impact analysis (BIA) as part of National Clinical Guideline (NCG) No. 1 (NEWS 2013) and one costing study. Two studies were conducted in Ireland, and one in the Netherlands.

Two of the studies included the NEWS, and one included the implementation of a rapid response system (RRS). The populations included acute adult inpatients, acute medical patients, and surgical patients. Hospital or ICU length of stay (LOS) were the key clinical outcomes included. The studies included suggest that EWSs have the potential to improve patient outcomes including ICU and hospital LOS and thus reduce health care.

Q5: Comparison of the effectiveness of modified early warning systems to the NEWS in use in specific adult non-pregnant sub-populations?:

Four studies included a comparison of a modified EWS (e.g. the CREWS – chronic respiratory EWS) to the NEWS in a sub-population of adults with respiratory conditions. For mortality, four studies including 302,198 patients, the modified EWSs had similar predictive ability to the NEWS. One study examined the effectiveness of modified EWS on cardiac arrest in 251,266 patients. In this study NEWS and NEWS2 had similar AUCs (0.70). None of the four studies which compared modified EWSs to the NEWS reported on LOS. For ICU transfer or admission, two studies including 262,532 patients with chronic respiratory conditions compared modified EWSs to the NEWS. In both studies the predictive ability of both the NEWS and the modified EWS (NEWS2, CROS, CREWS and S-NEWS) were almost identical. From the limited amount of research available, it appears that modified EWSs are no superior to the NEWS in predicting the review's primary outcomes in specific sub-populations. The certainty of the evidence was graded *very low* overall.

Q6: Why do health care professionals fail to escalate care as per the NEWS protocol?

The systematic search identified 18 qualitative studies from various countries, all conducted in hospital settings and including nurses only (ten studies), nurses and doctors only (three studies) or a mix of HCPs and staff (five studies). The studies measured participant's beliefs and opinions on various EWSs or rapid response systems using mainly face-to-face interviews or focus group techniques in a total sample size of 599 participants. A thematic analysis resulted in the generation of five key themes as barriers and facilitators to

escalation: *Governance, RRT Response, Professional Boundaries, Clinical Experience* and *Early Warning Systems Parameters*. Within these five themes, 22 sub-themes with multiple interdependencies were identified. The certainty of the evidence using the GRADE CERQual approach was judged to be *moderate* overall.

Conclusions:

A large number of EWSs have been developed internationally and are currently in use in adult (non-pregnant) populations to assist in the detection of physiological deterioration at the bedside. This review included 154 studies with 47 different named EWSs, which investigated the clinical and cost-effectiveness of EWSs on patient outcomes, the predictive performance of EWSs as well as qualitative studies on why health care professionals fail to escalate.

The methodological quality of these studies overall was poor and there was a high risk of bias, owing to significant heterogeneity in the interventions and populations studied. There was very low certainty in the evidence overall across the review's primary outcomes. While studies included in this review demonstrate considerable heterogeneity a clear trend and direction of findings is evident which supports the use of EWSs for the early recognition, escalation and response to clinical deterioration in adult patients in the acute hospital setting. Further research is warranted of a high methodological quality using standardised definitions of primary outcomes, assessing similar interventions in similar populations in order to measure the impact of the NEWS on patient outcomes. Research in the Irish setting is imperative.

1 Introduction

1.1 Description of the condition

Acute physiological deterioration is a time-crucial medical emergency and failure to detect and treat patient deterioration in a timely manner poses a threat to patient safety, which may lead to adverse patient outcomes.[6] Deterioration of a patient's condition in hospital is frequently preceded by measurable physiological abnormalities. Regular measurement and documentation of physiological parameters is an essential requirement for recognising clinical deterioration.[7] Early recognition of clinical deterioration, followed by prompt and effective action, can minimise the occurrence of adverse events such as cardiac arrest,[8] and may mean that a lower level of intervention is required to stabilise a patient.

Health care organisations adopt a multi-faceted approach including four main categories of interventions to detect and manage deteriorating patients more effectively (rapid response teams [RRTs]/medical emergency teams [METs], early warning scores [EWS], education programmes for health care staff, and standardised approaches to patient handover).[9] The overarching aim of these interventions is to facilitate early detection of deterioration by categorising an adult patient's severity of illness and prompting escalation of care as appropriate.

1.2 Description of the intervention

Traditionally, early warning systems have come in two primary configurations: single parameter criteria and aggregated weighted scores. The former originated in Australia over two decades ago as a set of equally weighted abnormal physiologic thresholds (e.g., respiratory rate >36), the presence of any of which would trigger the system. In contrast, aggregated weighted scoring systems, involve summing up points from multiple parameters based on the degree of derangement (e.g., two points for a respiratory rate of 21–29 and three points for ≥30).[10]

The National Early Warning System (NEWS) was the first National Clinical Effectiveness Committee (NCEC) commissioned National Clinical Guideline (NCG) and was endorsed by the Minister for Health.[1] It was published in February 2013 and a subsequent update to the guideline to include additional practical guidance specific to sepsis management was approved by the NCEC in August 2014. Subsequently, an updated systematic search of the literature specific to EWSs in adult patients was completed in 2015 by a team from University College Cork (UCC).[2]

The NEWS facilitates the timely assessment of, and response to the deterioration of acutely ill patients by:

- Classifying the severity of a patient's illness
- Providing prompts and structured communications tools to escalate care
- Following a definitive escalation plan.

Patient's vital signs (blood pressure, pulse, respirations etc.) are routinely recorded in acute hospitals. With the NEWS, each vital sign is allocated a numerical score from 0 to 3, on a colour coded observation chart (A score of '0' represents the least risk and a score of '3' represents the highest risk). Scores are then combined to give the patient's NEWS score. The NEWS observation chart is included in full in Appendix 1. A trend can be seen indicating an improvement in the patient's condition with a lowering of the score or deterioration in condition with an increase in the score, thereby facilitating monitoring of the patient's health status. Depending on the score, care can be escalated to senior medical staff as appropriate.[1] The NEWS is a clinical assessment tool and does not replace the clinical judgement of a qualified health care professional. Where there are concerns regarding a patient's condition, staff should not hesitate in contacting a senior member of the patient's medical team to review the patient, irrespective of the NEWS.[1]

The NEWS does not apply to children or pregnant women or patients being assessed in emergency departments (ED) or primary care settings. Early detection of deterioration in

these groups of patients is identified by different physiological parameters and signs to those of adult patients admitted to acute hospitals. For example, the Paediatric Early Warning System (PEWS)[11] and the Irish Maternity Early Warning System (IMEWS)[12] were developed for these specific clinical groups and the Emergency Medicine Early Warning System (EMEWS) for use in EDs is currently in development.

1.3 The purpose of this review

The NEWS NCG (No. 1) relates to the situation in an acute health care setting, where an adult patient's physiological condition is deteriorating. The NCG focuses on ensuring that a 'track and trigger' system is in place for adult patients whose condition is deteriorating, and outlines the clinical processes and organisational supports required to implement this guideline. The aim of this review is to update a systematic review of the clinical and economic literature on EWSs (also known as track and trigger systems) used in adult (non-pregnant) patients in acute health care settings for the detection or timely identification of clinical deterioration, with a particular focus on the NEWS. Any changes in the totality of the evidence on the NEWS for use in the assessment of adult patients in the acute health care setting will be used to inform the update to this NCG.

The proposed review questions for this update fall under the remit of two overarching categories as per the NCG:[1]

1. CLINICAL PROCESSES
    - Measurement and documentation of observations
    - Escalation of care
    - Emergency Response Systems
    - Clinical communication

2. ORGANISATIONAL PROCESSES
    - Organisational supports
    - Education

- Evaluation, audit and feedback

The review questions are as follows:

Q1. What EWSs or track and trigger systems are currently in use for the detection or timely identification of physiological deterioration in adult (non-pregnant) patients in acute health care settings? In line with the previous review update, studies investigating the development and efficacy of various EWSs will be compared under the following categorisations:

- Type of EWS
- General acute patients or specific sub-populations
- Vital sign parameters recorded and weightings given to each vital sign
- Single-parameter EWS compared to aggregate EWS
- Evaluation of chart design (paper-based EWS compared to electronic EWS)
- Implementation of EWSs and/or RRTs

Q2. How effective are the different EWSs in terms of improving key outcomes in adult (non-pregnant) patients in acute health care settings?

Primary Outcomes:

- Mortality
- Cardiac Arrest
- Length of stay (LOS)
- Transfer/admission to the Intensive Care Unit (ICU)

Secondary outcomes:

- Clinical deterioration in sub-populations
- Any other outcomes identified post-hoc

Q3. What education programmes (e.g. COMPASS©, other) have been established to train health care professionals (HCPs) relating to the implementation of EWSs or track and trigger systems for the detection or timely identification of physiological deterioration in adult (non-pregnant) patients in acute health care settings?

3.1 How effective were the various education programmes?

Primary outcomes:

- Increase in knowledge and performance
- Effect on patient outcomes
- Improved patient rescue strategies

Secondary outcomes:

- Improved documentation of patient observations
- Improved compliance
- Any other outcomes identified post-hoc

Q4. What are the findings from the economic literature on cost-effectiveness, cost impact and resources involved with the implementation of EWSs or track and trigger systems for the detection or timely identification of physiological deterioration in adult (non-pregnant) patients in acute health care settings?

The new review questions are as follows:

Q5. Are modified EWSs (e.g. the Chronic Respiratory Early Warning Score [CREWS]) more effective than the NEWS for the detection or timely identification of physiological deterioration in the following adult sub-populations in acute health care settings?

- Frail older adults
- Patients with chronic respiratory conditions (including chronic hypoxia, chronic physiological abnormalities and chronic obstructive pulmonary disease [COPD])

The NEWS is based on an EWS designed to maximise both sensitivity (the ability to detect patients at risk of dying) and specificity (the minimisation of false alarms) for unselected patients admitted to acute settings. The aim of question 5 is to investigate whether modified EWSs (such as CREWS) can improve specificity and maintain sensitivity in specific sub-populations where NEWS has been shown to trigger false alarms.[13]

Q6. Why do HCPs fail to escalate as per the NEWS escalation protocol? The previous systematic review update conducted by UCC [2] highlighted that HCPs were failing to escalate as per protocol and identified a number of barriers based on suggestions extracted from the literature. However, an in-depth understanding as to 'why' this is happening requires a qualitative approach to be included in this review update.

Review questions 1-4 are consistent with those set out in the previous searches which informed the NEWS guideline[1] published in 2013, and a subsequent systematic review update in 2016.[2] The purpose of this systematic review is to update the evidence for these four questions. A new search will be conducted for the two additional new questions (5 and 6).

2 Methods

This systematic review update presents the available evidence to estimate the clinical effectiveness and cost-effectiveness of the NEWS in Ireland. In reporting this systematic review we have adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria.[14] For the qualitative review question, we have adhered to the ENTREQ (Enhancing transparency in reporting the synthesis of qualitative research) guidelines.[15] The protocol for this systematic review has been registered on the PROSPERO database of systematic reviews and meta-analyses and was agreed on by the NEWS GDG in January 2018 at a guideline development meeting (Link: http://www.crd.york.ac.uk/PROSPERO/display_record.php?ID=CRD42018088048).

2.1 Criteria for including studies within this review

2.1.1 Search Process

Searches were conducted consistent with the search strategy developed by the research team involved in the previous review.[2] Key terms and their variations were associated with the PICOS (Population/Patient/Problem, Intervention, Comparison, Outcome and Study design) framework which is applicable when addressing a clearly defined clinical question relevant to a defined population group and clinical context.[16] Key terms included a combination of terms associated with "*early warning scoring systems*". The search strategy is detailed in Appendix 2. The economic literature search was based on the clinical literature search strategy with the addition of an economic filter for the Medline and EMBASE search.[17]

2.1.2 Types of participants, interventions, comparisons, outcomes and study design

The PICOS (or modified PICOS) for each review question (1-6) are presented separately in **Table 2.1**, **Table 2.2**, **Table 2.3**, **Table 2.4**, **Table 2.5** and **Table 2.6**.

Table 2.1 Specific PICOS for Review Question 1

Q1: What EWSs and or track and trigger systems are currently in use for the detection or timely identification of physiological deterioration in adult (non-pregnant) patients in acute health care settings?	
Population	-Adult (non-pregnant) patients in acute (hospital) health care settings admitted to an adult ward. -In Irish hospitals, patients aged 16 years or older are classified as adults. -More often, adult refers to patients aged 18 years or older.
Description/ Objective/Aims	Description of EWS: -EWS, e.g. NEWS -Modified EWS -VitalPAC™ EWS (ViEWS) -Track and Trigger System
Outcome(s)	-Type of EWS (NEWS, MEWS, comparisons of EWS) -Details of vital sign parameters recorded and weightings given to each vital sign -Single-parameter EWS compared to aggregate EWS -General acute patients or specific sub-populations -Evaluation of chart design (paper-based EWS compared to electronic EWS) -Implementation of EWSs and/or RRS or METs
Study design	Effectiveness studies, development and validation studies

Key: NEWS: National Early Warning System, MEWS: Modified Early Warning System, RRS: Rapid Response Systems, MET: Medical Emergency Team.

Table 2.2 Specific PICOS for Review Question 2

Q2: How effective are the different EWSs in terms of improving key patient outcomes in adult (non-pregnant) patients in acute health care settings?	
Population	-Adult (non-pregnant) patients in acute (hospital) health care settings admitted to an adult ward -In Irish hospitals, patients aged 16 years or older are classified as adults -More often, adult refers to patients aged 18 years or older
Intervention	Early warning scoring systems (EWS): EWS, Modified EWS, VitalPAC™ EWS (ViEWS), Track and Trigger System
Comparison	Usual care, other EWS
Outcome(s)	Primary: -Mortality -Cardiac arrest -Length of stay -Transfer/admission to the ICU or HDU Secondary: -Clinical deterioration in sub-populations -PROMs (validated tools) -Any other outcomes identified post-hoc
Study design	Effectiveness studies, development and validation studies

Key: ICU: Intensive Care Unit, HDU: High Dependency Unit, PROMS: Patient Reported Outcome Measures.

Table 2.3 Specific PICOS for Review Question 3

Q3: What education programmes have been established to train healthcare professionals (HCPs) relating to the implementation of EWSs or track and trigger systems for the detection/timely identification of physiological deterioration in adult (non-pregnant) patients in acute health care settings?	
Population	Stakeholders including HCPs and their managers

Intervention	Education programmes including but not limited to: ALERT™ COMPASS©
Comparison	Usual care, other education programme
Outcome(s)	Education outcomes *Primary:* -Increase in knowledge and performance -Effect on patient outcomes -Improved patient rescue strategies *Secondary outcomes:* -Improved documentation of patient observations -Improved compliance -Effectiveness of mode of delivery (i.e. online vs. face-to-face delivery) -Any other outcomes identified post-hoc
Study design	Effectiveness studies, development and validation studies

Key: HCP: Health care professional, ALERT™: Acute Life-threatening Early Recognition and Treatment.

Table 2.4 Specific PICOS for Review Question 4

Q4: What are the findings from the economic literature on cost-effectiveness, cost impact and resources involved with the implementation of EWSs or track and trigger systems for the detection or timely identification of physiological deterioration in adult (non-pregnant) patients in acute health care settings?	
Population	-Adult (non-pregnant) patients in acute (hospital) healthcare settings admitted to an adult ward -In Irish hospitals, patients aged 16 years or older are classified as adults -More often, adult refers to patients aged 18 years or older
Intervention	EWS, Modified EWS, VitalPAC™ EWS (ViEWS), Track and Trigger System
Comparison	Usual care, other EWS
Outcome(s)	**Cost utility analysis:** QALYs, -HYE, DALYs **Cost-effectiveness analysis:** Cost per unit of effect [cost per LYG], Effects per unit cost [LYG per Euro spent] **Cost-benefit ratios:** ICERs, Incremental cost-per QALY **Any measure of economic outcomes:** Resource use (Length of stay [hospital or ICU/HDU], ICU/HDU admissions, unexpected ICU/HDU admissions, use of RRT and MET), costs (Implementation costs, escalation costs, service utilisation costs, direct medical costs, indirect medical costs, education costs and cost savings)
Study design	Economic evaluation studies, costing studies

Key: QALYs: Quality-adjusted life years, HYE: Health Year Equivalent, DALYs: Disability Adjusted Life Years, LYG: Life Years Gained, ICERs: Incremental cost-effectiveness ratio, ICU: Intensive Care Unit, HDU: High Dependency Unit, RRT: Rapid Response System, MET: Medical Emergency Team.

Table 2.5 Specific PICOS for Review Question 5

Q5: Are modified EWSs (e.g. CREWS) more effective than the NEWS for the detection or timely identification of physiological deterioration in specific adult sub-populations in acute health care settings?	
Population	Sub-populations of adult patients in acute settings

	1) Frail older adults -Must be defined with a validated frailty scale for inclusion 2) Adults with chronic respiratory conditions including (chronic hypoxia, chronic hypoxaemia/hypoxemia, chronic physiological abnormalities, pulmonary fibrosis or COPD) -Chronic hypoxaemia will be defined based on target oxygen saturations levels of 86-92% and target oxygen saturations levels of 94-98% for others[13, 18]
Intervention	Modified EWS (e.g. CREWS)
Comparison	NEWS (Studies comparing CREWS to usual care will not be relevant to this question)
Outcome(s)	-Type of EWS (Name of modified EWS or NEWS) -Vital sign parameters recorded and weightings given to each vital sign -Single-parameter EWS compared to NEWS -Clinical deterioration and outcomes including mortality, cardiac arrest, LOS, transfer/admission to the ICU or HDU
Study design	Effectiveness studies, development and validation studies

Key: COPD: Chronic Obstructive Pulmonary Disorder, CREWS: Chronic Respiratory Early Warning System, NEWS: National Early Warning System, LOS: Length of stay, ICU: Intensive Care Unit, HDU: High Dependency Unit.

Table 2.6 Specific PICOS for Review Question 6

Q6: Why do HCPs fail to escalate as per the NEWS escalation protocol?	
Population	Stakeholders including HCPs and their managers
Phenomenon/Study aims	Evidence to identify the range of factors, including barriers and facilitators, in very high and high-income settings that influence why HCPs fail to escalate as per the NEWS protocol
Outcome(s)	Qualitative outcomes: Barriers and facilitators, which will be categorised as follows: -Management/organisational/setting specific issues -Education/training issues -EWS specific issues
Study design	Qualitative studies including focus group interviews, individual interviews, observation, document analysis with qualitative methods of analysis (i.e. thematic analysis, framework analysis, grounded theory)

Key: HCP: Health Care Professional, NEWS: National Early Warning Score.

2.1.3 Types of setting

Studies conducted in the acute hospital setting in countries classified as either very high or high human development countries on the Human Development Index were considered for inclusion in this review in order to maximise the transferability of the research findings to the Irish context.[19]

2.2 Search methods for identification of studies

2.2.1 Clinical and economic literature

The following electronic databases were searched for published literature for review questions 1-4 from November 2015 until February 19th 2018. In addition, the same databases were searched for the two new additional questions (question 5 on parameter adjustments in specific sub-populations including frail older adults and adults with chronic respiratory conditions, and question 6 on why HCPs fail to escalate as per protocol) from January 2011 in line with the previous review update search criteria until February 19th 2018.

- Academic Search Complete
- Cumulative Index to Nursing and Allied Health Literature (CINAHL)
- Applied Social Sciences Index and Abstracts (ASSIA)
- Medical Literature Analysis and Retrieval System Online (MEDLINE)
- PsycARTICLES
- PsycINFO
- Psychology and Behavioral Sciences Collection
- SocINDEX
- Exerptamedica Database (EMBASE)
- Health Management Information Consortium (HMIC)
- The Cochrane Library (www.cochranelibrary.com) which includes: The Cochrane Database of Systematic Reviews, The Cochrane Methodology Register (CMR) [ceased updating in 2012, archived in the Cochrane Library], The Cochrane Central Register of Controlled Trials (CENTRAL), Database of Abstracts of Reviews of Effects (DARE) [ceased updating in 2015, archived in the Cochrane Library], The Health Technology Assessment Database (HTA) [last update October 2016], and The National Health Service Economic Evaluation Database (NHS EED)[ceased updating in 2015, archived in the Cochrane Library] via MEDLINE (https://www.nlm.nih.gov/bsd/pmresources.html).

2.2.2 Other sources

This grey literature search was guided by the handbook produced by the Canadian Agency for Drugs and Technology in Health (CADTH)[20] to supplement the electronic database searches to find relevant clinical evaluations, economic evaluations, validation studies and guidelines. A detailed list of the grey literature databases and websites for guidelines on the use of early warning or track and trigger systems in adult (non-pregnant) patients in the acute health care setting which were searched on February 20th 2018 can be found in Appendix 3.

In addition, clinical trial registers were searched (e.g., WHO Clinical Trials Search Portal: http://apps.who.int/trialsearch/, which allows for searching multiple databases simultaneously) for completed but unpublished and on-going clinical trials on February 21st 2018. The search for economic evaluations was supplemented with searches of the following websites on February 21st 2018:

- Open Grey (http://www.opengrey.eu/)
- New York Academy of Medicine (https://nyam.org/)
- National Institutes of Health (NIH) (https://www.nih.gov/)
- Health Service Executive (HSE) (https://www.hse.ie/eng/)
- Health Information and Quality Authority (HIQA) (https://www.hiqa.ie/)
- Health Research Board (HRB) Ireland (http://www.hrb.ie/home/)
- Lenus (http://www.lenus.ie/hse/)
- World Health Organization (WHO) (http://www.who.int/en/)
- National Institute for Health and Care Excellence (NICE) (https://www.nice.org.uk/)
- Centre for Health Economics and Policy Analysis (CHEPA) (http://www.chepa.org/)
- Institute of Health Economics (Alberta Canada) (https://www.ihe.ca/)
- Department of Health UK (https://www.gov.uk/government/organisations/department-of-health-and-social-care)
- National Health Service UK (NHS) (https://www.england.nhs.uk/)
- Public Health Agency of Canada (https://www.canada.ca/en/public-health.html)

- Google Scholar and Google (https://scholar.google.com/, https://www.google.ie)
- National Coordinating Centre for Health Technology Assessment (NCCHTA) (https://www.nihr.ac.uk/funding-and-support/funding-for-research-studies/funding-programmes/health-technology-assessment/).

Finally, manual searching of the reference lists of any included study was conducted.

2.3 Inclusion and exclusion criteria

Inclusion and exclusion criteria for each review question (1-6) are outlined in **Table 2.7**.

Table 2.7 Inclusion and exclusion criteria according to review question

Inclusion criteria	Question 1 (EWS)	Question 2 (Outcomes)	Question 3 (Education)	Question 4 (Economics)	Question 5 (Sub-populations)	Question 6 (Qualitative)
Adult acute setting patients (16 years or older) (Excluding paediatric, obstetric, ED patients and DNR patients)	X	X	X	X	X	X
Investigated the implementation and or effectiveness of EWSs and or track and trigger systems developed to facilitate the early detection of deterioration and escalation of care	X	X		X	X	X
Investigated the effectiveness of education programmes used to train registered HCPs in relation to EWSs and or track & trigger systems (Excluding EWS not suitable for bedside monitoring)			X			
Acute hospital setting in countries categorised as either very high or high HDI[19]	X	X	X	X	X	X
Data were pre- and post-critical adverse clinical event(s) or pre-post EWS intervention or pre-post education intervention	X	X	X	X	X	X
Comparison of modified EWSs (e.g. CREWS) to the NEWS only in specific sub-populations (frail older adults, patients with severe respiratory conditions)					X	
Qualitative study design						X
Quantitative study designs of a randomised and non-randomised nature including effectiveness studies, development studies and economic studies (Excluding study designs with no intervention or outcome data, i.e. case reports or vignettes, early development studies, literature reviews, conference abstracts and letters)	X	X	X	X	X	
Grey literature	X	X	X	X	X	X
English language	X	X	X	X	X	X
*Published since November 2015 (Update)	X	X	X	X		
**Published since January 2011 (New review questions)					X	X

Key: An '**X**' denotes that the specific inclusion criteria apply to the particular review question. ED: Emergency Department, DNR: Do Not Resuscitate, EWS: Early Warning System, HCP: Health care Professional, HDI: Human Development Index, CREWS: Chronic Respiratory Early Warning System, NEWS: National Early Warning System. *Questions 1-4 are consistent with the previous review update which searched the literature until November 2015. **Questions 5 and 6 are new questions and the search began from the starting date of the last review update (January 2011).

2.4 Data collection and analysis

2.4.1 Selection of studies

All potentially eligible papers identified in the searches were exported to EndNote (Version 7) where duplicates were identified and removed. The titles and abstracts of the remaining citations were each reviewed independently by two people as per the inclusion and exclusion criteria to determine whether the papers merited a full text review. The full texts were obtained and independently evaluated by two members of the team. Any disagreements were resolved by discussion, or if necessary, a third reviewer (members of the GDG with clinical and subject matter expertise).

2.4.2 Data extraction and management

Data were extracted from clinical literature pertaining to the evaluation of EWSs or track and trigger systems under the following headings:

- Authors
- Year and country of publication
- Study design
- Aim of study
- Description of the intervention
- Study outcomes

The economic review data were extracted in relation to the following elements, in line with the HIQA guidelines for the retrieval and interpretation of economic evaluations of health technologies in Ireland:[21]

- Study question, population, intervention and type of EWS, comparator and setting
- Modelling methods
- Sources and quality of clinical data
- Sources and quality of cost data
- Cost data
- Resource usage
- Study outcomes, and methods used in synthesis

- Outcomes and benefits
- Methods for dealing with uncertainty.

Separate data extraction tables were used according to the review question:

- Empirical clinical papers relating to use of EWSs or track & trigger systems used in adult (non-pregnant) patients
- Evaluation of education programs involving the education or training of HCPs relating to EWSs or track & trigger systems used in adult (non-pregnant) patients
- Empirical economic literature relating to EWSs or track & trigger systems used in adult (non-pregnant) patients
- Empirical clinical papers relating to EWSs or track and trigger systems in frail, older adults or patients with severe respiratory conditions and whether it is appropriate to adjust physiological parameter cut-off values, and which parameters should be adjusted, in order to maximise the predictive ability of the NEWS
- Empirical qualitative papers relating to EWSs or track and trigger systems and why HCPs fail to escalate as per the NEWS protocol.

Data extraction was performed by two members of the review team independently using the agreed data extraction form to ensure consistency. Any discrepancies were resolved through discussion, or if required, consultation with a third reviewer.

2.4.3 Assessment of methodological limitations and risk of bias

Two reviewers independently assessed the methodological quality or risk of bias of included studies, using standardised critical appraisal instruments, with any disagreements resolved through discussion. Different study designs warrant different tools to assess methodological quality, thus the following instruments were used as appropriate (see ***Table 2.8***). In this review a number of different types of non-randomised and observational studies are included, these are defined below:[22]

- Non-randomised controlled trial - An experimental study in which people are allocated to different interventions using methods that are not random.
- Controlled before-and-after study - A study in which observations are made before and after the implementation of an intervention, both in a group that receives the intervention and in a control group that does not.

- Interrupted-time-series study - A study that uses observations at multiple time points before and after an intervention (the 'interruption'). The design attempts to detect whether the intervention has had an effect significantly greater than any underlying trend over time.
- Cohort study - study in which a defined group of people (the cohort) is followed over time, to examine associations between different interventions received and subsequent outcomes. A 'prospective' cohort study recruits participants before any intervention and follows them into the future. A 'retrospective' cohort study identifies subjects from past records describing the interventions received and follows them from the time of those records.

Table 2.8 Critical Appraisal Instruments

Study category	Critical appraisal instrument
RCTs	Cochrane Risk of bias tool[23]
NRCTs, CBA studies, ITS studies	Risk of bias criteria for Cochrane EPOC reviews[24]
Clinical practice guideline	AGREE II tool, 'rigour of development' domain (National Quality Assurance Criteria for Clinical Guidelines[25]
Observational designs	Newcastle Ottawa Scale[26]
Economic evaluations	1. CHEC-list for quality assessment[27], 2. ISPOR to assess transferability[28]
Development & validation studies	The QUADAS 2 Tool[29]
Qualitative studies	CASP[30] Qualitative Checklist

Key: RCT: Randomised Controlled Trial, **NRCT:** Non-Randomised Controlled Trial, **CBA:** Controlled Before-After study, **ITS**: Interrupted Time Series study, **EPOC**: Effective Practice and Organisation of Care, **AGREE:** Appraisal Of Guidelines For Research & Evaluation, **CHEC-list:** The Consensus Health Economic Criteria LIST, **ISPOR:** International Society for Pharmacoeconomics and Outcomes Research, **QUADAS:** Quality Assessment of Diagnostic Accuracy Studies, **CASP:** Critical Appraisal Skills Programme.

The Newcastle Ottawa Scale quality appraisal tool[26] was used for observational studies. We rated the quality of the studies (good, fair and poor) by awarding stars in each domain following the guidelines of the Newcastle–Ottawa Scale. A "good" quality score required 3 or 4 stars in 'selection', 1 or 2 stars in 'comparability', and 2 or 3 stars in 'outcomes'. A "fair" quality score required 2 stars in selection, 1 or 2 stars in comparability, and 2 or 3 stars in outcomes. A "poor" quality score reflected 0 or 1 star(s) in selection, or 0 stars in

comparability, or 0 or 1 star(s) in outcomes. In total where a study received '6' or more stars, it was considered a 'good quality study'. Where a study received '5' stars, it was considered a 'fair quality study' and where a study received '4 or less' stars it was considered a 'poor quality study', as described in Sharmin et al.[31]

2.5 Data synthesis

Review questions 1-5 (Quantitative)

The HIQA guidelines on clinical effectiveness were adhered to with regard to data synthesis.[32] A meta-analysis was not possible due to differences in how outcomes were measured (heterogeneity). A narrative synthesis, which takes methodological differences between primary studies into account, was completed and an overall picture of the evidence is presented. For the economic literature review, the evidence was compiled and condensed using a narrative synthesis and supported by evidence tables. The HIQA guidelines on retrieval and interpretation of economic evaluations of health technologies were adhered to.[21]

Review question 6 (Qualitative)

The evidence on why HCPs fail to escalate was synthesised in the form of a thematic analysis.[33, 34]

Two review team members read all included papers a number of times to achieve absorption of the data. Both review team members manually extracted the text from each study (results section only) and coded line by line in Excel, and developed initial sub-themes and overarching themes independently. Following multiple discussions and re-analysis of the draft themes and sub-themes as well as presentation of the findings to the guideline development group at a meeting in November 2018, the review team members reached consensus on the final overarching themes and sub-themes. The findings are presented

according to themes generated which were coded for each included study. Themes including barriers and facilitators to NEWS were sub-categorised as follows where possible:

- Management/organisational/setting specific issues
- Education/training issues
- EWS or Track and Trigger System specific issues
- Other

2.6 Assessing the certainty of the body of evidence using the GRADE approach

Review Questions 1-5

Where appropriate, 'Summary of findings' (SOF) tables using the GRADEpro software were generated for the primary outcomes of each review question.[35] The certainty of the evidence for each outcome was assessed using the GRADE approach as outlined in the GRADE handbook where appropriate.[36] We downgraded the evidence from high quality by one level for serious (or by two levels for very serious) limitations, depending on the assessments of the risk of bias, indirectness of evidence, serious inconsistency, imprecision of effect estimates, or potential publication bias. Evidence was graded as high, moderate, low or very low.[36]

Review question 6

For qualitative studies, the GRADE-CERQual (Confidence in the Evidence from Reviews of Qualitative research) approach was used to summarise confidence in the evidence.[37] Four components contribute to an assessment of confidence in the evidence for an individual review finding: methodological limitations, relevance, coherence, and adequacy of data. The CERQual components reflect similar concerns to the elements included in the GRADE approach for assessing the certainty of evidence on the effectiveness of interventions.

However, CERQual considers these issues from a qualitative perspective. Confidence in the evidence was graded as high, moderate, low, or very low for each key finding.

3 Results

3.1 Search results for all review questions

The search strategy for all review questions identified 54,271 potentially relevant records through searching the listed electronic databases and grey literature sources. After removing duplicates, 36,445 records were screened independently by two reviewers, with a further 36,110 references excluded based on titles and abstracts. A total of 335 full-text articles were assessed for eligibility. Of these, 203 references were excluded according to the inclusion and exclusion criteria (***section 14.4***). This resulted in 132 studies being included in the review. Manual checking of the reference lists of included studies identified a further 22 eligible studies, bringing the total number of studies included in this review to 154[1]. The breakdown of eligible studies for each review question is:

- N=123 studies for questions 1 and 2 (a description of EWSs and their effectiveness on patient outcomes)
- N=23 studies for question 3 (the effectiveness of different EWS-based educational interventions)
- N=3 studies for question 4 (an economic evaluation of the cost-effectiveness of EWSs)
- N=4 study for question 5 (the effectiveness of EWSs in specific sub-populations, i.e. frail elderly adults and patients with COPD or respiratory conditions).
- N=18 studies for question 6 (qualitative focus on why HCPs fail to escalate as per the NEWS protocol).

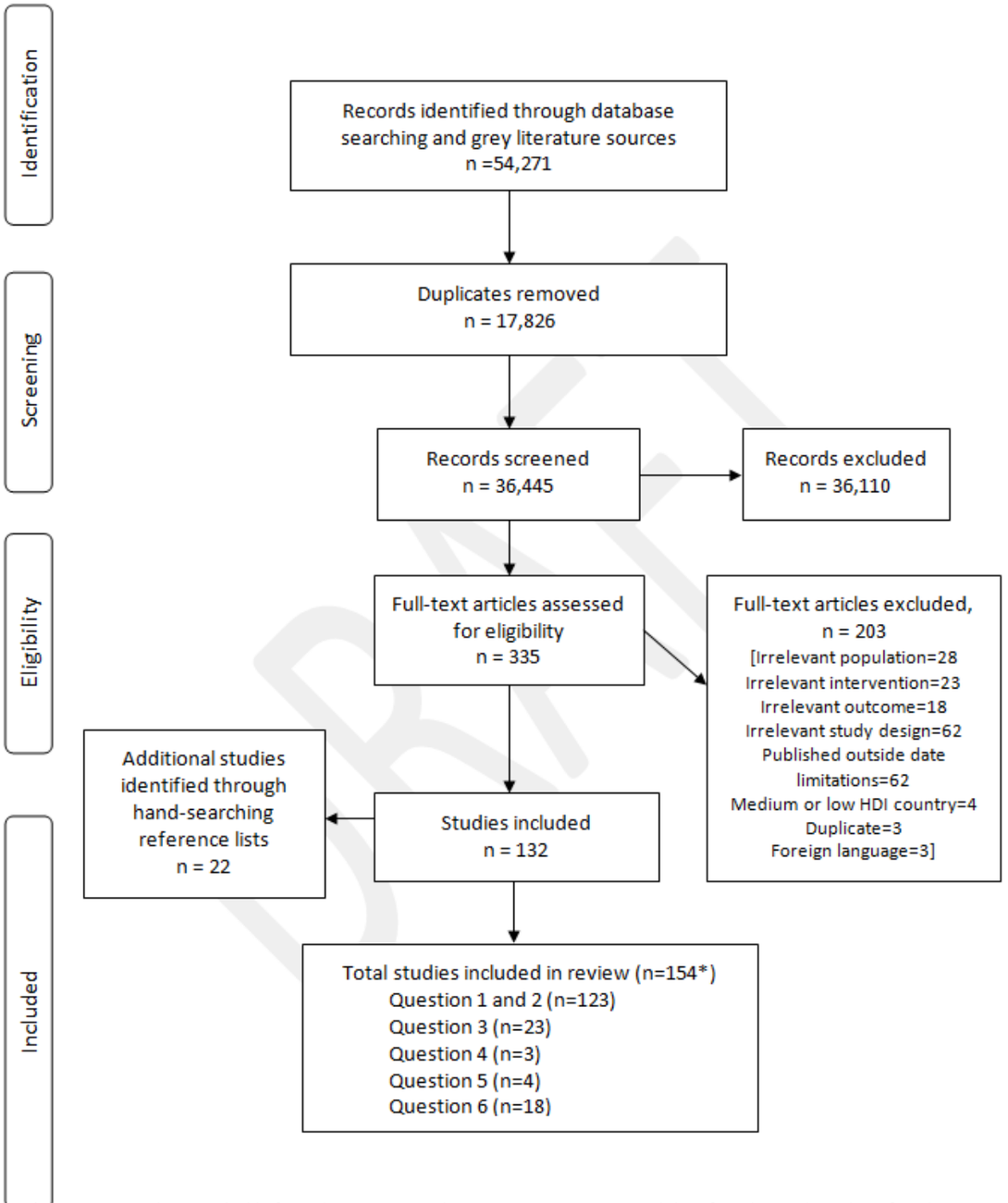
This process is depicted in **Figure 3.1**.

[1] Note some studies are eligible for inclusion in more than one review question and therefore the total number of studies across all six questions will not sum to n=154.

3.2 Presentation of results according to review question

The overall results, quality appraisal and the summary of the evidence for each review question (1-6) are presented in chapters 4-12.

Figure 3.1 Study flow diagram for all six questions in the systematic review



*Note some studies are eligible for inclusion in more than one review question and therefore the total number of studies across all six questions will not sum to n=154.

4 Results: A description of Early Warning Systems currently in use for the detection of physiological deterioration in adult (non-pregnant) patients in acute health care settings

4.1 Chapter overview

This chapter focusses on the literature pertinent to question 1 of the review. "*What early warning systems (EWSs) or track and trigger systems are currently in use for the detection of or timely identification of physiological deterioration in adult (non-pregnant) patients in acute health care settings?*" The characteristics of the different EWSs are described according to whether the study included one EWS or a multiple EWSs or focussed on EWS chart design, whether the system was paper-based or electronic, the frequency of recording of vital sign observations and whether it was an aggregate EWS or a single item EWS.

4.2 Characteristics of included studies

4.2.1 Study Country

In total, there were 123 studies eligible for inclusion. These studies were conducted across 22 different countries including Australia,[38-47] Belgium,[48, 49] Brazil,[50] Canada,[51-53] China,[54-56] Denmark,[57-60] France,[61, 62] Iran,[63] Israel,[64, 65] Italy,[66, 67] Japan,[68] New Zealand,[69] Portugal,[70] Saudi Arabia,[71] South Korea,[72-74] Sweden,[75] Switzerland, [76] Thailand,[77] The Netherlands,[78-86] Turkey,[87] the UK,[8, 13, 88-113] the USA,[114-157] and one study was conducted across two countries, the UK and the USA,[158] (**Table *4.1***, ***Table 4.2***)

4.2.2 Early Warning Systems

In total there were 47 different named EWSs (described in 80 studies which included one EWS, in 38 studies with two or more EWSs included, and in five studies focussed on chart design).

These included the following:

- NEWS[13, 59, 60, 70, 77, 90, 93, 94, 101-105, 107, 109-113, 120, 149, 155, 156]

- *MEWS[39, 48, 49, 54-57, 65-68, 74, 75, 78-80, 83, 87, 90, 95-98, 100, 103, 117, 122, 123, 127, 128, 131, 137, 138, 140-144, 146-155]
- ViEWS[58, 73, 89, 142, 144, 145, 149, 151]
- The Acute Physiology and Chronic Health Evaluation (APACHE II) EWS[56, 73, 140, 148, 151]
- SOFA[56, 75, 140, 151]
- The Chronic Respiratory EWS (CREWS)[13, 60, 107, 111]
- The Simplified Acute Physiology Score (SAPS) II[73, 148, 151]
- The Simple Clinical Score (SCS)[40, 65, 151]
- The Cardiac Arrest Triage Score (CART) EWS[143-145]
- The Rothman Index[140, 150, 152]
- SAPS III[49, 73, 75]
- The Rapid Emergency Medicine Score (REMS) EWS[65, 148, 151]
- The Worthing Physiological Scoring System (PSS)[104, 149]
- The Adult Deterioration Detection System (ADDS) EWS[47, 69]
- The Dutch Early Nurse Worry Indicator Score (DENWIS)[85, 86]
- The Systemic Inflammatory Response Syndrome (SIRS) EWS[41, 155]
- The quick Sequential Organ Failure Assessment (qSOFA) EWS[41, 155]
- electronic CART (eCART)[146, 156]
- The Mortality in Emergency Department Sepsis (MEDS) EWS[65, 151]
- APACHE III[148, 150]
- The Standardised EWS (SEWS)[144, 149]
- NEWS2[112]
- The Queensland ADDS (Q-ADDS) EWS[45]
- The Salford-NEWS[111{Pedersen, 2018 #7546]
- The Capital Region of Denmark NEWS Override System (CROS) EWS[60]
- The Vital Sign Score (VSS)[76]
- The Laboratory Decision Tree (LDT-EWS)[92]
- The Vital Sign Alert (VSA) EWS[114]
- The Patientrack EWS[88]
- The Electronic Physiological Surveillance System (EPSS) EWS[99]
- The Dutch Leakage (DULK) EWS[61]

- The Patient at Risk Score (PARS)[101]
- The Decision Tree EWS (DTEWS)[102]
- The Super Score EWS[54]
- The Adult Fever State Score (AFSS)[55]
- The Critical Vital Sign EWS[142]
- Binary NEWS[105]
- Short NEWS[70]
- Palliative NEWS[107]
- The ViEWS-L (includes lactate)[73]
- The Hypotension, Oxygen saturation, low Temperature, ECG change and Loss of independence (HOTEL) EWS[73]
- The Prince of Wales Emergency Department Score (PEDS)[148]
- The Global Modified EWS (GMEWS)[149]
- The single parameter Medical Early Response Intervention and Therapy (MERIT) EWS[144]
- The modified-MERIT EWS[144]
- The Sepsis Early Warning and Response System (EWRS)[139]
- The Predisposition/Infection/Response/Organ Dysfunction Score (PIRO) EWS[151]

*It should be noted that the MEWS does not refer to one singular EWS, and instead refers to a number of distinct EWSs.

Two studies compared 30 or more EWSs each.[8, 106]

There were also 13 other EWSs including: unnamed EWSs;[38, 84, 118, 121, 126, 140, 141, 144, 147, 148] Algorithm-based EWSs;[64, 132] and a centile-based EWSs.[144, 158] In addition, 23 studies used single items as criteria to activate emergency response systems.[46, 50-53, 62, 63, 71, 72, 81, 82, 115, 116, 119, 124, 125, 130, 133-136, 149, 157] One study reported using an EWS as part of a 5-item care bundle (known as the Emergency Laparotomy Pathway Quality Improvement Care [ELPQuiC]), but provided no details on the specific vital sign parameters recorded or the type of EWS.[91] Another study focusing on emergency response systems provided no details on the EWS component,[129] (**Table *4.1***,**Table *4.2***).

4.2.3 Early Warning System Chart Design

Five of the 123 included studies focussed on EWSs chart design.[42-44, 47, 108] All used paper-based EWSs only. Six different chart designs based on the ADDS EWS were assessed in one study and three different chart designs based on the same EWS in another study.[42, 44] The third study compared four different chart designs for BP and HR only.[43] The fourth study compared 12 different chart designs based on the PARS EWS used in six clinical scenarios.[108] The fifth study using an ADDS-based design compared data recording format, scoring system integration and scoring row placement.[47] The number and type of vital sign parameters varied across studies (**Table *4.3***).

4.2.4 Number and type of vital sign parameters reported

The number and type of parameters included varied from study to study. The number of parameters ranged from two (respiratory rate [RR] and heart rate [HR]) in Zimlichman et al.[64] to 398 in an algorithm-based EWS in Hackmann et al.,[116] and was not reported for some of the EWSs included in 25 studies.[8, 41, 48, 56, 73, 75, 80, 91, 96, 99, 104, 111, 127, 129, 134, 137, 140, 142, 144-147, 149, 150, 156] Some of the other most frequently reported parameters, beyond those included in the NEWS were: urine output, level of consciousness using the Glasgow coma scale (GCS), white blood cell (WBC) count, staff/family concern, age, and diastolic blood pressure (DBP) (**Table *4.1***, **Table *4.2***).

4.2.5 Paper-based or electronic EWSs

There were 60 electronic EWSs [8, 39, 41, 55, 59, 60, 64, 65, 68, 70-72, 78, 84-86, 88, 90, 92-94, 99, 102, 104-107, 111-114, 116-118, 120-123, 126, 127, 131, 132, 137, 139-142, 144-150, 152, 154-156, 158] and 19 paper-based EWSs.[13, 42-45, 47-49, 54, 57, 69, 79, 87, 98, 101, 108-110, 128] Forty-four studies did not report whether it was electronic or paper-based and it was not clear from the text.[38, 40, 46, 50-53, 56, 58, 61-63, 66, 67, 73-77, 80-83, 89, 91, 95-97, 100, 103, 115, 119, 124, 125, 129, 130, 133-136, 138, 151, 153, 157] (***Table 4.1, Table 4.2***)

4.2.6 Frequency of recording of vital signs

The frequency of recording of vital signs was not reported in the majority of included studies (n=83).[8, 13, 38-44, 46-48, 50-53, 55, 56, 62, 63, 65-70, 72-74, 76, 77, 80, 81, 84, 89-93, 96-99, 102-106, 108-111, 113, 115-121, 124-127, 129-137, 143-149, 151, 152, 157, 158] Where the frequency of recording of vital signs or parameters was recorded it varied from study to study. It was hourly in two studies,[54, 75] 4-hourly in nine studies,[71, 87, 88, 95, 114, 123, 128, 150, 153] 6-hourly in one study,[100] 6-7 hours on average in one study,[94] 8-hourly in eight studies,[57, 79, 82, 83, 85, 86, 122, 154] 4-8 hourly in one study,[156] 12-hourly in four studies,[49, 58, 59, 107] on admission and 4-hourly thereafter in one study,[87] admission and throughout in one study,[101] once a day in three studies,[61, 78, 138] according to physician orders in two studies,[45, 142] and continuous using real-time or near real-time data in seven studies.[60, 64, 112, 139-141, 155] (***Table 4.1, Table 4.2, Table 4.3***)

4.2.7 Aggregate EWSs

There were 71 studies which included one or more aggregated EWSs.[8, 13, 39-41, 45, 48, 49, 54-61, 65, 66, 68-70, 73, 75, 77-80, 83-90, 92-98, 100-107, 109, 110, 112-114, 117, 120, 122, 123, 128, 131, 138, 142-144, 146, 147, 149, 150, 152, 153] The scores and weighting assigned to vital signs varied from study to study (***Table 4.1***, ***Table 4.2***). For an overview of the scores and weightings, where reported in the relevant studies, please see ***Appendix 5***.

Table 4.1 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – one EWS only studies

Author, Country	No of parameters, Name of EWS	Parameters included in EWS								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[110]Abbott (2016), UK	10-item NEWS	x	X	x	x	x	x	x	Lactate, glucose, base excess	Paper-based	Not reported	Yes (0-3)
[117]Albert (2011), USA	12-item MEWS	x	X	x	x	X		x	Urine output, level of consciousness, WBC, difficulty breathing, new focal weakness, staff or family concern.	Electronic	Not reported	Yes (0-3)
[71]Al-Qahtani (2013), Saudi Arabia	Single items, not combined	x	X		x	X			Urine output, level of consciousness using GCS, staff concern about the patient	Electronic	4-hourly	No
[118]Bailey (2013), USA	7-item EWS with real-time automated alerts generated 24/7.	x	X		x	X			Shock index, anticoagulation use, DBP	Electronic (algorithm-based)	Not reported	No
[119]Beitler (2011), USA	Single items, not combined	x	X		x	X			Clinical judgement/concern	Not reported	Not reported	No
[57]Bunkenborg (2014), Denmark	6-item MEWS	x	X		x	X	x	x		Paper-based	8-hourly	Yes (0-3)
[120]Capan (2015), USA	7-item NEWS	x	X	x	x	X	x	x		Electronic (algorithm-based)	Not reported	Yes (0-3)
[121]Churpek (2013a), USA	8-item EWS	x	X	x	x	X	x	x	DBP	Electronic (algorithm-based)	Not reported	No
[122]Churpek (2012), USA	5-item MEWS	x			x	X	x	x		Electronic	8-hourly	Yes (0-3)
[123]Churpek (2015), USA	8-item MEWS	x	X		x	X		x	DBP, pulse pressure index (=SBP-DBP/SBP), shock index(=SBP/HR)	Electronic	4-hourly	Yes (0-3)

Table 4.1 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – one EWS only studies (continued)

Author, Country	No of parameters, Name of EWS	Parameters included in EWS								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[124]Davis (2015), USA	Single items, no specific EWS –criteria for activating RRT.	x	x		x	X	x	x	Chest pain, acute blood loss, Arterial Blood Gas test obtained, $PetCO_2$ rise; laboured breathing, persistent apneas, staff concern, family concern.	Not reported.	Not reported.	No
[48]DeMeester (2013b), Belgium	6-item MEWS	X	x		x	x	X	x		Paper-based	Not reported.	Yes (0-3)
[85, 86]Douw (2016, 2017), The Netherlands	16-item DENWIS	X	x	x	x	x		x	LOC, change in breathing, in circulation, rigors, change in mentation, agitation, pain, no progress, patient indicates feeling unwell, subjective nurse observation	Electronic	8-hourly	Yes (0-4)
[69]Drower (2013), New Zealand	8-item ADDS EWS	X	x	x	x	x	X	x	Urine output.	Paper-based	Not reported.	Yes (0-3)
[87]Durusu Tanriover (2016), Turkey	5-item MEWS	X			x	x	X	x		Paper-based	On admission and 4-hourly thereafter	Yes (0-3)
[76]Etter (2014), Switzerland	6-item VSS EWS	X	x		x	x			GCS, peripheral perfusion	Not reported.	Not reported.	No
[90]Faisal (2018), UK	6-item NEWS	X	x		x	x		x	DBP	Electronic	Not reported	Yes (0-3)
[109]Fareneden (2017), UK	7-item NEWS	X	x	x	x	x	X		Staff concern	Paper-based	Not reported	Yes (0-3)
[50]Gonçales (2012), Brazil	Single items, no specific EWS –criteria for activating RRT.	X	x		x	x				Not reported.	Not reported.	No
[116]Hackmann (2011), USA	Single item electronic medical record EWS	X	x		x	x			Electronic medical record included 398 variables. Highest-weighted variables from the training set included shock index, coagulation modifiers, DBP	Electronic (algorithm-based)	Not reported.	No
[51]Hayani (2011), Canada	Single items for activating RRS team	X	x		x	x			GCS, urine output.	Not reported.	Not reported.	Not reported.

Table 4.1 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – one EWS only studies (continued)

Author, Country	No of parameters, Name of EWS	Parameters included in EWS								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[89]Hollis (2016), UK	6-item ViEWS	X	x		x	x	X	x		Not reported	Not reported	Yes (0-3)
[115]Howell (2012), USA	Single items for activating RRS team	X	x		x	x			Acute change in conscious state, urine output, nursing concern.	Not reported.	Not reported.	Not reported.
[91]Huddart (2015), UK	EWS part-1 of a 5-part care bundle (ELPQuiC).	Not reported.							Not reported.		Not reported.	Not reported.
[92]Jarvis (2013), UK	7-item LDT-EWS								Haemoglobin, WBC, serum urea, serum albumin, serum creatinine, serum sodium, serum potassium.	Electronic	Not reported.	Yes (0-3)
[93]Jarvis (2015a), UK	7-item NEWS	x	X	x	x	x	x	x		Electronic	Not reported.	Yes (0-3)
[114]Jones (2013), USA	4-item VSA EWS	x	X		x	x				Electronic	4-hourly	Yes (0-2)
[88]Jones (2011), UK	4-item Patientrack	x			x	x	x			Electronic	4-hourly	Yes (0-3)
[45]Joshi (2017), Australia	7-item Q-ADDS	x	X	x	x	x	x	x		Paper-based	As requested	Yes (0-3)
[62]Jung (2016), France	Single items for RRS		X	x	x	x			Cardiac arrest, respiratory arrest or distress, coma, seizure	Not reported	Not reported	Not applicable
[38]Kansal (2012), Australia	4-item EWS	x			x	x			GCS	Not reported.	Not reported.	No
[125]Karpman (2013), USA	Single items for activating RRT.	x	X		x	x			Staff concern, acute chest pain, change in conscious state, new onset of symptoms suggestive of stroke.	Not reported.	Not reported.	No
[52]Karvellas (2011), Canada	Single items for activating MET team	x	X		x	x			Change in level of consciousness, staff concern.	Not reported.	Not reported.	No
[72]Kim (2017), South Korea	Single items for activating RRS.	x	X		x	x		x	pH, $PaCO_2$, PO_2, Lactic acid level, total CO_2 level	Electronic	Not reported.	No
[126]Kirkland (2013), USA	10-item EWS	x			x	x		x	DBP, mean arterial pressure, shock index, arterial oxygen saturation by pulse oximetry (SaO2), Braden scale, Hendrich II Fall Risk Score.	Electronic	Not reported.	No
[127]Kollef (2017), USA	MEWS	Not reported.								Electronic	Not reported.	Not reported.
[94]Kovacs (2016), UK	8-item NEWS	x	X	x	x	x	x	x	DBP	Electronic	6-7 hours on average	Yes (0-3)
[58]Liljehult (2016), Denmark	7-item ViEWS	x		x	x	x	x	x	SaO2	Not reported.	12-hourly	Yes (0-3)

Table 4.1 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – one EWS only studies (continued)

Author, Country	No of parameters, Name of EWS	Parameters included in EWS								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[78]Van Galen (2016), The Netherlands	8-items MEWS	x	X		x	x	x	x	Urine output, staff concern	Electronic	Once a day (morning)	Yes (0-3)
[79]Ludikhuize (2014), The Netherlands	8-items MEWS	x	X		x	x	x	x	Urine output, staff concern	Paper-based	8-hourly	Yes (0-3)
[80]Ludikhuize (2015), The Netherlands	MEWS	Not reported.								Not reported.	Not reported.	Yes (0-3)
[128]Mathukia (2015), USA	5-item MEWS	x			x	x	x	x		Paper-based	4-hourly	Yes (0-3)
[95]Moon (2011), UK	7-item MEWS	x	X		x	x	x	x	Urine output	Not reported.	4-hourly	Yes (0-3)
[129]Moriarty (2014), USA	Not reported – focus on RRT	Not reported.								Not reported.	Not reported.	Not reported.
[46]Massey (2015) Australia	Single items for activating RRT	x	X		x	x		x	GCS, urine output	Not reported	Not reported	Not applicable
[130]Moroseos (2014), USA	Single items for activating RRT	x	X		x	x		x	Conscious state, stridor-noisy airway, ABG orders for respiratory concerns, chest pain, transfusion >4U PRBC in last 24 hrs, decrease in HCT by > 6 points in last 24 hrs.	Not reported.	Not reported.	Not reported.
[96]Morris (2013), UK	Modified MEWS	Not reported.								Not reported	Not reported.	Yes (0-3)
[39]Mullany (2016), Australia	4-item MEWS	x	X		x	x				Electronic	Not reported.	Yes (0-3)
[61]Martin (2015), France	13-item DULK EWS	x				x		x	Oliguria (diuresis < 700 mL/d), agitation or lethargy, clinical deterioration, Ileus, gastroparesia, evisceration, abdominal or parietal pain, elevated WBC count, elevation blood creatinine or urea >5%, enteral nutrition tube or parenteral nutrition.	Not reported.	Minimum once a day.	Yes (0-2)
[40]Nguyen (2015), Australia	11-item SCS EWS	x	X	x		x		x	Age, ECG, diabetic (insulin oral glycaemic meds), BP, mental status, stand unaided.	Not reported.	Not reported.	Yes (not reported)
[68]Nishijima (2016), Japan	6-item MEWS	x			x	x	x	x	Staff concern	Electronic	Not reported.	Yes (0-3)

Table 4.1 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – one EWS only studies (continued)

Author, Country	No of parameters, Name of EWS	Parameters included in EWS								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[131]Parrish (2017), USA	7-item MEWS	x	X		x	x	x	x	O_2 delivery methods	Electronic	Not reported.	Yes (0-3)
[97]Patel (2011), UK	7-item MEWS	x				x	x	x	BP, urine catheterised, non-catheterised	Not reported.	Not reported.	Yes (0-3)
[98]Pattison (2012), UK	15-item MEWS	x				x		x	BP, urine output, potassium, magnesium, GCS, fluid assessment, chest exam, procalcitonin, cap refill, bowel assessment, ECG, DNAR order.	Paper-based	Not reported.	Yes (0-3)
[66]Peris (2012), Italy	5-item MEWS	x			x	x	x	x		Not reported.	Not reported.	Yes (0-3)
[59]Petersen (2016), Denmark	7-item NEWS	x	X	x	x	x	x	x		Electronic	12-hourly	Yes (0-3)
[132]Picker (2017), USA	36-item algorithm-based EWS	x	X		x	x		x	Age, alanine aminotransferase, alternative medicines, anion gap, anti-infectives, antieoplastics, aspartate aminotransferase, biologicals, DBP, serum calcium, serum calcium ionized, cardiovascular agents, CNS agents, Charlson index, coagulation modifiers, estimated creatinine clearance, GI agents, genitourinary tract agents, hormones, immunologic agents, serum magnesium, metabolic agents, miscellaneous agents, nutritional products, serum phosphate, serum potassium, psychotherapeutic agents, radiologic agents, respiratory agents, shock index, topical agents.	Electronic	Not reported.	No.
[133]Rothberg (2012), USA	Single items for activating MET	x	X		x	x	x		Staff concern	Not reported.	Not reported.	No.
[63]Sabahi (2012), Iran	Single items for activating RRT	x	X		x	x			Respiratory distress including wheezing and congestion, significant bleeding, changes in consciousness or seizures, chest pain, uncontrolled pain, restlessness	Not reported.	Not reported.	No.
[134]Salvatierria (2014), USA	Single items for activating RRT in 10 different hospitals.	Not reported.								Not reported.	Not reported.	Not reported.

Table 4.1 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – one EWS only studies (continued)

Author, Country	No of parameters, Name of EWS	Parameters included in NEWS								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[53]Scherr (2012), Canada	Single items for activating RRT in 2 different hospitals.	x			x	x	x		Staff concern, airway concerns.	Not reported.	Not reported.	No.
[99]Schmidt (2014), UK	EPSS – VitalPac EWS	Not reported.		Electronic	Not reported.	Not reported.						
[157]Sebat (2018), USA	Single items for activating RRT	x	X	x	x	x		x	Pain, mental status, capillary refill, urine output, base deficit, lactic acid	Not reported	Not reported	Not applicable
[135]Segon (2014), USA	Single items for activating RRT	x	X		x	x			Change in breathing pattern, urine output, seizures, change in mental status, staff concern, family concern.	Not reported.	Not reported.	No.
[136]Shah (2011), USA	Single items for activating RRT	x	X	x	x	x			Change in mental status, staff concern, threatened airway.	Not reported.	Not reported.	No.
[81]Simmes (2012), The Netherlands	Single parameter track and trigger system for activating MET.	x	X		x	x			Eye, motor verbal (EMV) score, staff concern.	Not reported.	Not reported.	No.
[82]Simmes (2013), The Netherlands	Single parameter track and trigger system for activating MET.	x	X		x	x			Eye, motor verbal (EMV) score, GCS.	Not reported.	8-hourly	No.
[83]Smith (2012), The Netherlands	8-item MEWS	x	X		x	x	x	x	Urine output, staff concern.	Not reported.	8-hourly	Yes (0-3)
[137]Stewart (2014), USA	MEWS	Not reported.								Electronic	Not reported.	Not reported.
[138]Stark (2015), USA	5-item MEWS	x			x	x	x	x		Not reported.	24-hourly	Yes (0-3)
[100]Suppiah (2014), UK	8-item MEWS	x	X	x	x	x	x	x	Urine output	Not reported.	6-hourly	Yes (0-3)
[158]Tarassenko (2011), UK and USA	4-item centile-based EWS	x	X		x	x				Electronic	Not reported.	No.

Table 4.1 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – one EWS only studies (continued)

Author, Country	No of parameters, Name of EWS	Parameters included in NEWS								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[67]Tirotta (2017), Italy	5-item MEWS	x			x	x	x	x		Not reported	Not reported	Not reported
[139]Umscheid (2015), USA	7-item sepsis EWRS	x			x	x		x	$PaCO_2$, WBC count, serum lactate	Electronic	Real-time	No
[77]Uppanisakorn (2018), Thailand	7-item NEWS	x	X	x	x	x	x	x		Not reported	Not reported	Yes (0-3)
[84]Van Rooijen (2013), The Netherlands	8-item EWS	x	X		x	x	x	x	Staff concern, urine output	Electronic	Not reported	Yes (0-3)
[74]Yoo (2015), South Korea	10-item MEWS	x			x	x		x	GCS, WBC count, platelets, lactate, CRP, procalcitonin	Not reported	Not reported	Not reported
[153]Young (2014), USA	7-item MEWS	x	X		x	x		x	Shortness of breath, changes in mental status	Not reported	4-hourly	Yes (0-3)
[64]Zimlichman (2012), Israel	2-item Early sense continuous measurement monitor	x				x				Electronic	Near real time	No

Key: The seven parameters listed are those that are specific to the National Early Warning Score (i.e. RR, SpO_2, FiO_2, SBP, HR, AVPU, and Temperature). **ABG:** Arterial blood gas test; **ADDS**: Adult deterioration detection system; **AVPU**: Alert voice pain unresponsive; **BP:** Blood pressure; **CNS**: Central nervous system; **CRP:** C-Reactive Protein; **DBP**: Diastolic blood pressure; **DENWIS**: Dutch Early Nurse Worry Indicator Score; **DNAR**: Do not attempt resuscitation; **DULK**: Dutch Leakage EWS; **ECG**: electrocardiogram; **ELPQuiC**: Emergency laparotomy pathway quality improvement care; **EPSS**: electronic physiological surveillance system; **EWRS**: Early warning response system; **FiO_2**: Inspired oxygen; **GCS**: Glasgow coma scale; **GI**: Gastrointestinal; **HCT**: haematocrit blood test; **HR**: Heart rate; **LDT-EWS**: Laboratory-based decision tree EWS; **LOC:** Level of consciousness; **MEWS:** Modified early warning score; **MET**: Medical emergency team; **NEWS**: National Early Warning score; **$PaCo_2$**: carbon dioxide; **PRBC**: Packed Red Blood Cells; **Q-ADDS**: Queensland ADDS; **RRT/RRS**: Rapid response team/system; **RR**: respiratory rate; **SBP:** Systolic blood pressure; **SCS**: Simple Clinical Score; **SpO_2**: Oxygen saturation; **ViEWS**: VitalPAC EWS; **VSA-EWS**: Vital sign alert system; **VSS**: Vital Sign Score; **WBC**: White blood cell count

Table 4.2 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – two or more EWSs

Author, Country	No of parameters, Name of EWSs	Parameters included in EWS								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[101]Abbott (2015), UK	7-item NEWS vs. 7-item PARS.	x	x	x	x	x	x	x		Paper-based	Admission & throughout	Yes (0-3)
		x	x		x	x	x	x	Urine output			Yes (0-3)
[140]Alaa (2018), USA	10-item EWS vs. MEWS, APACHE II, the Rothman Index and SOFA EWS.		x	x		x		x	DBP, eye opening, GCS, WBC, glucose, urea nitrogen.	Electronic (algorithm-based)	Real-time data	No
		Parameters not reported for MEWS, APACHE II, the Rothman Index and SOFA EWS.							Parameters not reported for MEWS, APACHE II, the Rothman Index and SOFA EWS.			
[141]Alvarez (2013), USA	14-item EWS vs.		x						Demographic (Age), vital signs (DBP) lab tests (aspartate aminotransferase [AST], PCO_2 <22, PCO_2>70, WBC >11, platelets <100, Potassium >51), physician orders (arterial blood gas, ECG, stat physician order) and summary variables (high risk floor assignment, MEWS)	Electronic (algorithm-based)	Near-real time data	No
	6-item MEWS	x	x		x	x		x	Diastolic BP			
[102]Badriyah (2014), UK	7-item DTEWS vs. 7-item NEWS	x	x	x	x	x	x	x		Electronic (algorithm-based)	Not reported	Yes (0-3)
		x	x	x	x	x	x	x				
[54]Bian (2015), China	5-item Super Score EWS vs. 5-item MEWS	x	x			x		x	urine volume, emotional state	Paper-based	Hourly	Yes (0-2)
		x			x	x	x	x				
[142]Bleyer (2011), USA	7-item Critical Vital Sign EWS vs. ViEWS and MEWS	x	x		x	x	x	x	Age	Electronic	According to physician orders	Yes (0-3)
		Not reported in paper.										
[41]Boulos (2017), Australia	SIRS EWS vs. qSOFA	Not reported in paper.								Electronic	Not reported	Yes (0-4)
												Yes (0-3)
[154]Churpek (2016), USA	9 machine learning techniques compared to the MEWS	x	x		x	x	x	x	Age, time since ward admission, No. previous ICU stays, electrolytes, creatinine, liver function tests, WBC count; glucose; BUN; platelet count; Hemoglobin; DBP; pulse pressure Index; calcium; bicarbonate; chloride; potassium; anion gap; sodium; alkaline phosphatase; serum glutamic oxaloacetic transaminase; total protein; total bilirubin; albumin	Electronic (algorithm-based)	8-hourly	No

Table 4.2 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – two or more EWSs (continued)

Author, Country	No of parameters, Name of EWS	Parameters included in EWS								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[143]Churpek (2012a), USA	4-item CART vs.	x				x			DBP, age	Electronic	Not reported.	Yes (0-22)
	5-item MEWS	x			x	x	x	x				Yes (0-3)
[144]Churpek (2013), USA Comparison of 8 different EWSs	5-item MEWS	x			x	x	x	x		Electronic	Not reported.	Yes (0-3)
	7-item ViEWS	x	x	x	x	x	x	x				Yes (0-3)
	6-item SEWS	x	x		x	x	x	x				Yes (0-3)
	4-item CART	x				x			DBP, age			Yes (0-22)
	Single parameter, MERIT	Not reported in study.										No
	Single parameter, modified MERIT	Not reported in study.										No
	Multiple parameter, Bleyer et al. EWS	Not reported in study.										No
	Tarassenko et al. centile-based EWS	x	x		x	x						Yes (0-3)
[145]Churpek (2014), USA	Cardiac arrest model vs.	x	x	x		x	x	x	Prior ICU stay, DBP, age, BUN, anion gap, haemoglobin, platelet count, potassium, WBC count.	Electronic	Not reported.	No.
	ViEWS	Not reported in study.										
[155]Churpek (2017), USA	SIRS	x				x		x	WBC count	Electronic	Near real time data	No
	qSOFA	x			x		x		GCS			
	MEWS	As reported in Smith (2013)[8]										
	NEWS											
[146]Churpek (2014a), USA	23-item eCART EWS vs.	x	x		x	x	x	x	White cell count, haemoglobin, platelets, sodium, potassium, chloride, bicarbonate, anion gap, BUN, creatinine, glucose, calcium, total protein, albumin, total bilirubin, aspartate aminotransferase, alanine aminotransferase, alkaline phosphatase	Electronic	Not reported.	No
	MEWS	Not reported in study.										Yes (0-3)
[103]Cooksley (2012), UK	7-item MEWS vs.	x	x		x	x	x	x	Urine output	Not reported.	Not reported.	Yes (0-3)
	7-item NEWS	x	x	x	x	x	x	x				Yes (0-3)
[104]Dawes (2014), UK	6-item Worthing PSS vs.	x	x		x	x	x	x		Electronic	Not reported.	Yes (0-3)
	NEWS	Not reported.										Yes (0-3)

Table 4.2 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – two or more EWSs (continued)

Author, Country	No of parameters, Name of EWS	Parameters included in EWS								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[49]DeMeester (2013a), Belgium	6-item MEWS vs. SAPS 3	x	x		x	x	x	x		Paper	12-hourly	Yes (0-3)
		Not reported.										
[13]Eccles (2014), UK	7-item CREWS vs.	x	x	x	x	x	x	x		Paper	Not reported.	Yes (0-3)
	7-item NEWS	x	x	x	x	x	x	x				Yes (0-3)
[147]Escobar (2012), USA	14-item electronic EWS vs.	x	x		x	x	x	x	Directive status; LAPS; COPS; COPS status; LOS; time of day; DBP; lab tests	Electronic	Not reported.	No
	MEWS	Not reported.										Yes (0-3)
[152]Finlay (2014), USA	26-item RI vs. 5-item MEWS	x	x		x	x		x	DBP, creatinine, BUN, serum chloride, serum potassium, serum sodium, WBC count, haemoglobin, Braden scale, neurological, genitourinary, respiratory, food, skin, GI, musculoskeletal, cardiac, psychosocial, safety, sinus rhythm	Electronic	Not reported.	No
		x			x	x	x	x				Yes (0-3)
[65]Ghanem-Zoubi (2011), Israel	5-item MEWS vs.	x			x	x	x	x		Electronic	Not reported.	Yes (0-3)
	14-item SCS vs.	x	x		x	x		x	Age, nursing home resident, mental status, functional status, diabetes (1 or 2), new stroke on presentation, coma without intoxication or overdose, breathless on presentation, abnormal ECG			Not reported
	10-item MEDS vs.	x	x						Age, nursing home resident, mental status, terminal illness, lower RTI, septic shock, platelet count, percent bands in differential count.			Not reported
	7-item REMS	x	x			x		x	Age, MAP, GCS			Not reported.
[111]Hodgson (2017), UK	NEWS vs. CREWS vs. S-NEWS	Not reported								Electronic	Not reported	Not reported

Table 4.2 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – two or more EWSs (continued)

Author, Country	No of parameters, Name of EWSs	Parameters included in EWSs								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[105]Jarvis (2015b), UK	7-item binary NEWS vs.	x	x	x	x	x	x	x		Electronic	Not reported.	Yes (0-1)
	7-item NEWS	x	x	x	x	x	x	x				
[106]Jarvis (2015c), UK	Compared 35 published EWS—33 previously compared by Smith et al[8] the CART model and the centiles EWS.	x	x	x	x	x	x	x	DBP, age	Electronic	Not reported.	Varies – 35 different EWSs
[73]Jo (2013), South Korea	VIEWS-L compared to	x	x	x	x	x	x	x	Lactate level (using arterial blood or venous blood lactate levels)	Not reported.	Not reported.	Yes (0-3)
	HOTEL, APACHE II, SAPS II, SAPS III and VIEWS EWS	Not reported.										Not reported.
[156]Kipnis (2016) USA	AAM model compared to the NEWS and eCART	x	x		x	x		x	DBP, neurological status, shock index, lab tests (anion gap, bicarbonate, glucose, hematocrit, lactate, BUN, creatinine, sodium, troponin, WBC count) LAPS2, COPS2, LOS, age, sex, care directive, season, time of day, admission category, hospital	Electronic (algorithm-based)	4-8 hourly	No
		Not reported										
[70]Luís (2017), Portugal	'Short NEWS' vs. 7-item NEWS	x	x	x	x	x	x			Electronic	Not reported	Yes (0-3)
		x	x	x	x	x	x	x				Yes (0-3)

Table 4.2 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – two or more EWSs (continued)

Author, Country	No of parameters, Name of EWSs	Parameters included in NEWS								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other - specify			
[148]Moseson (2014), USA	Compared 7-item REMS,	x				x		x	MAP, pulse oximetry, GCS total, age.	Electronic	Not reported.	Not reported.
	7-item MEWS,	x			x	x		x	GCS visual, GCS motor, GCS speech.			
	6-item Seymour EWS and	x			x	x			Pulse oximetry, GCS total, age			
	6-item PEDS (ED-based EWSs)				x				GCS total, metastatic cancer, serum glucose, serum bicarbonate, WBC			
	to 18-item SAPS II,			x	x	x		x	GCS total, age, metastatic cancer, hematologic malignancy, AIDS, medical admission, unplanned surgery, serum bicarbonate, WBC, 24-hr urine, serum BUN, serum potassium, serum sodium, serum bilirubin			
	18-item APACHE II, and	x		x		x		x	MAP, GCS total, age, chronic disease and elective post-op, chronic disease and emergency post-op, chronic disease and non-operative, immunosuppressed, WBC, hematocrit, serum Cr, serum potassium, serum sodium, A-a gradient, pH on ABG, acute renal failure.			
	31-item APACHE III (ICU-based EWS)	x				x		x	MAP, GCS, visual, motor and speech, age, chronic disease and elective post-op, chronic disease and non-operative, metastatic cancer, hematologic malignancy, Immunosuppressed, AIDS, hepatic failure/cirrhosis, serum glucose, WBC, hematocrit, urine output, serum Cr, serum BUN, serum potassium, serum sodium, serum bilirubin, PaO_2/FiO_2, A-a gradient, pH on ABG, pCO2 on ABG, renal failure.			
[60]Pedersen (2018), Denmark	7-item NEWS vs.	x	x	x	x	x	x	x		Electronic	Near-real time	Yes (0-3)
	7-item CROS vs.	x	x	x	x	x	x	x	Option for doctors to apply acceptable chronic value limits to all parameters except temperature for individual patients. NEWS variable values within the acceptable chronic value limits do not generate points. NEWS variable values outside the acceptable chronic limits generate the full NEWS points for that variable value.			
	7-item CREWS vs.	x	x	x	x	x	x	x	Points as in NEWS, except modified score for arterial oxygen saturation in patients with chronic hypoxaemia			
	7-item S-NEWS	x	x	x	x	x	x	x	Points as in NEWS, except modified score for arterial oxygen saturation based on an individual target range in patients with chronic hypoxaemia (usually 88-92%)			
[112]Pimentel (2018), UK	7-item NEWS	x	x	x	x	x	x	x		Electronic	Real-time	Yes (0-3)
	7-item NEWS2	x	x	x	x	x	x	x	Differs in weights assigned to SpO_2 only (below 88%)			Yes (0-3)

Table 4.2 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – two or more EWSs (continued)

Author, Country	No of parameters, Name of EWSs	Parameters included in EWSs								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other – specify			
[56] Qin (2017), China	APACHE II vs.	Not reported								Not reported	Not reported	Not reported
	Shock index vs.	HR/SBP										
	SOFA vs.	Not reported										
	7-item MEWS	x	x		x	x		x	Age, consciousness			Yes (0-3)
[75]Reini (2012), Sweden	5-item MEWS vs.	x			x	x	x	x		Not reported.	Hourly	Yes (0-3)
	SOFA and	Not reported.										Not reported.
	SAPS III	Not reported.										Not reported.
[149]Romero-Brufau (2014), USA	Single item RRT calling criteria compared to MEWS, SEWS, GMEWS, Worthing, ViEWS and NEWS EWS	x	x		x	x				Electronic	Not reported.	No
		Not reported for comparison EWSs.										Yes (0-3)
[150]Rothman (2013), USA	26-item RI compared to MEWS and APACHE III.	x	x		x	x		x	DBP, nursing assessments (cardiac, respiratory, GI, genitourinary, neurological, skin, safety, peripheral vascular, food/nutrition, psychosocial, musculoskeletal, Braden score), lab(creatinine, sodium, chloride, potassium, BUN, WBC, haemoglobin), cardiac rhythm.	Electronic	4-hourly	No
	MEWS and APACHE III.	Not reported for comparison EWSs.										Yes (0-3)
[113]Smith (2016), UK	NEWS vs.	x	x	x	x	x	x	x	DBP, date and time of observation set	Electronic	Not reported	Yes (0-3)
	44 different MET criteria	x	x	x	x	x	x	x	Threatened airway, respiratory/cardiac arrest, GCS, seizure, concern			No
[8]Smith (2013), UK	7-item NEWS compared to	x	x	x	x	x	x	x		Electronic	Not reported.	Yes (0-3)
	33 other EWSs.	Not reported.										
[107]Subbe (2017), UK	NEWS, CREWS or palliative NEWS (without a trigger) as appropriate	x	x	x	x	x	x	x		Electronic	12-hourly	Yes (0-3)
[55]Xiao (2012), China	8-item AFSS EWS vs. MEWS	x				x		x	MAP, age, past medical history, fever course, WBC count.	Electronic	Not reported.	Yes (0-3)

Table 4.2 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – two or more EWSs (continued)

Author, Country	No of parameters, Name of EWSs	Parameters included in EWSs								Paper-based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other – specify			
[151]Yu (2014), USA	Compared 9 EWS, 6-item SOFA vs.	x	x	x	x	x	x	x	MAP, PFR, bilirubin, GCS, platelets, creatinine.	Not reported.	Not reported.	Not reported.
	7-item ViEWS vs. 14-item PIRO vs.	x	x		x	x			Age, metastatic malignancy, nursing home resident, pneumonia, WBC, platelets, BUN, lactate, COPD, chronic liver disease			
	14-item SCS vs.	x	x		x	x		x	Age, nursing home resident, altered mental status, coma, functional status, SOB, Abn EKG, new stroke, diabetes.			
	10-item MEDS vs.	x	x						Age, metastatic malignancy, nursing home resident, pneumonia, altered mental status, WBC, platelets, septic shock.			
	6-item MEWS vs.	x			x	x	x	x	Age			
	15-item SAPS II vs.		x		x	x		x	Age, type of admission, metastatic malignancy, total bilirubin, GCS, WBC, sodium, potassium, bicarbonate, BUN, AIDS.			
	15-item APACHE II vs. 7 item REMS	x	x			x		x	Age, type of admission, MAP, GCS, WBC, sodium, potassium, pH, creatinine, hematocrit, glucose, Hx of severe organ insufficiency.			
		x	x			x		x	Age, MAP, GCS			

Key: The seven parameters listed are those that are specific to the National Early Warning Score (i.e. RR, SpO_2, FiO_2, SBP, HR, AVPU, and Temperature). **AAM:** Automated alert model; **ABG**: Arterial blood gas test; **Abn EKG**: abnormal ECG; **AFSS**: Adult Fever State Score; **AIDS**: Acquired immunodeficiency syndrome**; APACHE**: Acute Physiology and Chronic Health Evaluation; **AVPU**: Alert voice pain unresponsive; **BP**: Blood pressure; **BUN**: serum blood urea nitrogen; **CART**: Cardiac Arrest Triage Score; **COPD**: Chronic obstructive pulmonary disease; **COPS**: Colloid Osmotic Pressure status; **Cr**: creatinine; **CREWS**: Chronic respiratory EWS; **CROS**: Capital Region of Denmark Overide System; **DBP**: Diastolic blood pressure; **DTEWS**: Decision-tree EWS; **eCART:** electronic CART; **ECG**: electrocardiogram; **FiO_2**: Inspired oxygen; **GCS:** Glasgow coma scale; **GI:** Gastrointestinal; **GMEWS**: Global modified EWS; **HOTEL:** Hypotension, Oxygen saturation, low Temperature, ECG change and Loss of independence EWS; **HR**: Heart rate; **Hx:** History of; **ICU:** Intensive Care Unit; **LAPS**: leukocyte alkaline phosphatase; **LOS**: Length of stay; **MAP**: Mean arterial pressure; **MEDS**: Mortality in Emergency Department Sepsis; **MERIT**: Medical Early Response Intervention and Therapy; **MEWS**: Modified early warning score; **NEWS:** National Early Warning score; **PARS:** Patient at risk score; **PEDS**: Prince of Wales Emergency Department Score; **PIRO:** Predisposition/Infection/Response/Organ Dysfunction Score; **PFR:** peak flow rate; **qSOFA**: Quick SOFA; ; **RI**: Rothman Index; ICU: Intensive care unit; **REMS**: Rapid Emergency Medicine Score; **RTI**: Respiratory tract infection; **RRT/RRS**: Rapid response team/system; **RR:** respiratory rate; **SAPS**: Simplified acute physiology score; **SBP**: Systolic blood pressure; **SCS**: Simple Clinical Score; **SEWS**: Standardised EWS; **SIRS**: Systemic Inflammatory Response Syndrome; **S-NEWS**: Salford-NEWS **SOB**: Shortness of breath; **SOFA**: Sequential Organ Failure Assessment; **SpO_2**: Oxygen saturation; **ViEWS:** VitalPAC EWS; **ViEWS-L**: VitalPAC lactate; **WBC**: White blood cell count; **Worthing PSS:** Physiological Scoring System

Table 4.3 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – EWS chart design-based interventions

Author, Country	Study design, Setting	Sample size, Study duration	Paper-based or electronic chart	Intervention	Data collection	Parameters recorded on chart, Frequency
[42]Christofidis (2013), Australia	Quasi-experimental (mixed-design with chart experience group[between subjects] and chart-type [within subjects] as independent variables); two hospitals in Queensland	N=64 doctors and nurses with prior track and trigger EWS chart experience and N=37 participants with experience of EWS charts (without a track and trigger component) recruited between Sept 2010 and Apr 2011.	Paper-based	The study focuses on chart design. 6 different chart designs based on the adult deterioration detection system (ADDS) EWS were compared. Across 48 trials, participants viewed each set of patient data once. The 6 chart designs were each used on 8 trials, 4 times with abnormal patient data and 4 times with normal patient data in a random order and participants judged whether data observations were abnormal or normal. Responses and response times recorded in computerised programme.	Participants completed baseline questionnaire assessing clinical background. Training video presented in a random order to each participant was then viewed. Participant's knowledge of normal parameter ranges tested in 10-item MCQ.	RR, SpO_2, FiO_2, SBP, DBP, HR, temperature, urine output and level of consciousness. Not reported.
[43]Christofidis (2014), Australia	3x2x2 mixed design quasi experimental trial with 3 independent variables (participant group, graph format (separate versus overlapping) and alert system (track and trigger present versus absent)); Brisbane University and tertiary hospital.	N=41 nurses purposively sampled and N=113 novice chart users conveniently sampled from undergraduate psychology programme, recruited Jan and May 2011.	Paper-based	Comparison of 4 chart designs for BP and HR compared. 1) separate graphs for BP, HR 2) overlapping graphs for BP, HR 3) Integrated colour-based track and trigger system present 4) No track and trigger system present. Two groups: all nurses and a random selection of novices were assigned to watch a video on the 'Seagull method'. Remaining novices were 'untrained'. The seagull sign equates to a shock index score (e.g. heart rate) physiologically.	N=64 cases of genuine de-identified patient data, collected from several Australian hospitals used. Each case spanned 13 consecutive time points and included data for the 3 vital signs relevant to the 'Seagull Sign': SBP, DBP and HR. Four chart design extracts, based on observation chart designs currently used in Australia were created for use in this study.	BP, HR Not reported.

Table 4.3 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – EWS chart design-based interventions (continued)

Author, Country	Study design, Setting	Sample size, Study duration	Paper-based or electronic chart	Intervention	Data collection	Parameters recorded on chart, Frequency
[44]Christofidis (2015), Australia	Quasi-experimental factorial design (within-subjects, with scoring system design as the independent variable); University of Queensland	N=47 novice chart users who received course credit for participation Dec 2012 and Jan 2013.	Paper-based	The different ADDS based chart designs used in the experiment, varied only in relation to the arrangement of the rows for recording individual vital sign scores. These scoring-rows were either: 1. grouped together beneath all of the vital sign data ('grouped rows'); 2. separated, with each row presented immediately below the corresponding vital sign data ('separate rows') or 3. excluded altogether ('no rows'). All 3 chart designs included a row for recording overall early-warning scores at the bottom of the page	Novice chart-users were presented with realistic vital sign observations recorded on charts with 3 different scoring-system designs. Participants' response times and error rates for determining the overall scores were measured for 54 time-points per design. Each chart design was used on 3 blocks of trials (i.e. 54 trials per design) and the 9 cases were randomly assigned to the 3 chart designs for each participant. To prevent order effects, the blocks were presented in a different random order for each participant.	RR, SpO_2, FiO_2, SBP, DBP, HR, Temperature, urine output, level of consciousness. Not reported.
[108]Fung (2014), UK	Observational cohort study; Department of Surgery, Basildon and Thurrock University Hospitals, UK.	N=100 HCPs including n=53 foundation year physicians, n=8 senior house officers, n=7 specialist registrars, n=6 ward sisters and n=26 registered nurses; Study dates not reported.	Paper-based	PARS implemented as part of the Leading Improvements in Patient Safety Programme (LIPS) within hospital. This revised chart aimed to improve the detection and management of deteriorating patients by incorporating early warning scores with routine observations. 6 clinical scenarios (low-grade temperature, spiking temperature, tachypnea, Cushing's response, hypovolemic shock and normal observations) were identically depicted on old and new charts, creating 12 charts.	100 health care professionals were asked to study each of the charts, and the time taken to give a diagnosis was recorded. Time taken and accuracy of response were compared between the 2 charts. Old chart: graphic depiction of observations; New chart: EWS numerically depicted observations	RR, SpO_2, SBP, HR, AVPU, Temperature, Urine output. Not reported.

Table 4.3 Characteristics of EWSs currently in use for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings – EWS chart design-based interventions (continued)

Author, Country	Study design, Setting	Sample size, Study duration	Paper-based or electronic chart	Intervention	Data collection	Parameters recorded on chart, Frequency
Christofidis (2015a), [47]Australia	A 2 x 2 x 2 x 2 mixed factorial RCT design, with data-recording format (drawn dots vs. written numbers), scoring-system integration (integrated colour based system vs. non-integrated tabular system) and scoring-row placement (grouped vs. separate) varied within-participants and scores (present vs. absent) varied between-participants by random assignment; Brisbane University, in Queensland	N=205 novice chart users recruited from Brisbane University recruited between Mar 2011 - Mar 2014. N=188 included in final analysis.	Paper-based	Participants were assigned to one of two conditions using a random sequence generated by Microsoft Excel 2011:(1) 'scores present', where all charts had real scores recorded on them (n=102); or (2) 'scores absent', where all charts contained uninformative fillers (the letter 'U') in place of the real scores (n=103). Participants completed 64 trials where they saw real patient data presented on an observation chart. Each participant saw eight cases (four containing abnormal observations) on each of eight designs (which represented a factorial combination of the within participants variables). On each trial, they assessed whether any of the observations were physiologically abnormal, or whether all observations were normal.	Each participant was trained and tested individually in a quiet room. After completing a demographic questionnaire, participants watched a series of training videos that explained: (a) the ten vital signs included in the chart and their normal ranges; (b) track and trigger systems; and (c) how to use each chart design (presented in different random order). Key concepts and vital sign normal ranges were tested with a 10-item MCQ. Participants scoring below 100% studied a summary and retook the examination until they answered everything correctly. A final video explained the experiment and indicated that responses and response times would be recorded.	10 parameters included in the ADDS chart: RR, SpO_2, FiO_2, SBP, DBP, HR, temperature, 4-hour urine output, consciousness and pain Not reported

Key: EWS: Early warning system; **ADDS:** Adult deterioration detection system; **BP**: Blood pressure; **HR**: Heart rate; **MCQ**: Multiple choice question; **SBP**: Systolic blood pressure; **DBP**: Diastolic blood pressure; **RCT:** Randomised Controlled Trial; **RR**: Respiratory rate; **SpO_2**: Oxygen saturation; **FiO_2**: Inspired oxygen; **HCP**: Health care professional; **PARS:** Patient at risk score; **LIPS**: Leading improvements in patient safety programme; **AVPU**: Alert, voice, pain, unresponsive

4.3 Summary

In total, 123 studies conducted across 22 different countries were eligible for inclusion in this descriptive overview of EWSs in adult (non-pregnant) populations. The EWSs varied with 47 different named EWSs included (for example the NEWS, ViEWS, etc.), 13 unnamed EWSs, 23 studies which only included a single criterion for activating the emergency response system and two studies which did not provide details on the EWSs included. In addition, not only did the EWSs vary, but the number, type and frequency of measurement of vital sign parameters included varied with some studies having as little as two and one algorithm-based EWS including almost 400 parameters. The majority of the 79 studies, where it was reported, included electronic rather than paper based EWSs and 44 studies did not report or it was not clear, what type of EWS it was. Importantly, the majority of the 123 studies did not report how often parameters were measured (n=83) which can effect performance of an EWS, and where they did, it varied from study to study. There were 71 studies which included one or more aggregated EWSs and the weighting varied across studies.

Overall, a large number of EWSs have been described in the literature and reported in this descriptive overview. However these vary in many ways, making it difficult to compare the systems.

5 Results: The impact on patient outcomes and resource utilisation of early warning systems interventions for the detection of physiological deterioration in adult (non-pregnant) patients in acute health care settings

5.1 Chapter overview

This chapter in the systematic review focusses on the literature pertinent to question two of the review. "*How effective are the different EWSs in terms of improving key patient outcomes in adult (non-pregnant) patients in acute health care settings?*" This specific chapter reports on the afferent limb (i.e. recognition and escalation based-early warning systems) and their effectiveness in terms of the primary outcomes (mortality, cardiac arrest, length of stay, transfer or admission to the ICU), and secondary outcomes (clinical deterioration in sub-populations, PROMs [validated tools] and any other outcomes identified post-hoc).

5.2 Overview of studies focusing on the effectiveness of EWSs

There were 21 studies which focussed on the effectiveness of EWSs on various patient outcomes and resource utilisation.[48, 49, 57, 59, 66, 68, 69, 78, 79, 88, 91, 97, 99, 107, 109, 114, 118, 131, 132, 137, 153] These included three RCTs,[59, 118, 132] two nRCTs,[79, 107] one interrupted time series[57]and 15 observational studies (including before-after studies and cohort studies).[48, 49, 66, 68, 69, 78, 88, 91, 97, 99, 109, 114, 131, 137, 153] Sample size ranged from 39 patients in one study[131] to 105,647 in another[99] and was not reported in one study[114] (**Table 5.1**).

5.3 Overview of the early warning systems interventions

The type of EWS intervention varied from study to study. Ten of the 21 studies implemented some form of a MEWS intervention, including MEWS with a colour graphic observation chart;[49] MEWS with SBAR and ABCDE;[48] MEWS with a detailed protocol for escalation;[78, 153] MEWS (measured a minimum of three times daily) compared with as clinically indicated;[79] electronic calculation of MEWS using the patient medical record;[68, 137] a

Quality Improvement Project (QIP) study launched a framework for evaluating the impact of an electronic MEWS;[131] MEWS introduced with the existing Critical Care Outreach Service (CCOS);[97] and MEWS calculated by the anaesthetist to select the correct level of care (HDU or ICU) following surgery[66] (**Table 5.1**).

Of the remaining 11 studies, two studies used real-time or near real-time alerts, based on an algorithm, that were sent to nurses when patients had abnormal vital sign measurements.[114, 118] The NEWS was implemented in one study by means of a user friendly vital signs chart and a detailed protocol for action based on different NEWS scores.[109] Another study incorporated the systematic use of a validated EWS (unnamed) by doctors and nurses, a new colour-coded observation chart and a protocol for bedside action when abnormal vital sign scores were present.[57] One study introduced ADDS with a protocol for action.[69] One study incorporated the ELPQuiC bundle, a five part QIP bundle, one part of which was the use of an EWS (with no other details provided).[91] Another study used 'Patientrack', an electronic EWS with automated electronic alerts to the doctor.[88] One study introduced the EPSS EWS using VitalPAC handheld devices.[99] One study used electronic automated monitoring of patients applying NEWS, CREWS or palliative NEWS as appropriate.[107] Another study looked at whether EWS measurements at 8 hour intervals are associated with better outcomes than 12 hour intervals.[59] A further study focused on whether an EWS could identify patients wishing to focus on palliative care measures using scripted recommendations[132] (**Table 5.1**).

5.4 Primary outcomes

5.4.1 Mortality

Thirteen of the 21 studies examined the effectiveness of EWSs on mortality with no overall clear effect on this outcome.[48, 57, 59, 66, 68, 88, 91, 97, 99, 107, 109, 118, 132]

Mortality was considered in all three RCTs, one of which reported a statistically significant effect. Bailey et al.,[118] investigated the effect of introducing real-time algorithm-based

alerts (intervention group) compared to no alert (control group) on general medical ward patient mortality. This intervention notifying the nurse of the patient at risk did not improve outcomes (Patients with alerts were at 8.9-fold greater risk of death [95% CI: 7.4%-10.7%] than those without alerts [244 of 2,353 (10.4%; 95% CI: 9.2%-11.7%) vs 206 of 17,678 (1.2%; 95% CI: 1.0%-1.3%)], respectively; P<0.0001). Petersen et al.,[59] aimed to explore whether EWS measurements at 8 hour intervals (intervention group) were associated with better outcomes than 12 hour intervals (control). There was no significant difference in 72-hour mortality between groups (one patient died within each group) or in 30-day mortality where 1.1% and 1.8% (p=0.36) in the 8 hour group and 12 hour group died, respectively. Picker et al.,[132] conducted a pilot study to determine whether an EWS could identify patients wishing to focus on palliative care measures. Scripted recommendations were given by the primary medical team to patients in the intervention group. Control group patients received no such recommendations. No significant difference in-hospital mortality was found between the intervention (n=11, 12.4%) and control group (n=12, 10.3%), (p=0.64) (**Table 5.1**).

One nRCT examined the effectiveness of an EWS on mortality and reported a significant reduction. Subbe et al.,[107] investigated the mortality rate in the intervention group (an electronic automated vital sign monitoring system which sent alerts to the RRT) and control group (no alert sent to the RRT). In the intervention group there was a 6.5% mortality rate compared to an 8.1% mortality rate in the control group (difference 1.59%, 95% CI 0.05–3.13%, p=0.04). Reduced mortality was maintained in stepwise binary logistic regression analysis including age, gender and acuity (measured by type of ward) at step 1: there was reduced mortality for patients admitted during the intervention period (OR = 0.79, 95% CI 0.63–0.99; p=0.043). The same was true for the rate of patients with cardiopulmonary arrest (OR = 0.15, 95% CI 0.03–0.64; p = 0.011) (**Table 5.1**).

One interrupted time series considered mortality, the study, where the systematic use of an EWS was implemented along with a colour-coded observation chart and a protocol for bedside action, investigated the effect on unexpected mortality in patients with mainly

gastro-intestinal (GI) disorders.[57] Pre-intervention the unexpected mortality rate was 61 per 100 patient admission years. One year post-intervention, this had reduced to 25 per 100 patient admission years (p=0.053) and two years post-intervention this has reduced significantly to 17 per 100 patient years (p=0.013).

Eight before and after observational studies considered mortality and four found a significant effect. A retrospective QIP study by Huddart et al.[91] investigated the effect of implementing a five-part bundle (ELPQuiC), which included the use of an EWS on 30-day mortality. Before the implementation of ELPQuiC bundle, the case-mix adjusted risk of 30-day mortality was 15.6 per 100 patients treated. After implementation it was 9.6 per 100 (p=0.003). A study by Jones et al.,[88] where the Patientrack EWS which sent automated alerts was introduced, investigated the effect on hospital mortality. Before Patientrack was introduced there were 67 hospital deaths (9.5%) compared to afterwards when there were 59 hospital deaths (7.6%), p=0.19.

A retrospective study where a system was introduced to calculate a MEWS automatically using electronic medical health records examined in-hospital deaths.[68] Before the system was introduced the in-hospital death rate was 36.3 per 1,000 admissions. After the automatic system was introduced the in-hospital death rate was 35.4 per 1,000 (p>0.05). Another retrospective study where a MEWS was introduced alongside the pre-existing CCOS investigated the mortality rate.[97] Pre-MEWs the rate was 3.22 per 1,000 admissions. Post-MEWS it was 2.29 per 1,000 admissions, p=0.09. A study by Peris et al.,[66] investigated whether calculating MEWS before and after-surgery by an anaesthetist would improve mortality. In the intervention group in whom MEWS was calculated there were 32 deaths (7%) compared to the control group, where MEWS was not calculated, where 48 patients died (8%) (reported as not significant). A study by Meester et al.[48] considering a MEWS, SBAR and ABCDE intervention investigated the effect on unexpected death rates (death without DNR). Before the intervention the rate of unexpected death was 0.99 per 1,000 admissions. After the intervention this reduced to 0.34 per 1,000 admissions (p<0.001).

A retrospective study compared mortality in two different hospitals before and after the introduction of the EPSS EWS, an electronic EWS utilising handheld devices and the VitalPAC software.[99] In the Queen Alexandra hospital (QAH), the mortality rate was 7.75% before and 6.42% after (p<0.0001) equating to 397 fewer deaths. In the University Hospital Coventry (UHC), the mortality rate was 7.57% before and 6.15% after (p<0.0001), equating to 372 fewer deaths. A retrospective before-after study based in a London University hospital using the NEWS reported a non-significant increase in mortality (Before: n=190, After: n=234, described as not significant – no statistical estimate provided), (**Table 5.1**).[109]

5.4.2 Cardiac arrest

Seven of the 21 studies examined the effectiveness of EWSs on cardiac arrest with no clear effect on this outcome.[57, 68, 69, 88, 107, 114, 137]

One nRCT examined the effectiveness of an EWS on cardiac arrest reporting a significant reduction. Subbe et al.,[107] investigated the cardiac arrest rate in the intervention group (an electronic automated vital sign monitoring system which sent alerts to the RRT) and control group (no alert sent to the RRT). In the intervention group there was 0.8 cardiac arrests per 1,000 discharges compared to 6.5 per 1,000 discharges in the control group (p=0.002). Reduced cardiac arrest rates were maintained in stepwise binary logistic regression analysis including age, gender and acuity (measured by type of ward) at step 1: there were reduced rates for patients admitted during the intervention period (OR = 0.15, 95% CI 0.03–0.64; p = 0.011), (**Table 5.1**).

One interrupted time series study investigated cardiac arrests. A study where the systematic use of an EWS was implemented along with a colour-coded observation chart and a protocol for bedside action investigated the effect on cardiac arrest rates before and after implementation in patients with mainly gastro-intestinal (GI) disorders.[57] Pre-intervention seven patients suffered a cardiac arrest after which five died. Post-intervention three suffered a cardiac arrest after which two died (no statistical tests reported), (**Table 5.1**).

Five before and after observational studies investigated cardiac arrests with two showing a significant effect. Drower et al.[69] investigated cardiac arrest rates before and after the implementation of the ADDS chart with a protocol for action. Pre-ADDs there were 4.67 cardiac arrests per 1,000 admissions. Post-ADDS there were 2.91 cardiac arrests per 1,000, a 38% reduction, p=0.005. A retrospective study before and after the implementation of the VSA EWS investigated the effect of this automated electronic medical record based EWS on cardiac arrests.[114] Before the VSA was implemented there were 16 cardiac arrests. After the VSA was implemented there were three cardiac arrests (no statistical test reported). A study by Jones et al.,[88] where the Patientrack EWS which sent automated alerts was introduced, investigated the effect on cardiac arrests. Before Patientrack was introduced there were three cardiac arrests (0.4%) compared to afterwards where there were no cardiac arrests, p=0.21. A study where a system was introduced to calculate a MEWS automatically using electronic medical health records examined in-hospital cardiac arrest rate.[68] Before the system was introduced the in-hospital cardiac arrest rate was 5.21 per 1,000 admissions. After the automatic system was introduced the in-hospital cardiac arrest rate was 2.39 per 1,000 (p<0.01). A study by Stewart et al.,[137] investigated the number of cardiopulmonary arrests (CPAs) before and after the implementation of a MEWS into the electronic health record system. There were 14 CPAs before and 11 CPAs after implementation (p=0.88), (**Table 5.1**).

5.4.3 Length of Stay (LOS)

Five of the 21 studies examined the effectiveness of EWSs on LOS, with one study reporting a significant reduction in LOS.[59, 66, 88, 118, 132]

All three RCTs investigated the effect of EWSs on length of stay with none finding a significant reduction. Bailey et al.[118] investigated the effect of introducing real-time algorithm-based alerts (intervention group) compared to no alert (control group) on general ward patient LOS. This intervention notifying the nurse of the patient at risk did not reduce the LOS in the intervention group, in fact it was associated with a significantly longer LOS

(intervention group: 7.01 days; control group: 2.94 days, p<0.001). Petersen et al.,[59] aimed to explore whether EWS measurements at 8 hour intervals (intervention group) were associated with better outcomes than 12 hour intervals (control). There was no difference in LOS between the two groups (intervention median 1.0 days, IQR 0.6-2.3; control median 1.0 days, IQR 0.6-2.2 days, p=0.89). A prospective randomised pilot study to determine whether an EWS could identify patients wishing to focus on palliative care measures was conducted by Picker et al.[132] Scripted recommendations were given by the primary medical team to patients in the intervention group. Control group patients received no such recommendations. No significant difference in the median hospital LOS was found between the intervention (median=4 days, IQR 3-11 days) and control group (median 5 days, IQR 3-10 days), (p=0.60), (**Table 5.1**).

Two before-after observational studies investigated the effect of EWSs on LOS, with one finding a significant reduction. A study by Jones et al.,[88] where the Patientrack EWS which sent automated alerts was introduced, investigated the effect on LOS. Before Patientrack was introduced LOS was 9.7 days (95% CI 4.7-19.8) compared to afterwards where LOS was 6.9 days (95% CI 3.3-13.9), p<0.001). A study by Peris et al.,[66] investigated whether calculating a MEWS before and after-surgery by an anaesthetist would improve LOS. In the intervention group where MEWS was calculated hospital mean LOS was 7 ± 10 days. In the control group the LOS was 8 ± 11 days (no statistical test reported), (**Table 5.1**).

5.4.4 Transfer or admission to the intensive care unit (ICU)

Ten of the 21 studies examined the effectiveness of EWSs on ICU admission or transfer with three reporting a significant effect.[48, 57, 59, 66, 88, 107, 109, 118, 132, 153]

Three RCTs investigated the effect of EWSs on ICU admission or transfer and one found a reduction in ICU rates and one found an increase. Bailey et al.[118] investigated the effect of introducing real-time algorithm-based alerts (intervention group) compared to no alert (control group) on ICU transfer for a general ward patient. This intervention notifying the

nurse of the patient at risk did not improve the transfer rate. Patients meeting the alert threshold were at nearly 5.3-fold greater risk of ICU transfer (95% CI: 4.6-6.0) than those not satisfying the alert threshold (358 of 2,353 [15.2%; 95% CI: 13.8%-16.7%] vs 512 of 17,678 [2.9%; 95% CI: 2.7%-3.2%], respectively; p<0.0001). Petersen et al.,[59] aimed to explore whether EWS measurements at 8 hour intervals (intervention group) were associated with better outcomes than 12 hour intervals (control). There was no difference in ICU admission rates between the two groups (p=0.49). A prospective randomised pilot study to determine whether an EWS could identify patients wishing to focus on palliative care measures was conducted by Picker et al.[132] Scripted recommendations were given by the primary medical team to patients in the intervention group. Control group patients received no such recommendations. A significant difference in ICU transfer was found between the intervention (n=11, 12.4%) and control group (n=32, 27.4%), (p=0.009), (**Table 5.1**).

One nRCT examined the effectiveness of EWSs on ICU admission or transfer. A study by Subbe et al.,[107] investigated the ICU admission rate in the intervention group (an electronic automated vital sign monitoring system which sent alerts to the RRT) and control group (no alert sent to the RRT). In the intervention group the ICU admission rate was 9 per 1,000 discharges compared to 12 per 1,000 in the control group (p=0.16), (**Table 5.1**).

One interrupted time series study investigated the effect of EWSs on ICU admission or transfer, where the systematic use of an EWS was implemented along with a colour-coded observation chart and a protocol for bedside action investigated the effect on ICU admission in patients with mainly GI disorders.[57] Pre intervention 17 patients were admitted to the ICU, with the same number admitted post-intervention (no statistical test reported).

Five before and after observational studies investigated the effect on ICU admission or transfer. A study by Jones et al.,[88] where the Patientrack EWS which sent automated alerts was introduced investigated the effect on critical care utilisation. Before Patientrack was introduced there were 14 patients admitted (totalling 51 bed days) compared to afterwards when there were 5 patients admitted (totalling 26 bed days), p=0.04. A study by Farenden

et al.,[109] where the NEWS was introduced, reported an insignificant increase in ICU admissions (before: n=44, after: n=54 [not significant – no statistical estimate provided]). A MEWS, SBAR and ABCDE study investigated the effect on unplanned ICU admissions.[48] Before intervention the unplanned ICU rate was 13.1 per 1,000 admissions. After intervention this increased to 14.8 per 1,000 admissions (p=0.001). A study by Peris et al.,[66] investigated whether calculating a MEWS before and after surgery by an anaesthetist would improve identification of those in need of transfer to the HDU. In the intervention group where MEWS was calculated, 102 patients (21%) were admitted to the HDU compared to the control group where MEWS was not calculated, where 82 patients were admitted to the HDU (14%) (p=0.0008). The authors also reported the number of patients admitted to the ICU (n=26, 11% in the intervention group and n=67, 5% in the control group, p=0.001). A retrospective QIP study,[153] where a protocol employing a lower MEWS score to trigger escalation was implemented for nurses and a recommendation to check serum lactate level if infection was suspected, reported that ICU transfer rates 'remained stable' (no statistical estimates or numbers provided), (**Table 5.1**).

5.5 Secondary outcomes

5.5.1 Clinical deterioration in sub-populations

No study reported on clinical deterioration in specific sub-populations.

5.5.2 Patient reported outcome measures (PROMS)

No study examined the effectivenss of EWSs on PROMS.

5.5.3 Post-hoc identified outcomes

Six post-hoc outcomes including serious adverse events, compliance with EWSs, resource utilisation, survival to discharge, deterioration at 24 hours and palliative care measures were identified. These are reported in ***section 5.5.3.1*** to ***section 5.5.3.6***.

5.5.3.1 Serious adverse events (SAEs)

Serious adverse events (SAEs) were reported in five of the 21 studies with one finding a significant effect.[48, 49, 57, 79, 109] The definition varied and usually included a composite of outcomes.

A nRCT by Ludikhuize et al.,[79] where the intervention group measured a MEWS a minimum of three times daily and the control group measured a MEWS as clinically indicated investigated the effect on adverse events (defined as unplanned ICU admission and cardiopulmonary arrests (CPA)). The rate of adverse events in the intervention ward (MEWS protocol) was 13.4 per 1,000 hospital admissions before and 8.5 per 1,000 hospital admissions after (difference of 4.9/1000, 95% CI -0.004 to 0.014). In the control group (MEWS as clinically indicated), the rate of adverse events before was 9.1 per 1,000 and 6.5 per 1,000 after (difference of 2.6/1000, 95% CI -0.006 to 0.012).

Bunkenborg et al.[57] was an interrupted time series study and reported a composite outcome of unexpected mortality, ICU admission and cardiac arrest as SAEs. Pre-intervention (introduction of an EWS, observation chart and a protocol for bedside action) the number of SAEs was 31. Post-intervention this dropped to 21 (no statistical test reported).

A before-after MEWS observational study by DeMeester et al.[49] defined SAEs as "an unexpected occurrence involving death or serious physical or psychological injury, or the risk thereof up to five days post discharge". Pre-intervention the rate of SAEs was 5.7%. Post-intervention this reduced to 3.5% ($p>0.05$). Another before-after MEWS, SBAR and ABCDE study by DeMeester et al.,[48] defined SAEs as unexpected death (no DNR order), unplanned ICU admission or cardiac arrest team (CAT) calls. Before the rate of SAEs was 4.4 per 1,000 admissions. After intervention this increased to 6.7 per 1,000 admissions ($p<0.05$). A before-after observational study by Farenden et al.,[109] where the NEWS was implemented, defined SAEs as sepsis or septic shock and found an insignificant increase

after the NEWS (before: n=69, after: n=98, reported as 'not significant' – no statistical estimates provided), (**Table 5.1**).

5.5.3.2 Compliance with Early Warning Systems

Compliance with EWSs (including documentation of vital sign parameters, accuracy of reporting and clinical response) was reported in four of the 21 studies with two showing a significant effect between those implementing a MEWS compared to those not doing so.[49, 78, 79, 88]

A before-after MEWS observational study by DeMeester et al.,[49] measured the mean patient observation frequency per nursing shift. The mean patient observation frequency per nursing shift pre-intervention was 0.999 (95% CI 0.964 – 1.035). Post-intervention the mean patient observation frequency per nursing shift was 1.073 (95% CI 1.036 – 1.110), p=0.005. A before-after observational study by Jones et al.,[88] where the Patientrack EWS which sent automated alerts was introduced, investigated the compliance with EWS protocol in terms of accuracy of documentation, documentation of clinical response (to a patient with an EWS of 3, 4 or 5 on recheck as per the EWS protocol) and clinical response for EWS greater than five (trigger score for escalation and response necessary). Before, the accuracy of EWS reporting was 27%, compared to 22% after, p=0.07. Documentation of clinical response was present in 29% before and 78% after (p<0.001). There was a clinical response to EWS greater than five in 67% of instances before the intervention and in 96% of instances after the intervention (p<0.003), (**Table 5.1**).

A prospective cohort study where a MEWS was implemented with a detailed protocol for escalation reported on the compliance of HCPs with the system.[78] In total, 89% of patients had their vital sign parameters recorded as per the protocol and 71% were calculated correctly. A nRCT by Ludikhuize et al.,[79] where the intervention group measured a MEWS a minimum of three times daily and the control group measured MEWS as clinically indicated, investigated compliance with the MEWS and RRS protocol. Nurses calculated a MEWS in

70% (2,513/3,585) of the measurements on protocol wards (intervention) and in 2% (65/3,013) on control wards (p<0.001). A critical MEWS (≥3) was recorded by nurses in 9% (338/3,585) on the protocolised compared with 1% (35/3,013) on the control wards. Comparing the actually documented MEWS with the retrospective MEWS calculations, a critical MEWS was identified in 11% (381/3,585) on the protocolised compared with 7% (217/3,013) on the control wards indicating the presence of calculation errors. In 43% (1,552/3,585) of measurements on protocol wards, the complete set of vital signs including MEWS was measured compared with 1% (31/3,013) on control wards. A "perfect" measurement of all vital signs including MEWS without calculation errors was present in 14% (483/3,585) of protocolised measurements compared with 0.3% (8/3,013) of control measurements. When critical MEWS were measured by nurses on protocolised wards, a delay of 20 hours (IQR 5.5–54.0) was observed between the first registered critical MEWS and the notification of the physician, compared with 44 hours on control wards (p=0.79), (**Table 5.1**).

5.5.3.3 Resource utilisation

Eight of the 21 studies included outcomes reporting on resource utilisation with mixed results.[48, 69, 79, 107, 109, 131, 137, 153]

A nRCT by Ludikhuize et al.,[79] where the intervention group measured a MEWS a minimum of three times daily and the control group measured MEWS as clinically indicated investigated the effect on RRT calls. In the intervention group there were 11.8 RRT calls per 1,000 admissions pre and 19.6 RRT calls per 1,000 admissions post. In the control group there were 8.0 RRT calls per 1,000 admissions pre and 6.5 RRT calls per 1,000 admissions post.

A before-after MEWS, SBAR and ABCDE study investigated the effect on cardiac arrest team (CAT) calls.[48] Before the rate was 3.15 per 1,000 admissions and after intervention this reduced to 2.97 per 1,000 admissions (non-significant). A prospective before-after

controlled intervention study by Subbe et al.,[107] investigated the number of RRT notifications in the intervention group (an electronic automated vital sign monitoring system which sent alerts to the RRT) and the control group (no alert sent to the RRT). In the intervention group there was 231 per 1,000 admissions compared with 189 per 1,000 in the control group (p=0.001), (**Table 5.1**).

A before-after observational study by Drower et al.[69] investigated the effect before and after the implementation of the ADDS chart with a protocol for action on the number of MET calls. Pre-ADDs there were 90 MET calls. Post-ADDS there were 109 MET calls (not statistically significant). A retrospective before and after electronic MEWS implementation as part of a QIP initiative investigated the rate of RRT calls and CPA calls.[131] There were 12.5 RRT calls per 1,000 discharges before and 10.8 per 1,000 after (a 14% decrease). There were 1.19 CPA calls per 1,000 discharges before and 1.16 per 1,000 after (a 2.5% decrease). A retrospective before- after observational study by Stewart et al.,[137] investigated the number of RRT calls before and after the implementation of a MEWS into the electronic health record system. There were 39 RRT calls before and 55 RRT calls after (p=0.29). A before-after observational study by Farenden et al.,[109] investigated the effect before and after the implementation of the NEWS on the number of referrals to the RRT per 1,000 admissions. Before there were n=191 (32.8 per 1,000) RRT referrals and after there were n=234 (36.5 per 1,000), p=0.260. A retrospective QIP study by Young et al.,[153] investigated the effect of lowering a MEWS trigger score on the proportion of codes per 100 unit discharges and the proportion of preventable codes. A significant decrease was found for both (proportion of codes per 100 unit discharges: **p**re: 0.014, post: 0.005, significant decrease, p=0.0001; proportion of preventable codes per 100 unit discharges: pre: 0.008, post: 0.003, significant decrease, p=0.008), (**Table 5.1**).

5.5.3.4 Survival to discharge

A retrospective before- after study of an electronic MEWS implementation as part of a QIP initiative investigated the rate of survival to discharge in patients with a RRT call.[131] Before

implementation, 95% survived (19/20) and after 82% survived (14/17). This study also looked at survival to discharge in patients with a CPA call. Equal numbers survived before and after the introduction of an electronic MEWS (1/2, 50%), (**Table 5.1**).

5.5.3.5 Deterioration (EWS ≥2) at 24 hours

One study, an RCT by Petersen et al.,[59] aimed to explore whether EWS measurements at 8 hour intervals (intervention group) were associated with better outcomes than 12 hour intervals (control). There was no difference in deterioration rates at 24 hours between the two groups (p=0.44), (**Table 5.1**).

5.5.3.6 Palliative care measures

A prospective randomised pilot study to determine whether an EWS could identify patients wishing to focus on palliative care measures was conducted by Picker et al.[132] Scripted recommendations were given by the primary medical team to patients in the intervention group. Control group patients received no such recommendations. Advance directives (a way of making your voice heard when you can no longer communicate) were documented in 37.1% of the intervention group and 15.4% of the control group, (p<0.001). In the intervention group 36.0% has a resuscitation status documented compared with 23.1% in the control group (p=0.043). There was a palliative care consultation in 7.9% of the intervention group and 6.0% of the control group (p=0.60), (**Table 5.1**).

Table 5.1 Studies of the impact of EWSs interventions on patient outcomes and resource utilisation (Q2 Effectiveness of EWSs interventions)

Author, Study design	Setting, Country	Sample size, Type of patient	Study duration	Description of intervention	Outcomes
RCTs					
[118]Bailey (2013), Randomised controlled crossover design	8 general wards, 1,250-bed hospital, USA	N=19,116, General ward patients (intervention n=9,911; control 10,120)	July 2007 - Dec 2011	Real-time alerts generated by an algorithm designed to predict ICU transfer were sent via pager to charge nurses on the intervention ward only. Control ward charge nurses did not receive an alert.	**Primary outcome: Mortality** Intervention group (alert): 244/2,353 (10.4%, 95% CI 7.4% - 10.7%) Control group (no alert): 206/17,678 (1.2%, 95% CI 1.0%-1.3%, p<0.0001) **Primary outcome: ICU transfer** Intervention group (alert): 358/2,353 (15.2%, 95% CI 13.8%-16.7%) Control group (no alert): 512/17,678 (2.9%, 95% CI 2.7%-3.2%, p<0.0001) **Primary outcome: LOS** Intervention group (alert): 7.01 days Control group (no alert): 2.94 days, p<0.001
[59]Petersen (2016), RCT (pragmatic, ward-level, un-blinded).	Bispebjerg University Hospital, 700-bed, Copenhagen, Denmark.	N=1,346 surgical or medical ward patients included. N=690 allocated to the 12h group (control) and n=656 to the 8h group (intervention).	Two phases (Sept – Oct, and Nov –Dec 2014).	To explore whether EWS measurements at 8h intervals (intervention) is associated with better outcomes than 12h intervals (control). Phase 1 (weeks 1–7) surgical patients were allocated to the intervention arm and medical patients to the control arm. In phase 2 (weeks 8–15) monitoring frequencies were crossed over, and the medical patients allocated to the intervention arm and surgical patients to the control arm.	**Primary outcome: mortality 30-day, mortality 72 hours** One patient in each group died within 72 h of admission, 30-day mortality was 1.1% vs. 1.8% (p = 0.36) in the 8 h group and the 12 h-group, respectively. **Primary outcome: LOS** LOS median 1.0 (IQR 0.6–2.3) and 1.0 (0.6–2.2) days (p = 0.89) in 8h and 12 h group, respectively. **Primary outcome: ICU admission** No significant difference (p=0.49). **Secondary outcome post hoc: Deterioration (EWS>2) at 24 hours** Intention-to-treat analysis showed no differences between the 8 h (9.3%) and 12 h group (8.1%) for the primary outcome (EWS>2 at 24 h), p = 0.44.
[132]Picker (2017), Prospective, randomised pilot study.	1,250-bed Barnes-Jewish Hospital, Missouri, USA.	N=206 patients; 89 intervention (43.2%) and 117 controls (56.8%) admitted to 8 general medical wards.	Jan-Dec 2015	To determine whether an EWS could identify patients wishing to focus on palliative care measures, for patients assigned to the intervention arm specific study tasks were carried out as scripted recommendations to the primary medical team in order to not usurp the team's relationship with the patient. Scripted discussions and tasks were developed by the investigators the palliative care team and communicated to all patient care teams by one investigator to maintain consistency.	**Primary outcome: Hospital mortality**: Intervention: 11 (12.4%); Control: 12 (10.3%); p=0.64. **Primary outcome: LOS**: Intervention: median 4 (IQR3, 11); Control: median 5 (IQR 3, 10); p=0.60 **Primary outcome ICU transfer:** Intervention: 11 (12.4%), Control: 32 (27.4%), p=0.009. **Secondary outcome post-hoc: Advance directives documented:** Intervention: 33 (37.1%); Control: 18 (15.4%); p<0.001 **Secondary outcome post-hoc: Resuscitation status documented:** Intervention: 32 (36.0%); Control: 27 (23.1%); p=0.043. **Secondary outcomes: post-hoc: Palliative care consultation:** Intervention: 7 (7.9%); Control: 7 (6.0%); p=0.60.

Table 5.1 Studies of the impact of EWSs interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	Study duration	Description of intervention	Outcomes
nRCTs					
[79]Ludikhuize (2014), nRCT	1,000-bed University Hospital, Amsterdam, the Netherlands.	N=373 patients in the intervention ward (protocolised, 8-hourly MEWS) and N=432 patients in the control wards (MEWS as clinically indicated), in medical or surgical wards between Sept and Nov 2011.	Sept-Nov 2011 (2 months).	10 wards were randomized to the protocolised arm to measure the MEWS a minimum of three times daily and eight wards to the control arm, i.e. MEWS measurements when clinically indicated. Randomization performed after stratification according to surgical or medical ward. Patients were excluded when thresholds were uncertain (specific vital signs and/or MEWS) or if the physician raised the threshold for calling, e.g. MEWS of 5 instead of 3. Intention to treat analysis used.	**Secondary: Post hoc: SAEs (including unplanned ICU admission and CPAs):** Intervention group (**protocol wards):** Before 13.4/1,000 AEs; After 8.5/1,000 (95% CI: −0.004 to 0.014). Control group (MEWS as required): Before: 9.1/1,000; After 6.5/1,000 (95% CI: −0.006 to 0.012). **Secondary outcome: post-hoc: No of RRT activations:** Intervention group (**protocol wards):** Before 11.8/1,000; After 19.6/1,000 Control group (MEWS as required): Before 8.0/1,000; After: 6.5/1,000. **Secondary outcome: Post-hoc: Compliance with the MEWS and RRS protocol:** Nurses calculated a MEWS in 70% (2,513/3,585) of the measurements on protocol wards (intervention) and in 2% (65/3,013) on control wards. (p<0.001). Compliance of vital sign measurements 3 times per day on the protocol wards achieved in 68% (819/1,205). On control wards, retrospective review of vital signs indicated abnormal observations warranting the need for calculation of a MEWS according to the protocol in 41% (1,232/2,977) of all measurements. In 4% (47/1,232) of the measurements, the score was actually determined. A "perfect" measurement of all vital signs including MEWS without calculation errors was present in 14% (483/3,585) of protocolised measurements compared with 0.3% (8/3,013) A critical MEWS (≥3) was recorded by nurses in 9% (338/3,585) on the protocolised versus 1% (35/3,013) on the control wards. Comparing the actually documented MEWS with the retrospective MEWS calculations, a critical MEWS was identified in 11% (381/3,585) on the protocolised versus 7% (217/3,013) on the control wards indicating the presence of calculation errors. In 43% (1,552/3,585) of measurements on protocol wards, the complete set of vital signs including MEWS was measured compared with 1% (31/3,013) on control wards. Delay in notification of the physician: The presence of delay was analysed in 99 patients. In 49% (28/57) of the patients in the protocol arm and 50% (2/4) in the control arm, delays were present in identifying deterioration. When critical MEWS were measured by nurses on protocolised wards, a delay of 20 h (IQR 5.5–54.0) was observed between the first registered critical MEWS and the notification of the physician, versus 44 h on control wards (p = 0.79).

Table 5.1 Studies of the impact of EWSs interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	Study duration	Description of intervention	Outcomes
nRCTs					
[107]Subbe (2017), Prospective before-after controlled intervention study.	University-affiliated hospital, UK.	N=2,139 patients before (control wards 1 and 2, Oct 2012- Oct 2013) and n=2,263 after the intervention (Feb 2014 – Apr 2015, intervention wards 1 and 2), admitted to the general medical ward.	Patient data were collected from 15 Oct 2012 to 16 Oct 2013 for the control period in ward 1 and from 1 Oct 2012 to 2 Oct 2013 for the control period in ward 2. Data were collected in the intervention phase from 17 Feb 2014 in ward 1 and 28 Apr 2014 in ward 2 until all the interventions ceased in both wards on 17 Apr 2015. Additional control data were collected in ward 2 from 17 Feb 2014 to 17 Apr 2014 to run parallel with the intervention start period in ward 1 for 2 months.	Hypothesised that the application of monitoring technology with automated notification of the RRT would improve the reliability of escalation of care for clinically deteriorating patients on general wards, and result in improved patient outcomes. NEWS, CREWS or palliative (NEWS without a trigger) EWS were used as appropriate. For the intervention, an electronic automated advisory vital signs monitoring system (Intelivue Guardian Solution (IGS) with cableless sensors and MP5SC spot-check monitors, Philips Healthcare, Boeblingen, Germany) was deployed to each study ward. The monitoring system electronically transfers and displays data obtained by the bedside nurses using spot-check monitors or by cableless sensor devices, automatically calculating EWS.	**Primary outcome: Mortality:** Intervention: 147/2,263 (6.5%) Control: 173/2,139 patients (8.1%), p = 0.04. **Primary outcome: Cardiac arrest:** Intervention: N=2 (0.8/1,000 discharges, 0.4% of RRT notifications), Control: N=14, 6.5/1,000 discharges, 3.5% of RRT notifications, p=0.002. **Primary outcome: ICU admission** Intervention: N=21 (9/1,000 discharges) Control: N=26, (12/1,000 discharges), p=0.16. **Secondary outcome: Post-hoc: RRT notifications:** Intervention: 1.43 per patient, 231/1,000 admissions (23.1%), Control: 1.33 per patient, 189/1,000 admissions (18.9%), p=0.001

Table 5.1 Studies of the impact of EWSs interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	Study duration	Description of intervention	Outcomes
Interrupted time series studies					
[57]Bunkenborg (2014), interrupted times series intervention study	4 medical and surgical wards of a 750-bed university hospital, Denmark	N=1,870 adult patients with mainly GI disorders pre-intervention (2009); N=2,079 post-intervention (2010, 4 months) and N=2,234 post-intervention (2011, 4 months)	3 x 4-month study periods between 2009 and 2011.	Three components: 1) a new monitoring practice – systematic use of a validated EWS by nurses and physicians; 2) an observation chart with scoring severity colour-coded; 3) algorithm for bedside action which was colour coded with instructions on who to call and when to call and how often to re-evaluate. Green coding for EWS score of 0 and red for scores ≥5 for urgent action. A 4-hour training session provided for all nurses and nursing assistants pre-intervention and 45-minutes of training for physicians. Feedback sessions also incorporated by main investigator.	**Primary outcome: unexpected mortality (per 100 patient admission years)** Pre-intervention: 61 Post-intervention1 (2010): 25 (p=0.053) Post-intervention2 (2011): 17 (p=0.013) **Primary outcome: ICU admission** Pre-intervention: 17 Post intervention (2011): 17 (no p-values provided) **Primary outcome: survival after cardiac arrest** Pre-intervention: 2/7 survived Post intervention (2011): 1/3 survived (no p-values provided) **Secondary: Post hoc: SAES:** Pre-intervention: 31 Post intervention (2011): 21 (no p-values provided)
Before-after observational studies (uncontrolled)					
[48]DeMeester (2013b), before-(Jul 2010 – Apr 2011), after (May 2011-Mar 2012) study.	Antwerp University Hospital, tertiary referral, Belgium.	N=210,074 inpatient days and 37,239 admissions between July 2010 and Mar 2012, medical and surgical ward patients.	10 months pre-intervention and 10 months post-intervention.	Following introduction of MEWS in Nov 2009, an educational intervention of SBAR and ABCDE training was implemented for all nurses. The intervention was step 2 of the introduction of the afferent limb of a RRS. This included patient observation, measurement of vital signs, patient assessment, recognition of clinical deterioration, call criteria for triggering a response and policy to communicate with the health care workers of the efferent limb of the RRS.	**Primary: unexpected deaths (deaths without a DNR)** Pre-intervention: 16 (0.99/1,000 admissions) Post-intervention: 5 (0.34/1,000 admissions), p<0.001. **Primary: Unplanned ICU admissions** Pre-intervention: 51 (13.1/1,000 admissions) Post-intervention: 105 (14.8/1,000 admissions), p=0.001 **Secondary: Post hoc: SAEs (unexpected deaths, unplanned ICU admissions, CAT calls)** Pre-intervention: 81 (4.4/1,000 admissions) Post-intervention: 126 (6.7/1,000 admissions), p<0.05 **Secondary: Post hoc: CAT calls** Pre-intervention: 3.15/1,000 admissions Post-intervention: 2.97/1,000 admissions, non-significant.

Table 5.1 Studies of the impact of EWSs interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	Study duration	Description of intervention	Outcomes
Before-after observational studies (uncontrolled)					
[114]Jones (2013), Retrospective before-after observational study.	525-bed teaching hospital, Virginia, USA.	Sample size not reported. Only reported that 3 medical-surgical step-down nursing units were included.	Before-EWS implementation (Jun 2009 – May 2010), After (Jun 2010-May 2011).	The Vital Sign Alert System (VSA) EWS implemented in Jun 2010, created by nurses in the hospital. The program was designed to scan each patient's EMR every 60 seconds, recalculating scores whenever new vital sign data were available. Color-coded VSA scores were also added to the nurses' patient lists, so they were readily available to nurses using mobile computers at the bedside. Double-clicking on a patient's VSA score opened the VSA algorithm, prompting timely nursing action when a score was out of the target range. Scores in range (≤2) – continue to monitor every 4 h. Score 3-4: perform complete assessment (assess the following: urine output, telemetry, mean arterial pressure, peripheral perfusion, heart and breath sounds, change in LOC/speech, new symptoms). Notify charge nurse of issues and charge nurse to notify medical response team and evaluate as necessary – monitor vital signs every 2 h until score is <=3.Score 5-8: Notify charge nurse, Notify medical doctor, Consider calling medical response team. Monitor vital signs every hour until score is <5, then every 2 h until score is <3.	**Primary outcome: Cardiac arrest** Before VSA-EWS implementation: n=16 events. After VSA-EWS implementation: n=3 (no statistical test reported).
[68]Nishijima (2016), Retrospective before-after observational study.	331-bed Chubu Hospital, Japan.	N= 15,462 patients before MEWS (Apr 2011-Sept 2012) and N=17,961 patients after MEWS (Oct 2013 – Mar 2015). All patients eligible except ICU and DNR patients.	18-months pre and 18 months post MEWS implement-ation.	A system was introduced to calculate the MEWS automatically when vital signs were entered into the patient's medical record by a ward nurse. The MEWS system was used routinely on all inpatients. An evaluation was conducted one or more times each day depending on the patient's illness severity, and the highest score was used in this study.	**Primary outcome: In-hospital deaths**: Before: 36.3 per 1,000 After: 35.4 per 1,000 (not significant p >0.05). **Primary outcome: In-hospital cardiac arrests**: Before: 5.21 per 1,000 (79/15,170) After: 2.39 per 1,000 (43/17,961), p<0.01).

Table 5.1 Studies of the impact of EWSs interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	Study duration	Description of intervention	Outcomes
Before-after observational studies (uncontrolled)					
[88]Jones (2011), Retrospective before-after observational study.	Manchester Royal Infirmary, UK	N=1,481 consecutive adult patients admitted to the MAU.	Before Patientrack implement-ation (Nov-Dec 2007); After (Aug-Sept 2008)	'Patientrack' was implemented on a central web server with an underlying data repository. The study had 3 phases. The first phase entailed baseline data capture. The second phase involved implementation of the electronic observation capture and EWS calculation. Patient bedside observations were taken manually and the results were entered into a personal digital assistant (PDA). The PDA was connected to a wireless network that allowed the results to be presented as a whole-of-ward view. Doctors were alerted by the traditional systems (i.e., nurse call, switchboard to page doctors, or personal notification). The third phase was the alert phase — electronic observation capture (as above) with automated electronic alerts to the doctor.	**Primary outcome: Hospital mortality** Before: 67 (9.5%) After: 59 (7.6%), p=0.19 **Primary outcome: Cardiac arrest** Before: 3 (0.4%) After: 0, p=0.21 **Primary outcome: LOS** Before: 9.7 days 95% CI(4.7-19.8) After: 6.9 days, 95% CI(3.3-13.9) p<0.001. **Primary outcome: Critical care utilisation:** Before: 14 patients (51 bed days) After: 5 patients (26 bed-days), p=0.04. **Secondary outcomes: post-hoc: Compliance with EWS protocol**. *EWS accuracy* – 81% of observations measured and summed correctly. Before: 27% After: 22%, p=0.07. *Documentation of clinical response*: Before: 29%, After: 78% after (p<0.001). *Clinical response for EWS greater than 5*: Before: 67% of instances After: 96% of instances (p<0.003)
[97]Patel (2011), Retrospective before-after study.	Leicester Royal Infirmary Hospital, UK.	N=32,149 patients admitted to the orthopaedic trauma unit Jan 2002 and Dec 2009.	Three years pre-MEWS (2002-2004) and 4 years post (2006-2009).	A MEWS system implemented in the summer of 2005 coupled with the existing CCOS. Data were obtained from the coding dept.	**Primary outcome: mortality** Pre-MEWS: 3.22 per 1,000 admissions After: 2.29 per 1,000 admissions, Decreased mortality rate : all patients: 0.9% (95% CI 0.53, 1.31; p=0.09)

Table 5.1 Studies of the impact of EWSs interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	Study duration	Description of intervention	Outcomes
Before-after observational studies (uncontrolled)					
[131]Parrish (2017), Before-after observational study.	70-bed suburban acute care facility, USA.	N=39 patients with RRT calls before (Jun-Aug 2014) and after MEWS (Oct-Dec 2014) in the medical-surgical wards, and from Dec 2014-Feb 2015 in the telemetry unit.	3 months pre-MEWS and 6 months after (3 on the medical-surgical wards, and 3 on the telemetry wards).	A QIP initiative was launched to provide a framework for evaluating the impact of the electronic MEWS using three evaluation metrics: the number of RRT calls, the number of CPAs and survival to discharge after a RRT call or CPA.	**Secondary outcome: post hoc: CPA calls per 1,000 discharges**: 2 arrests (before), 2 arrests (after), all in telemetry ward. 1.19 per 1,000 (before), 1.16 per 1,000 (after, 2.5% decrease). **Secondary outcome: Post-hoc: Incidence of RRT calls per 1,000 discharges**: 21 RRT calls (before), 18 RRT calls (after), 12.5 per 1,000 (before), 10.8 per 1,000 after, 14% decrease. **Secondary outcome: post-hoc: Survival to discharge in patients with a RRT**: 19/20 (95%) before and 14/17 (82%) after. **Secondary outcome: post-hoc: Survival to discharge in patients with a CPA call:** 1/2 (50%) before and 1/2 (50%) after.
[66]Peris (2012), Prospective before- after study.	Careggi Teaching Hospital, Florence, Italy.	N=1,082 (n=604 controls, n=478 intervention) patients who underwent general anaesthesia within 3 h following surgical indication were included.	Before MEWS (control group) admitted Jan 2008 - Mar 2009. After MEWS group (Apr 2009 and Jan 2010).	To determine if MEWS calculation can help the anaesthetist select the correct level of care to avoid inappropriate admission to the ICU and to enhance the use of the HDU after emergency surgical procedures, in the intervention group, MEWS was calculated by the anaesthetist on duty before surgical procedure and before discharge from the operating room.	**Primary outcome: Mortality** Intervention (MEWS) group: 7% (n=32) Control group: 8% (n=48), Not significant. **Primary outcome: Hospital LOS** Intervention (MEWS) group: mean 7 SD ±10 days Control group: mean 8 SD ±11 days **Primary outcome: HDU admission** Intervention (MEWS) group: 21% (n=102) Control group: 14% (n=82) p=0.0008 **Primary outcome: ICU admission:** Intervention (MEWS) group: 11% (n=26) Control group: 5% (n=67), p=0.001.

Table 5.1 Studies of the impact of EWSs interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	Study duration	Description of intervention	Outcomes
Before-after observational studies (uncontrolled)					
[69]Drower (2013), Before-after observational study (Apr 2009 – Mar 2011)	Waikato Hospital, 600-bed, Auckland, New Zealand	N=21,806 pre-intervention and N=22,378 post-intervention, adult admissions.	23 months.	ADDS EWS chart with protocol for action introduced. Developed within the hospital.	**Primary outcome: Cardiac arrest** Pre-intervention: 4.67 per 1,000 Post-intervention: 2.91 per 1,000 Mean difference: 1.77 (95% CI 0.59-2.95. p=0.005), 38% reduction. **Secondary: post hoc: Number of MET calls** Pre-intervention: n=90, 7.5 medical emergencies per month Post-intervention: n=109, 9.1 medical emergencies per month (not statistically significant).
[99]Schmidt (2014), Retrospective before-after observational study.	2 large acute general hospitals in the UK.	Hospital 1 (QAH): Before: 27,959, after: 29,676. Hospital 2 (UHC): Before: 21,771, after: 26,241.	July 2004 to Jun 2011.	To determine whether introducing an electronic physiological surveillance system (EPSS), specifically designed to improve the collection and clinical use of vital signs data, reduced hospital mortality, the VitalPAC wireless handheld device, prompts nurses to take bedside observations and then calculates the EWS instantly was introduced in both hospitals.	**Primary outcome: Mortality:** QAH hospital: Before (2004): 7.75% (2,168/27,959) After (2010): 6.42% (1,904/29,676), p<0.0001 397 fewer deaths. UHC hospital: Before (2006): 7.57% (1,648/21,771) After (2010): 6.15% (1,614/26,241). p<0.0001. 372 fewer deaths.
[137]Stewart (2014), Retrospective before (12 months) after (12 months) MEWS.	242-bed acute care hospital, Pennsylvania, USA.	N=39 medical-surgical patients with RRT calls before MEWS and N=55 patients with RRT calls post MEWS implementation.	24 months.	MEWS implemented into the electronic health record system in 2012. No other details provided.	**Primary outcome: Cardiopulmonary arrests:** Before: 14, After 11, p=0.88 **Secondary outcome: Post-hoc: No of RRT calls:** Before: 39 RRT activations before MEWS After: 55 RRT activation post MEWS, p=0.29

Table 5.1 Studies of the impact of EWSs interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	Study duration	Description of intervention	Outcomes
Before-after observational studies (uncontrolled)					
Farenden et al (2017),[109] Retrospective before-after observational study.	586-bed University College Hospital, London, UK	N=191 patients from adult non-obstetric wards 2 months before NEWS implementation in 2013 and N=234 patients 2 months after NEWS implementation in 2014	Before NEWS implementation (May-June 2013), After NEWS implementation (May-June 2014)	The NEWS was implemented in April 2014, including a user friendly vital signs chart and a detailed protocol for action based on different NEWS scores. Training in the calculation and use of the NEWS was provided to all staff to facilitate effective implementation.	**Primary outcome: Mortality** Before: n=190 After: n=234 (not significant) **Primary outcome: ICU admission** Before: n=44 After: n=54 (not significant) **Secondary outcome, post-hoc: SAE (Sepsis or septic shock)** Before: n=69 After: n=98 (not significant) **Secondary outcome, post hoc: Resource utilisation, referrals to RRT per 1,000 admissions** Before: n=191 (32.8 per 1,000) After: n=234 (36.5 per 1,000), p=0.260
[153]Young (2014), QIP retrospective study	897-bed university hospital, Chicago, Illinois.	N=2,471 patients before and n=5,027 after, haematology/oncology patients.	Before MEWS intervention (control group) admitted between April 2007 and Feb 2008. After MEWS intervention (March 2008 to Sept 2009).	A protocol employing a lower MEWS score to trigger escalation was implemented for nurses and a recommendation to check serum lactate level if infection was suspected was implemented for physicians to identify deteriorating patients who required the attention of the RRT in March 2008.	**Primary outcome: Transfer to the ICU** "ICU transfer rates remained stable" – no statistical tests reported. **Secondary outcome, post hoc: Resource utilisation** **Proportion of codes per 100 unit discharges:** Pre: 0.014 Post: 0.005, significant decrease (p=0.0001) **Preventable codes per 100 unit discharges:** Pre: 0.008 Post: 0.003, significant decrease (p=0.008)

Table 5.1 Studies of the impact of EWSs interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	Study duration	Description of intervention	Outcomes
Before-after observational studies (uncontrolled)					
[49]DeMeester (2013a), Before (Nov 2008- Feb 2009) and after (Jun 2009 –Oct 2009) MEWS implementation observational study.	Antwerp University Hospital, tertiary referral, Belgium.	N=530 patients before, N=509 after MEWS implementation, from 14 different medical and surgical wards post ICU discharge.	4 months pre and 5 months post MEWS implementation	MEWS implemented as a standard nurse observation protocol in Nov 2009 and a colour graphic observation chart. Patients observed at ICU discharge, at admission to the ward, 4 hours after admission to the ward and 12 hourly thereafter according to the study protocol.	**Secondary: Post hoc: SAEs up to 5 days post-ICU discharge** pre-intervention: 5.7% Mean post intervention: 3.5%. A 2.2% reduction (-0.4% - 4.7%), p>0.05 **Secondary: Post hoc: Nurse observation frequency** Mean pre-intervention: 0.999 (95% CI 0.964–1.035) Mean post intervention: 1.073 (95% CI 1.036–1.110), p =0 .005.
[78]Van Galen (2016), Prospective cohort study.	Large urban university hospital, the Netherlands.	N=1,053 patients admitted to 6 wards (acute admission unit, general surgery, internal medicine, trauma surgery, vascular surgery/ urology/nephrology ward and the pulmonary ward Oct-Nov 2015.	7 weeks recruitment (Oct-Nov 2015) and 30 day follow-up.	MEWS implemented with detailed protocol for escalation. According to the hospital wide protocol, every morning at the end of the nightshift or at the beginning of the dayshift, nurses were requested to determine the MEWS using vital parameter measurements recorded in the electronic system. During the implementation of the protocol staff were trained extensively and the protocol card containing the protocol distributed. MEWS was calculated by hand and electronically documented in patients' charts. Once a patient reaches a critical MEWS (≥3) nurses were to contact the doctor in charge immediately. The doctor must then assess the patient within 30 minutes and draft a plan for treatment, evaluate this after 60 minutes or call a RIT team. The RIT may also directly be called by the nurses or the doctor at the outset.	**Secondary outcomes: post-hoc: Compliance with EWS protocol:** 89% (3,270/3,673 vital parameter measurements). **Correctly calculated MEWS**: 2,600/3,673 (71%).
[91]Huddart (2015), QIP observational study.	4 NHS hospitals, UK.	N=299 before; N=427 after ELPQuiC bundle implementation; Emergency laparotomy surgery patients.	ELPQuiC bundle implemented in Dec 2012. Data reviewed 4 months before and 4 months after.	ELPQuiC bundle implemented as part of QIP initiative. 5-part bundle: 1)Initial assessment with EWS, 2) Early antibiotics, 3) Interval between decision and operation less than 6 h,4) Goal-directed fluid therapy and 5) postoperative intensive care across 4 hospitals simultaneously. Followed the 'Plan, Do, Study, Act' approach. Anonymised data were entered by each hospital into the Electronic Database for Global Education.	**Primary outcome: Mortality** **Overall case mix-adjusted risk of 30-day mortality:** Before: 15.6% per 100 (12.5%-18.9%) After: 9.6% per 100 (7.4-11.8%), p=0.003 (Risk ratio 0·614, 95% CI 0.451 to 0.836; *P* =0·002).

Key: ABCDE: Airway, Breathing, Circulation, Disability, Exposure; **ADDS**: Adult deterioration Detection System; **CAT**: Cardiac arrest team; **CCOS**: Critical care outreach service; **CPA**: Cardiopulmonary arrest; **CREWS**: Chronic respiratory EWS; **DNR**: Do not resuscitate; **ELPQuic**: Emergency Laparotomy Pathway Quality Improvement Care; **EMR**: Electronic medical record; **EPSS**: Electronic patient surveillance system; **EWS**: Early warning system; **GI:** Gastrointestinal; **HDU**: High dependency unit; **ICU**: Intensive care unit; **LOC**: Level of consciousness; **LOS:** Length of stay; **MAU**: Medical assessment unit; **MET**: Medical emergency team; **MEWS**: Modified EWS; **NEWS**: National early warning score; **NHS**: National Health Service; **PDA**: Personal digital assistant; **QAH**: Queen Alexandra Hospital; **QIP**: Quality improvement project; **RCT**: Randomised clinical trial; **RRS/T**: Rapid response system/team; **SAE**: Serious adverse events; **SBAR**: Situation, Background, Assessment, Response; **UHC**: University Hospital Coventry; **VSA:** Vital Sign Alert system;

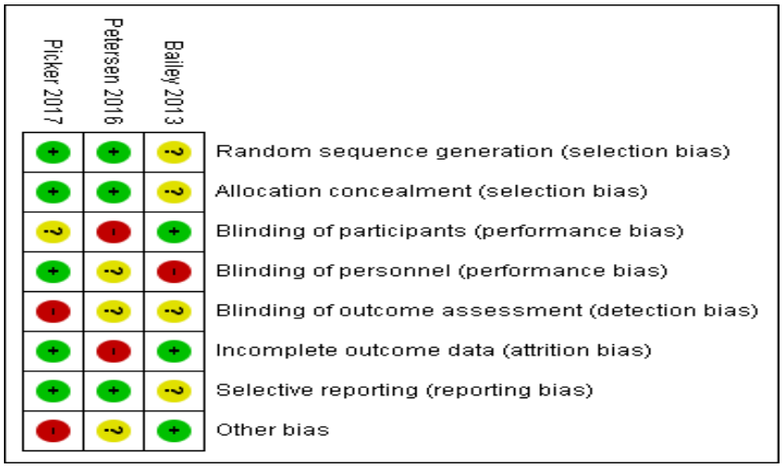
5.6 Methodological quality

A number of different study designs were included (three RCTs, two nRCTs, one ITS study, and 15 observational studies, including before-after and cohort studies) in this systematic review update and therefore the methodological quality was appraised using different tools. The quality of included studies is presented according to the different study designs.

5.6.1 RCTs

The Cochrane risk of bias tool[23] was used to appraise the methodological quality of the three included RCTs.[59, 118, 132] One trial by Picker et al. was deemed to have a low risk of bias overall and the other two trials had an unclear risk of bias overall[59, 118] (**Figure *5.1***).

Figure 5.1 Risk of bias summary for RCTs of EWS interventions and deterioration in adults in acute health care



Allocation

Random sequence generation

Two of the trials described the method of sequence generation used and had a low risk of bias.[59, 132] One trial selected eight wards within one hospital and matched them on alert

rate before assigning them to groups using a random number generator creating a potential risk of selection bias[118] (***Figure 5.2***).

Allocation concealment

Two of the trials described the method of allocation and had a low risk of bias.[59, 132] Bailey et al.[118] provided insufficient details and had an unclear risk of bias (***Figure 5.2***).

Blinding participants and personnel (performance bias)

One trial had a low risk of bias as patients had no knowledge - the outcome was ICU transfer.[118] One trial had a high risk of bias as the participants were not blinded to the intervention, [59] and one trial had an unclear risk of bias as it was not clear whether participants were blinded or not.[132] Blinding of personnel was low risk in one trial,[132] high risk in Bailey et al. [118] as the staff knew there was an intervention (received alert) and knowledge could have affected decision to transfer patients to the ICU. One trial did not report whether personnel were blinded and had an unclear risk of bias (***Figure 5.2***).[59]

Detection bias

Picker et al. [132] had a high risk of detection bias as outcome assessors were not blinded, and two trials had an unclear risk at it was not clear whether outcome assessors were blinded (***Figure 5.2***).[59, 118]

Incomplete outcome data

Two trials described loss to follow-up and accounted for participants.[118, 132] Petersen et al. [59] had a high risk of attrition bias as 60% of patients were lost to follow up, mainly due to early discharge, which is well above the estimated dropout rate of 20% reported in the study (***Figure 5.2***).

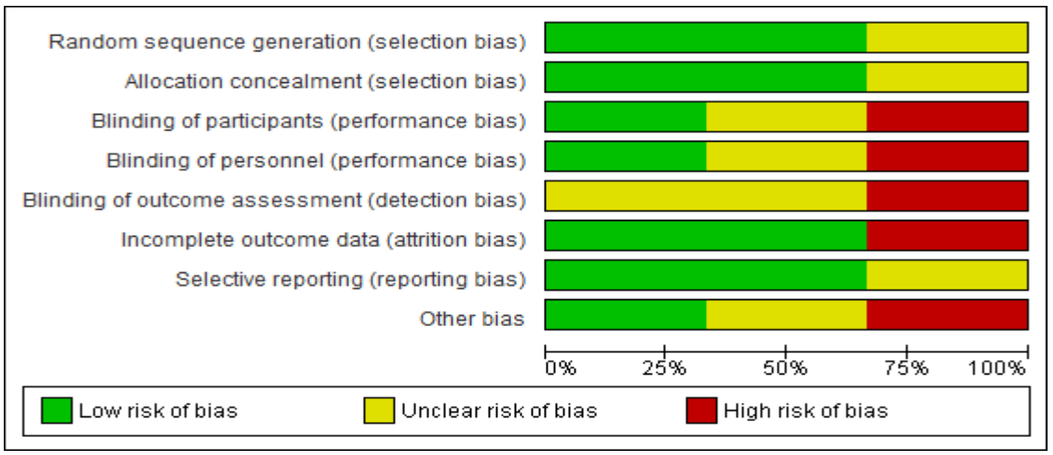
Selective reporting

Two trials had a low risk of bias for selective outcome reporting with results provided for the specified outcomes.[59, 132] Bailey et al.[118] had an unclear risk of bias as insufficient details were provided (**Figure *5.2***).

Other potential sources of bias

Bailey et al.[118] had a low risk of other bias. Picker et al.[132] was deemed to have a high risk of other bias due to the study being conducted on weekdays only which may incorporate a case mix bias. Peterson et al.[59] had an unclear risk of other bias due to the greater proportion of patients with an initial EWS score of zero which could introduce bias, since this group potentially was less severely ill on admission, and therefore less prone to deterioration (**Figure *5.2***).

Figure 5.2 Risk of bias graph for included RCTs of EWS interventions and deterioration in adults in acute health care settings



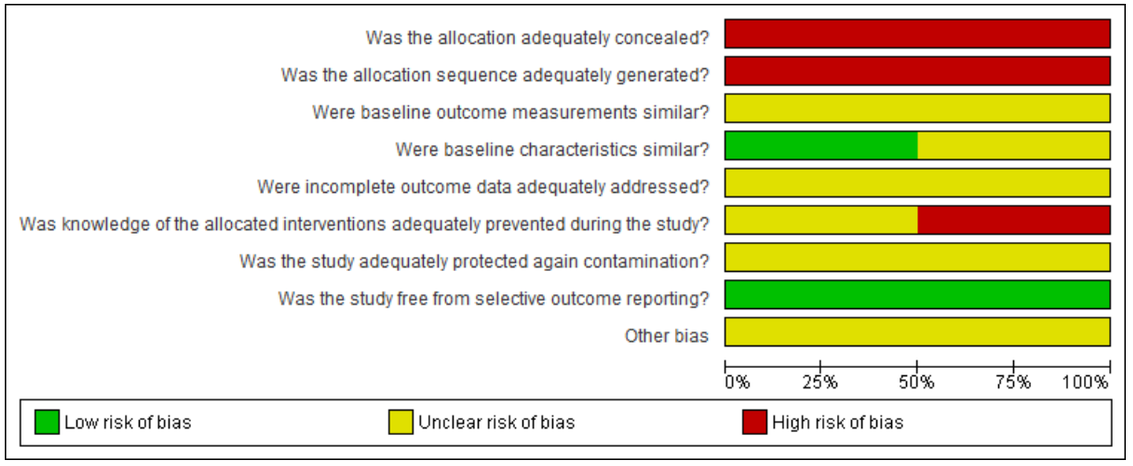
5.6.2 Non-RCTs

The Cochrane Effective Practice and Organisation of Care (EPOC) tool[24] was used to assess the methodological quality of the two non-RCT (nRCT) studies[79, 107] across nine domains.

5.6.2.1 nRCT studies

Both nRCT studies were deemed to have an unclear risk of bias overall across the domains (**Figure *5.3***).[79, 107]

Figure 5.3 Risk of bias summary for nRCTs of EWS interventions and deterioration in adults in acute health care settings



Allocation

Allocation concealment and Random sequence generation

Both studies had a high risk of bias for allocation concealment and random sequence generation as they were non-randomised control trials (**Figure *5.4***).[79, 107]

Baseline outcome measurements similar

Both trials had an unclear risk of bias as they did not report baseline outcome measures and it was not possible to determine whether baseline outcome measurements were similar as a result (**Figure *5.4***).[79, 107]

Baseline characteristics similar

Subbe et al.[107] had a low risk of bias for baseline characteristics however Ludikhuize et al.[79] had an unclear risk of bias as baseline characteristics were not reported (**Figure *5.4***).

Incomplete outcome data

Both studies had an unclear risk of bias for incomplete outcome data. No flow diagram was provided in either study.[107] In one study the control ward dropped out due to logistical reasons (excluding 5,752 measurements) and the number of patients was not reported (**Figure *5.4***).[79]

Knowledge of the allocated interventions prevented (Blinding)

Subbe et al. had a high risk of bias as the study was not blinded.[107] Ludikhuize et al. had an unclear risk of bias as to whether knowledge of the allocated interventions was prevented as it was not clear from the paper or explicitly stated (**Figure *5.4***).[79]

Protected against contamination

Both trials had an unclear risk of contamination.[79, 107] Both were single hospital studies and the authors acknowledged that nurses from the control wards might have been informed about the intervention – introducing a Hawthorne effect (**Figure *5.4***).

Selective outcome reporting

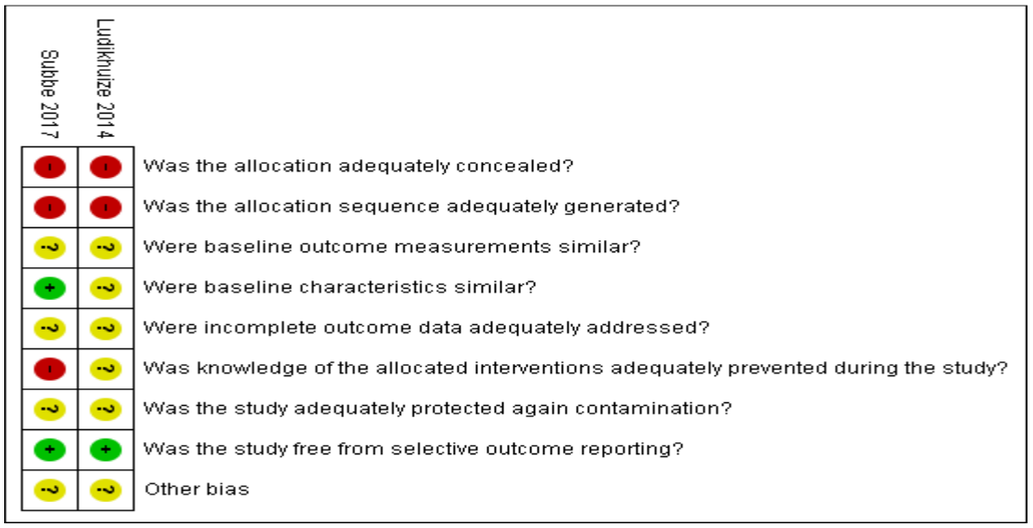
Both trials had a low risk of bias for selective outcome reporting as all outcomes were reported (**Figure *5.4***).[79, 107]

Other potential sources of bias

Both studies had an unclear risk of other potential sources of bias.[79, 107] Subbe et al. received funding from the manufacturer of the wireless sensor. Ludikhuize et al. by excluding patients absent from the ward for a significant part of the day (could include

sicker patients getting treatment) may underestimate the effect of the intervention. In addition, the intervention was implemented shortly after the RRS was introduced – so RRS may not have been fully effective. There was a short study duration (3 months) which may not be long enough for outcomes such as death to occur (11 deaths in total), (***Figure 5.4***).[79]

Figure 5.4 Risk of bias graph for included nRCTs of EWS interventions and deterioration in adults in acute health care settings



5.6.3 Observational (uncontrolled) studies

The Newcastle Ottawa Scale quality appraisal tool[26] was used for the one interrupted times series study and the 15 before-and-after observational studies. We rated the quality of the studies (good, fair and poor) by awarding stars in each domain following the guidelines of the Newcastle–Ottawa Scale. A "good" quality score required 3 or 4 stars in 'selection', 1 or 2 stars in 'comparability', and 2 or 3 stars in 'outcomes'. A "fair" quality score required 2 stars in selection, 1 or 2 stars in comparability, and 2 or 3 stars in outcomes. A "poor" quality score reflected 0 or 1 star(s) in selection, or 0 stars in comparability, or 0 or 1 star(s) in outcomes. In total where a study received '6' or more stars, it was considered a 'good quality study'. Where a study received '5' stars, it was considered a 'fair quality study' and where a study received '4 or less' stars it was considered a 'poor quality study', as described in Sharmin et al.[31]

5.6.4 Interrupted time series studies

There was one interrupted time series study.[48, 57, 66] It received five stars in total and was considered 'fair quality' across the following domains (exposed cohort representative, selection of the non-exposed cohort, ascertainment of the exposure, comparability of cohorts in the design and assessment of the outcome).

Table 5.2 Quality assessment of interrupted time series studies on the effectiveness of EWS interventions

Study	Selection				Comparability		Outcome			Overall quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
Interrupted time series studies										
[57]Bunkenborg (2014)	*	*	*	Statement of 'no history of CA or ICU admission/ transfer' was not provided	*	Does not control for additional factors in analysis phase	*	4-month post-intervention 1 and 4-month post-intervention 2	No statement of follow-up.	5 stars (FAIR QUALITY)

Key: CA: Cardiac Arrest; **ICU:** Intensive Care Unit.

5.6.4.1 Before-after observational studies

There were 15 before-after observational studies.[48, 49, 66, 68, 69, 78, 88, 91, 97, 99, 109, 114, 131, 137, 153] Of these, five studies were considered 'good quality' overall and received six or more stars across the different domains of selection, comparability and outcome.[68, 88, 97, 99, 109] Three studies were considered 'fair quality' overall and received five stars across the different domains of selection, comparability and outcome.[69, 78, 91] Seven studies were rated as 'poor quality' overall receiving four or less stars across the domains (**Table 5.3**).[48, 49, 66, 114, 131, 137, 153]

Table 5.3 Quality Assessment of before-and-after observational cohort studies on the effectiveness of EWS interventions

Study	Selection				Comparability		Outcome			Overall Quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts in analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
DeMeester (2013a)[49]	*	*	*	Did not include any of the review's primary outcomes	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	SAEs 5 days post ICU discharge, study follow-up 8 months.	No statement of follow-up, retrospective review of patient charts	4 stars (POOR QUALITY)
[48]De Meester (2013b)	*	*	*	Statement of 'no history of ICU admission/ transfer' was not provided	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	10 months pre- and post-intervention	No statement of follow-up, retrospective chart review	4 stars (POOR QUALITY)
Drower (2013)[69]	*	*	*	Statement of 'no history of CA' was not provided	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	*	No statement of follow-up, retrospective review of patient charts	5 stars (FAIR QUALITY)
Farenden et al (2017)[109]	*	*	*	Statement of 'no history of ICU admission' was not provided	*	Does not control for additional factors in analysis phase	*	2 months post NEWS implementation	*	6 stars (GOOD QUALITY)

Table 5.3 Quality assessment of before-and-after observational studies on the effectiveness of EWS interventions [continued]

Study	Selection				Comparability		Outcome			Overall Quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts in analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
Huddart (2015)[91]	Patients with emergency laparoscopic surgery	*	*	*	*	Does not control for additional factors in analysis phase	*	8-months follow-up period.	No statement of follow-up.	5 stars (FAIR QUALITY)
Jones (2013a)[114]	Single centre pilot study – no details provided	Single centre pilot study – no details provided	*	Statement of 'no history of CA' was not provided	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	*	No details provided on sample size	3 stars (POOR QUALITY)
Jones (2011)[88]	*	*	*	Statement of 'no history of CA or ICU admission/ transfer' was not provided	*	Does not control for additional factors in analysis phase	*	1 month	*	6 stars (GOOD QUALITY)
Patel (2011)[97]	*	*	*	*	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	*	Retrospective analysis.	6 stars (GOOD QUALITY)

Table 5.3 Quality assessment of before-and-after observational studies on the effectiveness of EWS interventions [continued]

Study	Selection				Comparability		Outcome			Overall Quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts in analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
[66]Peris (2012)	emergency abdominal surgery patients	*	*	Statement of 'no history of ICU admission/ transfer' was not provided	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	*	No statement of follow-up.	4 stars (POOR QUALITY)
Schmidt (2014)[99]	*	*	*	*	*	Does not control for additional factors in analysis phase	*	*	Retrospective analysis.	7 stars (GOOD QUALITY)
Stewart (2014)[137]	patients with RRS activations, single hospital	*	*	Statement of 'no history of CA' was not provided	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	*	No statement, retrospective review	4 stars (POOR QUALITY)
Nishijima (2016)[68]	*	*	*	Statement of 'no history of CA' was not provided	*	Does not control for additional factors in analysis phase	*	*	No statement of follow-up, retrospective review of patient charts	6 stars (GOOD QUALITY)

Table 5.3 Quality assessment of before-and-after observational studies on the effectiveness of EWS interventions [continued]

Study	Selection				Comparability		Outcome			Overall Quality
	S1 Exposed cohort representative	**S2 Selection of non-exposed cohort**	**S3 Ascertainment of exposure**	**S4 Outcome not present at beginning**	**C1 Comparability of cohorts in design phase**	**C2 Comparability of cohorts in analysis phase**	**O1 Assessment of outcome**	**O2 Follow-up sufficient for outcome to occur**	**O3 Adequate follow-up**	**Total stars**
Parrish (2017)[131]	N=21 patients with RRT calls in a single hospital	N=18 patients with RRT calls	*	Did not include any of the review's primary outcomes	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	3 months review of QIP records for 18 patients in total.	No statement of follow-up, QIP design.	2 stars (POOR QUALITY)
Van Galen (2016)[78]	*	*	*	Did not include any of the review's primary outcomes	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	No statement on who did assessment	*	*	5 stars (FAIR QUALITY)
Young et al (2014)[153]	Haematology-oncology patients from a single hospital	Haematology-oncology patients from a single hospital	*	Statement of 'no history of ICU transfer' was not provided	Does not control for additional factors in design phase (seasonality)	*	*	*	No statement of follow-up.	4 stars (POOR QUALITY)

Key: CA: Cardiac Arrest; **ICU**: Intensive Care Unit; **RRT**: Rapid Response Team; **SAE**: Serious Adverse Event.

5.7 Certainty of the evidence

We assessed the overall certainty of the evidence for question 2 of the review (*How effective are the different EWSs in terms of improving key patient outcomes in adult (non-pregnant) patients in acute healthcare setting?*). A narrative summary of findings table was created using GRADEpro software for the following primary outcomes: Mortality, cardiac arrest, LOS, and transfer or admission to the ICU.

Overall the certainty of the evidence is '*very low*' owing to a high risk of bias in the various study designs, a high risk of confounding in the observational studies, small sample sizes and inconsistency in the results probably owing to the heterogeneous nature of the EWS interventions applied as well as the variety of single centre settings in various countries where the findings may not be applicable to other health care settings (**Table *5.4***).

Table 5.4 Summary of findings table for primary outcomes in the effectiveness of EWS interventions (Q2)

Summary of findings:

EWS interventions for detecting acute physiological deterioration

Patient or population: Adult patients (aged 16+ years)
Setting: Acute health care settings; High or very high HDI
Intervention: EWS interventions
Comparison: other EWS/ usual care

Outcomes	Impact	№ of participants (studies)	Certainty of the evidence (GRADE)
Mortality	The definition of mortality within the 13 studies varied as did the EWS interventions applied. As a result the findings varied. 6/13 studies found no change in mortality rates as a result of use of the EWS intervention. 7/13 studies found a significant effect on mortality.	244,340, 13 studies (3 RCTs, 1 nRCT, ITS study, 8 observational studies)	⊕◯◯◯ VERY LOW [a,b,c,d]
Cardiac arrest[2]	The definition of cardiac arrest within the 7 studies varied as did the EWS interventions applied. As a result the findings varied. 4/7 studies found no change in cardiac arrest rates as a result of use of the EWS intervention. 3/7 studies found a significant effect on cardiac arrest rates (a reduction).	89,767, 7 studies (1 nRCT, 1 ITS study, 5 observational studies)	⊕◯◯◯ VERY LOW [a,b,c,d]
Length of stay (LOS)	4/5 of the included studies found no change in length of stay (LOS) as a result of use of the EWS intervention. One before-after observational study where an electronic EWS was introduced with automated alerts found a significant reduction in LOS.	24,146, 5 studies (3 RCTs, 2 observational studies)	⊕◯◯◯ VERY LOW [a,b,d]
Transfer or admission to the ICU	7/10 studies found no change in ICU admission or transfer rates and 3/10 studies found an improvement/reduction in ICU admission or transfer rates as a result of use of the EWS intervention. Given the varying definition of the outcome and heterogeneous nature of the interventions applied this is to be expected.	79,893, 10 studies (3 RCTs, 1 nRCT, 1 ITS study, 5 observational studies)	⊕◯◯◯ VERY LOW [a,b,c,d]

***The risk in the intervention group** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).
CI: Confidence interval

GRADE Working Group grades of evidence
High certainty: We are very confident that the true effect lies close to that of the estimate of the effect
Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

a. Downgraded one level due to risk of bias in the RCTs and nRCTS
b. Downgraded one level due to risk of bias as observational studies were of poor quality and at a high risk of confounding
~~c. Downgraded one level for inconsistency in~~ findings given the heterogeneous nature of the EWS interventions applied
~~d. Downgraded one level for imprecision due to small sample size and low event rate~~

[2] Note: the sample size was not reported by one study included for the outcome cardiac arrest.

5.8 Discussion

For the studies specific to the effectiveness of EWSs (afferent limb), evidence from the review is inconsistent. For the primary outcome mortality, of the 13 studies which examined the effectiveness of EWSs on mortality, seven found a significant effect in mortality rates as a result of use of the EWS in a total of 244,340 patients. Of the 13 studies, six reported no change in mortality as a result of use of the EWSs.

For cardiac arrest, in seven studies (no RCTs identified) and 89,767 patients in total, four out of the seven studies showed no change in the occurrence cardiac arrest as a result of use of the EWS, while three studies showed a significant reduction in cardiac arrest. In terms of LOS, four out of the five studies including 24,146 patients in total (and three RCTs), showed no change in mean or median LOS as a result of EWSs. For the fourth primary outcome, ICU transfers or admission rates the findings were mixed. Ten studies, including 79,893 patients overall, reported this outcome, with three studies showing an improvement in ICU transfers or admission rates while five studies showed no change, and two studies reporting a worsening of the rates.

The quality of evidence to evaluate the effect of EWS interventions on patient outcomes is poor due to a number of factors. There were only three RCTs identified and the remaining studies had higher risk of bias based on their study design. The following limitations were noted: small sample size in some studies and low event rates; a wide variation in the EWS interventions used, the definition of the outcomes varied from study to study (for example mortality may have included death within 24 hours in one study and 30-day mortality in another). The settings varied and the population included varied. All of these add significant heterogeneity to the review findings and as a result a meta-analysis was not possible.

Future research is needed to address limitations highlighted in this review. Ideally study designs of a more rigorous methodological quality are needed, preferably RCTs. A

standardised approach to the EWS interventions used and the outcomes included are warranted.

5.9 Conclusion

The findings from the 21 included studies which look at EWS interventions and their effect on patient outcomes and resources utilisation in adult patients in acute settings is of poor quality overall. The findings are contrasting owing to the heterogeneous nature of the interventions included but there was no clear evidence of an effect on primary outcomes such as mortality and cardiac arrest.

6 The effectiveness of different EWS chart designs (Q2)

6.1 Chapter overview

This chapter discusses the studies which focussed specifically on early warning systems chart designs as the key intervention element and the effect on response time to recognise physiological deterioration and the accuracy of reporting on the results of the score by the study participants (including healthcare professionals (HCPs) and students).These studies form part of review question two (effectiveness of EWS interventions).

6.2 Early Warning System Chart Design

Five studies focussed on paper-based EWS chart designs.[42-44, 47, 108] There was one RCT,[47] three nRCTs (quasi-experimental studies)[42-44] and one observational cohort study.[108] One included nurses and novice chart users,[43] two included a mix of HCPs[42, 108] and two included novices in terms of EWS charts from a university setting only.[44, 47] The number and type of vital sign parameters varied across studies (please refer to ***4.2.3***, in chapter 4 Descriptive overview of EWSs, for details on parameters included).

6.3 Results for studies focussing on chart design

The results will be discussed according to the three EWS types considered. Three of the studies considered chart designs based on the ADDS EWS.[42, 44, 47] The fourth study compared four different EWS chart designs which included BP and HR only.[43] The final study compared 12 different chart designs using the PARS EWS.[108]

6.3.1 ADDS-based chart design to measure novices ability to recognise clinical deterioration through percentage errors and response time

An RCT by Christofidis et al.,[47] compared eight different chart formats based on the ADDS observation chart in university novice chart users using four formats (**Table 6.1**). Response time and error rates were recorded for each design in a 2x2x2x2 mixed factorial design in the two groups.

Percentage Errors

Participants for whom scores were absent made 2.57% fewer errors (95% CI 1.19-3.94) using drawn dots (vs. written numbers), ($p<0.001$). For participants with scores present, there was no effect seen for data-recording format ($p>0.05$). Participants for whom scores were absent made 2.24% fewer errors (95% CI 0.75-3.73) using an integrated colour-based (vs. tabular) system, ($p<0.05$). This effect was not significant for participants with scores present ($p>0.05$). Participants made 2.13% fewer errors (95% CI 1.01-3.25) using an integrated colour-based (vs. tabular) system when scoring rows were grouped ($p<0.001$). This effect was not significant when scoring rows were separate ($p>0.05$), (**Table 6.1**).

Response time

Participants for whom scores were absent responded 2.24 seconds faster (95% CI 1.76-2.72) using drawn dot (vs. written number) observations ($p<0.001$) and participants with scores present responded 0.42 seconds faster (95% CI 0.10-0.74), ($p<0.05$). Participants for whom scores were absent responded 3.94 seconds faster (95% CI 3.40-4.48) using an integrated colour based (vs. tabular) system, ($p<0.001$) and participants with scores present responded 0.69 seconds faster (95% CI 0.32-1.06), ($p<0.001$). Participants for whom scores were absent responded 0.62 seconds faster (95% CI 0.14-1.09) using grouped (vs. separate) scoring rows, ($p<0.05$). Participants with scores present responded 0.59 seconds faster (95% CI 0.15-1.04) using separate (vs. grouped) scoring rows, ($p<0.05$), (**Table 6.1**).

6.3.2 ADDS-based chart designs based on scoring rows

A further quasi-experimental factorial design (within subjects, with scoring system design as the independent variable) by Christofidis et al.[44] compared three different chart designs based on the ADDS EWS in novice chart users (psychology undergraduates). The scoring rows were either: 1) grouped together beneath all of the vital sign data ('grouped rows'); 2) separated, with each row presented immediately below the corresponding vital sign data

('separate rows') or 3) excluded altogether ('no rows'). All three chart designs included a row for recording overall early warning scores at the bottom of the page.

Response time in recognising clinical deterioration

For 'no rows' compared with 'separate rows': participants responded 6.35 seconds faster (95% CI 5.83–6.87) than when there were separate rows (p<0.001). In the second comparison, 'no rows' compared with 'grouped rows': participants responded 7.69 seconds faster (95% CI 7.17–8.20) than when there were grouped rows (p<0.001). For the final comparison, 'separate rows' compared with 'grouped rows': participants were 1.34 seconds faster (95% CI 0.82–1.86), (p<0.001). In addition, for each chart, response times were positively correlated with 'target' early warning scores [e.g. score 0-8] indicating that the more at risk the patient, the slower responses were likely to be ('grouped rows', p<0.001; 'separate rows', p<0.001; 'no rows', p<0.001), (**Table 6.1**).

Error rate in recognising clinical deterioration

For 'no rows' for scoring individual vital signs compared with 'separate rows': participants made 2.48% fewer errors (95% CI 0.86–4.11) when there were 'no rows' rather than 'separate rows' (p=0.008). For 'no rows' compared with 'grouped rows': participants made 2.76% fewer errors (95% CI 1.01–4.50) when there were 'no rows' than when there were 'grouped rows' (p=0.007). However, there was no significant difference found between the 'separate rows' and 'grouped rows' conditions (p=1), (**Table 6.1**).

6.3.3 ADDS-based chart design to measure HCPs ability to recognise clinical deterioration through percentage errors and response time

An nRCT by Christofidis et al.,[42] investigated the effect of six different chart designs (based on the ADDS EWS) by measuring HCPs' ability to recognise normal and abnormal observations and clinical deterioration. Two groups, the first with 'prior multiple parameter track and trigger chart experience' and the second with 'graphical chart without track and

trigger experience' were assessed for the percentage of errors they made and their response time in recognising clinical deterioration.

Percentage errors

In the 'prior track and trigger chart experience' group, the ADDS chart without a BP table was the best chart design (the HCPs made 9% of errors [95% CI 6-13%]) while the no track and trigger numerical chart was the worst design (34% errors [95% CI 28-38%]). In the 'no prior track and trigger chart experience' group, the ADDS chart without a BP table was again the best chart design (the HCPs made 7% of errors [95% CI 3-11%]) while the no track and trigger graphical chart was the worst design (38% errors [32-46%]), (**Table 6.1**).

Response time

In terms of response time, the 'prior track-and-trigger chart experience group' responded faster than the 'no prior track-and-trigger graphical chart experience group' on their own chart, (p=0.033). Response time in the 'prior track and trigger experience chart' group ranged from 12 seconds (95% CI 11-13 seconds) in the ADDS chart with BP compared with 18 seconds (95% CI 16-21 seconds) in the no track and trigger numerical chart (best to worst chart design based on percentage of errors). Response time in the 'no prior track and trigger chart experience' group ranged from 12 seconds (95% CI 9-13 seconds) in the ADDS chart with a BP table compared with 17 seconds (95% CI 14-19 seconds) in the no track and trigger numerical chart (best to worst chart design based on percentage of errors).

6.3.4 Chart designs for BP and HR

A 3x2x2 mixed design experiment by Christofidis et al.[43] compared four different chart designs. There were two groups: 'seagull trained nurses and novices (psychology undergraduates)' and novices only (who did not receive seagull training). Seagull training involved the use of a visual cue called the 'Seagull Sign' to detect physiological abnormalities.

Response time in recognising clinical deterioration

For all participants there was no significant difference found between participant groups (all p values>0.10). There were significant effects of graph format, (p<0.001) and alerting system, (p=0.01), with a faster response (**Table 6.1**) seen when both graph format and alerting system were present, (p=0.002). Simple effects tests revealed that participants responded faster using separate (compared to overlapping) graphs both on charts with a track-and-trigger system, (p<0.001), and without (p<0.001). Separate graphs also yielded faster responses in the presence (compared to absence) of a track-and-trigger system (p<0.001).

In seagull trained nurses and novices only there was no significant effect of participant groups (all p values>0.70). However, there were significant effects on response time for graph format, (p=0.03) and alerting system, (p<0.001), and an additional effect when both graph format and alerting system were present, (p=0.02). When a track-and-trigger system was present, participants responded faster using separate (compared with overlapping) graphs, (p=0.002). For separate graphs, participants also responded faster using designs with (compared with without) a track-and-trigger system, (p<0.001). It is worth noting from the table that the difference between groups is literally seconds.

Percentage errors in recognising clinical deterioration

There were no significant participant group effects (all p values >0.10) in recognising clinical deterioration. However, there were significant effects on graph format, (p<0.001) and alerting system, (p=0.008), with a greater effect seen (**Table 6.1**) when both a graph format and alerting system were present, (p=0.001). Simple effects tests revealed that participants made fewer errors using separate (compared with overlapping) graphs, both on charts with a track-and-trigger system (p<0.001) and without (p<0.001). Separate graphs also yielded fewer errors in the presence (compared with absence) of a track-and-trigger system, (p<0.001).

6.3.5 Comparison of old chart (graphic depiction of observations) and new chart (EWS numerically depicted observations)

A fifth study investigated two different chart designs, the old chart design currently in use by the participants (which had a graphic depiction of observations) and a new chart, where the EWS numerically depicted observations. This observational cohort study by Fung et al.,[108] used six clinical scenarios (1. Low-grade temperature; 2. Spiking temperature; 3. Tachypnea; 4. Cushing's response; 5. Hypovolemic shock; and 6. Normal observations), identically depicted on old and new charts, creating 12 charts.

Response time

The old chart was associated with faster responses in all six clinical scenarios, reaching statistical significance in five of the six scenarios ($p<0.0001$, for five scenarios). Overall, response to the old chart was 1.6 times faster ($p<0.0001$) than the new chart (**Table 6.1**).

Accuracy

Additionally, participant's responses were more accurate in detecting deterioration in all of the six clinical scenarios on the old chart (graphical depiction) compared with the new chart (numerical depiction), reaching statistical significance in three of the scenarios ($p<0.0001$ for two scenarios, $p=0.0008$ for one scenario). Overall, the old chart was 15% more accurate (90% versus 75%, $p<0.0001$), (**Table 6.1**).

Table 6.1 The impact of EWS chart design-based interventions on patient outcomes (Q2 Effectiveness of EWS interventions)

Author, Study design	Description of intervention	Outcomes
RCTs		
Christofidis (2015a),[47] 2x2x2x2 mixed factorial design RCT Sample: 205 novice chart users (university students)	Comparison of 8 different chart formats based on the ADDS chart: 1. Data recording format (drawn dots versus written numbers) 2. Scoring system integration (integrated colour-based system versus non-integrated tabular system) 3. Scoring row placement (grouped versus separate) 4. Scores (present versus absent)	**Outcome, secondary post-hoc: Response time** Data recording format (drawn dots versus written numbers): Participants for whom scores were absent responded 2.24 seconds faster (95% CI 1.76-2.72) using drawn dot (vs. written number) observations (p<0.001) and participants with scores present responded 0.42 seconds faster (95% CI 0.10-0.74), (p<0.05). Significant main effect of data recording format: p<0.001. Scoring system integration (integrated colour-based system versus non-integrated tabular system): Participants for whom scores were absent responded 3.94 seconds faster (95% CI 3.40-4.48) using an integrated colour-based (vs. tabular) system, (p<0.001) and participants with scores present responded 0.69 seconds faster (95% CI 0.32-1.06), (p<0.001). Significant main effect of scoring system integration: p<0.001 Scoring row placement (grouped versus separate): Participants for whom scores were absent responded 0.62 seconds faster (95% CI 0.14-1.09) using grouped (vs. separate) scoring rows, (p<0.05). Participants with scores present responded 0.59 seconds faster (95% CI 0.15-1.04) using separate (vs. grouped) scoring rows, (p<0.05). Insignificant effect of scoring row placement: p=0.941. Participants responded 2.89 seconds faster (95% CI 2.38-3.39) using an integrated colour based (vs. tabular) system when scoring rows were grouped (p<0.001) and 1.78 seconds faster (95% CI 1.32-2.23) when scoring rows were separate, (p<0.001). Significant scoring system integration by scoring row placement interaction, (p<0.001) In addition, there was a main effect of scores, indicating that participants for whom scores were present (vs. absent) responded faster overall, (p<0.001). However, this effect was also qualified by the interactions with data recording format, scoring system integration and scoring row placement outlined above. **Outcome, secondary post-hoc: Percentage errors:** Data recording format (drawn dots versus written numbers): Significant main effect of data recording format: p<0.001, qualified by a significant data recording format x scores interaction, (p<0.05). Participants for whom scores were absent made 2.57% fewer errors (95% CI 1.19-3.94) using drawn dots (vs. written numbers), (p<0.001). For participants with scores present, there was no effect of data recording format (p>0.05). Scoring system integration (integrated colour-based system versus non-integrated tabular system): Participants for whom scores were absent made 2.24% fewer errors (95% CI 0.75-3.73) using an integrated colour-based (vs. tabular) system, (p<0.05). This effect was not significant for participants with scores present (p>0.05). Significant main effect of scoring system integration: p<0.05 Scoring row placement (grouped versus separate): Participants made 2.13% fewer errors (95% CI 1.01-3.25) using an integrated colour-based (vs. tabular) system when scoring rows were grouped (p<0.001). This effect was not significant when scoring rows were separate (p>0.05). Scoring row placement yielded no significant interaction with scores (p>0.05)

Table 6.1 The impact of EWS chart design based interventions on patient outcomes (Q2 Effectiveness of EWS interventions) [continued]

Author, Study design	Description of intervention	Outcomes
nRCTs		
[42]Christofidis (2013), Quasi-experimental design Sample: a mix of 101 HCPs	6 different chart designs based in the ADDS EWS were compared, measuring HCPs ability to recognise normal and abnormal observations and clinical deterioration. 1. ADDS chart with BP table 2. ADDS without BP table 3. Multiple parameter track and trigger chart 4. Single parameter track and trigger chart 5. No track and trigger graphical chart 6. No track and trigger numerical chart	**Outcome, secondary post hoc: Percentage of errors in recognising clinical deterioration:** 'Track and trigger chart experience group': ADDS with BP table: 10% (95% CI 7-14%) ADDS without BP table: 9% (95% CI 6-13%) Multiple parameter track and trigger chart: 15% (95% CI 10-20%) Single parameter track and trigger chart: 21% (95% CI 16-26%) No track and trigger graphical chart: 30% (95% CI 26-36%) No track and trigger numerical chart: 34% (95% CI 28-38%) 'Graphical chart without track and trigger experience group': ADDS with BP table: 9% (95% CI 4-14%) ADDS without BP table: 7% (95% CI 3-11%) Multiple parameter track and trigger chart: 28% (95% CI 20-34%) Single parameter track and trigger chart: 23% (95% CI 17-30%) No track and trigger graphical chart: 38% (95% CI 32-46%) No track and trigger numerical chart: 37% (95% CI 30-43%) **Outcome, secondary post hoc: Response time in recognising clinical deterioration** The 'multiple parameter track-and-trigger chart experience group' responded faster than the 'no track and trigger graphical chart experience group' on their own chart, (p= 0.033). Response time in the 'multiple parameter group' ranged from 12 seconds (95% CI 11-13) in the ADDS chart with BP compared with 18 seconds (95% CI 16-21) in the no track and trigger numerical chart (best to worst chart design). Response time in the 'no track and trigger graphical chart experience group' ranged from 12 seconds (95% CI 9-13) in the ADDS chart with BP compared with 17 seconds (95% CI 14-19) in the no track and trigger numerical chart (best to worst chart design).

Table 6.1 The impact of EWS chart design-based interventions on patient outcomes (Q2 Effectiveness of EWS interventions) [continued]

Author, Study design	Description of intervention	Outcomes
nRCTs		
[43]Christofidis (2014), 3x2x2 mixed-design experiment Sample: nurses (41) and novice chart users (113)	Comparison of 4 chart designs for BP and HR: 1. Separate graphs for BP, HR 2. Overlapping graphs for BP, HR 3. Integrated colour-based track and trigger system present 4. No track and trigger system present.	**Outcome, secondary post hoc: Response time in recognising clinical deterioration** All participants: Simple effects tests revealed that participants responded faster using separate (9 seconds, 95% CI 8-9.5 seconds) vs. overlapping (10 seconds, 95% CI 9-11 seconds)) graphs *both on charts with a track-and-trigger system*, (p<0.001), and *without* (p<0.001) [separate 9 seconds, 95% CI 8.5-10 seconds; overlapping 10 seconds, 95% CI 9.5-11 seconds)). Separate graphs also yielded faster responses in the presence (vs. absence) of a track-and-trigger system (p<0.001). No significant main or interaction effect of participant group (all p-values > 0.10). There were significant main effects of graph format, (p<0.001) and alerting system, (p=0.01), qualified by a significant graph format and alerting system interaction, (p=0.002). Seagull cases and seagull trained nurses and novices only: When a track-and-trigger system was present, participants responded faster using separate (8 seconds, 95% CI 7-9 seconds) vs. overlapping (9 seconds, 95% CI 8-10 seconds) graphs, (p=0.002). There were no significant main or interactive effects of participant group (all p values> 0.70). There were significant main effects of graph format, (p=0.03) and alerting system, (p <0.001), qualified by a significant graph format and alerting system interaction, (p=0.02). **Outcome, secondary post hoc: Percentage errors in recognising clinical deterioration** For all cases no significant main or interactive effect of participant group (all p values >0.10). There were significant main effects of graph format, (p<0.001) and alerting system, (p=0.008), qualified by a significant graph

		format and alerting system interaction, (p=0.001). Simple effects tests revealed that participants made fewer errors using separate (9 seconds, 95% CI 8-11 seconds) vs. overlapping (17 seconds, 95% CI 14-20 seconds) graphs, both on charts with a track and trigger system (p < 0.001) and without (p<0.001). Separate graphs also yielded fewer errors in the presence (vs. absence) of a track and trigger system, (p<0.001).
[44]Christofidis (2015), Quasi-experimental factorial design. Sample: 47 novices in terms of EWS charts from a university setting only.	3 different ADDS based chart designs included. The scoring-rows were either: 1. grouped together beneath all of the vital sign data ('grouped rows'); 2. separated, with each row presented immediately below the corresponding vital sign data ('separate rows') or 3. excluded altogether ('no rows'). All 3 chart designs included a row for recording overall early-warning scores at the bottom of the page	**Outcome, secondary post hoc: Response time in recognising clinical deterioration** 1. No rows versus separate rows: participants responded 6.35 seconds faster (95%CI 5.83–6.87) than when there were separate rows (p<0.001) 2. No rows versus grouped rows: 7.69 seconds faster (95%CI 7.17–8.20) than when there were grouped rows (p<0.001). 3. Separate versus grouped rows: participants were 1.34 seconds faster (95%CI 0.82–1.86) with separate vs. grouped rows (p<0.001). In addition, for each chart, response times were positively correlated with 'target' early-warning scores [e.g. score 0-8] indicating that the more at risk the patient, the slower responses were likely to be. Grouped rows, p<0.001; separate rows, p<0.001; no rows, p<0.001. **Outcome, secondary post hoc: Error rate in recognising clinical deterioration** 1. No rows versus separate rows: participants made 2.48% fewer errors (95%CI 0.86–4.11) when there were no rows for scoring individual vital signs rather than separate rows (p=0.008). 2. No rows versus grouped rows: 2.76% fewer errors (95%CI 1.01–4.50) when there were no rows than when there were grouped rows (p=0.007). 3. However, there was no significant difference between the separate and grouped rows conditions (p=1.00).

Table 6.1 The impact of EWS chart design-based interventions on patient outcomes (Q2 Effectiveness of EWS interventions) [continued]

Author, Study design	Description of intervention	Outcomes	
Observational (uncontrolled studies)			
[108]Fung (2014), Observational cohort study Sample: a mix of 100 HCPs	PARS implemented as part of the Leading Improvements in Patient Safety Programme within hospital. This revised chart aimed to improve the detection and management of deteriorating patients by incorporating early warning scores with routine observations. 6 clinical scenarios (low-grade temperature, spiking temperature, tachypnea, Cushing's response, hypovolemic shock and normal observations) were identically depicted on old and new charts, creating 12 charts. Old chart: graphic depiction of observations; New chart: EWS numerically depicted observations	**Outcomes: Secondary post-hoc: Response time (in seconds)** **Scenario: Low grade pyrexia** Old chart: 5.4 (95% CI 3.4-7.9); New chart: 9.5 (95% CI 7.3-13.0), factor faster 1.8 (p<0.0001) **Scenario: Spiking pyrexia** Old chart: 3.9 (95% CI 2.7-6.5); New chart: 7.7 (95% CI 5.3-10.4), factor faster 2.0 (p<0.0001) **Scenario: Tachypnea** Old chart: 4.2 (95% CI 2.9-7.1); New chart: 4.8 (95% CI 3.2-7.4), factor faster 1.1 (p=0.32) **Scenario: Shock** Old chart: 3.1 (95% CI 1.9-4.8); New chart: 5.3 (95% CI 3.3-7.5), factor faster 1.7 (p<0.0001) **Scenario: Cushing's response** Old chart: 2.6 (95% CI 1.9-4.4); New chart: 7.8 (95% CI 5.1-11), factor faster 3.0 (p<0.0001) **Scenario: Normal** Old chart: 5.4 (95% CI 3.4-8.0); New chart: 12.8 (95% CI 10-18.2), factor faster 2.4 (p<0.0001) **Overall speed:** Old chart: 4.5 (95% CI 2.7-7.4); New chart: 7.2 (95% CI 4.1-11), factor faster 1.6 (p<0.0001)	**Outcomes: Secondary post-hoc: Accuracy** **Scenario low grade pyrexia**: Old chart:55%; New chart:44%, p=0.16 **Scenario spiking pyrexia**: Old chart:100%; New chart:100%, p=1.0 **Scenario tachypnea**: Old chart:98%; New chart:78%, p<0.0001 **Scenario Shock**: Old chart:91%; New chart:89%, p=0.81 **Scenario Cushing's response** Old chart:96%; New chart:53%, p<0.0001 **Normal**: Old chart:98%; New chart:84%, p=0.0008 **Overall accuracy**: Old chart:90%; New chart:75%, p<0.0001

Key: ADDS: Adult deterioration detection system; **BP**: Blood pressure; **HCP:** Health care professional; **HR**: Heart rate; **PARS**: Patient at risk score.

6.4 Methodological quality

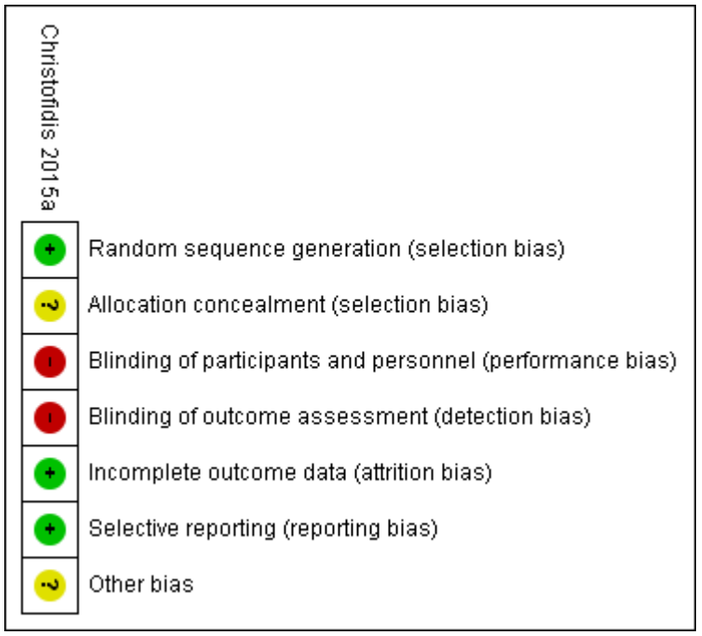
Three different study designs were included (one RCT, three nRCTs and one observational cohort study). The quality of included studies is presented according to the different study designs.

6.4.1 RCTs

The Cochrane risk of bias tool[23] was used to appraise the methodological quality of the included RCT.[47]

The single RCT was deemed to have an overall unclear risk of bias owing to an unclear risk of bias across two domains (allocation concealment, other bias) and a high risk of bias in two domains (blinding of participants and personnel and blinding of outcome assessment). [***Figure 6.6.1.***].

Figure 6.6.1. Risk of bias summary for RCTs of EWS chart design-based interventions



Allocation concealment and random sequence generation

There was no allocation concealment reported and the trial was deemed to have an unclear risk of bias.[47] Prior to testing, participants were assigned to one of two conditions using a random sequence generated by Microsoft Excel 2011 and the trial was judged to have a low risk of bias in this domain.[47]

Incomplete outcome data

The study had a low risk of bias for attrition and all participants were accounted for.[47]

Knowledge of the allocated interventions prevented (Blinding of participants and personnel)

The study was not blinded and had a high risk of bias as a result.[47]

Blinding of outcome assessment

The study was not blinded for outcome assessment and it was judged to have a high risk of bias as a result. [47]

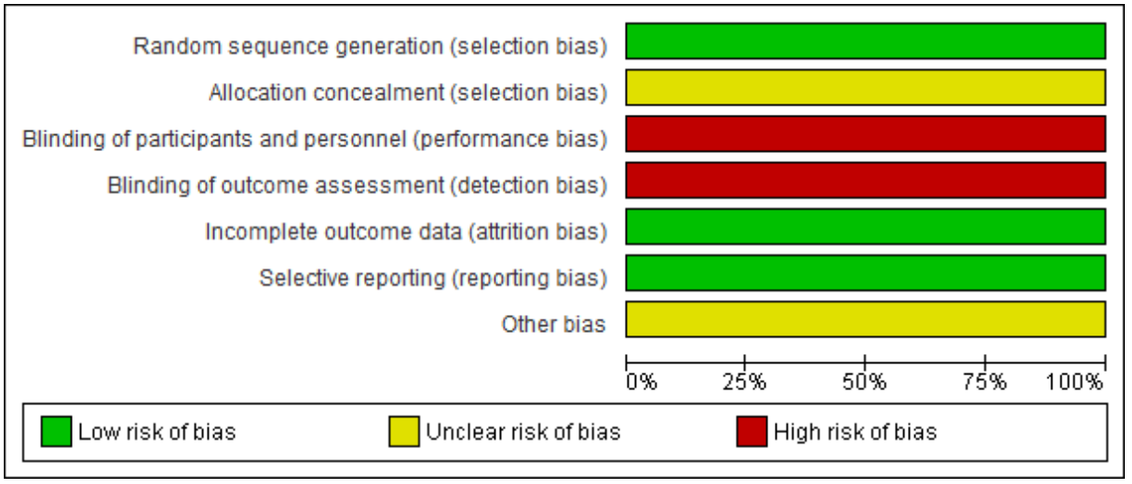
Selective outcome reporting

The study reported all pre-specified outcomes and had a low risk of bias as a result.[47]

Other potential sources of bias

The study had an unclear risk of bias as the sample included university students and novice charts users and so the findings may not be generalisable to HCPs or the clinical setting. In addition, the students received course credit to participate (**Figure 6.6.2**).[47]

Figure 6.6.2 Risk of bias graph for RCTs of EWS chart design-based interventions

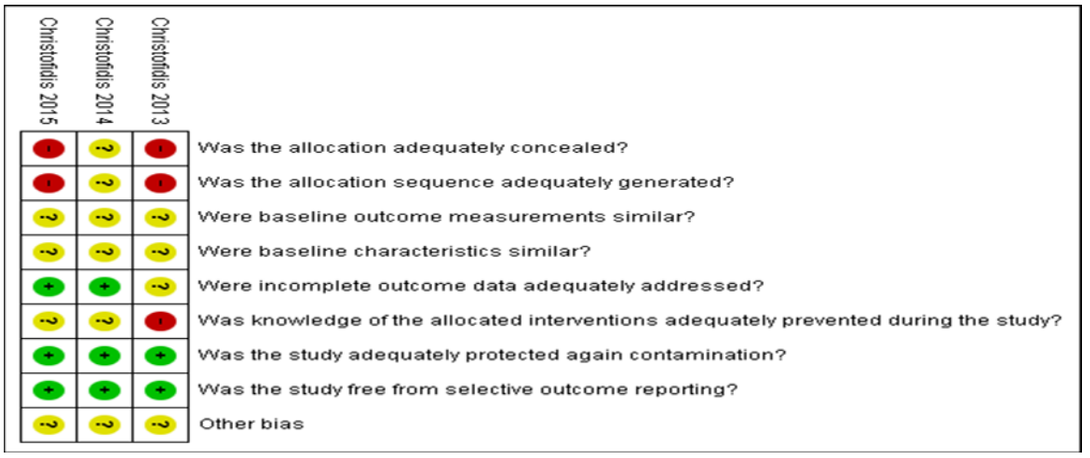


6.4.2 Non-RCTs

The Cochrane Effective Practice and Organisation of Care (EPOC) tool[24] was used to assess methodological quality of the three nRCT studies[42-44] across nine domains.

The three nRCT studies were deemed to have an unclear risk of bias overall across seven out of the nine domains (all three studies had a low risk of bias for selective outcome reporting and protection from contamination) (***Figure 6.6.3***).[42-44]

Figure 6.6.3 Risk of bias summary of nRCTs of EWS chart-based interventions



Allocation

Allocation concealment and random sequence generation

Two of the three studies had a high risk of bias for allocation concealment and random sequence generation as they were non-randomised control trials.[42, 44] Christofidis et al. (2014)[43] had an unclear risk of bias for allocation concealment as the included purposive sample of nurses all received the intervention, however the convenience sample of novices group were randomly assigned to the intervention using an automated excel spread sheet which allocated each novice participant to a training condition at random (***Figure 6.6.4***).

Baseline outcome measurements similar

All three trials had an unclear risk of bias as none of them reported baseline outcome measures and as a result it was not possible to determine whether baseline outcome measurements were similar or not (***Figure 6.6.4***).[42-44]

Baseline characteristics similar

All three studies had an unclear risk of bias as baseline characteristics were not reported (***Figure 6.6.4***).[42-44]

Incomplete outcome data

Two studies had a low risk of bias for attrition as all participants were accounted for.[43, 44] Christofidis et al. (2013)[42] had an unclear risk of bias for incomplete outcome data. There was no statement of the total number of eligible staff approached, non-responders or flow diagram and thus it was difficult to establish accurate numbers and follow up (***Figure 6.6.4***).

Knowledge of the allocated interventions prevented (blinding)

Christofidis et al. (2013)[42] had a high risk of bias as it was not blinded. Two studies had an unclear risk of bias as to whether knowledge of the allocated interventions was prevented as it was not clear from the papers or explicitly stated (***Figure 6.6.4***).[43, 44]

Protected against contamination

All three studies were deemed to have a low risk of bias and were adequately protected against study contamination (***Figure 6.6.4***).[42-44]

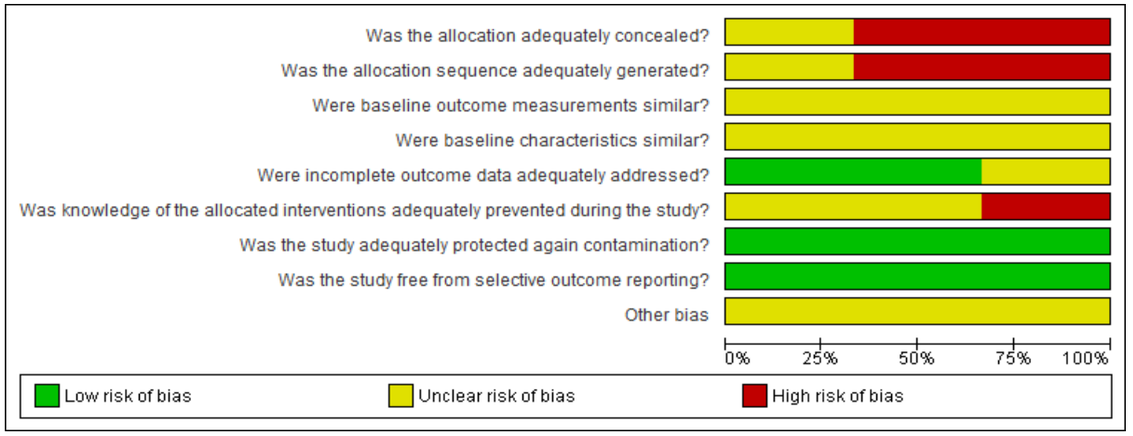
Selective outcome reporting

All three studies adequately reported outcomes and had a low risk of bias for selective outcome reporting as a result (***Figure 6.6.4***).[42-44]

Other potential sources of bias

All three studies were deemed to have an unclear risk of other potential sources of bias.[42-44] In Christofidis et al. (2013)[42], the charts used for the no track and trigger experience group were different in design than the ones they actually used in their own hospital so results may not be representative and all participants were compensated 100 Australian dollars for their time. In Christofidis et al. (2014),[43] the novice users were recruited from a university and not an actual clinical environment and the representativeness of the sample (purposive nursing sample) is questionable. Participants were also paid 75 Australian dollars to participate and the convenience undergraduate sample was given course credit to participate. In Christofidis et al. (2015),[44] again students received course credit to participate; it was not based in an actual clinical setting and the psychology students experience may not be generalisable to nurses, doctors and HCPs in general. The findings also only apply to paper based charts in all three studies,[42-44] (***Figure 6.6.4***).

Figure 6.6.4 Risk of bias graph of nRCTs of EWS chart-based interventions



6.4.3 Observational studies

The Newcastle Ottawa Scale quality appraisal tool[26] was used for the single observational study. We rated the quality of the study (good, fair and poor) by awarding stars in each domain following the guidelines of the Newcastle–Ottawa Scale as described previously (***section 5.6.3***). The study received two stars in total and was considered 'poor quality' overall (***Table 6.2***).

Table 6.2 Quality assessment of single observational study investigating the effectivenss of EWS chart design-based interventions

Study	Selection				Comparability		Outcome			Overall Quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts in analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
Observational studies (uncontrolled)										
[108]Fung (2014)	100 HCPs from a single UK hospital.	No description.	*	*	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	Recorded by study investigators, unclear whether they were blinded or if any objective measure used	Immediate – no follow-up.	No statement of follow-up, or number of HCPs eligible to be included.	2 stars (POOR QUALITY)

Key: HCP: Health care professional

6.5 Discussion and conclusion

Five studies focussed on the effectiveness of different EWS chart designs on specific outcomes including response time (of study particpants to recognise physiological deterioration) and accuracy (of documentation and recognition of deterioration). Each study assessed a different chart design, or a different component and it is not possible to combine the findings overall.

An RCT compared four different design features based on the ADDS observation chart in novice chart users and found that participants responded faster (for both scores present and absent) and made fewer errors (for scores absent only) using drawn dot (vs. written number) observations and an integrated colour-based (vs. non-integrated tabular) scoring system. A nRCT compared six different chart designs using the ADDS EWS and found that the ADDS chart without a separate BP table was the best design and no track and trigger chart designs were the worst in terms of response time and error rates. Another nRCT using the ADDS EWS compared three different chart designs and found that no rows rather than grouped rows or separate rows was the best chart design in terms of response time and error rates.

The fourth study compared four different chart designs for two parameters only (BP and HR) and found that separate rather than overlapping graphs were best for HR and BP in terms of both recognising deterioration in patients and in reducing the percentage of errors made by participants. The fifth study compared two different chart designs (the old chart currently in use by participants where early warning scores were graphically depicted, and the new chart where scores were numerically depicted). The graphic depictions of observations was found to be better than numerical depictions in terms of response time in all six clinical scenarios used and resulted in more accurate responses (less errors) in all six clinical scenarios (reaching statistical significance in three). This however could be due to familiarity with the old chart design.

The findings of these five studies are only applicable to paper-based EWSs; we found no relevant studies of electronic EWSs. It must be acknowledged that the results are from five single studies looking at different components of early warning systems chart design, making an overall conclusion of the evidence difficult. In addition, where a significant effect was reported (in particular for response time), the difference was not clinically significant. Further research is warranted into optimal EWS chart designs, in both paper-based and electronic systems. The certainty of the evidence is not assessed as these studies did not include any of the primary outcomes of this review and so a summary of findings table is not presented. However, our results indicate that different chart designs may well have a clinically important impact on the rates of recording errors on observation charts, but given the poor quality of the included studies this would need to be interpreted with caution.

7 Results: The predictive value in terms of patient outcomes and resource utilisation of EWS interventions for the detection of physiological deterioration in adult (non-pregnant) patients in acute health care settings

7.1 Chapter overview

This chapter in the systematic review focusses on the literature pertinent to question 2 of the review. "*How effective are the different EWSs in terms of improving key patient outcomes in adult (non-pregnant) patients in acute health care settings?*" with a specific focus on the predictive ability of EWSs. This chapter specifically addresses studies which measure the predictive ability of EWSs in terms of the primary (mortality, cardiac arrest, LOS, transfer or admission to the ICU) and secondary outcomes (clinical deterioration in sub-populations, PROMs [validated tools] and any other outcomes identified post-hoc [composite outcome of serious adverse events, acute heart failure, hospital-acquired acute kidney injury, total number of responses and interventions]).

7.2 Overview of studies focussing on the predictive ability of EWSs

Sixty eight studies investigated the predictive ability of one or more EWS.[8, 13, 40, 41, 49, 54-56, 58, 60, 61, 64, 65, 67, 70, 73-78, 83-87, 89, 90, 92-94, 100-106, 110-113, 116, 118, 120-123, 126, 138-152, 154-156, 158] There was one RCT,[118] two before-after studies,[49, 139] 18 prospective cohorts,[40, 61, 65, 67, 70, 75, 77, 78, 83-87, 100, 101, 104, 110, 148] 43 retrospective cohorts,[8, 13, 41, 54-56, 58, 60, 64, 73, 74, 76, 89, 90, 92-94, 102, 103, 105, 106, 111-113, 116, 120, 121, 123, 138, 140-146, 149, 150, 152, 154-156, 158] and four case control studies.[122, 126, 147, 151] The sample size ranged from 62 elective surgical patients[138] to 374,838 adult patients (**Table *7.1***).[156]

7.3 Overview of EWSs included

Eight studies investigated the predictive ability of NEWS alone.[70, 77, 90, 93, 101, 110, 113, 120] Five studies investigated the predictive ability of a MEWS alone.[67, 74, 78, 100, 138] Thirty studies investigated the predictive ability of a number of existing EWSs.[8, 13, 40, 41, 49, 56, 60, 65, 73, 75, 76, 89,

94, 103-106, 111, 112, 143, 144, 146, 148-152, 155, 156, 158) Twenty-five studies investigated the predictive ability of newly-developed (often algorithm-based) EWSs, which were compared to other existing EWSs in most studies.(54, 55, 58, 61, 64, 83-87, 92, 102, 116, 118, 121-123, 126, 139-142, 145, 147, 154)

7.4 Primary outcomes

7.4.1 Mortality

In total, 33 of the 68 studies examined the predictive ability of EWSs for mortality with varying predictive ability reported.(8, 40, 41, 56, 60, 67, 70, 73, 75, 76, 87, 92-94, 102, 104-106, 111-113, 118, 121, 138, 139, 142, 144, 146, 148, 150, 152, 154, 155, 158)

A single RCT was included. One randomised controlled crossover study in general ward patients using a prediction model by Bailey et al.,(118) tested the sensitivity and specificity of the model to predict death. The model had a sensitivity of 54.2% (95% CI 49.6-58.8%) and a specificity of 89.2% (95% CI 88.8-89.7%), with a PPV of 10.4% (95% CI 9.2-11.7%) and a NPV of 98.8% (95% CI 98.7-99.0%), (**Table *7.1***).

Thirty-two observational cohort studies were included with ten examining a single EWS, 15 comparing a number of different EWSs and seven investigated the predictive ability of newly-developed (often algorithm-based) EWSs, which were compared to other existing EWSs in most studies. Ten of the 32 observational cohort studies investigated the predictive ability of a single EWS, with three considering NEWS(70, 93, 113), two studies considering a MEWS(67, 138) and one study each considering VSS,(76) SCS,(40) ViEWS,(94) Rothman index(150) and a centile based EWS.(158)

In a retrospective cohort study by Jarvis et al.,(93) including more than 45,000 patients and 942,000 observation sets, the authors calculated the 24-hour risk of serious clinical outcomes including mortality for vital signs observation sets with NEWS values of 3, 4 and 5, separately determining risks when the score did/did not include a single score of 3. Aggregate NEWS values of 3 with a component score of 3 had a significantly lower risk (OR: 0.26) than an aggregate value of 5 (OR: 1.0).

In a cohort of 330 patients admitted to either a medical, surgical or haematology ward, Luís et al.,[70] compared the predictive ability of NEWS, to individual parameters within NEWS (HR, RR, Temperature, SBP, SpO_2, FiO_2 and AVPU) as well as to a model excluding temperature and a model excluding SBP. NEWS overall (AUC 0.94, 95% CI 0.91-0.98) was superior in predicting mortality than any of the individual parameters within NEWS. When temperature was removed from the NEWS model, the AUC increased to 0.97 (95% CI 0.94, 0.99) and when SBP was removed the AUC dropped to 0.90 (95% CI 0.86-0.95). In terms of sensitivity and specificity the model removing temperature from NEWS had the highest sensitivity (97.2%) and specificity (80.7%) at a cut-off of 5.5.

Smith et al.,[113] retrospectively examined the ability of the NEWS compared to 44 different sets of MET calling criteria to predict mortality in a large UK hospital study including 66,712 unique patients, where an AUC of 0.91 (95% CI 0.91-0.92) was reported. The NEWS at a cut-off of 7 had superior sensitivity (54.2%) and specificity (97.2%) to all of the different MET calling criteria.

In a retrospective cohort study Stark et al.,[138] compared the ability of the max MEWS (highest MEWS score on the day of the event) to predict mortality in 62 elective surgical patients who had a cardiopulmonary arrest. Max MEWS of three and four both had AUCs >0.70 and were superior to max MEWS of 5 or more which had AUCs <0.70. The sensitivity and specificity of max MEWS three and four were greater than max MEWS of five or more in addition and had greater NPVs.

In 526 sepsis-diagnosed patients from 14 different regions of Italy, Tirotta et al.,[67] investigated the ability of a MEWS to predict in-hospital mortality. Overall the MEWS had poor discriminatory ability (AUC 0.60, 95% CI 0.52-0.67). When dichotomized as low risk vs high risk (MEWS < 4 vs. >4), the MEWS had a sensitivity of 35% (95% CI, 24–46%) and a specificity of 83% (95% CI, 80–87%), a NPV of 88% (95% CI, 44–91%) and a PPV of 27% (95% CI, 18–37%) for in-hospital mortality (**Table *7.1***).

In a cohort of 1,317 patients with MET calls the VSS EWS was retrospectively applied to assess its ability to predict mortality.[76] The VSS EWS was a poor predictor of mortality (AUC 0.63).

In a prospective cohort of 752 patients admitted to the AMU, Nguyen et al.,[40] assessed the ability of the SCS EWS to predict mortality (in-hospital and 30-day mortality). When only age was included in the model, the AUC was 0.66 for overall mortality. This increased when age and the SCS were combined (AUC 0.80). Similar findings were generated for in-hospital mortality and 30-day mortality. In addition, a SCS of 11 had a sensitivity of 72.9% and specificity of 81.1% to predict 30-day mortality, compared to a sensitivity of 81.3% and specificity of 73.3% at a score of 10.

In a retrospective cohort study including three different hospitals by Rothman et al.,[150] and electronic medical record data from over 148,000 patients the ability of the RI EWS to predict 24-hour mortality was compared in the three different hospitals. The RI had excellent discriminatory ability in all three (AUCs all >0.92).

In a retrospective cohort study by Tarassenko et al.,[158] including 863 acutely ill in-hospital medical surgical patients, a centile-based alerting system was modelled using the aggregated database. The alerting system was constructed using the hypothesis that an EWS of 3 (which, in most systems, initiates a review of the patient) should be generated when a vital sign is below the 1st centile or above the 99th centile for that variable. Normalised histograms (unit area under the curve) and cumulative distribution functions were generated for four key vital signs (HR, RR, SpO_2 and SBP). When compared with EWSs based on a 'future outcome', the cut-off values in this centile-based system were most different for RR and SBP. With four-hourly observations in a 12-h shift, about 1 in 8 at-risk patients would trigger this centile-based alerting system during the shift. The authors state that a centile-based EWS will identify patients with abnormal vital signs regardless of their eventual outcome and might therefore be more likely to generate an alert when presented with patients with 'redeemable morbidity or avoidable mortality'.

Kovacs et al.,[94] compared the ability of ViEWS to predict death within 24 hours in a cohort study of over 87,000 medical and surgical patients. The predictive ability of ViEWS was similar across all groups (all observations non-elective medical, all observations non-elective surgical, random observations non-elective medical, random observations non-elective surgical) with all yielding AUC's >0.90.

Fifteen of the 32 observational cohort studies compared the predictive ability of a number of existing EWSs.[8, 41, 56, 60, 73, 75, 105, 106, 111, 112, 144, 146, 148, 152, 155]

A retrospective cohort study by Boulos et al.,[41] compared the predictive ability of SIRS compared to qSOFA in a cohort of patients with MET calls where sepsis was the trigger from medical, surgical and mental health settings to predict 28-day in-hospital mortality. Both SIRS (AUC 0.54) and qSOFA (AUC 0.64) had poor predictive ability. SIRS had better sensitivity (86.4%) than qSOFA (62.1%). The SIRS PPV was 23.7% compared to a PPV of 31.3% for qSOFA and a NPV of 86% for SIRS versus 85.1% for qSOFA.

A retrospective cohort study by Churpek et al.,[144] including over 59,000 medical and surgical patients compared the predictive ability of eight different EWSs using vital sign data extracted from the electronic database. The CART EWS (AUC 0.88, 95% CI 0.86-0.90), ViEWS (AUC 0.88, 95% CI 0.86-0.91) and SEWS (AUC 0.88, 95% CI 0.86-0.90) all had similar predictive ability for mortality. The MERIT EWS had the lowest (AUC 0.74, 95% CI 0.71-0.76) followed by the modified MERIT (AUC 0.79 95% CI 0.76-0.81).

In over 269,000 patients from five hospitals in a retrospective cohort design, Churpek et al.,[146] compared the electronic CART (eCART) to a MEWS by splitting the data into 60% development and 40% validation. The eCART (AUC 0.93, 95% CI 0.93-0.93) was superior to the MEWS (AUC 0.88, 95% CI 0.88-0.88) in predicting mortality.

A prospective observational cohort study by Dawes et al.,[104] compared the Worthing PSS EWS (in data from 2005 [validation] and 2010 [re-validation]) to the NEWS to predict mortality. When the final Worthing PSS score in the AMU (2010) was compared to the

NEWS it had superior predictive ability for mortality (AUC 0.88, 95% CI 0.83-0.94 vs. AUC 0.76, 95% CI 0.72-0.80).

In a retrospective cohort of more than 32,000 general medical or surgical patients, Finlay et al.,[152] compared the ability of a MEWS and the Rothman index (RI) to predict mortality. In this cohort, the RI (AUC 0.93, 95% CI 0.92-0.93) was superior to the MEWS (AUC 0.82, 95% CI 0.82-0.83) in predicting mortality. A MEWS score of four had a sensitivity of 49.8% (and a specificity of 93.6%) compared to an RI score of -16 which had a sensitivity of 48.9% (and a specificity of 97.1%) and a RI of 30 which had a sensitivity of 76.8% (and a specificity of 90.4%). The MEWS and RI had similar PPVs and NPVs.

In a study by Jarvis et al.,[106] including more than 64,000 observation sets the authors investigated the performance of 35 previously published EWSs using three methods of observation selection (1, all observations; 2, one randomly chosen observation set per episode and 3, one observation set per episode based on choosing a random point in time with each episode). The AUC is lowest for any given EWS when all observations in the dataset were used and highest when one random observation is selected per episode. All observations range: AUC 0.76 (centiles-based EWS by Tarrassenko et al.,[158]) to AUC 0.90 (NEWS). Observations chosen at random range: AUC 0.78 (Tarrassenko centiles-based EWS) to AUC 0.91 (NEWS) and for observations chosen at random point in time range: AUC 0.77 (Tarrassenko centiles-based EWS) to AUC 0.91 (NEWS).

In a small retrospective cohort study of 151 patients, Jo et al.,[73] compared the predictive ability of ViEWS-L (with lactate level) to ViEWS, HOTEL, APACHE II, SAPS II and SAPS III. The ViEWS-L (AUC 0.80, 95% CI 0.73-0.88) was superior to VIEWS (AUC 0.74, 95% CI 0.66-0.82), HOTEL (AUC 0.66, 95% CI 0.58-0.75) and APACHE II (AUC 0.69, 95% CI 0.58-0.75), and on par with SAPS II (AUC 0.80, 95% CI 0.73-0.87) and SAPS III (AUC 0.80, 95% CI 0.73-0.88) in predicting mortality.

In a study by Jarvis et al.,[105] the authors investigated the effectiveness of EWSs that have only two possible scores, 0 (normal, i.e., low risk) or 1 (abnormal, i.e., increased risk), for each vital sign. The simplified EWS, referred to as 'binary EWS', are based on previously existing standard EWSs (36 published 'standard' EWS—the 34 previously compared by Smith et al.,[8] plus CART and the centiles EWS.[158]) All aggregate EWSs and binary EWS had an AUC ≥0.70 for predicting mortality. Binary EWS had lower discriminatory ability than the standard EWS in general for predicting death, but these differences were not statistically significant. Binary NEWS had significantly better discriminatory ability than all other standard EWS, except the standard NEWS.

In a prospective cohort by Moseson et al.,[148] the authors compared in 227 critically ill patients admitted to the ICU directly from the ED; the APACHE II, APACHE III, and SAPS II [ICU scores] to a MEWS, REMS, PEDS, and a pre-hospital critical illness prediction score developed by Seymour et al.,[159] [ED-based scores] and their ability to predict 60-day mortality. The ICU scores outperformed the ED scores with higher AUC values. There were no differences in discrimination among the ED-based scoring systems (AUC 0.69 to 0.74) or among the ICU-based scoring systems (AUC 0.77 to 0.79).

The SOFA, SAPS III and a MEWS EWSs were compared in a prospective cohort study by Reini et al.,[75] including 518 patients admitted to the ICU for their ability to predict ICU-mortality. The SOFA EWS had the best predictive ability (AUC 0.91, 95% CI 0.86-0.97) compared to the MEWS (AUC 0.80, 95% CI 0.72-0.88) and SAPS III (AUC 0.89, 95% CI 0.83-0.94). The SOFA (at a score of 8) and SAPS III (at a score of 70) had similar sensitivity and specificity and were superior in sensitivity to the MEWS (at a score of 6).

In a population of more than 35,000 patients with real-time vital sign data, Smith et al.,[8] compared the ability of NEWS to detect death to 33 other EWSs currently in use. The NEWS had an AUC of 0.89 (95 % CI 0.89-0.90) and was superior to all other 33 EWSs whose AUCs ranged from 0.81 to 0.86.

A study by Churpek et al.,[155] compared the NEWS, a MEWS, qSOFA and SIRS in predicting in-hospital mortality. The NEWS had a higher predictive ability (AUC 0.79) than the MEWS (AUC 0.75), the qSOFA (AUC 0.69) and the SIRS (AUC 0.68).

Qin et al.,[56] compared the ability of the APACHE II, MEWS, the Shock Index, the SOFA and a modified-MEWS (based on the conventional MEWS, which also included age and transcutaneous oxygen saturation) to predict 28-day death in a cohort of 292 patients with septic shock in a single Chinese hospital. The APACHE II had the best discriminatory ability (AUC 0.78) and the Shock index had the worst (AUC 0.53). The MEWS had an AUC of 0.61 and the SOFA an AUC of 0.62. The modified MEWS had an AUC of 0.70. The optimal threshold for the APACHE II was reported to be 23.5, 6.5 for the MEWS, 0.78 for the shock index and 11.5 for the SOFA EWS in predicting 28-day death.

Pimentel et al.,[112] compared the NEWS and NEWS2 using a cohort of 251,266 acute admissions from five UK hospitals to predict in-hospital death within 24 hours. They split the cohort into three groups: patients with recorded type two respiratory failure (T2RF) [n=1,394], those at risk of T2RF [n=48,898], and patients not at risk of T2RF [n=202,094]. Across the three groups, the NEWS had slightly better discriminatory ability than the NEWS2 in predicting in-hospital death within 24 hours. For example, in patients with T2RF, the NEWS had an AUC of 0.86 (95% CI 0.85, 0.87) and the NEWS2 had an AUC of 0.84 (95% CI 0.83, 0.85). In patients with T2RF the NEWS2 at cut-offs of 5 and 7 reduced sensitivity by 10% and 14%.

In a Danish cohort of 11,266 patients with chronic respiratory disease, Pedersen et al.,[60] compared the NEWS, CROS, CREWS and S-NEWS EWSs in predicting 48-hour mortality. All four EWSs had similar predictive ability (NEWS AUC 0.85, CROS AUC 0.82, CREWS AUC 0.85 and S-NEWS AUC 0.84). Applying any of the NEWS modifications resulted in lower sensitivities, and NPV, and high specificities and PPV, both when using a total score of 6 or 9 as cut-off values.

Hodgson et al.,[111] compared the predictive ability of the NEWS, CREWS and S-NEWS in a cohort of 39,470 patients from two UK hospitals. The cohort was split into two, patients with an acute exacerbation of COPD (AECOPD) [n=2,361] and non-COPD patients [n=37,109]. When including first admissions only data, in the AECOPD group, the NEWS had an AUC of 0.74, the CREWS had an AUC of 0.72 and the S-NEWS had an AUC of 0.62. In the non-COPD group, the NEWS had an AUC of 0.77. Similar findings were reported when all inpatient episode data were included. The NEWS had a higher sensitivity but lower specificity than the CREWS and S-NEWS across all groups.

Seven of the 32 observational cohort studies investigated the predictive ability of newly-developed (often algorithm-based) EWSs, which were compared to other existing EWSs in most studies.[87, 92, 102, 121, 139, 142, 154]

A retrospective cohort study by Badriyah et al.,[102] using decision tree analysis and a data mining technique to create the DTEWS in over 35,000 acute medical admissions compared the predictive ability of this electronic system to NEWS. The DTEWS had a similar AUC for mortality to the NEWS (AUC 0.90, 95% CI 0.90-0.91 vs. AUC 0.89, 95% CI 0.89-0.90). The authors also found that a trigger point of 5 for DTEWS and 4 for NEWS would detect 83% of those who die within 24 hours of a given EWS value, requiring a response to only 25% of either DTEWS or NEWS values.

A retrospective cohort study including over 27,000 medical patients by Bleyer al.,[142] compared the predictive ability of the critical vital sign EWS to the ViEWS and a MEWS. A critical vital sign (these included SBP, temperature, SpO_2, RR and level of consciousness) was arbitrarily defined as the level at which a patient who sustained the given vital sign during an admission had a 5% or greater chance of dying. The predictive ability of the critical vital sign EWS was similar to ViEWS (AUC 0.86) and NEWS (AUC 0.87) for ages 60-70 years (AUC 0.84), ages >70 (AUC 0.87) and ages >80 (AUC 0.86).

In a retrospective cohort study, Churpek et al.,[121] developed an EWS based on location and time-stamped vital signs obtained from the hospital electronic medical record. Four models were generated (one for each outcome, Model 1: ICU transfer, Model 2: Cardiac arrest, Model 3: Mortality, and Model 4: Composite outcome) in one half of the training dataset and validated in the other half. The ability of the different models to predict mortality ranged from 0.73 to 0.82, with Model 3 having the best AUC.

A prospective cohort study including 108 medical patients by Durusu-Tanriover et al.,[87] compared the predictive ability of a MEWS to the individual vital signs. The highest total MEWS score and the highest neurological score (AVPU) had the best predictive ability for mortality (AUC 0.85, 95% CI 0.77-0.91 and AUC 0.85, 95% CI 0.77-0.91, respectively). Sensitivity and specificity of the individual parameters varied with the highest BP score having a sensitivity of 100% compared to 85.7% for the MEWS highest total score (**Table *7.1***). Specificity ranged from 33.6% (BP) to 100% for highest neurological score.

In a cohort of more than 86,000 adult medical patients, Jarvis et al.,[92] developed a laboratory-based decision tree EWS (LDT-EWS) in a single set (n=3,496) and validated it in 22 different sets (n=3,428-4,093) to predict in-hospital mortality. The AUC was for the LDT-EWS ranged from 0.75 (95% CI 0.72-0.78) to 0.80 (95% CI 0.77-0.82), with similar AUC's found in males only and females only.

In a cohort of over 31,000 adult non-ICU patients admitted to one of three different hospitals, Umscheid et al.,[139] examined the ability of the 7-item sepsis EWRS to detect mortality in a before-after intervention study. The EWRS had low sensitivity (6%) and specificity (16%) to detect mortality in the derivation cohort (with very similar findings for the validation cohort). The EWRS had a PPV of 97% and NPV of 26% to detect mortality in the derivation cohort (with very similar findings for the validation cohort).

Churpek et al.,[154] compared nine different machine learning techniques to a MEWS in 269,999 hospitalised medical-surgical ward patients from five US hospitals in predicting

ward death. Eight out of the nine different machine learning techniques were superior to the MEWS, with the random forest model (AUC 0.94) having the highest discriminatory ability and the decision tree model having the lowest (AUC 0.87). The MEWS had an AUC of 0.88.

7.4.2 Cardiac arrest

In total, 15 of the 68 studies examined the predictive ability of EWSs for cardiac arrest with varying predictive ability reported.[8, 93, 94, 102, 105, 112, 113, 121-123, 143-146, 154]

There were 14 retrospective cohort studies included which were compared to other existing EWSs in most studies with three examining a single EWS, six comparing a number of different EWSs and five investigated the predictive ability of newly-developed (often algorithm-based) EWS.

Three of the retrospective cohort studies investigated the predictive ability of a single EWS, with two considering NEWS[70, 93, 113], and one study considering ViEWS.[94]

In a retrospective cohort study by Jarvis et al.,[93] including more than 45,000 patients and 942,000 observation sets, the authors calculated the 24-hour risk of serious clinical outcomes including cardiac arrest for vital signs observation sets with NEWS values of 3, 4 and 5. They also determined the risks when the score did/did not include a single score of 3. Aggregate NEWS values of 3 with or without a component score of 3 have significantly lower risks (OR: 0.24 and 0.21) than an aggregate value of 5 (OR: 1.0).

Smith et al.,[113] examined the ability of the NEWS compared to 44 different MET calling criteria sets to predict cardiac arrest in a cohort of 66,712 patients in a large UK hospital. The NEWS had an AUC of 0.78 (95% CI 0.76, 0.78), a sensitivity of 22.2% and a specificity of 97.0%. The position of the NEWS ROC curve was above and to the left of all MET criteria points, indicating better discrimination.

Kovacs et al.,[94] compared the ability of ViEWS to predict cardiac arrest in a cohort of over 87,000 medical and surgical patients. The predictive ability of ViEWS was similar across all groups (all observations non-elective medical, all observations non-elective surgical, random observations non-elective medical, random observations non-elective surgical) with all yielding AUCs >0.70.

Six of the retrospective cohort studies investigated the predictive ability of a number of existing EWSs.[8, 106, 112, 143, 144, 146]

A retrospective cohort study by Churpek et al.,[144] including over 59,000 medical and surgical patients, compared the predictive ability of eight different EWSs using vital sign data extracted from the electronic database. The CART EWS had the best predictive ability (AUC 0.83, 95% CI 0.79-0.86) followed by ViEWS (AUC 0.77, 95% CI 0.72-0.82). The MERIT EWS had the lowest AUC (0.63, 95% CI 0.59-0.68) and poor discriminatory power to predict cardiac arrest.

A retrospective cohort study by Churpek et al.,[143] including over 47,000 patients, compared the predictive ability of the CART score to a MEWS using ward vital signs collected from admission to discharge. The CART score was superior to the MEWS in terms of predicting cardiac arrest (AUC 0.84 vs. AUC 0.76).

In over 269,000 patients from five hospitals, Churpek et al.,[146] compared the electronic CART (eCART) to a MEWS by splitting the data into 60% development and 40% validation. The eCART (AUC 0.83, 95% CI 0.82-0.83) was superior to the MEWS (AUC 0.71, 95% CI 0.70-0.73) in predicting cardiac arrest. At a specificity of 90%, the eCART had higher sensitivity (54%) for cardiac arrest compared with the MEWS (39%).

In a retrospective cohort study by Jarvis et al.,[105] the authors investigated the effectiveness of EWSs that have only two possible scores, 0 (normal, i.e., low risk) or 1 (abnormal, i.e., increased risk), for each vital sign. The simplified EWSs, referred to as 'binary EWS', were based on previously existing standard EWSs (36 published 'standard' EWS—the 34

previously compared by Smith et al.,[8] plus CART and the centiles EWS.[158]) All aggregate EWSs and binary EWSs had an AUC ≥0.60. Binary EWSs had lower discriminatory ability than the standard EWSs in general for predicting cardiac arrest, but these differences were not statistically significant. Binary NEWS had significantly better discriminatory ability than all other standard EWSs, except the standard NEWS.

In a population of more than 35,000 patients with real-time vital sign data, Smith et al.,[8] compared the ability of NEWS to detect cardiac arrest to 33 other EWSs currently in use. The NEWS had an AUC of 0.72 (95% CI 0.69-0.76) and was superior to all other 33 EWSs whose AUCs ranged from 0.61 to 0.71.

Pimentel et al.,[112] compared the predictive ability of the NEWS and NEWS2 in a cohort of 251,266 adult acute admissions from five UK hospitals to predict cardiac arrest. Three groups were compared: those with T2RF (n=1,394), those at risk of T2RF (n=48,898) and patients with no risk (control) of respiratory failure (n=202,094). Both the NEWS and NEWS2 had similar discriminatory ability in each of the three groups (AUCs > 0.70).

Five of the retrospective cohort studies investigated the predictive ability of newly-developed (often algorithm-based) EWSs, which were compared to other existing EWSs in most studies.[102, 121, 123, 145, 154]

A retrospective cohort study by Badriyah et al.,[102] using decision tree analysis and a data mining technique to create the DTEWS in over 35,000 acute medical admissions compared the predictive ability of this electronic system to NEWS. The DTEWS had a similar AUC for cardiac arrest to the NEWS (AUC 0.71, 95% CI 0.67-0.75 vs. AUC 0.72, 95% CI 0.69-0.76).

A retrospective cohort study by Churpek in 109 cardiac arrest patients, 2,543 ICU transfer patients and 56,000 controls compared the predictive ability of the newly developed cardiac arrest EWS (using electronic health record data) to the ViEWS.[145] The AUC for the cardiac arrest model to predict a cardiac arrest event was 0.88 (95% CI 0.84-0.91) and superior to the ViEWS (AUC: 0.78, 0.73-0.83). Similar findings were generated for the model's ability to

predict cardiac arrest within 24 hours (**Table *7.1***). The cardiac arrest model had a sensitivity of 65% compared to ViEWS (41%) and a specificity of 93%. The derived model had a specificity of 95% (compared to ViEWS – 85%) at the cut-off with 60% sensitivity.

A further retrospective cohort study by Churpek et al.,[121] where the authors developed an EWS based on location and time-stamped vital signs obtained from the hospital electronic medical record was included. Four models were generated (one for each outcome, Model 1: ICU transfer, Model 2: Cardiac arrest, Model 3: Mortality, and Model 4: Composite outcome) in one half of the training dataset and validated in the other half. The ability of the different models to predict cardiac arrest ranged from AUC 0.74 to 0.76, with Models 1 and 4 having the best AUCs.

In a cohort of over 269,000 patients admitted to five different hospitals, Churpek et al.,[123] compared the predictive ability of vital signs (Temperature, RR, HR, SBP, DBP, Pulse pressure index, Shock index, SpO_2) and a MEWS prior to cardiac arrest in elderly (>65 years) and non-elderly (<65 years) patients using data from prospectively collected electronic health records. In both the elderly (AUC 0.71, 95% CI 0.68-0.75) and non-elderly (AUC 0.85, 95% CI 0.82-0.88) the MEWS had the best predictive ability to detect cardiac arrest, followed by RR (highest value), (Elderly AUC: 0.67, 95% CI 0.64-0.71; non-elderly AUC: 0.82, 95% CI 0.79-0.86) and shock index (highest value), (Elderly AUC: 0.67, 95% CI 0.63-0.70; non-elderly AUC: 0.76, 95% CI 0.72-0.81).

Churpek et al.,[154] compared nine different machine learning techniques to a MEWS in a cohort of 269,999 hospitalised medical-surgical patients from five US hospitals. All nine machine learning techniques had superior discriminatory ability (AUCs ranged from 0.74 to 0.83) when compared to the MEWS (AUC 0.71).

A single case control study was included. A nested case-control study by Churpek et al.,[122] including 88 cases of cardiac arrest and 352 matched controls in medical and surgical wards. The accuracy of a MEWS and routinely collected vital signs (RR, HR, DBP, SBP, pulse pressure

index, temperature and SpO_2) were compared using the maximum and minimum values for each to predict cardiac arrest. The MEWS (AUC 0.77, 95% CI 0.71-0.82) followed by maximum RR (AUC 0.72, 95% CI 0.65-0.78) had the best predictive ability. Maximum temperature (AUC 0.48, 95% CI 0.42-0.56) and maximum DBP (AUC 0.53, 95% CI 0.45-0.60) had the lowest AUCs for predicting cardiac arrest.

7.4.3 LOS

One prospective cohort study examined the predictive ability of an EWS on LOS.[40] In 752 patients admitted to the AMU, Nguyen et al.,[40] assessed the ability of the SCS EWS to predict LOS longer than three days. When only age was included in the model, the AUC was 0.65. This increased when age and the SCS were combined (AUC 0.70). A SCS of 7 had a sensitivity of 66.2% and specificity of 63.6% to predict LOS.

7.4.4 Transfer or admission to the ICU

In total 20 of the 68 studies examined the predictive ability of EWSs on transfer or admission to the ICU with varying predictive ability reported.[8, 49, 60, 74, 93, 94, 102, 105, 112, 113, 116, 118, 121, 140, 143-147, 154]

Of these 20 studies, one RCT, one before-after study, 17 cohort studies and one retrospective case control study[147] examined ability to predict transfer or admission to the ICU.

One randomised controlled crossover trial in general ward patients using a prediction model by Bailey et al.,[118] tested the sensitivity and specificity of the model to predict ICU transfer. The model had a sensitivity of 41.1% (95% CI 37.9-44.5%) and a specificity of 89.6% (95% CI 89.2-90.0%), with a PPV of 15.2% (95% CI 13.8-16.7%) and a NPV of 97.1% (95% CI 96.8-97.3%), (**Table *7.1***).

One before-after intervention study by DeMeester et al.,[49] compared the predictive ability of a MEWS to SAPS, reporting that the SAPS (AUC 0.70) was superior to the MEWS (AUC

0.60). A SAPS score of three had a sensitivity of 61% compared to 40% for a MEWS score of three. Specificity for SAPS was 74% compared to 76% for the MEWS (**Table *7.1***).

There were 17 cohort studies which examined the ability of EWSs to predict transfer or admission to the ICU with four examining a single EWS, seven comparing a number of different EWSs and six investigated the predictive ability of newly-developed (often algorithm-based) EWSs, which were compared to other existing EWSs in most studies.

Four of these 17 cohort studies investigated the predictive ability of a single EWS, with two considering NEWS[70, 93, 113], one considering a MEWS[74] and one study considering ViEWS.[94]

In a retrospective cohort study by Jarvis et al.,[93] including more than 45,000 patients and 942,000 observation sets, the authors calculated the 24-hour risk of serious clinical outcomes including unplanned ICU transfer for vital signs observation sets with NEWS values of 3, 4 and 5, separately determining risks when the score did/did not include a single score of 3. Aggregate NEWS values of either 3 or 4 with a component score of 3 have significantly lower risks (OR: 0.23 and 0.46) than an aggregate value of 5 (OR: 1.0).

Smith et al.,[113] compared the NEWS to 44 different MET calling criteria in a large UK hospital including over two million vital sign sets from 66,712 patients to predict unplanned ICU admission. The NEWS had an AUC of 0.86 (95% CI 0.85-0.86), a sensitivity of 37.4% and specificity of 97.1%. For all outcomes (mortality, cardiac arrest and unplanned ICU admission) the position of the NEWS ROC curve was above and to the left of all 44 different MET criteria points, indicating better discrimination.

Yoo et al.,[74] investigated the predictive ability of a MEWS compared to MEWS with blood lacate (MEWS BLA) in 100 septic patients in a single hospital in South Korea to predict ICU transfer. When blood lactate was added the AUC was 0.90 compared to MEWS alone where the AUC was 0.82. At a cut-off of 5.5, the MEWS had higher sensitivity (81.6%) than the MEW BLA at a cut-off of 3.05 (73.7%) but lower specificity (66.1% versus 87%).

Kovacs et al.,[94] compared the ability of ViEWS to predict unplanned ICU transfer in a cohort of over 87,000 medical and surgical patients. The predictive ability of ViEWS was similar across all groups (all observations non-elective medical, all observations non-elective surgical, random observations non-elective medical, random observations non-elective surgical) with all yielding AUCs >0.80 (***Table 7.1***).

Seven of the cohort studies investigated the predictive ability of a number of existing EWSs (8, 60, 105, 112, 143, 144, 146)

A retrospective cohort study by Churpek et al.,[144] including over 59,000 medical and surgical patients compared the predictive ability of eight different EWSs using vital sign data extracted from the electronic database. The CART EWS had the highest AUC (0.77, 95% CI 0.76-0.78) and the MERIT EWS had the lowest (AUC 0.64, 95% CI 0.63-0.65).

A retrospective cohort study by Churpek et al.,[143] including over 47,000 patients compared the predictive ability of the CART score to a MEWS using ward vital signs collected from admission to discharge. The CART score was superior to the MEWS in terms of predicting ICU transfer (AUC 0.71 vs. AUC 0.67).

In over 269,000 patients from five hospitals, Churpek et al.,[146] compared the electronic CART (eCART) to a MEWS by splitting the data into 60% development and 40% validation. The eCART (AUC 0.75, 95% CI 0.74-0.75) was superior to the MEWS (AUC 0.68, 95% CI 0.68-0.68) in predicting ICU transfer.

In a study by Jarvis et al.,[105] the authors investigated the effectiveness of EWSs that have only two possible scores, 0 (normal, i.e., low risk) or 1 (abnormal, i.e., increased risk), for each vital sign. The simplified EWSs, referred to as 'binary EWS', were based on previously existing standard EWSs (36 published 'standard' EWS—the 34 previously compared by Smith et al.,[8] plus CART and the centiles EWS).[158] All aggregate EWSs and binary EWSs had an AUC ≥0.70 for predicting unplanned ICU admission (except Bakir EWS and CART). Binary EWSs had lower discriminatory ability than the standard EWS in general but these

differences were not significant. Binary NEWS had significantly better discriminatory ability than all other standard EWSs, except the standard NEWS.

In a population of more than 35,000 patients with real-time vital sign data, Smith et al.,[8] compared the ability of NEWS to detect unanticipated ICU admission to 33 other EWSs currently in use. The NEWS had an AUC of 0.86 (95% CI 0.85-0.87) and was superior to all other 33 EWSs whose AUCs ranged from 0.57 to 0.83.

Pimentel et al.,[112] investigated the ability of the NEWS and NEWS2 to predict unanticipated ICU admission in a cohort of 251,266 acute adult admissions in five UK hospitals. The cohort as previously described was split into three groups: those with documented T2RF (n=1,394), those at risk of T2RF (n=48,898) and those with no risk of T2RF (n=202,094). Similar to the findings for mortality and cardiac arrest, the two EWSs had similar predictive ability across the three groups for unanticipated ICU admission. For example, in the group with documented T2RF, the NEWS had an AUC of 0.81 (95% CI 0.79, 0.83) and the NEWS2 had an AUC of 0.82 (95% CI 0.80, 0.84). In those patients at risk of T2RF, the NEWS had an AUC of 0.81 (95% CI 0.81, 0.82) almost identical to the NEWS2 (AUC 0.81, 95% CI 0.81, 0.82).

Pedersen et al.,[60] compared the predictive ability of the NEWS to modified EWSs including the CROS, CREWS and S-NEWS in a cohort of 11,266 patients with a diagnosis of chronic respiratory disease for ICU admission in Denmark. All four EWSs had similar AUCs (NEWS AUC 0.79, S-NEWS AUC 0.79, CREWS AUC 0.81 and CROS AUC 0.81). Similar to the findings for mortality, applying any of the NEWS modifications (CREWS, CROS, S-NEWS) resulted in lower sensitivities and NPV, and higher specificities and PPV, when using a total score of 6 or 9 (**Table *7.1***).

Six of the cohort studies investigated the predictive ability of newly-developed (often algorithm-based) EWSs, which were compared to other existing EWSs in most studies.[102, 116, 121, 140, 145, 154]

A retrospective cohort study by Alaa et al.[140] in general medical patients developed and validated a model using electronic medical records and compared it a MEWS, SOFA, APACHE II and the RI EWS. The AUC for ICU admission for this model (AUC 0.81) was superior to the other EWSs (MEWS AUC 0.64, SOFA AUC 0.62, APACHE II AUC 0.63 and RI AUC 0.72). The proposed risk model at a true positive rate (TPR) of 60, had a positive predictive value (PPV) of 30%. The risk score offers a lower false alarm rate compared to all other EWSs for all TPR settings (40%, 50%, 60%, 70% and 80%).

A retrospective cohort study by Badriyah et al.,[102] using decision tree analysis and a data mining technique to create the DTEWS in over 35,000 acute medical admissions compared the predictive ability of this electronic system to NEWS. The DTEWS had a similar AUC for unanticipated ICU admission to the NEWS (AUC 0.86, 95% CI 0.85-0.87 vs. AUC 0.86, 95% CI 0.85-0.87).

A retrospective cohort study by Churpek et al.,[145] in 109 cardiac arrest patients, 2,543 ICU transfer patients and 56,000 controls compared the predictive ability of the newly developed ICU transfer model (using electronic health record data) to the ViEWS. The AUC for the ICU transfer model to predict ICU transfer was 0.77 (95% CI 0.76-0.78) and superior to the ViEWS (AUC: 0.73, 95% CI 0.72-0.74). Similar findings were found for the model's ability to predict ICU transfer within 24 hours.

A further retrospective cohort study in which Churpek et al.,[121] developed an EWS based on location and time-stamped vital signs obtained from the hospital electronic medical record was included. Four models were generated (one for each outcome, Model 1: ICU transfer, Model 2: Cardiac arrest, Model 3: Mortality, and Model 4: Composite outcome) in one half of the training dataset and validated in the other half. The ability of the different models to predict ICU transfer ranged from 0.68 to 0.71.

In a retrospective cohort study of 19,000 general patients, Hackmann et al.,[116] measured the predictive ability of an electronic EWS with over 300 parameters to predict ICU transfer

and compared it to a real-time simulator of the model in just over 1,200 patients in a mini trial. The electronic model had an AUC of 0.88 and when compared to a real-time simulator of the model the AUC was 0.73. The electronic model had similar sensitivity (49%) and specificity (95%) to the real-time simulator of the model (sensitivity 41%, specificity 95%). This was also true for the PPV and NPV in both models.

Churpek et al.,[154] compared nine different machine learning techniques to a MEWS in a cohort of 269,999 medical-surgical patients from five US hospitals to predict ICU transfer. Similar to the findings for cardiac arrest and mortality, the random forest model had the best predictive ability (AUC 0.78) and the MEWS had the lowest (AUC 0.68). RR, HR, age and SBP were the most important predictor variables in the random forest model.

There was a single case-control study which examined the ability of an EWS to predict transfer or admission to the ICU.

One retrospective case control study including over 43,000 surgical and medical patients from 14 hospitals in the USA compared a 14-item electronic EWS to a MEWS in terms of unplanned ICU transfer.[147] In the derivation cohort the MEWS had an AUC of 0.71 (95% CI 0.70-0.72) compared to the electronic EWS which had an AUC of 0.85 (95% CI 0.83-0.86). The EWS had superior AUC in the validation cohort (MEWS: 0.70, 95% CI 0.69-0.71 vs. electronic EWS 0.78, 95% CI 0.75-0.80). Similar findings were produced when only one randomly selected observation per patient was included (**Table *7.1***).

7.5 Secondary outcomes

7.5.1 Clinical deterioration in sub-populations

In total, 13 of the 68 studies examined the ability of EWSs to predict clinical deterioration in sub-populations.[13, 55, 56, 58, 61, 64, 65, 67, 74, 100, 103, 120, 151] with 12 cohort studies and one case control study.

Of the 12 cohort studies examining predictive ability, four investigated a single EWS, four compared a number of existing EWSs and four investigated newly developed EWSs.

Four of the 12 cohort studies investigated the predictive ability of a single EWS, with one considering NEWS[120] and three considering a MEWS.[74]

A retrospective cohort study by Capan et al.,[67, 100, 120] used electronic medical records to identify optimal patient-centred RRT activation rules using the NEWS. There were 12 statistically significant sub-populations identified in the study. Of these there were two categories of patients with distinct RRT thresholds. Highly frail surgical patients with no previous deterioration events had an optimal RRT activation at NEWS of 1-4 and moderately frail medical patients had an optimal RRT activation threshold at a NEWS of ≥7 to detect clinical deterioration (**Table *7.1***).

In a prospective cohort by Suppiah et al.,[100] including 142 acute pancreatitis patients, the ability of a MEWS to detect severe acute pancreatitis was examined using the highest MEWS value and the mean MEWS value for each patient. The AUC for the highest MEWS was 0.92 (95% CI 0.85-1.00) and this was similar to the mean MEWS (AUC 0.91, 95% CI 0.84-0.99). The sensitivity (95.5%) and specificity (90.8%) for the highest MEWS (≥3) was similar to that of the mean MEWS (>1) sensitivity (95.5%) and specificity (87.5%) in detecting severe acute pancreatitis.

Tirotta et al.,[67] included 526 sepsis-diagnosed patients from 31 different medical wards in Italy to investigate the predictive ability of a MEWS for in-hospital mortality. The MEWS had an AUC of 0.60 (95% CI 0.52, 0.67) and when dichotomised as low risk vs high risk (MEWS < 4 vs. >4), the MEWS had a sensitivity of 35% (95% CI, 24–46%) and a specificity of 83% (95% CI, 80–87%), a NPV of 88% (95% CI, 44–91%) and a PPV of 27% (95% CI, 18–37%) for in-hospital mortality.

Yoo et al.,[74] included 100 patients with sepsis or septic shock and compared a MEWS with MEWS and blood lactate (MEWS BLA) in predicting ICU transfer. Both had good

discriminatory power (MEWS AUC 0.82, MEWS BLA 0.90). The MEWS with a cut-off of 5.5 had higher sensitivity (81.6%) than the MEWS-BLA (73.7%) at a cut-off of 3.05 and lower specificity (66.1% versus 87%).

Four of the 12 cohort studies investigated the predictive ability of a number of existing EWSs.[13, 56, 65, 103]

A retrospective cohort study by Cooksley et al.,[103] including 840 oncology patients compared NEWS and a MEWS to predict 30-day mortality and critical care unit admission. Both the NEWS and the MEWS were poor predictors of 30-day mortality in oncology patients (AUC 0.59 and AUC 0.55 respectively). The findings were similar for critical care unit admission with an AUC of 0.62 for the NEWS and an AUC of 0.60 for the MEWS.

A retrospective cohort study by Eccles et al.,[13] compared the predictive ability of CREWS to NEWS in a subgroup of patients with chronic hypoxaemia. The CREWS (AUC 0.91, 95% CI 0.85-0.98) was similiar to the NEWS (AUC 0.88, 95% CI 0.79-0.96) in this subpopulation of patients with respiratory conditions.

A prospective cohort by Ghanem-Zoubi et al.,[65] in patients with a specific validated diagnosis of sepsis compared the ability of four different EWSs (MEWS, SCS, MEDS and REMS) to predict mortality. The 14-item SCS (AUC 0.77, 95% CI 0.74-0.80) and the 7-item REMS (AUC 0.77, 95% CI 0.73-0.80), both of which included age as a parameter were superior to the 5-item MEWS (AUC 0.69, 9% CI 0.65-0.73) in predicting mortality. Similar findings were generated for 5-day in-hospital mortality and 28-day in-hospital mortality.

Qin et al.,[56] compared the APACHE II, MEWS, Shock Index, SOFA and New MEWS in a sample of 292 patients admitted with shock (hypovolemic, septic, cardiogenic and mixed) in a single Chinese university hospital. In this sub-population, the MEWS had poor predictive ability (AUC 0.61) and the APACHE II had the highest AUC (0.78) in predicting 28-day death.

Four of the 12 cohort studies investigated the predictive ability of newly-developed (often algorithm-based) EWSs, which were compared to other existing EWSs in most studies.[55, 58, 61, 64]

A retrospective cohort study by Liljehult et al.,[58] including 274 stroke patients compared the ability of the 7-item ViEWS (on admission and max ViEWS) to the Scandinavian Stroke Scale to predict mortality. Max ViEWS (AUC 0.94, 95% CI 0.91-0.98) was similiar to admission ViEWS (AUC 0.85, 95% CI 0.76-0.95) and the Scandinavian Stroke Scale (AUC 0.90, 95% CI 0.84-0.96).

In a prospective cohort of 100 patients undergoing elective colorectal surgery, Martin et al.,[61] estimated the ability of the DULK score to predict anastomotic leakage (AL) following surgery. The DULK score had good predictive ability with an AUC of 0.86 (95% CI 0.76-0.96), sensitivity of 91.7% and a specificity of 55.7% at a score of >3. The PPV was 22% at a DULK score of >3.

Xiao et al.,[55] in a retrospective cohort compared the ability of a MEWS and the AFSS to clinical deterioration defined as death and severe fever in a sample of 357 patients presenting to fever clinics in Beijing. The AFSS had an AUC of 0.95 for mortality and 0.96 for severe fever, superior to the MEWS which had an AUC of 0.76 for mortality.

Zimlichman et al.,[64] conducted a retrospective cohort analysis including 113 patients with respiratory conditions including pneumonia, COPD, asthma exacerbation, pulmonary edema or patients who needed supplemental oxygen on admission who had their vital signs measured using the Earlysense continuous monitor with alerts switched off to identify optimal cut-offs for threshold and 24-hour trend alerts using RR and HR parameters. Both RR and HR combined provided the optimal AUC for threshold alerts (AUC 0.75) compared to the AUC for the parameters individually in detecting clinical deterioration (defined as ICU transfer, ventilation or cardiac arrest). This was also true for the optimal 24-hour trend alert where RR and HR combined provided the best predictive ability (AUC 0.93).

There was a single case-control study.

Yu et al.,[151] compared the ability of seven different EWSs (REMS, SOFA, PIRO, ViEWS, SCS, MEDS and MEWS) to predict clinical deterioration defined as critical care consult, ICU admission or death in a 328 cases (ICD-9 diagnosis of infections) and 328 matched controls over two time periods (0-12 hours, and 12-72 hours) in patients admitted with a diagnosis of infection. At 0-12 hours the SOFA EWS had the best predictive ability (AUC 0.78, 95% CI 0.74-0.81) and the REMS EWS was the poorest predictor of clinical deterioration (AUC 0.67, 95% CI 0.62-0.71). At 12-72 hours all except MEDS had poor discrimination for mortality (AUCs<0.70), (**Table *7.1***).

7.5.2 PROMS

No study examined the ability of EWSs to predict PROMS.

7.5.3 Post-hoc identified outcomes

7.5.3.1 Composite outcome of SAEs

In total, 23 of the 68 studies included a composite outcome of serious adverse events (SAEs)[8, 49, 77, 78, 83, 85, 86, 89, 94, 101, 102, 105, 110, 112, 113, 121, 126, 141, 146, 149, 154-156] with one before-after study, 21 cohort studies and one case control study.

There was a single before-after intervention study.

DeMeester et al.,[49] defined a SAE as death without a DNAR or ICU re-admission in a before-after intervention study investigating the predictive ability of a MEWS at different shifts before the SAE occurred. A MEWS score of two in in the shift which the SAE occurred had similiar predictive ability (AUC 0.79, 95% CI 0.63, 0.96) compared to one shift before the SAE (AUC 0.75, 95% CI 0.57-0.93) and two shifts before the SAE (AUC 0.77, 95% CI 0.59, 0.95) (**Table *7.1***).

There were 21 cohort studies with eight examining a single EWS, seven comparing a number of different EWSs and seven investigated the predictive ability of newly-developed (often algorithm-based) EWSs, which were compared to other existing EWSs in most studies.

Eight of the cohort studies investigated the predictive ability of a single EWS, with four considering NEWS,[77, 101, 110, 113] two considering ViEWS[89, 94] and two considering a MEWS.[78, 83]

A prospective cohort study by Abbott et al.[101] defined this as critical care admission or death with 48 hours of admission. The authors strived to identify the optimal NEWS threshold and found that patients admitted to the AAU with a NEWS score of ≥3 were more likely to meet the primary endpoint and for every one point increase in NEWS, there was a 55% increased risk of the composite outcome (**Table *7.1***).

Uppanisakorn et al.,[77] investigated the predictive ability of the NEWS at discharge ($NEWS_{dc}$) from the ICU to the destination ward for the composite outcome of clinical deterioration with 24 hours (defined as acute respiratory failure or circulatory shock). The AUC for $NEWS_{dc}$ was 0.93 (95% CI 0.90-0.95) and a $NEWS_{dc}$ score of 7 gave the best sensitivity (92.3%) and specificity (85.1%).

Abbott et al.,[110] compared the NEWS and the NEWS combined with lactate, glucose and base excess biomarkers to predict a composite outcome of critical care unit admission or death. The NEWS alone had the best predictive ability (AUC 0.74) compared to lactate (AUC 0.57), glucose (AUC 0.38) and base excess (AUC 0.52).

Smith et al.,[113] compared the NEWS to 44 different MET calling criteria sets to predict the composite outcome of cardiac arrest, unplanned ICU admission or mortality. The NEWS had an AUC of 0.88 (95% CI 0.88, 0.88), sensitivity of 44.5% and specificity of 97.4% at a cut-off of 7. Sensitivity of the 44 sets of MET criteria ranged from 19.6% to 71.2% and specificity ranged from 71.5% to 98.5% (**Table *7.1***).

Kovacs et al.,[94] compared the ability of ViEWS to predict a combined outcome (defined as death within 24 hours, cardiac arrest or unplanned ICU transfer) in a cohort of over 87,000 medical and surgical patients. The predictive ability of ViEWS was similar across all groups (all observations non-elective medical, all observations non-elective surgical, random observations non-elective medical, random observations non-elective surgical) with all yielding AUC's >0.80 (**Table *7.1***).

Hollis et al.,[89] included 522 surgical patients admitted over a one year period in a single US hospital and a composite outcome of SAEs (defined as surgical site infection, organ surgical site infection, myocardial infarction, pneumonia, wound disruption, sepsis, unplanned return to the operation room, bleeding/transfusion, acute renal failure, cerebral vascular accident, unplanned intubation, sepsis shock, MET activation, unplanned ICU transfer, cardiac arrest or death). The EWS (based on ViEWS measurements taken on the ward only) had an AUC of 0.90, and a sensitivity of 81% and specificity of 84% and PPV of 27%.

A MEWS ability to predict a composite outcome (defined as death, reanimation, unexpected ICU admission, emergency operations and severe complications) was examined by Smith et al.,[83] in 572 general and trauma surgery ward patients. The AUC was 0.87 (95% CI 0.81-0.93) with a sensitivity of 74% and specificity of 82% at a score of three. Sensitivity dropped to 54% for an increased specificity of 94% at a MEWS score of four or more.

Van Galen et al.,[78] determined the sensitivity and specificity of a MEWS in a cohort of 1,053 patients from six different wards to predict their composite outcome of death, cardiac arrest, ICU admission or re-admission. A MEWS of >3 had 61% sensitivity and 83% specificity, with a PPV of 12.5% and NPV of 98.1%.

Seven of the cohort studies investigated the predictive ability of a number of existing EWSs.[8, 105, 112, 146, 149, 155, 156]

In over 269,000 patients from five hospitals, Churpek et al.,[146] compared the electronic CART (eCART) to a MEWS by splitting the data into 60% development and 40% validation.

The eCART (AUC 0.77, 95% CI 0.76-0.77) was superior to the MEWS (AUC 0.70, 95% CI 0.70-0.70) in predicting the composite outcome (of mortality, cardiac arrest and ICU transfer).

In a retrospective cohort study by Jarvis et al.,[105] the authors investigated the effectiveness of EWSs that have only two possible scores, 0 (normal, i.e., low risk) or 1 (abnormal, i.e., increased risk), for each vital sign. The simplified EWSs, referred to as 'binary EWS', were based on previously existing standard EWSs (36 published 'standard' EWSs—the 34 previously compared by Smith et al.,[8] plus CART and the centiles EWSs).[158] In this study the NEWS followed by binary NEWS were the best predictors of mortality, cardiac arrest and ICU admission (composite outcome) compared to over 30 other published EWSs. In terms of sensitivity and specificity, a NEWS aggregate score ≥5 for any adverse outcome had a sensitivity of 69.7% and a specificity of 94.2%, similar to the binary NEWS (score ≥3), which had a sensitivity of 67.7% and a specificity of 92.9% (**Table *7.1***).

In a retrospective cohort study by Romero-Brufau et al.,[149] including more than 34,000 hospitalised patients, the authors compared the ability of the ViEWS, a MEWS, the GMEWS, the SEWS, the Worthing EWS and NEWS to predict the composite outcome (defined as resuscitation call, RRS activation or unplanned transfer to the ICU), in a time-dependent manner (3, 8, 12, 24 and 36 h after the observation). PPVs ranged from less than 1% (Worthing, 3 h) to 21% (GMEWS, 36 h). Sensitivity ranged from 7% (GMEWS, 3 h) to 75% (ViEWS, 36 h). Used in an automated fashion, these would correspond to 1,040–215,020 false positive alerts per year.

In a population of more than 35,000 patients with real-time vital sign data, Smith et al.,[8] compared the ability of NEWS to detect a composite outcome of death, cardiac arrest or unanticipated ICU admission to 33 other EWSs currently in use. The NEWS had an AUC of 0.87 (95% CI 0.86-0.87) and was superior to all other 33 EWSs whose AUCs ranged from 0.73 to 0.83 (**Table *7.1***).

Kipnis et al.,[156] included a composite outcome defined as transfer to the ICU or death outside of the ICU and compared the NEWS, eCART and an algorithm-based EWS, the Advanced Alert Model (AAM) using data from 21 hospital databases in the US. Overall the three EWSs had similar predictive ability (NEWS AUC 0.76, AAM AUC 0.82, eCART AUC 0.79).

Churpek et al.,[155] included a composite outcome defined as death or ICU stay and compared the NEWS, MEWS, qSOFA and SIRS in 12,154 patients from a single US hospital with suspicion of infection. The NEWS (AUC 0.73) was superior in terms of predicting this composite outcome to the qSOFA (AUC 0.64) and SIRS (AUC 0.61).

Pimentel et al.,[112] compared the predictive ability of the NEWS and NEWS2 in a cohort of 251,266 adult acute admissions from five UK hospitals to detect the composite outcome (defined as in-hospital death within 24 hours, unanticipated ICU admission or cardiac arrest). As described earlier, the cohort was split into three groups: those with documented T2RF, those at risk of T2RF and those with no risk of T2RF (control). Again, the findings were similar to those reported for the outcomes individually where both the NEWS and modified NEWS2 had comparable predictive ability. In the T2RF group the NEWS had an AUC of 0.83 whilst the NEWS2 had an AUC of 0.830.

Seven of the cohort studies investigated the predictive ability of newly-developed (often algorithm-based) EWSs, which were compared to other existing EWSs in most studies.[83, 85, 86, 102, 121, 126, 141, 154]

A retrospective cohort study by Alvarez et al.,[141] compared an automated near real time electronic medical record EWS to a MEWS in general medical patients. The primary outcome was defined as resuscitation events or death (RED) and included out of ICU hospital codes (cardiopulmonary arrests (CPAs) or acute respiratory compromise events) and unplanned transfers to the ICU. The newly developed automated EWS was superior to the MEWS in predicting RED events (Automated EWS AUC: 0.85, 95% CI 0.82-0.87; MEWS AUC: 0.75, 95% CI 0.71-0.78) (**Table *7.1***).

A retrospective cohort study by Badriyah et al.,[102] using decision tree analysis and a data mining technique to create the DTEWS in over 35,000 acute medical admissions compared the predictive ability of this electronic system to NEWS. The DTEWS had a similar AUC for the composite outcome (cardiac arrest, death or unanticipated ICU admission within 24 hours) to the NEWS (AUC 0.88, 95% CI 0.87-0.88 vs. AUC 0.87, 95% CI 0.87-0.88).

Churpek et al.,[121] developed an EWS based on location and time-stamped vital signs obtained from the hospital electronic medical record. Four models were generated (one for each outcome, Model 1: ICU transfer, Model 2: Cardiac arrest, Model 3: Mortality, and Model 4: Composite outcome) in one half of the training dataset and validated in the other half. The ability of the different models to predict the composite outcome ranged from 0.68 to 0.71, with Models 1 and 4 having the best AUC.

Douw et al.,[85] investigated the predictive ability of the nine worry variables within the Dutch Early Nurse Worry Indicator Score (DENWIS) combined with the existing EWS to predict the composite outcome (defined as unplanned ICU/HDU admission or unexpected in-hospital mortality) in 3,522 surgical patients. The EWS alone had an AUC of 0.86 (95% CI 0.82, 0.90). When only including the nine worry indicators in the model, an AUC of 0.81 (95% CI 0.77, 0.85) was reported. When combining the EWS and nine worry indicators (the DENWIS) an AUC of 0.91 (95% CI 0.88, 0.93) was reported.

A further study was conducted by Douw et al.,[86] in the same population of surgical patients where a prediction model was constructed weighing all of the DENWIS indicators by multiplying the regression coefficients by five to accomplish full advantage of the discriminative value between the indicators. For the composite outcome of unplanned ICU/HDU admission or unexpected in-hospital mortality the DENWIS had an AUC of 0.85 (95% CI 0.80, 0.89).

Churpek et al.,[154] compared nine different machine learning techniques to a MEWS in a large cohort of 269,999 hospitalised medical-surgical ward patients in five US hospitals to

predict the composite outcome (defined as ward death, ward to ICU transfer or ward cardiac arrest). Similar to the findings for mortality, cardiac arrest and ICU transfer individually, the random forest model had the best predictive ability (AUC 0.801) and the MEWS the worst (AUC 0.70).

In a single retrospective case control study by Kirkland et al.,[126] the predictive ability of a time-dependent electronic model to identify future events (defined as unplanned ICU transfer, unexpected death or RRT calls) in a cohort of 1,882 patients was examined. Lead times were divided into 2 to 12 hours, 12 to 24 hours, or 24 to 48 hours prior to an event. The single-entry model looked at each set of clinical variables individually. Serial 24 hours looked at trends of each clinical variable over 24 hours. Serial 7 days looked at trends of each clinical variable over 7 days. For future events (2-12 hours), serial 24-hour trends had the superior predictive ability (AUC 0.71). For future events (12-24 hours and 24-48 hours), serial 7 day trends had the best predictive ability (AUC 0.73, and AUC 0.66 respectively).

7.5.3.2 Acute heart failure

One study examined the ability of EWSs to predict acute heart failure.[54] A retrospective cohort study by Bian et al.,[54] compared the newly developed Super Score to a MEWS to predict acute heart failure. The Super Score was superior to the MEWS (AUC 0.81 vs. AUC 0.66), $p<0.05$. When age was added to the Super Score the AUC was 0.82. The Super Score was able to predict acute heart failure 3.9 ±1.9 hours (1-17 hours) earlier (**Table *7.1***).

7.5.3.3 Hospital-acquired Acute Kidney Injury (AKI)

One study examined the ability of EWSs to predict AKI.[90]In a retrospective cohort of over 33,000 emergency medical admissions, Faisal et al.,[90] developed four models (NEWS only; NEWS plus age and sex; NEWS plus sub-components of NEWS; and NEWS plus two-way interactions) comparing index NEWS values and maximum NEWS values ability to predict hospital-acquired AKI >48 hours after admission. Maximum NEWS values were better able to predict AKI than index NEWS values across all four models (AUC's >0.69). In addition, the

maximum NEWS had higher sensitivity and specificity and PPV across the different probability thresholds for hospital-acquired AKI than the index NEWS (**Table *7.1***).

7.5.3.4 Total number of responses and interventions (including infusion prescription, change in medication and ICU consultation)

One study examined the ability of EWSs to predict the total number of responses to EWS activations and interventions applied.[84] Van Rooijen et al.,[84] measured the sensitivity and specificity of an 8-item EWS from a database including 71,911 EWS values. Whenever the threshold was exceeded (EWS ≥3) it was registered within the database. At a threshold of 4, the sensitivity of the EWS was 74% and specificity was 51%. At a threshold of 5, the sensitivity was 52% and specificity 73%. The authors concluded that a threshold of three for triggering remains the optimal threshold for activation (**Table *7.1***).

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions)

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUR, Outcome	Sensitivity (Se), Specificity (Sp), Outcome	PPV, NPV, Outcome	Identifying optimal threshold cut-offs, Outcome
RCTs						
[118]Bailey (2013), Randomised controlled crossover design	1250-bed hospital, USA	A. N=19,116 general ward patients (intervention n=9,911; control 10,120) B. Period of July 2007 through Jan 2010 used to train and retrospectively test the prediction model. The period from Jan 2011 through December 2011 used to prospectively validate the model during a randomised trial using alerts generated from the prediction model. 36 input variables for model. 8 included in final model. C. Algorithm-based EWS D. Logistic regression analysis.	-	**Primary outcome:** Death Se: 54.2 (95% CI 49.6-58.8) Sp: 89.2 (95% CI 88.8-89.7) **Primary outcome:** ICU transfer Se: 41.1 (95% CI 37.9-44.5) Sp: 89.6 (95% CI 89.2-90.0)	**Primary outcome:** Death (2.2%) PPV: 10.4 (95% CI 9.2-11.7) NPV: 98.8 (95% CI 98.7-99.0) **Primary outcome:** ICU transfer (4.5%) PPV: 15.2 (95% CI 13.8-16.7) NPV: 97.1 (95% CI 96.8-97.3)	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued.

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, Outcome	Sensitivity (Se), Specificity (Sp), Outcome	PPV, NPV, Outcome	Identifying optimal threshold cut-offs, Outcome
Before-after intervention studies						
[49]DeMeester (2013a), Before-after intervention study.	14 medical and surgical wards, Antwerp University Hospital, Belgium	A. N=1,039 patients discharged to the wards from the ICU. B. Retrospective review of patient records. C. MEWS and SAPS D. ROC analysis	**Primary outcome: ICU transfer or admission** **MEWS score of 3 at ICU discharge**: AUC=0.60 **SAPS of 3 at ICU admission:** AUC=0.70 **Secondary outcome: post hoc:** SAEs (died without DNR, ICU admission) **Shift of the SAE, MEWS 2;** AUC=0.79 (95%CI 0.63,0.96) **One shift before the SAE, MEWS 3;** AUC=0.75 (95%CI 0.57,0.93) **2 shifts before the SAE, MEWS 3**; AUC=0.77 (95%CI 0.59,0.95)	**Primary outcome: ICU transfer or admission** **MEWS score of 3 at ICU discharge:** Se=40.0% Sp=76.0% **SAPS of 3 at ICU admission**: Se=61.0% Sp=74.0% **Secondary outcome: post hoc:** SAEs (died without DNR, ICU admission) **Shift of the SAE, MEWS 2;** Se=69.2% Sp=84.6% **One shift before the SAE, MEWS 3;** Se=61.5% Sp=92.3% **2 shifts before the SAE, MEWS 3**; Se=61.5% Sp=88.5%	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued.

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, Outcome	Sensitivity (Se), Specificity (Sp), Outcome	PPV, NPV, Outcome	Identifying optimal threshold cut-offs, Outcome
Before-After studies						
[139]Umscheid (2015), Retrospective development, Prospective validation and before-after intervention study.	University of Pennsylvania Health System (3 hospitals), USA.	A. Adult non-ICU patients admitted to acute inpatient units from Oct 1 to Oct 31, 2011 for tool derivation, Jun 6 to Jul 5, 2012 for tool validation, and Jun 6 to Sept 4, 2012 - Jun 6, 2013 to Sept 4, 2013 for pre-implementation/post-implementation analysis=31,093 included. B. The EWRS was initially activated for a pre implementation "silent" period (Jun 6, 2012–September 4, 2012) to both validate the tool and provide the baseline data to which the post implementation period was compared. During this time, new admissions could trigger the alert, but notifications were not sent. Admissions from the 1st 30 days of the pre implementation period were used to estimate the tool's screen positive rate, test characteristics, predictive values, and likelihood ratios. The post implementation (Live) Period and Impact Analysis The EWRS went "live" Sept 12, 2012, upon which new admissions triggering the alert would result in a notification and response. C. EWRS D. Cox regression.		**Primary outcome: Mortality:** A "positive" trigger as a score >=4, Derivation cohort: Se: 6%, Sp: 16% Validation cohort: Se: 6%, Sp: 17%	**Primary outcome: Mortality:** A "positive" trigger as a score >=4, Derivation cohort: PPV 97%, NPV 26% Validation cohort: PPV 97%, NPV 28%	-

Table 7.1 Studies of the predictive value of EWS scores (Q2 Effectiveness of EWS interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWS included D. Model	AUC, Outcome	Sensitivity (Se), Specificity (Sp), Outcome	PPV, NPV, Outcome	Identifying optimal threshold cut-offs, Outcome
Cohort studies						
[141]Alvarez (2013), Retrospective cohort	Urban academic hospital, USA	A. N=7466 patients admitted to the internal medicine wards or ICU between May 2009 and Mar 2010. B. Clinical prediction model created in the derivation same (50% randomly selected from total cohort) and validated in the remaining 50% of the cohort. C. Algorithm based-EWS D. Multivariate logistic regression.	**Outcome:** Resuscitation events or death [RED] (defined as out of ICU hospital codes and unplanned transfers to the ICU. Hospital codes included CPA and acute respiratory compromise (ARC) events) **Automated EWS:** Derivation AUC 0.87, 95% CI 0.85-0.89; Validation AUC 0.85, 95% CI 0.82-0.87. **MEWS:** AUC 0.75, 95% CI 0.71-0.78.	**Outcome:** RED **Se automated EWS**: 51.6% **Se MEWS**: 42.2% **Sp automated EWS**: 94.3% **Sp MEWS**: 91.3%	**Outcome:** RED (1.2% in cohort) **PPV automated EWS** 10% **PPV MEWS** 5.6%. **NPV automated EWS** 99.4% **NPV MEWS** 99.2%	-
[102]Badriyah (2014), Retrospective cohort	Hospital, UK	A. N=35,585 consecutive acute medical admissions (198,755 vital signs) between May 2006 and Jun 2008. B. Decision tree (DTEWS) developed using data mining classification technique for building trees by recurring splitting or partitioning of datasets into homogenous groups. DTEWS developed using 0,1,2,3 weighting system. Data obtained via personal digital assistants running the VitalPAC software. C. DTEWS, EWS D. Decision tree analysis.	**Outcome:** death DTEWS: AUC 0.90, 95% CI 0.90-0.91 NEWS: AUC 0.89, 95% CI 0.89-0.90 **Outcome**: cardiac arrest DTEWS: AUC 0.71, 95% CI 0.67-0.75 NEWS: AUC 0.72, 95% CI 0.69-0.76 **Outcome**: unanticipated ICU admission DTEWS: AUC 0.86, 95% CI 0.85-0.87 NEWS: AUC 0.86, 95% CI 0.85-0.87 **Outcome:** composite outcome within 24hr DTEWS: AUC 0.88, 95% CI 0.87-0.88 NEWS: AUC 0.87, 95% CI 0.87-0.88	-	-	**Outcome:** Death within 24 hrs. The detection of 83% of those who die within 24 hrs of a given EWS value requires a response to only 25% of either DTEWS or NEWS values. Trigger point of 5 for DTEWS and 4 for NEWS.

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[54]Bian (2015), Retrospective cohort study	Shandong University Hospital, China	A. N=433 patients triaged to the acute heart failure unit or the chest pain centre between Nov 2011 - Jun 2014. B. All admission and follow-up data retrieved from hospital charts. Model developed using 12 variables and only 5 significant variables were included in the new scoring system 'Super Score'. C. Algorithm-based EWS and MEWS D. Logistic regression analysis.	**Secondary outcome post hoc: Acute heart failure (AHF)** Super Score AUC: 0.81 Super Score + Age: 0.82 MEWS AUC: 0.66, p<0.05 Super Score predicted AHF 3.9 ± 1.9 hrs (1-17 hrs) earlier.	-	-	-
[142]Bleyer (2011), Retrospective cohort study	872-bed hospital, USA	A. N=27,722 patients (1.15 million individual VS measurements) admitted to a tertiary hospital Jan 2008 - Jun 2009. B. All VS measurements obtained from hospital database. Categories representing different intervals were determined for each vital sign, and the prevalence of admissions with vital signs in each range, together with proportionate mortality, were determined. A critical VS was arbitrarily defined as the level at which a patient who sustained the given VS during an admission had a 5% or greater chance of mortality. C. Algorithm-based EWS, ViEWS, MEWS D. Logistic regression analysis.	Critical vital signs i.e. levels and ranges associated with a ≥5% chance of mortality were identified as SBP (<85mmHg), HR (>120 bpm), temp (<35 or >38.90C), SpO_2 (<91%), RR (≤12 or ≥24), and level of consciousness (any other than 'Alert'). **Primary outcome: mortality** New critical VS EWS: AUC (1 point for ages 60-70): 0.84 AUC (1 point for ages >70): 0.87 AUC (1 point for ages >80): 0.86 ViEWS AUC: 0.86 MEWS AUC: 0.87	-	-	-
[41]Boulos (2017), Retrospective cohort study	Monash Health, a 2170-bed network of 5 hospitals, Australia	A. N=646 patients with MET call where sepsis was the trigger from medical, surgical and mental health units in 2015 (n=4,496 MET calls). B. Medical records reviewed and scores calculated using physiological data measured at time of MET call. C. qSOFA, SIRS D. Kaplan Meier survival curves.	**Primary outcome: 28-day in-hospital mortality:** SIRS AUC: 0.54 qSOFA AUC: 0.64	**Primary outcome: 28-day in-hospital mortality:** Se SIRS: 86.4% Se qSOFA: 62.1	**Primary outcome: 28-day in-hospital mortality**: (22%) PPV SIRS: 23.7% PPV qSOFA: 31.3% NPV SIRS: 86.0% NPV qSOFA:85.1%	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[104]Dawes (2014), Prospective observational study	Western Sussex Hospitals Trust, UK.	A. N=3,184 AMU patients (Feb 2010-July 2010) B. Automatically calculated once entered into handheld device. Compared 2010 with 2005 data (revalidation). C. Worthing PSS score, NEWS D. Logistic regression analysis.	**Primary outcome: Mortality** Worthing PSS score final in AMU (2010 data) AUC: 0.88 (95% CI 0.83-0.94). NEWS AUC: 0.76 (95% CI 0.72-0.80).	-	-	-
[120]Capan (2015), Retrospective cohort study	Mayo Clinic, USA	A. N=38,356 medical and surgical patients admitted to a single hospital Jan – Dec 2011. B. Electronic medical health records were used to identify optimal patient-centred RRT activation rules. 12 statistically significant sub-populations were identified. C NEWS. D. Semi-Markov decision process (SMDP) models.	-	-	-	**Secondary outcome: clinical deterioration in sub-populations:** 2 categories of patients with distinct RRT thresholds (1) highly frail surgical patient with no previous deterioration events optimal RRT activation at a NEWS of 1-4; (2) moderately frail medical patient optimal RRT activation at a NEWS of ≥7.

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[144]Churpek (2013), Retrospective cohort study	Urban academic hospital, USA	A. N=59,643 medical and surgical patients admitted between Nov 2008 – Aug 2011. B. Ward vital signs extracted from electronic database and the EWS were retrospectively calculated from every simultaneous ward VS set in the entire dataset. C.MERIT, Modified MERIT, EWS, MEWS, SEWS, ViEWS, CART D. Accuracy calculated using the AUC, Se and Sp using the patient's highest score prior to the event.	**Primary outcome, mortality:** MERIT: 0.74 (95% CI 0.71-0.76) Modified MERIT: 0.79 (95% CI 0.76-0.81) Bleyer et al. EWS: 0.84 (95% CI 0.82-0.87) Tarassenko centile-based EWS: 0.83 (95% CI 0.80-0.86) MEWS: 0.87 (95% CI 0.84-0.89) SEWS: 0.88 (95% CI 0.86-0.90) ViEWS: 0.88 (95% CI 0.86-0.91) CART: 0.88 (95% CI 0.86-0.90) **Primary outcome, cardiac arrest:** MERIT: 0.63 (95% CI 0.59-0.68); Modified MERIT: 0.69 (95% CI 0.65-0.74) Bleyer et al. EWS: 0.73 (95% CI 0.68-0.78) Tarassenko centile-based EWS: 0.70 (95% CI 0.65-0.76) MEWS: 0.76 (95% CI 0.71-0.81) SEWS: 0.76 (95% CI 0.71-0.81) ViEWS: 0.77 (95% CI 0.72-0.82) CART: 0.83 (95% CI 0.79-0.86) **Primary outcome, ICU transfer:** MERIT: 0.64 (95% CI 0.63-0.65) Modified MERIT: 0.69 (95% CI 0.68-0.70) Bleyer et al. EWS: 0.72 (95% CI 0.71-0.73) Tarassenko centile-based EWS: 0.71 (95% CI 0.69-0.72) MEWS: 0.74 (95% CI 0.73-0.75) SEWS: 0.75 (95% CI 0.74-0.76) ViEWS: 0.73 (95% CI 0.72-0.75) CART: 0.77 (95% CI 0.76-0.78)	**Primary outcome, cardiac arrest:** **SEWS** >3 Se 55 Sp 85, >4 Se 38 Sp 94, >5 Se 19 Sp 97 **MEWS** >3 Se 67 Sp 80, >4 Se 39 Sp 91, >5 Se 20 Sp 96 **ViEWS** >8 Se 60 Sp 83, >9 Se 41 Sp 91, >10 Se 29 Sp 95 **CART** >16 Se 61 Sp 84, >20 Se 49 Sp 90 >24 Se 35 Sp 95	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C.EWSs Included D. Model	AUC, outcome	Sensitivity, Specificity, outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[145]Churpek (2014), Retrospective cohort study	500-bed academic hospital, USA	A. N=56,649 controls, N=109 cardiac arrest patients and N=2,543 ICU transfers hospitalised between Nov 2008-Aug 2011. B. Data extracted from the electronic health record to predict cardiac arrest and ICU transfer. Validated using three-fold cross validation C. Algorithm based-EWS, ViEWS D. Logistic regression.	**Primary outcome, cardiac arrest: EVER experienced event:** Cardiac arrest model AUC: 0.88 (0.84-0.91); VitalPAC (ViEWS) AUC: 0.78 (0.73-0.83); **Within 24 hrs:** Cardiac arrest model AUC: 0.88 (0.88-0.89), VitalPAC (ViEWS) AUC: 0.74 (0.72-0.75). **Primary outcome, transfer to ICU: EVER experienced event:** ICU transfer model AUC: 0.77 (0.76-0.78); VitalPAC (ViEWS) AUC: 0.73 (0.72-0.74); Within 24 hrs: ICU transfer model AUC: 0.76 (0.76-0.76), VitalPAC (ViEWS) AUC: 0.73 (0.72-0.73)	**Primary outcome: cardiac arrest:** Specificity of 93%, cardiac arrest model had a Se 65% compared to ViEWS (41%). The derived model had a specificity of 95% (compared to ViEWS – 85%) at the cut-off with 60% Se.	-	-
[143]Churpek (2012a) Retrospective cohort study.	Academic tertiary care hospital, USA	A. N=88 cardiac arrest patients, N=2,820 ICU transfer patients and N=44,519 controls hospitalised between Nov 2008 - Jan 2011. B. Ward vital signs from admission to discharge were used. C. CART, MEWS D. Logistic regression.	**Primary outcome: cardiac arrest** CART score AUC: 0.84 MEWS AUC: 0.76 **Primary outcome: ICU transfer** CART score AUC: 0.71 MEWS AUC: 0.67	**Primary outcome: cardiac arrest** CART score: At a specificity of 89.9%, the CART score (cut-off >17) had a Se 53.4% compared to the MEWS (cut-off >4) Se 47.7%. Compared to the MEWS at cut-off >4 (specificity 89.9%), the CART score at cut-off >20 had a specificity of 91.9% with the same Se (47.7%).	-	-
[121]Churpek (2013a) Retrospective cohort study.	Academic tertiary care hospital, USA	A. N=59,643 general and surgical patients admitted between Nov 2008 - Aug 2011. B. Location and time-stamped vital signs obtained from hospital EMR. 1st half of dataset used to derive four logistic regression models (one for each outcome) and the second half of the dataset used to validate each model to detect each of the four outcomes. C. Algorithm based EWS D. Logistic regression	**Primary outcome: Mortality** Model 1 AUC: 0.77 Model 2 AUC: 0.73 Model 3 AUC: 0.82 Model 4 AUC: 0.78 **Primary outcome: Cardiac arrest** Model 1 AUC: 0.76 Model 2 AUC: 0.74 Model 3 AUC: 0.75 Model 4 AUC: 0.76 **Primary outcome: Transfer to the ICU** Model 1 AUC: 0.71 Model 2 AUC: 0.68 Model 3 AUC: 0.69 Model 4 AUC: 0.71 **Primary outcome: Combined outcomes** Model 1 AUC: 0.71 Model 2 AUC: 0.68 Model 3 AUC: 0.70 Model 4 AUC: 0.71	-	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[123]Churpek (2015), Retrospective cohort study.	Five hospitals in the USA	A. N=269,956 adult patients admitted between Nov 2008-Jan 2013. B. Patient characteristics and vital signs prior to cardiac arrest were compared between elderly (>65years) and non-elderly (<65 years) patients and extracted from prospectively collected databases and electronic health records. C. Individual VS, MEWS D. Mixed-effects regression model with patient-level random effects.	**Primary outcome: Cardiac arrest** Temp, highest value: Elderly: - ; Non-elderly: 0.53 (0.47-0.58) Temp, lowest value: Elderly: 0.56 (0.52-0.60) Non-elderly: 0.65 (0.60-0.70); RR, highest value: Elderly: 0.67 (0.64-0.71); Non-elderly: 0.82 (0.79-0.86) RR, lowest value: Elderly: 0.57 (0.53-0.61); Non-elderly: 0.54 (0.49-0.59); HR, highest value: Elderly: 0.63 (0.60-0.67); Non-elderly: 0.77 (0.73-0.81); SBP, highest value: Elderly: - ; Non-elderly: 0.57 (0.52-0.62); SBP, lowest value: Elderly: 0.65 (0.61-0.69); Non-elderly: 0.67 (0.62-0.73); DBP, highest value: Elderly: - ; Non-elderly: 0.59 (0.54-0.64); DBP, lowest value: Elderly: 0.60 (0.56-0.63); Non-elderly: 0.65 (0.60-0.70); Pulse pressure index, highest value: Elderly: 0.48 (0.44-0.52); Non-elderly: 0.60 (0.54-0.66); Pulse pressure index, lowest value: Elderly: 0.57 (0.54-0.61); Non-elderly: 0.68 (0.63-0.73); Shock index, highest value: Elderly: 0.67 (0.63-0.70); Non-elderly: 0.76 (0.72-0.81); Oxygen saturation, lowest value: Elderly: 0.55 (0.51-0.59); Non-elderly: 0.69 (0.64-0.74) MEWS, Highest value; Elderly: 0.71 (0.68-0.75); Non-elderly: 0.85 (0.82-0.88) '-' denotes AUC was statistically worse than 0.50 and thus not predictive.	-	-	-
[146]Churpek (2014a) Retrospective cohort study.	Five hospitals in the USA	A. N=269,999 adult patient admissions between Nov 2008 - Jan 2012. B. Dataset was split into development (60%) and validation (40%) to develop the new model (eCART). C. eCART, MEWS D. Logistic regression.	**Primary outcome: Mortality** eCART AUC: 0.93 [95% CI, 0.93–0.93] MEWS AUC: 0.88 [95% CI, 0.88–0.88] **Primary outcome: cardiac arrest** eCART AUC: 0.83 [95% CI, 0.82–0.83] MEWS AUC: 0.71 [95% CI, 0.70–0.73] **Primary outcome: ICU transfer** eCART AUC: 0.75 [95% CI, 0.74–0.75] MEWS AUC: 0.68 [95% CI, 0.68–0.68] **Secondary outcome: combined outcomes** eCART AUC: 0.77 [95% CI,0.76–0.77] MEWS AUC: 0.70 [95% CI, 0.70–0.70] P<0.01 for all comparisons.	At a Sp 90%, the eCART score had a Se 54% for cardiac arrest within 24 hrs compared with 39% for MEWS. Conversely, at a similar Se (65% and 67% for eCART score and MEWS), the eCART had a Sp 85% versus 71% for MEWS.	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[87]Durusu-Tanriover (2016), Prospective cohort study	University Hospital, Turkey.	A. N=108 patients admitted to a medical ward (dates not reported). B. Prospectively recruited patients from non-acute wards and nurses calculated. C. Individual VS, MEWS D. ROC analysis	**Primary outcome: Mortality** Highest neurological score (cut-off: >0): AUC: 0.85 (95% CI 0.77, 0.91) Highest temp score (cut-off: >1) AUC: 0.79 Highest systolic BP (cut-off: >0): AUC: 0.72 MEWS Highest total score (cut-off: >4) AUC: 0.85 (95% CI 0.77, 0.91)	**Primary outcome: Mortality** Highest neurological score (cut-off: >0): Se: 71.4% Sp: 100% Highest temp score (cut-off: >1) Se: 85.7% Sp: 71.2% Highest systolic BP (cut-off: >0): Se: 100% Sp: 33.6% MEWS Highest total score (cut-off: >4) Se: 85.7% Sp: 94.1%	**Primary outcome: Mortality (6%)** Highest neurological score (cut-off: >0): NPV: 98.1% PPV: 100% Highest temp score (cut-off: >1) NPV: 98.6% PPV: 17.1% Highest systolic BP (cut-off: >0): NPV: 100% PPV: 9.5% MEWS Highest total score (cut-off: >4) NPV: 99% PPV: 50%	-
[13]Eccles (2014), UK, Retrospective cohort study.	2 NHS district general hospitals, UK	A. N=196 admissions to the respiratory ward between Aug - Oct 2012. B. Data obtained from medical notes and observation charts with NEWS scores recorded prospectively. Patients split into 2 groups, those with target SpO_2 of 88-92% (chronic hypoxaemia, CH group) and those with target SpO_2 saturations of 94-98% (O group). CREWS score retrospectively applied for comparison. C. NEWS, CREWS D. ROC analysis.	**Secondary outcome: Clinical deterioration in sub-populations 30-day Mortality** CH patients NEWS AUC: 0.88 (95% CI 0.79–0.96). CH patients CREWS AUC: 0.91 (95% CI 0.85–0.98). All patients NEWS AUC: 0.83 (0.70–0.96) O patients NEWS AUC: 0.75 (0.52–0.98).	-	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[76]Etter (2014), Retrospective cohort study	960-bed University Hospital, Switzerland	A. N=1,628 MET calls in 1,317 patients admitted to the dept of intensive care medicine between Oct 2009 and Dec 2013. B. Data on patient characteristics, parameters related to MET activation and patient outcomes were extracted from the QIP database. The VSS EWS which is the sum of the occurrence of each VS abnormality were calculated for all physiological parameters retrospectively. C. VSS D. ROC analysis.	**Primary outcome: Mortality** VSS AUC: 0.63 Max VSS 24 hrs before MET event AUC: 0.62	-	-	-
[152]Finlay (2014), Retrospective cohort study	Abington Memorial, 665-bed teaching hospital, USA	A. N=32,472 patients admitted to general medical surgical wards between Jul 2009 and Jun 2010. B. Scores were computed retrospectively using the EMR where sufficient data were available. C. MEWS, RI D. ROC analysis.	**Primary outcome: Mortality** RI AUC: 0.93 (95% CI 0.92-0.93) MEWS AUC: 0.82 (95% CI 0.82-0.83), p<0.0001.	**Primary outcome: Mortality** MEWS Score= 4: Se=49.8% Sp=93.6% RI Score =-16: Se=48.9% Sp=97.1% RI Score =30: Se=76.8% Sp=90.4%	**Primary outcome: Mortality (1.9%)** MEWS Score= 4: PPV=5.2% NPV=99.6% RI Score =-16: PPV=10.6% NPV=99.6% RI Score =30: PPV=5.3% NPV=99.8%	-
[92]Jarvis (2013), Retrospective cohort.	Portsmouth Hospital, UK.	A. N=86,472 discharged adult medical patients. B. Using a database of combined haematology and biochemistry results, decision tree (DT) analysis was used to generate a lab DT EWS for each gender. LDT-EWS was developed for a single set (n=3,496) and validated in 22 other discrete sets each of three months long (total n=82,976, n=3,428-4,093). C. algorithm based EWS D.Decision Tree analysis.	**Primary outcome: In-hospital mortality (from 22 validation sets)** AUC Males and females combined: Ranged from 0.75 (0.72-0.78) to 0.80 (0.77-0.82). AUC Males: Ranged from 0.74 (0.70-0.78) to 0.82 (0.79-0.85). AUC Females: Ranged from 0.74 (0.70-0.77) to 0.82 (0.79-0.85).	-	-	LDT-EWS score of 4 threshold: would mean that 40.7% of all lab test results datasets would trigger and 79.7% of all patients subsequently dying would be visited. LDT-EWS score of 5: Males: 36.7% calls triggered, 75.8% deaths visited. LDT-EWS score of 4: Females: 35.2% calls triggered, 75.3% deaths visited.

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[90]Faisal (2018), Retrospective cohort study	700-bed York hospital, UK	A. N=33,608 emergency medical admissions Jan 2014 and December 2015. B. Electronic NEWS and patient data including whether AKI status extracted. Authors developed 4 models using index NEWS values and max NEWS values to predict AKI onset. C. NEWS D. Logistic regression analysis.	**Secondary outcome: Post hoc, hospital AKI >48 hrs after admission** Model AO (INDEX NEWS alone): AUC 0.59 (95% CI 0.58- 0.61) Model A1 (plus age, sex): AUC 0.68 (95% CI 0.67, 0.69) Model A2 (plus subcomponents of NEWS): AUC 0.68 (95% CI 0.67, 0.69) Model A3: (plus 2-way interactions): AUC 0.69 (95% CI 0.67, 0.70) Model B0 (MAX NEWS only): AUC 0.75 (95% CI 0.73, 0.76) Model B1 (plus age, sex): AUC 0.77 (95% CI 0.75, 0.78) Model B2 (plus subcomponents of NEWS): AUC 0.77 (95% CI 0.76, 0.78) Model B3: (plus 2-way interactions): AUC 0.77 (95% CI 0.76, 0.78)	**Secondary outcome: Post hoc, hospital AKI >48 hrs after admission** **Probability 0.0337** Index NEWS 1 (Model A0): Se (87.22%), Sp (20.09%) Index NEWS 1 (Model A3): Se (80.75%), Sp (46.17%) Max NEWS (Model B3): Se (78.99%), Sp (61.26%) **0.0373** Index NEWS 2 (Model A0): Se (66.13%), Sp (48.11%) Index NEWS 2 (Model A3): Se (76.46%), Sp (51.16%) Max NEWS (Model B3): Se (75.75%), S (64.59%) **0.0413** Index NEWS 3 (Model A0): Se (36.59%) Sp (75.23%) Index NEWS 3 (Model A3): Se (69.88%), Sp (56.32%) Max NEWS (Model B3): Se (72.96%), Sp (67.48%) **0.0457** Index NEWS 4 (Model A0): Se (27.11%), Sp (83.08%) Index NEWS 4 (Model A3): Se (63.56%), Sp(62.12%) Max NEWS (Model B3): Se (70.24%), Sp (74.63%) **Secondary outcome: Post hoc, hospital AKI >48 hrs after admission** **0.0506** Index NEWS 5 (Model A0): Se (19.84%), Sp (88.13%) Index NEWS 5 (Model A3): Se (55.33%), Sp (68.13%) Max NEWS (Model B3): Se (67.60%), Sp (73.14%) **0.0560** Index NEWS 6 (Model A0): Se (13.96%), Sp (92.01%) Index NEWS 6 (Model A3): Se (46.95%), Sp (74.27 Max NEWS (Model B3): Se (63.26%), Sp (75.74%)	**Secondary outcome: Post hoc, hospital AKI >48 hrs after admission** **0.0337** Index NEWS 1 (Model A0): PPV (4.4%) Index NEWS 1 (Model A3): PPV (5.95%) Max NEWS (Model B3): PPV (7.92%) **0.0373** Index NEWS 2 (Model A0): PPV (5.10%) Index NEWS 2 (Model A3): PPV (6.12%) Max NEWS (Model B3): PPV (8.28%) **0.0413** Index NEWS 3 (Model A0): PPV (5.87%) Index NEWS 3 (Model A3): PPV (6.32%) Max NEWS (Model B3): PPV (8.65%) **0.0457** Index NEWS 4 (Model A0): PPV (6.33%) Index NEWS 4 (Model A3): PPV (6.61%) Max NEWS (Model B3): PPV (9.12%) **Secondary outcome: Post hoc, hospital AKI >48 hrs after admission** **0.0506** Index NEWS 5 (Model A0): PPV (6.59%) Index NEWS 5 (Model A3): PPV (6.83%) Maximum NEWS (Model B3): PPV (9.60%) **0.0560** Index NEWS 6 (Model A0): PPV (6.87%) Index NEWS 6 (Model A3): PPV (7.15%) Max NEWS (Model B3): PPV (9.91%)	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions)

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[65]Ghanem-Zoubi (2011), Prospective cohort study.	Community-based University hospital, Israel.	A. N=1,072 patients with sepsis admitted to a 110-bed general internal medicine ward between Feb 2008 - Apr 2009. B. Prospective collection of patients with sepsis using the computerised system and a validated definition of sepsis. C. MEWS, SCS, MEDS, REMS D. Logistic regression analysis.	**Secondary outcome: Clinical deterioration in sub-populations mortality** **AUC for in-hospital mortality overall** MEWS: 0.69 (0.65-0.73) SCS 0.77 (0.74-0.80) MEDS 0.73 (0.70-0.77) REMS, 0.77 (0.73-0.80) **5-day in-hospital mortality** MEWS: 0.73 (0.68-0.78) SCS 0.79 (0.76-0.83) MEDS 0.77 (0.73-0.81) REMS, 0.80 (0.76-0.84) **28-day in-hospital mortality** MEWS: 0.70 (0.66-0.74) SCS 0.79 (0.75-0.82) MEDS 0.75 (0.71-0.78) REMS, 0.79 (0.75-0.81)	-	-	-
[116]Hackmann (2011), Retrospective cohort and mini clinical trial design	Single hospital, USA	A. N=19,116 general patients admitted between Jul 2007 and Jan 2010. Mini 'real-time simulation' trial included n=1,204 patients between Oct and Dec 2010. B. 2-tier system: (1) automatic identification of patients at risk of clinical deterioration using EWS from existing electronic database calculated using machine learning algorithms, and (2) real-time detection of clinical event based on real-time VS data collected from on-body technology attached to those high-risk patients. Data is sent to the EMR and EWS scores are assigned to patients in real time using 'machine-learning techniques' to analyse the data. C. algorithm based EWS D. Logistic regression.	**Primary outcome: Transfer to the ICU** New electronic model AUC: 0.88. Using a 'real-time simulator' of the model, the predictive value for transfer to ICU was; AUC = 0.73	**Primary outcome: Transfer to the ICU** New electronic model Se: 0.49 Sp: 0.95 Using a 'real-time simulator' of the model: Se: 0.41 Sp: 0.95	**Primary outcome: Transfer to the ICU** (*N* of events not reported) New electronic model: PPV: 0.31 NPV: 0.97 Using a 'real-time simulator': PPV: 0.29 NPV: 0.97	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[106]Jarvis (2015c), Retrospective cohort.	Portsmouth Hospital, UK.	A. N=64,285 observation sets available for analysis from patients admitted between May 2011 - Dec 2012. B. Database of vital signs constructed using data which were recorded in real-time at the bedside using handheld devices. The authors investigated the performance of EWSs using three methods of observation selection: 1) all observations, 2) one randomly chosen observation set per episode and 3) one observation set per episode based on choosing a random point in time within each episode. C. Compared 35 previously published EWS using AUCs. D. ROC analysis.	**Primary outcome: Mortality within 24 hrs of an observation set.** AUC is lowest for any given EWS when all observations in the dataset were used, highest when one random observation is selected per episode and intermediate when one random observation is selected for each episode based on choosing a random time point in the patient's stay. All observations range: AUC 0.76 (Centiles EWS by Tarrassenko) to AUC 0.90 (RCP-NEWS) Observations chosen at random range: AUC 0.78 (Tarrassenko centiles EWS) to AUC 0.91 (RCP-NEWS) Observations chosen at random point in time range: AUC 0.77 (Tarrassenko centiles based EWS) to AUC 0.91 (RCP-NEWS).	-	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[93]Jarvis (2015a), Retrospective cohort.	Portsmouth Hospital, UK.	A. N=942,887 complete valid observation sets from 45,678 completed episodes of care in adult patients Apr 2010 and May 2011. B. Vital signs data were recorded in real-time at the bedside using handheld electronic equipment running the VitalPAC software. Patient outcomes were identified using the hospital's patient administration system (for outcome of death), and its cardiac arrest and ICU admission databases. C. NEWS D. Efficiency curves.	-	-	-	**Primary outcome: Mortality** Odds of death increased with each increase of 1 point in the aggregate NEWS scores. Where a single VS had a score of 3, the odds increased, but not significantly. NEWS 5 OR =1.00 (0.72, 1.29) NEWS 3 (with a component=3) OR=0.26 (95%CI 0.12, 0.42) NEWS 4 (with a component=3) OR=0.53 (95%CI 0.25, 0.85) NEWS 3 (no component=3) OR=0.20 (95%CI 0.12, 0.28) NEWS 4 (no component=3) OR=0.38 (95%CI 0.22, 0.56). **Primary outcome: cardiac arrest** NEWS 5 OR =1.00 (0.59, 1.44) NEWS 3 (with a component=3) OR=0.24 (95%CI 0.00, 0.55) NEWS 4 (with a component=3) OR=0.66 (95%CI 0.17, 1.26) NEWS 3 (no component=3) OR=0.21 (95%CI 0.07, 0.36). NEWS 4 (no component=3) OR=0.43 (95%CI 0.14, 0.74) **Primary outcome: Unplanned ICU transfer** NEWS 5 OR =1.00 (0.55, 1.49) NEWS 3 (with a component=3) OR=0.23 (95%CI 0.00, 0.52) NEWS 4 (with a component=3) OR=0.46 (95%CI 0.00, 0.99) NEWS 3 (no component=3) OR=0.22 (95%CI 0.09, 0.38) NEWS 4 (no component=3) OR=0.45 (95%CI 0.13, 0.80)
[73]Jo (2013), Retrospective cohort study	1,000-bed urban academic tertiary hospital, South Korea.	A. N=151 adult patients admitted to the medical ICU Apr 2010 and Mar 2011. B. Demographics, clinical data, physical findings and lab results at ED presentation were collected by trained abstractors. Outcomes determined by discharge records. C. VIEWS-L (with lactate) compared to VIEWS, Hypotension oxygen saturation, temp, ECG change and loss of independence (HOTEL), APACHE II, SAPS II or SAPS III EWS D. ROC analysis.	**Primary outcome: Mortality overall** VIEWS-L AUC 0.80,(95% CI 0.73-0.88), VIEWS AUC 0.74 (95% CI 0.66-0.82), p=0.009 HOTEL AUC 0.66 (95% CI 0.58-0.75), p<0.001 APACHE II AUC 0.69 (95% CI 0.58-0.75), p=0.024 SAPS II AUC 0.80 (95% CI 0.73-0.87), p=0.944 SAPS III AUC 0.80 (95% CI 0.73-0.88), p=0.97	-	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[105]Jarvis (2015b), Retrospective cohort.	Portsmouth Hospital, UK.	A. N=68,576 discharges of 46,944 unique adult patients between May 2011 - Dec 2012. B. Database of vital signs constructed using data which were recorded in real-time at the bedside using handheld devices. The authors investigated the effectiveness of EWSs that have only 2 scores, 0 (normal, i.e., low risk) or 1 (abnormal, i.e., increased risk), for each vital sign. C. The simplified EWS, referred to as 'binary EWS', were based on previously existing standard EWSs (36 published 'standard' EWS—the 34 previously compared by Smith et al.[8], plus CART and the Centiles EWS). D. ROC analysis.	**Primary outcome: Mortality** All aggregate EWSs and binary EWS AUC≥0.70. Binary EWS had lower discriminatory ability than the standard EWS in general for predicting death, but these differences were not statistically significant. The exception was Bakir's EWS and CART. Binary NEWS had significantly better discriminatory ability than all other standard EWS, except the standard NEWS. **Primary outcome: Cardiac arrest** All aggregate EWSs and binary EWS AUC≥0.60. Binary EWS had lower discriminatory ability than the standard EWS in general for predicting cardiac arrest, but these differences were not statistically significant. The exception was Bakir's EWS and CART. Binary NEWS had significantly better discriminatory ability than all other standard EWS, except the standard NEWS. **Primary outcome: ICU admission** All aggregate EWSs and binary EWS AUC ≥0.70 for predicting unplanned ICU admission (except Bakir EWS and CART). Binary EWS had lower discriminatory ability than the standard EWS in general but these differences were not significant. Binary NEWS had significantly better discriminatory ability than all other standard EWS, except the standard NEWS.	**NEWS aggregate score ≥5; any adverse outcome**: Se=69.7% Sp=94.2% **Binary NEWS score ≥3; Any adverse outcome**: Se=67.7% Sp=92.9%	**NEWS aggregate score ≥5; Any adverse outcome (3.4%):** PPV=11.8% NPV=99.6% **Binary NEWS score ≥3, Any adverse outcome**: PPV=9.6% NPV=99.6%	A score of 3 in Binary NEWS is closest to the standard triggering score of 5 in NEWS. NEWS would generate a trigger in 10.20% of observations and 29.01% of episodes, and would trigger in the 24h before an adverse outcome in 92.57%of cases. For Binary NEWS, 11.78% of observation sets would result in a trigger (35.27% of episodes) and 93.05% of episodes ending in an adverse outcome would trigger in the 24h preceding that outcome.

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions)

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[58]Liljehult (2016), Retrospective cohort study.	Copenhagen University Hospital, Denmark.	A. N=274 patients who on admission were suspected of ischemic or haemorrhagic stroke were included. B. Data systematically collected to audit and secure the implementation process on all patients in 2012 (May-September). All data were extracted retrospectively from electronic patient files. 1st set of vital signs recorded used in analysis as well as the highest EWS during the hospitalisation period. C. newly-developed EWS D. ROC analysis.	**Secondary outcome clinical deterioration in a subpopulation: Mortality** (p values are differences between survivors and non-survivors) Admission ViEWS: AUC: 0.85 (0.76-0.95), p<0.001 Max ViEWS: AUC: 0.94 (0.91-0.98), p<0.001 No difference between areas: p=0.07. Scandinavian Stroke Scale: AUC 0.90 (0.84-0.96), p<0.001. Not different to admission EWS (p=0.44) or max EWS (p=0.16). For individual parameters, only RR (AUC 0.67, p=0.005) and AVPU (AUC 0.72, p<0.001) were significantly better at distinguishing between survivors and non-survivors than pure chance.	**Primary outcome: Mortality** Admission EWS 1 Se=79.2% Sp=80.1% Admission EWS 4 Se=50% Sp=97.3% Max EWS EWS 1 Se=100% Sp=45.3% EWS 4 Se=95.8% Sp=87.0%	**Primary outcome: Mortality** Admission EWS 1 PPV=27.1% NPV=97.6% EWS 4 PPV=63.2% NPV=95.4% Max EWS EWS 1 PPV=14.7% NPV=100% EWS 4 PPV=41.1% NPV=99.5%	-
[70]Luis (2017), Prospective cohort study.	Lisbon Central Hospital, Portugal.	A.N=330 patients admitted to 2 medical wards, 3 surgical wards and 1 haematology ward Dec 1st and 31st 2012. B. Authors evaluated the individual parameters of the NEWS model for an appropriate detection of the outcomes, building an aggregate system properly adapted to the suited convenience sample based on nursing records for admitted patients. C. NEWS D. ROC analysis.	**Primary outcome: Mortality** NEWS overall: AUC 0.94 (0.91, 0.98), p<0.001. HR: AUC 0.77 (0.67, 0.86), p<0.001. RR: AUC 0.62 (0.51, 0.73), p=0.025. Temp: AUC 0.51 (0.41, 0.61), not significant. SBP: AUC 0.71 (0.62, 0.81), not significant. SpO_2: AUC 0.73 (0.63, 0.83), p<0.001. FiO_2: AUC 0.83 (0.77, 0.89), p<0.001. AVPU: AUC 0.78 (0.68, 0.88), p<0.001. Model 1 (excluding temp): AUC 0.97 (0.94-0.99), p<0.001 Model 2 (excluding SBP): AUC 0.90 (0.86-0.95), p<0.001.	**Primary outcome: Mortality** NEWS=6.5: Se 91.2%, Sp 78.4%, Model 1<5.5: Se 97.2%, Sp 80.7%, Model 2=4.5: Se 82.4%, Sp 82.8%	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome		Sensitivity, Specificity, outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
[94]Kovacs (2016), Retrospective cohort study	Portsmouth Hospitals NHS Trust, UK.	A. N=87 399 admissions, comprising 2,017,455 observation sets. Of these, 35,174 were admissions to surgical specialities (792,889 observation sets) and 52,225 admissions to medical specialties (1,174,574 observation sets) over 31 months (25/05/2011 and discharged on or before 31/12/2013). B. Data were categorised as elective or non-elective surgical or medical admissions. Staff entered patients' vital signs data at the bedside into handheld devices running the VitalPAC software following the hospital protocol. For each admission (or episode of care) three outcomes (death, cardiac arrest and unanticipated ICU admission) were extracted from the appropriate hospital databases. C. NEWS D. ROC analysis.	**Primary outcome: Death within 24 hrs:** All observations, non-elective surgical AUC 0.91 (0.90, 0.92) All observations, non-elective medical AUC 0.90 (0.89, 0.90), p=0.003 Random observations, non-elective surgical AUC 0.91 (0.89, 0.94) Random observations, non-elective medical AUC 0.92 (0.92, 0.93), p=0.522 **Primary outcome: Cardiac arrest within 24 hrs:** All observations, non-elective surgical AUC 0.76 (0.73, 0.79) All observations, non-elective medical AUC 0.74 (0.73, 0.75), p=0.345 Random observations, non-elective surgical AUC 0.72 (0.66, 0.77) Random observations, non-elective medical AUC 0.74 (0.72, 0.76), p=0.508	**Primary outcome: Unanticipated ICU admission within 24 hrs:** All observations, non-elective surgical AUC 0.86 (0.85, 0.86) All observations, non-elective medical AUC 0.86 (0.85, 0.87), p=0.555 Random observations, non-elective surgical AUC 0.83 (0.81, 0.85) Random observations, non-elective medical AUC 0.87 (0.85, 0.88), p<0.001 **Combined outcome:** All observations, non-elective surgical AUC 0.87 (0.86, 0.88) All observations, non-elective medical AUC 0.87 (0.87, 0.87), p=0.874 Random observations, non-elective surgical AUC 0.84 (0.83, 0.86) Random observations, non-elective medical AUC 0.88 (0.88, 0.89), p<0.001	-	-	ViEWS value of 5 would trigger for 12.3% of observations performed on non-elective medical or surgical admissions, and this would result in the detection of 70.2% of combined outcomes. ViEWS value of 4 would have a similar efficiency (11.0% of observations detecting 70.9% of Combined Outcomes) for non-elective admissions to medical or surgical specialties.
[78]Van Galen (2016), Prospective cohort study	Large urban university hospital, The Netherlands.	A.N=1,053 patients admitted to 6 different wards between Oct and Nov 2015. B. Charts of all included patients were checked by the investigator to obtain the patients' MEWS and to determine whether scores were documented correctly. All patients followed up for 30 days after inclusion. Max Score per patient used to perform the predictive analysis. C. MEWS D. ROC analysis.	-		**Composite outcome:** death, cardiac arrest, ICU admission and re-admission: MEWS >3: Se: 61%, Sp: 83%	**Composite outcome (3.9%):** Death, cardiac arrest, ICU admission MEWS >3: PPV: 12.5%, NPV: 98.1%	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
[148]Moseson (2014), Prospective observational cohort study.	Academic tertiary hospital, San Francisco, USA.	A. N=227 patients admitted to the ICU with acute medical or surgical complications. B. Prospective cohort, scores calculated by computer and manually checked at random. C. Compared ED-based EWS (REMS, MEWS, Seymour and PEDS) to ICU-based EWS (SAPS II, APACHE II, APACHE III) D. ROC analysis.	**Primary outcome: 60-day mortality** ED data: REMS: 0.70 (0.61, 0.78) MEWS: 0.69 (0.62, 0.77) PEDS 0.70 (0.62-0.79) Seymour: 0.74 (0.67-0.81) ICU data: APACHE-II 0.77 (0.70-0.85) APACHE-III 0.79 (0.72-0.87) SAPS II 0.79 (0.72, 0.86).	-	-	-
[61]Martin (2015), Prospective cohort study.	French hospital, France.	A. N=100 consecutive patients undergoing elective colorectal surgery with anastomosis between Jun 2012 - Jun 2013. B. Parameters were measured at the bedside and the score calculated. Each patient had a routine visit 4 weeks post surgery and followed for three months or longer by appointment visits or telephone. C. The Dutch leakage score (DULK) D. ROC analysis.	**Secondary outcome clinical deterioration in a subpopulation: AL-related mortality** [3]AUC: 0.86 [0.76 – 0.96]	**Primary outcome: AL-related mortality** Se: 91.7% (at a DULK score >3 threshold) Sp: 55.7% (at a DULK score >3 threshold)	**Primary outcome: AL-related mortality (17%)** PPV: 22% (at a DULK score >3 threshold)	-
[40]Nguyen (2015), Prospective cohort study.	680-bed hospital, Australia.	A. N=752 AMU patients (Feb and Aug 2013). B. Calculated retrospectively to predict mortality and LOS. C. Simple clinical score (SCS) EWS D. Logistic regression.	**Primary outcome: Mortality** AUC using age: 0.66; AUC using age and SCS: 0.80 **Primary outcome: 30-day mortality:** AUC using age: 0.68; AUC using age and SCS: 0.85 **Primary outcome: In-hospital mortality:** AUC using age: 0.65; AUC using age and SCS: 0.82 **Primary outcome: LOS (>3 days)** AUC using age: 0.65; AUC using age and SCS: 0.70	**Primary outcome: 30-day mortality (6.4%):** SCS threshold:11; Se: 72.9%; Sp: 81.1% **Primary outcome: In-hospital mortality (4.3%):** SCS threshold:10; Se: 81.3%; Sp: 73.3% **Primary outcome: LOS (>3 days)** SCS threshold: 7; Se: 66.2%; Sp: 63.6%	-	-

[3] Author was contacted for the correct AUC and 95% CIs as these were incorrectly reported in the paper.

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[150]Rothman (2013), Retrospective cohort study.	Three US hospitals, USA.	A. Model construction: N=22,265. Model validation: in-patient data from 3 hospitals: total admissions: n=148,985. B.A single dataset for model construction and 5 datasets for validation using the EMR. C. Rothman Index (RI) D. ROC analysis.	**Primary outcome: 24-hr mortality:** Hospital A: RI AUC: 0.93 (95% CI, 0.93–0.93) Hospital B: RI AUC: 0.94 (95% CI, 0.94– 0.95) Hospital C: RI AUC: 0.92 (5% CI, 0.91–0.94)	-	-	-
[75]Reini (2012), Prospective cohort study.	600-bed Linkoping Hospital, Sweden.	A. N=518 patients admitted to the general ICU between Oct 2008 - Dec 2009. B. Demographic data in addition to the scores and ICU LOS obtained from computer-based ICU registry. C. MEWS, SOFA, SAPS III D. ROC analysis.	**Primary outcome – ICU mortality** MEWS AUC: 0.80 (0.72-0.88). SOFA AUC: 0.91 (0.86-0.97). SAPS III AUC 0.89 (0.83-0.94).	**Primary outcome – ICU mortality** MEWS-in (MEWS on admission to ICU) of 6: Se 62% and Sp 85%. SOFA of 8: Se 83% and Sp 82%. SAPS III of 70: Se 83% and Sp 82%.	-	-
[83]Smith (2012), Prospective cohort study.	University hospital, The Netherlands.	A. N=572 consecutive patients admitted to the general and trauma surgery ward of a university hospital (Mar–Sept 2009). B. Authors investigated the relationship between the EWS and the composite endpoint consisting of death, reanimation, unexpected ICU admission, emergency surgery and severe complications. C. EWS D. ROC analysis.	**Secondary outcome post hoc: Composite outcome (Death, reanimation, unexpected ICU admission, emergency operations and sever complications).** AUC: 0.87 (0.81 to 0.93).	**Secondary outcome post hoc: Composite outcome (Death, reanimation, unexpected ICU admission, emergency operations and sever complications).** Se MEWS of at least 3 was 74 (59 to 85) Sp was 82 (78 to 85) Whilst an EWS≥4 as a positive test result equated to a Se 54% and Sp 94%.	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

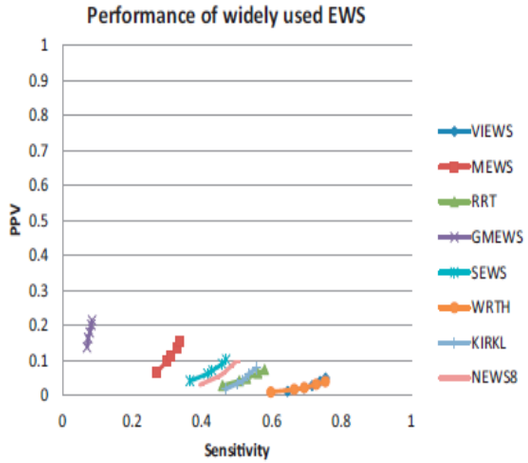
Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[149]Romero-Brufau (2014), Retrospective cohort study.	2 academic hospitals, USA.	A. N=6,948,689 unique time points from N=34,898 unique consecutive hospitalised patients in 2011. B. We developed a longitudinal database that included patients' data at the minute level throughout each patient's hospital stay. Vital signs were manually collected and entered into the EMR by a nurse. C. EWSs (MEWS, SEWS, GMEWS, Worthing, ViEWS and NEWS), with the RRT single parameter calling criteria currently in use in the institution D. Calculated a variety of triggers using the MEWS, ViEWS, SEWS, GMEWS, NEWS and Worthing scores and own RRT criteria in a rolling fashion through episodes of care. The score was updated every time a new parameter was entered into the EMR, and last values were carried forward to complete the rest of the required parameters to calculate the score. Published thresholds used to create rule triggers.	 Figure reproduced from paper (page 550).	**Secondary outcome: post hoc:** composite outcome of resuscitation calls, RRT activation or unplanned ICU transfer). Positive predictive values ranged from less than 0.01 (Worthing, 3 h) to 0.21 (GMEWS, 36 h). Se ranged from 0.07 (GMEWS, 3 h) to 0.75 (ViEWS, 36 h). Thus MEWS had the best Sp, but missed many events; VIEWS detected more events, but identified many false positive alerts. Used in an automated fashion, these would correspond to 1040–215,020 false positive alerts per year.		
[100]Suppiah (2014), Prospective cohort study.	University hospital, Leeds, UK.	A. N=142 patients with acute pancreatitis admitted Jan and Dec 2010. B. A prospective database was analysed to determine value of MEWS in identifying severe acute pancreatitis (SAP) and predicting poor outcome. C. MEWS D. ROC analysis.	**Secondary outcome: clinical deterioration in a subpopulation: SAP** Highest MEWS: AUC 0.92, 95% CI: 0.85 – 1.00 Mean MEWS: AUC 0.91, 95% CI: 0.84–0.99	**Secondary outcome: clinical deterioration in a subpopulation: SAP** Highest MEWS ≥3: Se 95.5%, Sp: 90.8% Mean MEWS >1: Se 95.5%, Sp 87.5%.	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[8]Smith (2013), Retrospective cohort analysis.	Portsmouth hospital, UK.	A. N=198,755 observation sets collected from 35,585 consecutive, completed acute medical admissions between May 2006 and Jun 2008. B. A database of vital signs collected in real-time from completed consecutive admissions to beds in the Medical Assessment Unit (MAU) of the hospital was developed. We tested the ability of NEWS to discriminate patients at risk of cardiac arrest, unanticipated ICU admission or death within 24 h of a NEWS value. C. NEWS and 33 other EWSs currently in use D. ROC analysis.	**Primary outcome: Death** NEWS AUC: 0.89 (95 % CI 0.89–0.90), Other EWSs AUC: ranged from 0.81(95 % CI 0.80–0.82) to 0.86 (95 % CI 0.850–0.87) **Primary outcome: Cardiac arrest:** NEWS AUC: 0.72 (95 % CI 0.68–0.76), Other EWSs AUC: ranged from 0.61 (95 % CI 0.57–0.65) to 0.71 (95 % CI 0.67–0.74) **Primary outcome: Unanticipated ICU admission:** NEWS AUC: 0.86 (95 % CI 0.85–0.87), Other EWSs AUC: ranged from 0.57 (95 % CI 0.55–0.57) to 0.83 (95 % CI 0.81–0.84) **Secondary outcome post hoc: Combined outcomes** NEWS AUC: 0.87 (95 % CI 0.86–0.87) Other EWSs AUC: ranged from 0.73 (95 % CI 0.72–0.74) to 0.83 (95 % CI 0.82–0.84).	-	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[138]Stark (2015), Retrospective cohort study.	Ronald Regan UCLA hospital, USA.	A. N=62 elective surgical patients admitted Jan 2013 and Mar 2014 with code blue events. B. Using the EMR, for all patients, the previously validated MEWS was calculated using routine vital signs and nursing assessments. The MEWS was calculated on admission and at 24-hour intervals preceding the event using the earliest recorded complete set of vitals on that day (72 hrs, 48 hrs, 24 hrs, and event-day). A "Max MEWS" was calculated for event-day after reviewing all complete sets of recorded vital signs before the event on the day of cardiopulmonary arrest. C. MEWS D. ROC analysis.	**Primary outcome: Mortality after CPA** Max MEWS 3 AUC: 0.73 Max MEWS 4 AUC: 0.73 Max MEWS 5 AUC: 0.68 Max MEWS 6 AUC: 0.59 Max MEWS 7 AUC: 0.61	**Primary outcome: Mortality after CPA** Max MEWS 3 Se (%) 97 Sp (%) 40 Max MEWS 4 Se (%) 91 Sp (%) 48 Max MEWS 5 Se (%) 68 Sp (%) 68 Max MEWS 6 Se (%) 50 Sp (%) 72 Max MEWS 7 Se (%) 47 Sp (%) 80	**Primary outcome: Mortality after CPA (56.5%)** Max MEWS 3 PPV (%) 69 NPV (%) 91 Max MEWS 4 PPV (%) 71 NPV (%) 80 Max MEWS 5 PPV (%) 74 NPV (%) 61 Max MEWS 6 PPV (%) 71 NPV (%) 51 Max MEWS 7 PPV (%) 76 NPV (%) 53	-
[103]Cooksley (2012), Retrospective cohort study	Specialist oncology hospital, UK.	A. N=840 oncology patients admitted Apr 2009 and Jan 2011. B. Data collected from proformas completed by the acute oncology nurse specialist and data used to retrospectively calculate the scores. C. NEWS, MEWS D. Logistic regression analysis.	**Secondary outcome: clinical deterioration in sub-populations 30-day mortality** MEWS AUC: 0.55 NEWS AUC: 0.59 **Secondary outcome: clinical deterioration in sub-populations critical care unit admission** MEWS AUC: 0.60 NEWS AUC: 0.62	-	-	-
[84]Van Rooijen (2013), Prospective cohort study.	700-bed teaching hospital, The Netherlands.	A. 71,911 EWS values were obtained, 31,728 (44%) on medical wards and 40,183 (56%) on surgical wards from May 2010 – May 2011. B. EWS was calculated from vital parameters in all patients. Cut-off value was defined as EWS $\geq$ 3. It was registered whenever the threshold was exceeded within the database. C. EWS D. Se and Sp calculated using appropriate formulas.	-	-	-	**Outcome:** Se was calculated from the total number of responses and interventions Threshold: 4 Se: 74% Sp: 51% Threshold: 5 Se: 52% Sp: 73%

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[158]Tarassenko (2011), Retrospective cohort study.	Data from three clinical studies in the UK and US between 2004 and 2008, in three hospitals.	A. N=64,622 h of vital-sign data, acquired from N=863 acutely ill in-hospital medical surgical patients. B. A centile-based alerting system modelled using the aggregated database. The alerting system was constructed using the hypothesis that an EWS of 3 (which, in most systems, initiates a review of the patient) should be generated when a VS is below the 1st centile or above the 99th centile for that variable. C. EWS centile based D. Normalised histograms (unit area under the curve) and cumulative distribution functions.	**Table 3** Range of values for each weighting for the main vital signs (RR, HR, SysBP and SpO_2) in the proposed centile-based EWS derived from evidence base of 64,622 h of continuously recorded vital sign data from 863 patients. Score: 3 | 2 | 1 | 0 | 1 | 2 | 3 BR: ≤7 | 8–10 | 11–13 | 14–25 | 26–28 | 29–33 | ≥34 HR: ≤50 | 51–58 | 59–63 | 64–104 | 105–112 | 113–127 | ≥128 SBP: ≤85 | 86–96 | 97–101 | 102–154 | 155–164 | 165–184 | ≥185 SpO_2: ≤84 | 85–90 | 91–93 | ≥94 (Table reproduced from publication). A centile-based EWS system will identify patients with abnormal vital signs regardless of their eventual outcome and might therefore be more likely to generate an alert when presented with patients with 'redeemable morbidity or avoidable mortality'. When observations were made every 4 h during a 12-h shift, approximately 12% of the at-risk patients (1 in 8) would be expected to generate an alert during the shift.			
[55]Xiao (2012), Retrospective cohort study.	Beijing Friendship Hospital, China.	A. Records of 357 patients presenting with acute fever in fever clinics, general wards and the ICUs of the Beijing Friendship Hospital Apr 2001 and Dec 2008 were analysed. B. 357 adult patients with acute fever were divided into 2 groups: 180 patients with a severe state and 177 patients with a mild state. Clinical data were collected retrospectively using a unified case observation table and included symptoms, signs and lab data of patients. For establishment of AFSS, the 357 cases were included, and the worst clinical value for each indicator used. C. MEWS, AFSS D. ROC analysis.	**Secondary outcome clinical deterioration in a subpopulation: Death** MEWS AUC: 0.76 (SE ± 0.111) AFSS AUC: 0.95 (SE ±0.021). **Secondary outcome clinical deterioration in a subpopulation: Severe acute fever** AFSS: 0.96 (95% CI 0.94-0.99)	-	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[101]Abbott (2015), Prospective cohort study.	Teaching hospital, UK.	A: N=445 adults admitted to AAU between Mar and Apr 2013. B: Patient notes and PARS observation charts reviewed during 1st 48 hrs. NEWS score retrospectively calculated in database for each set of measurements available alongside PARS. C: NEWS D. Logistic regression to identify optimal threshold. PARS thresholds not identified as insignificant association with the composite outcome primary outcomes (p=0.056).	-	-	-	Composite outcome: Critical care admission or death within 48 hrs, NEWS>1: OR 3.23, p=0.073 NEWS>2: OR 7.03, p=0.003 NEWS>3: OR 8.12, p<0.001 NEWS>4: OR 6.36, p=0.001 NEWS>5: OR 6.02, p=0.002 NEWS>6: OR 11.66, p<0.001 NEWS>7: OR 15.11, p<0.001 Every NEWS-point increase associated with a 55% increased risk.
[140]Alaa (2018), Retrospective cohort study.	Ronald Regan tertiary hospital, USA	A. N=6,321 critical care patients admitted to a general medical floor between 2013 and 2016. B. Risk scoring model trained with n=5,130 patients and tested with the most recently admitted 1,191 patients (2015-2016) using hospital EMR. Training set split into n=4130 patients for training and N=1,000 for validation. C. Risk model EWS, MEWS, SOFA, APACHE II, Rothman Index. D. Risk modelled using a continuous time model and latent class analysis and patient sub-types modelled accounting for heterogeneity of patients.	**ICU admission rate** Proposed risk model G=6: AUC 0.81 MEWS: AUC 0.64 SOFA: AUC 0.62 APACHE II: AUC 0.63 Rothman Index: AUC 0.72	-	**ICU admission rate (<10%)** Proposed risk model G=6: TPR=60, PPV=30% MEWS: TPR=60, PPV=11% SOFA: TPR=60, PPV=12% APACHE II: TPR=60, PPV=12% Rothman Index: TPR=60, PPV=15% The risk score offers a lower false alarm rate compared to all other EWS for all TPR settings	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C.EWSs included D.Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[64]Zimlichman (2012), Retrospective cohort study.	2 tertiary academic hospitals, Israel.	A. N=113 patients admitted to a medical ward with a diagnosis of an acute respiratory condition including pneumonia, COPD, asthma exacerbation, congestive heart failure with pulmonary edema or congestion, and patients who needed supplemental oxygen on admission. B. Enrolled patients were monitored for HR and RR by the Earlysense monitor with the alerts turned off. Retrospective analysis of VS data performed on a derivation cohort to identify optimal cut-offs for threshold and 24-hour trend alerts. This was internally validated through correlation with clinical events recognised through chart review. Patient enrolment Jan to Dec of 2008. C.VS based. D. ROC analysis.	**Secondary outcome: clinical deterioration in a subpopulation. Composite outcome defined as ICU transfer, ventilation or cardiac arrest:** **AUC for threshold alerts:** RR (<8, >40): 0.69 (p<0.0004) HR (<40, >115): 0.74 (p<0.026) RR and HR: 0.75 (p<0.0001) **AUC for 24-hour trend alerts:** RR (a rise of 5 or more breaths per minute): 0.85 (p<0.0016) HR (a rise of 20 or more beats per minute): 0.9 (p<0.0048) RR and HR: 0.93 (p<0.0026)	**Secondary outcome: clinical deterioration in a subpopulation. Composite (ICU transfer, ventilation or cardiac arrest):** **HR Threshold alerts:** Se: 82% Sp: 67% **RR Threshold alerts:** Se: 64% Sp: 81% **HR & RR Threshold alerts:** Se: 55% Sp: 94%	**Secondary outcome: clinical deterioration in a subpopulation. Composite outcome defined as ICU transfer, ventilation or cardiac arrest: (8%):** **HR Threshold alerts:** PPV: 21% NPV: 97% **RR Threshold alerts:** PPV: 26% NPV: 95% **HR and RR Threshold alerts:** PPV: 50% NPV: 95%	-
[110]Abbott (2016), Single hospital prospective cohort study	Large teaching hospital, UK.	A. N=322 adult medical patients from the acute admissions unit over 20 days between 25th March and 13th April 2013. B. Blood gas results and physiological observations were recorded at admission. NEWS was calculated retrospectively and combined with the biomarkers. C. NEWS D. AUC analysis.	**Secondary outcome post hoc: SAE (critical care unit admission or death)** **NEWS:** AUC 0.74, p<0.01 **Lactate:** AUC 0.57, p=0.34 **Glucose:** AUC 0.38, p=0.07 **Base excess:** AUC 0.52, p=0.85	-	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome		Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies							
[154]Churpek (2016), Observational cohort study	Five hospitals in Illinois, USA (One tertiary academic hospital; 2 suburban teaching hospitals; and 2 community hospitals)	A. N= 269,999 hospitalised medical-surgical ward patients admitted between November 2008 until Jan 2013 in a large multicentre study. B. Using EHRs the dataset was split at each hospital into derivation (60%) and validation (40%) cohorts. C. Different machine learning techniques (Logistic regression; Tree-based models; K-Nearest Neighbours; Support Vector Machines; and Neutral Networks) compared to the MEWS. D. AUC analysis.	**Primary outcome: mortality** Random forest: AUC 0.94 K-nearest neighbours: AUC 0.93 Gradient boosted machine: AUC 0.93 Logistic (linear): AUC 0.92 Support vector machine: AUC 0.92 Neural network: AUC 0.92 Bagged tree: AUC 0.92 Logistic (spine): AUC 0.91 MEWS: AUC 0.88 Decision tree: AUC 0.87 **Primary outcome: cardiac arrest** Random forest: AUC 0.83 Logistic (linear): AUC 0.81 K-nearest neighbours: AUC 0.81 Gradient boosted machine: AUC 0.81 Support vector machine: AUC 0.81 Bagged tree: AUC 0.79 Neural network: AUC 0.79 Logistic (spine): AUC 0.78 Decision tree: AUC 0.74 MEWS: AUC 0.71	**Primary outcome: ICU transfer.** Random forest: AUC 0.78 Gradient boosted machine: AUC 0.78 Bagged tree: AUC 0.77 Support vector machine: AUC 0.77 Neural network: AUC 0.77 Logistic (spine): AUC 0.75 K-nearest neighbours: AUC 0.73 Decision tree: AUC 0.72 Logistic (linear): AUC 0.71 MEWS: AUC 0.68 **Secondary outcome post-hoc: Composite outcome of ward death, ward to ICU transfer or ward cardiac arrest** Random forest: AUC 0.80 Gradient booted machine: AUC 0.79 Bagged trees: AUC 0.79 Support vector machine: AUC: 0.79 Neutral network: AUC 0.78 Logistic (spline): AUC 0.77 K-nearest neighbours: AUC 0.75 Logistic (linear): AUC 0.73 Decision tree: AUC: 0.73 MEWS: 0.70 RR, HR, age, and SBP were the most important predictor variables in the random forest model	**Secondary outcome post-hoc: Composite outcome of ward death, ward to ICU transfer or ward cardiac arrest (16,452/269,999)** At the 75% Se cut-off 31% of the observations in the validation dataset were above the risk threshold associated with this Se for random forest model compared to 37% for logistic spline model, 44% for logistic linear term model and 50% for MEWS.	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions)

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[155]Churpek (2017), Observational cohort study	University of Chicago, an urban tertiary care hospital with 500 beds	A. N=12,154 patients with a suspicion of infection on the wards (n=18,523 ED patients not included in this systematic review, but were presented in this study separately) admitted between Nov 2008 - Jan 2016. B: All time and location-stamped vital signs, lab orders and demographic data from the EHR were de identified and put on a server. C. qSOFA, SIRS, MEWS and NEWS D. AUC analysis.	**Outcome: In-hospital mortality – ward patients only** NEWS: AUC 0.79 (95% CI 0.77-0.82) MEWS: AUC 0.75 (95% CI 0.73-0.77) qSOFA: AUC 0.69 (95% CI 0.67-0.72) SIRS: AUC 0.68 (95% CI 0.66-0.69) **Secondary outcome post hoc: SAE (death or ICU stay – ward patients only)** NEWS: AUC 0.73 (95% CI 0.71-0.75) MEWS: AUC 0.69 (95% CI 0.67-0.72) qSOFA: AUC 0.64 (95% CI 0.62-0.66) SIRS: AUC 0.61 (95% CI 0.58-0.62)	Results not presented separately for ward patients (included ED and ward patients combined)	Results not presented separately for ward patients (included ED and ward patients combined)	Results not presented separately for ward patients (included ED and ward patients combined)
[85]Douw (2016), Prospective cohort study.	500-bed tertiary University affiliated teaching hospital, Netherlands.	A: N=3522 surgical patients, admitted between March 2013 and April 2014. B: Data from the electronic patient files were extracted from the hospital's data warehouse. Nine DENWS indicators of worry together with the EWS totalled ten variables for prediction model. C.DENWIS, algorithm based EWS D. AUC analysis.	**Secondary outcome post hoc: SAE (unplanned ICU/HDU admission or unexpected in-hospital mortality)** EWS: AUC 0.86 (95% CI 0.82-0.90) Worry: AUC 0.81 (95% CI 0.77-0.85) EWS <7: AUC 0.74 (95% CI 0.69-0.79) DENWIS model (10 variables): AUC 0.85 (95% CI 0.80-0.89) DENWIS model plus worry: AUC 0.87 (95% CI 0.84-0.91) EWS plus DENWIS model: AUC: 0.91 (95% CI 0.88-0.93)	-	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[86]Douw (2017), Observational cohort study	500-bed University affiliated teaching hospital, Netherlands	A: N=3522 patients admitted to three surgical wards between March 2013 and April 2014 B. The DENWIS was incorporated to the electronic nursing files and measured 8-hourly with EWS vital signs. All data extracted from electronic patient files. A prediction model was constructed weighing all the DENWIS indicators by multiplying the regression coefficients by five to accomplish full advantage of the discriminative value between the indicators. EWS trigger value of 7. C. DENWIS D. AUC analysis.	**Secondary outcome post hoc: SAE (unplanned ICU/HDU admission or unexpected in-hospital mortality).** DENWIS (all indicators) AUC: 0.85 (95% CI 0.80-0.89)	**Secondary outcome post hoc: SAE (unplanned ICU/HDU admission, unexpected in-hospital mortality)** (102/3522, 2.9%) Se for all DENWIS-scores min 2% (DENWIS≥25; n=2), max 69.6% (DENWIS≥1; n=2712). Sp min 77.2% (DENWIS≥1), max 100% (DENWIS≥25).	**Secondary outcome post hoc: SAE (unplanned ICU/HDU admission or unexpected in-hospital mortality)** (102/3522, 2.9%) PPV for all DENWIS-scores had a min of 8.4% for DENWIS≥1and a max of 66.7% (DENWIS≥ 25). NPV min 97.2% (DENWIS≥ 25) and max 98.8% (DENWIS≥1).	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[111]Hodgson (2017), Observational retrospective cohort study	2 UK hospitals.	A: N=39,470 patients admitted between March 2012 - February 2014 (n=2,361 admissions in 942 individuals with an acute exacerbation of COPD (AECOPD) and n=37,109 non-COPD admissions in 20,415 comparison patients) B. NEWS calculated automatically using handheld electronic devices to predict inpatient mortality. C. NEWS, CREWS, S-NEWS D. AUC analysis	**Primary outcome: Inpatient mortality** **1st admissions:** AECOPD cohort: NEWS=AUC 0.74 (95% CI 0.66-0.82) CREWS=AUC 0.72 (95% CI 0.63 to 0.80) Salford-NEWS=AUC 0.62 (95% CI 0.53 to 0.70). AMU cohort NEWS=AUC 0.77 (95% CI 0.75 to 0.78) **All inpatient episodes** AECOPD cohort NEWS=AUC 0.69 (95% CI 0.64 to 0.75), CREWS=AUC 0.70 (95% CI 0.64 to 0.75) Salford-NEWS=AUC 0.67 (95% CI 0.61 to 0.72). AMU cohort NEWS=AUC 0.75 (95% CI 0.74 to 0.76)	**Primary outcome: Inpatient mortality** For AECOPD cohort, for their 1st admission, using Score ≥5 COPD: NEWS: Se 76% (61 to 88) Sp 57% (54 to 61) CREWS: Se 48% (32 to 64) Sp 88% (85 to 90) Salford-NEWS: Se 24% (12 to 39) Sp 91% (89 to 93) For AMU cohort, for their 1st admission, using Score ≥5 COPD: NEWS: Se 43% (40 to 46) Sp 90% (90 to 91) For AECOPD cohort, for their 1st admission, using Score ≥7 COPD: NEWS: Se 60% (43 to 74) Sp 80% (77 to 83) CREWS: Se 13% (6 to 23) Sp 96% (95 to 97) Salford-NEWS: Se 14% (5 to 29) Sp 95% (94 to 97) For AMU cohort, for their 1st admission, using Score ≥7 COPD: NEWS: Se 25% (23 to 28) Sp 96% (96 to 97)	**Primary outcome: Inpatient mortality** For AECOPD cohort, for their 1st admission, using Score ≥5 COPD: NEWS: PPV 8% (5 to 11) NPV 98% (97 to 99) CREWS: PPV 15% (10 to 23) NPV 97% (96 to 98) Salford-NEWS: PPV 11% (5 to 19) NPV 96% (95 to 97) For AMU cohort, for their 1st admission, using Score ≥5: NEWS: PPV 17% (16 to 19) NPV 97% (97 to 97) For AECOPD cohort, for their 1st admission, using Score ≥7 COPD: NEWS: PPV 12% (8 to 18) NPV 98% (96 to 99) CREWS: PPV 21% (10 to 37) NPV 93% (91 to 95) Salford-NEWS: PPV 12% (5 to 25) NPV 96% (95 to 97) For AMU cohort, for their 1st admission, using Score ≥7: 25% (22 to 28) NPV 96% (96 to 97)	-
[89]Hollis (2016), Retrospective cohort study	Single hospital, USA	A: N=522 surgical patients admitted from 2013 to 2014. B. QIP data on all surgical procedures merged with enterprise data on vital signs, ICU transfer status and MET activation. ViEWS measurements on ward locations only were used to achieve the lowest acuity setting. C. ViEWS D. AUC analysis	**Secondary outcome posthoc: SAEs** (surgical site infection including organs, myocardial infarction, pneumonia, wound disruption, sepsis, unplanned return to operating theatre, bleeding/ transfusion, acute renal failure, cerebral vascular accident, unplanned intubation, septic shock, MET activation, unplanned ICU transfer, cardiac arrest, death) (n=105/522, 20%) **EWS:** AUC 0.90	-	-	Using a threshold of 8: Se 81%, Sp 84% PPV 27%

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[156]Kipnis (2016), Retrospective cohort	21 US hospitals, USA	A. 649,418 episodes N=374,838 patients between 1/1/2010 and 31/12/2013. B. Data collected from 21 hospital databases. Highest, lowest and most deranged VS values used, most recent lab tests in the past 72 hrs. Split the data into a training 1 cohort (used for variable selection and model fitting), Training 2 cohort (used to compare model performance and set a final model from the Training 1 models set) and Validation (used for assessing the performance of the final model and contained half of all eligible episodes. C.AAM, NEWS, eCART D. Regression analysis used to develop model and AUC analysis used to measure performance of the Advanced Alert Monitor (AAM) model.	**Secondary outcome post hoc:** Composite: Transfer to the ICU or death outside the ICU: **Episode-based c-statistics** c-statistic (AUC) AAM: 0.82 (95% CI 0.81-0.83) c-statistic (AUC) NEWS: 0.76 (95% CI 0.75-0.78) c-statistic (AUC) eCART: 0.79 (95% CI 0.77-0.80) **Hourly based c-statistics** c-statistic (AUC) AAM: 0.82 c-statistic (AUC) NEWS: 0.74 c-statistic (AUC) eCART: 0.74	**Secondary outcome post hoc:** Composite: Transfer to the ICU or death outside the ICU: Overall Se AAM: 49% compared to the eCART (44%) and NEWS (40%) at the training cut-offs. Sp similar for all three scores. **Also reported according to the 21 centres individually:** Se: ranging from 0.38 – 0.56 Sp: ranging from 0.88-0.95 Hourly based c-statistic: ranged from 0.76-0.85	**Secondary outcome post hoc:** Composite: Transfer to the ICU or death outside the ICU: **PPV for AAM**: 16.2% compared to the eCART (14.4%) and the NEWS (15.2%). NPV for all three scores: 98%, indicated 2% of non-alerted patients eventually experienced an outcome. **Also reported according to the 21 centres individually:** PPV ranging from 0.11 – 0.23 NPV: ranging from 0.97 – 0.99	**Secondary outcome post hoc:** Composite: Transfer to the ICU or death outside the ICU: Threshold for eCart=50; NEWS=8; and AAM=7.5 52% of AAM alerts occurring within 12 hrs; 65% within 24 hrs and 35% more than 24 hrs before the event. Likewise, 54% and 50% of eCART and NEWS alerts occurred within 12 hrs of the event, and 67% and 65% within 24 hrs of the event.
[60]Pedersen (2018), Retrospective cohort study	Single hospital in Copenhagen, Denmark	A. N=11,266 patients with a diagnosis of chronic respiratory disease (COPD or chronic hypoxaemia) recorded during 2014. B. All complete NEWS records were used in the data analysis to predict 48-hour mortality and ICU admission. C. NEWS, CROS, CREWS, S-NEWS D. AUC analysis.	**Primary outcome: 48-hour mortality** **NEWS:** AUC 0.85 (95% CI 0.85-0.86) **CROS:** AUC 0.82 (95% CI 0.82-0.83) **CREWS:** AUC 0.85 (95% CI 0.84-0.85) **S-NEWS:** AUC 0.84 (95% CI 0.84-0.85) **Primary outcome: ICU admission** **NEWS:** AUC 0.79 (95% CI 0.78-0.79) **CROS:** AUC 0.81 (95% CI 0.81-0.82) **CREWS:** AUC 0.81 (95% CI 0.80-0.81) **S-NEWS:** AUC 0.79 (95% CI 0.78-0.80)	**Primary outcome: 48-hour mortality (6+points)** **NEWS:** Se: 73.1 (95% CI 71.7-74.4) **; S**p: 81.8 (95%CI 81.7-81.9) **CROS:** Se: 53.4%; Sp: 90% **CREWS:** Se: 60.7%; Sp: 88.4% **S-NEWS:** Se: 68.3%; Sp: 83.0% **Primary outcome: ICU admission (6+ points)** **NEWS:** Se: 60.7% (95% CI 59.3-62.1) Sp: 81.7 (95%CI 81.6-81.8) **CROS:** Se: 52.4% **;** Sp: 90.1% **CREWS:** Se: 54.1%; Sp: 88.4% **S-NEWS:** Se: 59.1%; Sp: 83.0%	**Outcome: 48-hour mortality (6+ points)** **NEWS:** PPV :4.0 (95%CI 3.9-4.2); NPV: 99.7 (95%CI 99.6-99.7) **CROS:** PPV : 5.3%; NPV: 99.5% **CREWS:** PPV :5.2%; NPV: 99.5% **S-NEWS:** PPV :4.0%; NPV:99.6% **Outcome: ICU admission (6+ points)** **NEWS:** PPV : 3.9 (95%CI 3.7-4.0) NPV: 99.4 (95%CI 99.4-99.4) **CROS:** PPV : 6.0%, NPV: 99.4% **CREWS:** PPV: 5.3%; NPV: 99.4% **S-NEWS:** PPV: 4.0%; NPV: 99.4%	Applying any of the NEWS modifications resulted in lower sensitivities and NPV, and higher specificities and PPV, both when using a total score of **6 or 9** as cut-off levels. Only results for scores of 6 presented. *Supp appendix with paper includes scores 1-9

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions)

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome		Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies							
[112]Pimentel (2018), Multicentre, retrospective cohort study	Five acute hospitals from 2 UK NHS Trusts, UK.	A.N=251,266 adult acute admissions Jan 2012 - Dec 2016. B. Data were obtained from completed adult admissions who were not fit enough to be discharged alive on the day of admission with at least one complete set of vital signs recorded. Divided into three groups: 1) Patients with recorded type II respiratory failure (T2RF) [n=1,394], 2) Patients at risk of T2RF (n=48,898), and 3) Patients not at risk of T2RF (n=202,094). C. NEWS, NEWS2 D. AUC analysis	**Primary outcome: in-hospital death within 24-hrs** 1) Patients with recorded T2RF: NEWS: AUC 0.86 (95% CI 0.85-0.87) NEWS2: AUC 0.84 (95%CI 0.83-0.85) 2) Patients at risk of T2RF: NEWS: AUC 0.88 (95% CI 0.88-0.88) NEWS2: AUC 0.86 (95%CI 0.86-0.86) 3) Patients not at risk of T2RF (control) NEWS: AUC 0.91 (95%CI 0.91-0.91) NEWS2: AUC 0.89 (95% CI 0.89-0.89) **Primary outcome: unanticipated ICU admission** Documented T2RF NEWS: 0.81 (0.79 - 0.83) NEWS2: 0.82 (0.80 - 0.84) At risk T2RF NEWS: 0.81 (0.81 - 0.82) NEWS2: 0.81 (0.81 - 0.82) Neither at risk or documented NEWS: 0.84 (0.84 - 0.84) NEWS2: 0.83 (0.83 - 0.84)	**Primary outcome: cardiac arrest** Documented T2RF NEWS: 0.70 (0.65 - 0.75) NEWS2: 0.71 (0.66 - 0.75) At risk T2RF NEWS: 0.76 (0.74 - 0.77) NEWS2: 0.74 (0.73 - 0.75) Neither at risk or documented NEWS: 0.78 (0.78 - 0.79) NEWS2: 0.77 (0.76 - 0.78) **Secondary outcome post hoc: composite** Documented T2RF NEWS: 0.83 (0.82 - 0.85) NEWS2: 0.83 (0.82 - 0.84) At risk T2RF NEWS: 0.86 (0.85 - 0.86) NEWS2: 0.84 (0.84 - 0.85) Neither at risk or documented NEWS: 0.88 (0.88 - 0.88) NEWS2: 0.87 (0.864 - 0.87)	**Primary outcome: in-hospital death within 24 h** Documented T2RF Score>5 / Score>7 NEWS: Se 90.7 / 73.9, Sp 57.8 / 88.8 NEWS2: Se 80.9 / 60.1, Sp 68.8 / 87.3 At risk T2RF Score>5 / Score>7 NEWS: Se 78.5 / 57.6, Sp 82.4 / 93.9 NEWS2: Se 73.2 / 51.8, Sp 80.6 / 83.6 Neither at risk or documented Score>5 / Score>7 NEWS: Se 72.0 / 51.7, Sp 93.6 / 98.1 NEWS2: Se 73.5 / 54.5, Sp 87.4 / 95.7	**Primary outcome: in-hospital death within 24 h** Documented T2RF Score>5 / Score>7 NEWS: PPV 2.5 / 4.6 NEWS2: PPV 3.0 / 5.3 At risk T2RF Score>5 / Score>7 NEWS: PPV 3.2 / 6.6 NEWS2: PPV 2.7 / 5.7 Neither at risk or documented Score>5 / Score>7 NEWS: PPV 5.0 / 11.2 NEWS2: PPV 2.7 / 5.7	**Outcome: in-hospital death with 24-hrs** Patients with documented T2RF: NEWS2 at cut-offs of 5 & 7 reduced Se approximately 10% and 14%. For patients at risk of T2RF, NEWS2 cut-offs of 5 and 7 reduces Se by 5-6%. Finally, if used in error for patients not at risk of T2RF at the suggested cut-offs, NEWS2 is slightly more sensitive than NEWS.

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[56]Qin (2017), Retrospective cohort study	West China Hospital of Sichuan University	A. N=292 patients admitted with shock (hypovolemic, septic, cardiogenic and mixed) Jan 2013 and Jan 2014. B. Data were retrospectively collected for 28-day prognosis of death. C. Shock index ,APACHE II, MEWS, SOFA scores, modified MEWS D. AUC analysis.	**Primary outcome: 28-day death** APACHE II: AUC 0.78 MEWS: AUC0.61 Shock index: AUC 0.53 SOFA: AUC 0.63 modified-MEWS: AUC 0.70	-	-	**Outcome: 28-day death** Optimal threshold: APACHE II: 23.5 MEWS: 6.5 Shock index: 0.78 SOFA: 11.5
[77]Uppanisakorn (2018), Prospective observational study.	Songklanagarind Hospital medical ICU, Thailand	A. N=440/500 patients discharged from the medical ICU Dec 2015 and Oct 2016. B. NEWS at ICU discharge ($NEWS_{dc}$) calculated before transfer of the patient to the destination ward. Clinical deterioration (acute respiratory failure or circulatory shock within 24hrs of ICU discharge) recorded by researchers. C. NEWS D. AUC analysis.	**Secondary outcome post-hoc : SAE (clinical deterioration within 24 hrs defined as acute respiratory failure or circulatory shock)** $NEWS_{dc}$ AUC: 0.93 (95% CI 0.90-0.95)	**Secondary outcome post-hoc : SAE (clinical deterioration within 24 hrs defined as acute respiratory failure or circulatory shock)** $NEWS_{dc}$ >7 gave the best Se(92.3%) and Sp(85.1%)		

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[113]Smith (2016), Retrospective cohort study	A large NHS District hospital, UK	A. N=2,245,778 VS sets (n=103,998 admissions) and n=66,712 unique patients between May 25th 2011 to December 31st 2013 in adult in-patient areas (except critical care units). B. VS data were recorded using VitalPAC software. Outcomes were taken from the hospital's patient administration system, cardiac arrest database and ICU admission database. C. NEWS and 44 different MET criteria. D. AUC analysis.	**Primary outcome: Mortality** NEWS: AUC: 0.91 (95% CI 0.91-0.92) **Primary outcome: Cardiac arrest** NEWS: AUC: 0.78 (95% CI 0.76-0.78) **Primary outcome: Unplanned ICU admission** NEWS: AUC: 0.86 (95% CI 0.85-0.86) **Secondary outcome post hoc: Composite outcome: (Cardiac arrest, Unplanned ICU admission, Mortality)** NEWS: AUC: 0.88 (95% CI 0.88-0.88)	**Primary outcome: Death** Se 54.2 (cut-off 7) Sp 97.2 **Primary outcome: Cardiac Arrest** Se 22.2 Sp 97.0 **Primary outcome: Unanticipated ICU Admission** Se 37.4 Sp 97.1 **Secondary outcome post hoc: Composite (Cardiac arrest, Unplanned ICU admission, Mortality)** Se NEWS=7: 44.5% Sp NEWS=7: 97.4% **Se 44 sets of MET criteria:** ranged from 19.6% to 71.2% **Sp 44 sets of MET criteria:** ranged from 71.5% to 98.5%. For all outcomes, the position of the NEWS ROC curve was above and to the left of all MET criteria points, indicating better discrimination. Similarly, the positions of all MET criteria points were above and to the left of the NEWS efficiency curve, indicating higher workloads (trigger rates).	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Cohort studies						
[67]Tirotta (2017), Secondary analysis of a multicentre prospective study (The SNOOPI study)	31 Italian medical wards, in 14 different regions in Italy.	A. N=526 consecutive sepsis-diagnosed patients admitted to 31 different medical wards (dates not reported). B. secondary analysis of data collected for SNOOPI study. Patients followed-up from admission until discharge. Data collected at enrolment. C. MEWS D. AUC analysis	**Primary outcome: In-hospital mortality** MEWS AUC: 0.60 (95% CI 0.52-0.67)	**Primary outcome: In-hospital mortality** MEWS dichotomized as low risk vs. high risk (MEWS < 4 vs. >4): Se 35% (95% CI, 24–46%); Sp 83% (95% CI, 80–87%) MEWS: >1 Se: 0.65 (95% CI 0.53–0.75) Sp: 0.42 (95% CI 0.38–0.48) MEWS >2 Se 0.55 (95% CI 0.43–0.66) Sp: 0.59 (95% CI 0.54–0.63) MEWS >3: Se 0.38 (95% CI 0.28–0.50) Sp: 0.71 (CI 0.67–0.75) MEWS >4: Se: 0.35 (95% CI 0.24–0.46) Sp 0.83 (95% CI 0.80–0.87) MEWS>5: Se 0.23 (95% CI 0.15–0.34) Sp: 0.91 (95% CI 0.88–0.93) MEWS >6: Se 0.17 (95% CI 0.10–0.27) Sp: 0.95 (95% CI 0.93–0.97) MEWS >7: Se 0.10 (95% CI 0.049–0.20) Sp: 0.98 (95% CI 0.96–0.99)	**Primary outcome: In-hospital mortality** MEWS dichotomized as low risk vs high risk (MEWS < 4 vs.>4): NPV 88% (95% CI, 44–91%); PPV: 27% (95% CI, 18–37%) MEWS: >1: PPV 0.17 (95% CI 0.13–0.21) NPV: 0.87 (CI 0.82–0.92) MEWS >2: PPV: 0.19 (95% CI 0.14–0.25) NPV: 0.88 (95% CI 0.84–0.91) MEWS >3: PPV 0.19 (CI 0.13–0.26) NPV: 0.86 (CI 0.82–0.90) MEWS >4: PPV: 0.19 (95 CI 0.13–0.26) NPV 0.86 (95% CI 0.82–0.90) MEWS >5: PPV: 0.31 (95% CI 0.20–0.45) NPV: 0.87 (95% CI 0.84–0.90) MEWS>6: PPV: 0.37 (95% CI 0.22–0.55) NPV 0.87 (95% CI 0.83–0.90) MEWS >7: PPV: 0.42 (95% CI 0.21–0.66) NPV: 0.88 (95% CI 0.85–0.90)	-
[74]Yoo (2015), Retrospective cohort study.	University-affiliated urban, tertiary care hospital in South Korea	A. N=100/186 patients with sepsis/septic shock who were screened or contacted by the MET Jan 2012 - Aug 2012. B. Usefulness of the MEWS and blood lactate (BLA) to predict ICU transfer was assessed by reviewing retrospectively medical records of enrolled patients and clinical, demographic and lab data were collected. C. MEWS, MEWS with BLA D. Predictive ability using the C-statistic	**Primary outcome: ICU transfer** MEWS alone: AUC 0.82 MEWS with BLA: AUC 0.90	**Primary outcome: ICU transfer** MEWS (Cut-off: 5.5): Sen: 81.6%, Spec: 66.1% MEWS with BLA (cut-off 3.05): Sen: 73.7%, Spec: 87%	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Case control studies						
[151]Yu (2014), Retrospective nested case control study.	2 hospitals, New York, USA.	A. N=328 cases (an infection ICD-9 code present) and N=328 matched controls. B. Calculated nine well-validated prediction scores for 328 cases and 328 matched controls. The cohort included non-ICU ward patients admitted to the hospital with a diagnosis of infection, and cases were patients in this cohort who experienced clinical deterioration, defined as requiring a critical care consult, ICU admission, or death. We then compared each prediction score's ability, over the course of 72 hrs, to discriminate between cases and controls. All clinical variables were collected retrospectively from either an electronic database or paper medical records. C. REMS, SOFA, PIRO, ViEWS, SCS, MEDS, MEWS D. ROC analysis.	**Secondary outcome clinical deterioration in a subpopulation: composite outcome (critical care consult, ICU admission, or death). 0- to 12-hour interval:** REMS AUC 0.67 (95%CI 0.62, 0.71) SOFA AUC 0.78 (95% CI 0.74, 0.81) PIRO AUC 0.76 (95% 0.72-0.79), ViEWS AUC 0.75 (95% 0.71-0.79) SCS AUC 0.74 (95%CI 0.70-0.78) MEDS AUC 0.74 (95%CI 0.70-0.78) MEWS AUC 0.73 (95%CI 0.69-0.77) **12- to 72-hour interval:** all scores, with the exception of MEDS (AUC=0.69 (95%CI 0.63-0.74) at 24 to 48 hrs and AUC=0.71(95%CI 0.64-0.78) at 48-72 hrs), no longer performed with acceptable discrimination for mortality (AUC <0.70).	-	-	-
[122]Churpek (2012), Retrospective nested case-control study.	Academic tertiary care hospital, USA.	A. N=88 cases (cardiac arrest) matched to N=352 controls in medical and surgical wards between Nov 2008 - Jan 2011. B. Cases were consecutive adults who experienced a cardiac arrest identified from a prospective register. Controls were selected from the same ward and matched using a random number generator. C. VS EWS D. Created ROC curves, calculated AUC using the trapezoidal rule.	**Primary outcome: Cardiac arrest** RR max AUC 0.72 (0.65-0.78) min AUC 0.56 (0.49-0.62) HR max AUC 0.68 (0.61-0.74) min AUC 0.56 (0.49-0.63) DBP max AUC 0.53 (0.45-0.60) min AUC 0.60 (0.53-0.67) SBP max AUC 0.55 (0.48-0.62) min AUC 0.58 (0.50-0.65) Pulse pressure index max AUC 0.61 (0.54-0.68) min AUC 0.58 (0.50-0.65) Temp max AUC: 0.48(0.42-0.56) min AUC: 0.55 (0.48-0.63) SpO_2 min AUC: 0.54 (0.47-0.61) MEWS: max AUC 0.77 (0.71-0.82)	**Primary outcome: Cardiac arrest** Max RR >20: Se 67 (56-77) Sp 70 (51-80) Max HR >110: Se 44 (29-57) Sp 80 (70-88) Max pulse >0.55: Se 49 (38-61) Sp 67 (56-80) Min DBP <50: Se 45 (33-55), Sp 77 (57-84) Max MEWS >2: Se 69 (61-83), Sp 69 (59-83)	-	-

Table 7.1 Studies of the predictive value of EWSs scores (Q2 Effectiveness of EWSs interventions) continued

Author, Study design	Setting, Country	A. Sample size and details B. Data collection C. EWSs included D. Model	AUC, outcome	Sensitivity (Se), Specificity (Sp), outcome	PPV, NPV, outcome	Identifying optimal threshold cut-offs, outcome
Case control studies						
[126]Kirkland (2013), Retrospective case control study.	1157-bed, academic, tertiary referral hospital, Minnesota, USA.	A. Derivation cohort n=1,882 eligible patients. Among them, 68 suffered events; these patients were matched to up to 3 control patients, 267 patients as the derivation group. Validation cohort n=1,946 eligible patients, 77 of whom suffered events, with 1869 control patients between 2008 - 2009. B. A time-dependent data set was developed to model looking forward in time for a serious clinical event. Lead times were divided into 2 to 12 hrs, 12 to 24 hrs, or 24 to 48 hrs prior to an event. The single-entry model looked at each set of clinical variables individually. Serial 24 hrs looked at trends of each clinical variable over 24 hrs. Serial 7 days looked at trends of each clinical variable over 7 days. C. algorithm based EWS D. Logistic regression using the generalized estimating equations (GEE) approach.	**Primary outcome: Future event (defined as an unplanned ICU transfer, unexpected death, or RRT call)** Future event 2-12 hrs: Single entry: 0.68 Serial 24-hrs: 0.71 Serial 7-days: 0.66 Future event 12-24 hrs: Single entry: 0.67 Serial 24-hrs: 0.65 Serial 7-days: 0.73 Future event 24-48 hrs: Single entry: 0.63 Serial 24-hrs: 0.65 Serial 7-days: 0.66 AUC validation group: 0.71 (0.68-0.74).	-	-	-
[147]Escobar (2012), Retrospective case control study	14 hospitals in Northern California, USA.	A.N=4,036 events and N=39,782 controls admitted between Nov 2006 and Dec 2009 to general medical and surgical wards. B. Unit of analysis was a 12-hour patient shift. Shifts where patients experienced an unplanned ICU transfer were 'event shifts' and shifts without a transfer were comparison shifts. Electronic medical health records were used to split the dataset 50-50 into development and validation datasets to develop the model. MEWS was retrospectively applied for comparison. C. algorithm based EWS, MEWS D. Logistic regression.	**Primary outcome: unplanned transfer to the ICU** All diagnoses: MEWS derivation AUC: 0.71 (95% CI, 0.70–0.72) MEWS validation AUC: 0.70 (95% CI 0.69–0.71) Electronic EWS derivation AUC: 0.85 (0.83–0.86) Electronic EWS validation AUC: 0.78 (0.75–0.80) **Primary outcome: unplanned transfer to the ICU** 1 randomly selected observation per patient: MEWS derivation AUC: 0.71 (0.69–0.73) MEWS validation AUC: 0.70 (0.69–0.71) Electronic EWS derivation: 0.86 (0.84–0.88) Electronic EWS validation: 0.78 (0.76–0.80)	-	-	-

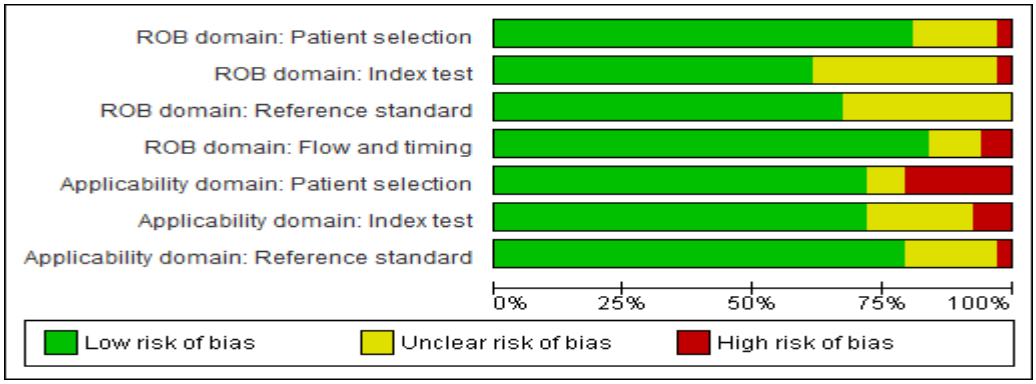
Key: AAU: Acute assessment unit; **PARS:** Patient at risk score; **ICU:** Intensive care unit; **MEWS**: Modified early warning score; **SOFA**: Sequential organ failure assessment; **APACHE**: Acute physiology and chronic health evaluation; **AUC**: Area under the receiver operating curve; **PPV**: Positive predictive value; **NPV**: Negative predictive value; **TPR**: True positive rate; **NEWS**: National early warning score**; DTEWS**: Decision tree-EWS; **RED**: Resuscitation events or death; **CPA**: cardiopulmonary arrests; **ARC**: Acute respiratory compromise; **MET:** Medical emergency team; **qSOFA**: quick-SOFA; **SIRS**: Systemic inflammatory response system; **AHF:** Acute heart failure; **SBP**: Systolic blood pressure; **RR**: Respiratory rate; **ViEWS**: VitalPAC EWS; **RRT/S**: Rapid response team/system; **MERIT**: Medical Early Response Intervention and Therapy; **SEWS**: Standardised

EWS; **CART**: Cardiac arrest triage score; **DBP**: Diastolic blood pressure; **SpO_2**: Oxygen saturation; **eCART:** electronic CART; **Worthing PSS:** Physiological Scoring System; **SAPS**: Simplified acute physiology score; **SAE**: Serious adverse event; **DNR**: Do not resuscitate; **CH**: Chronic hypoxaemia; **CREWS**: Chronic respiratory EWS; **QIP**: Quality improvement project; **VSS:** Vital sign system; **AKI**: Acute kidney injury; **RI**: Rothman Index; **EMR**: Electronic medical record; **SCS**: Simple clinical score; **MEDS**: Mortality in Emergency Department Sepsis; **REMS**: Rapid Emergency Medicine Score; **LDT-EWS**: Laboratory based decision tree EWS; **ViEWS-L**: VitalPAC EWS with lactate; **HOTEL:** Hypotension, Oxygen saturation, low Temperature, ECG change and Loss of independence EWS; **RCP:** Royal College of Physicians; **AVPU**: Alert, voice, pain, unresponsive; **FiO_2**: Inspired oxygen; **PEDS**: Prince of Wales Emergency Department Score; **DULK**: Dutch leakage EWS; **ED**: Emergency department; **AL**: Anastomatic leakage; **AMU**: Acute Medical unit; **LOS**: Length of stay; **SCS**: Simple clinical score; **GMEWS**: Global modified EWS; **AFSS**: Adult Fever State Score; **MAU**: Medical assessment unit; **EWRS**: Early warning response system; **ICD**: International classification of disease; **AFSS**: Adult fever state score; **PIRO**: Predisposition, insult, response, organ dysfunction; **COPD**: Chronic obstructive pulmonary disorder.

7.6 Methodological quality

The QUADAS II tool[29] was used to assess the risk of bias in the 68 included studies which assessed the predictive ability of EWSs.[8, 13, 40, 41, 49, 54-56, 58, 60, 61, 64, 65, 67, 70, 73-78, 83-87, 89, 90, 92-94, 100-106, 110-113, 116, 118, 120-123, 126, 138-152, 154-156, 158] This included four risk of bias domains (patient selection, index test, reference standard and flow and timing) and three applicability domains (patient selection, index test and reference standard). Overall, the studies were deemed to have a low risk of bias across the seven domains (**Figure *7.1***).

Figure 7.1 Risk of bias summary of the predictive studies



Risk of bias domain: Patient selection

In total, 55 of the 68 studies had a low risk of bias for patient selection (i.e. a consecutive or random sample was used, a case-control design was avoided and the study avoided inappropriate exclusions).[8, 13, 40, 41, 54, 60, 61, 65, 67, 73-78, 83-87, 89, 90, 92-94, 100-106, 111-113, 116, 118, 120, 121, 123, 138-150, 152, 154-156] Two studies had a high risk of bias for patient selection,[87, 151] due to using a case-control design and not including a consecutive or random sample. In total, 12 studies had an unclear risk of bias for patient selection, [13, 49, 56, 58, 64, 70, 76, 110, 122, 126, 158] as it was not clear exactly how the sample were selected or not reported.

Risk of bias domain: Index test

In total, 42 of the 68 studies had a low risk of bias for the index test (i.e. a description of the index test and how it was conducted was provided; a threshold was specified if one was

used; and the conduct or interpretation of the index test was deemed not to have been biased).[40, 49, 54-56, 60, 61, 64, 67, 70, 74, 77, 78, 83-87, 89, 90, 94, 100, 106, 110-113, 118, 122, 123, 139-143, 149, 150, 154-156] Two studies had a high risk of bias for the index test.[76, 102] One developed a decision tree EWS (DTEWS) using a database of vital signs and known patient outcomes which could introduce bias.[102] In the other study the results were likely interpreted with the knowledge of the reference standard results and no threshold cut-off was specified.[76] There were 24 studies with an unclear risk of bias for the index test,[8, 13, 41, 58, 65, 73, 75, 92, 93, 101, 103-105, 116, 120, 126, 138, 144, 146-148, 151, 152, 158] where it was not clear or not reported on how the index test was conducted.

Risk of bias domain: Reference standard

In total, 45 of the 68 studies had a low risk of bias for the reference standard (i.e. the reference standard and how it was conducted and interpreted was described; the reference standard was likely to correctly classify the target condition; and it was interpreted without the knowledge of the index test results).[8, 13, 40, 41, 54-56, 60, 64, 67, 70, 74, 78, 84-87, 89, 90, 94, 101, 102, 104, 105, 110-113, 118, 120-122, 126, 140-146, 149, 150, 154-156] No study had a high risk of bias for the reference test and 23 studies had an unclear risk of bias,[49, 58, 61, 65, 73, 75-77, 83, 92, 93, 100, 103, 106, 116, 123, 138, 139, 147, 148, 151, 152, 158] mainly due to the reference standard not being described or unclear details reported. In six studies[58, 75, 100, 116, 138, 158] there was no reference standard (and so this risk of bias domain was not applicable).

Risk of bias domain: Flow and timing

In total, 57 of the 68 studies had a low risk of bias for flow and timing (i.e. any patient who did not receive the index or test or reference standard or was excluded from the analysis was described; time intervals between the index test and reference standard were described and the patient flow was unlikely to introduce bias).[8, 13, 40, 41, 49, 55, 56, 58, 60, 64, 65, 67, 70, 73-78, 83, 84, 89, 90, 92-94, 100-102, 105, 106, 110-113, 116, 118, 120-123, 126, 138, 140-151, 156, 158] Four studies had a high risk of bias for flow and timing as the reasons some patients were excluded from the

analysis were not described.[85-87, 103] Seven studies had an unclear risk of bias for flow and timing as they did not report clearly on patients who received the index and reference standard and numbers excluded from the analysis, or the time intervals between both.[54, 61, 104, 139, 152, 154, 155]

Applicability domain: Patient selection

Forty-nine of the 68 studies had a low risk of bias for patient selection (i.e. they included patients who matched the review question).[8, 40, 41, 49, 70, 75-78, 83, 84, 90, 92-94, 101, 102, 104-106, 110-113, 116, 118, 120-123, 126, 139-152, 154-156, 158] Fourteen studies had a high risk of bias for patient selection.[55, 56, 60, 64, 65, 67, 73, 74, 85-87, 89, 100, 103] These studies included selective subpopulations deemed not completely generalisable to the review (oncology patients, heart failure patients, sepsis or shock patients, critically ill patients in Korea, patients with acute pancreatitis, patients with an ICD-9 diagnosis of acute fever and patients with acute respiratory failure). Five studies had an unclear risk of bias for the applicability of the patients selected as details on the patients included were not reported.[13, 54, 58, 61, 138]

Applicability domain: Index test

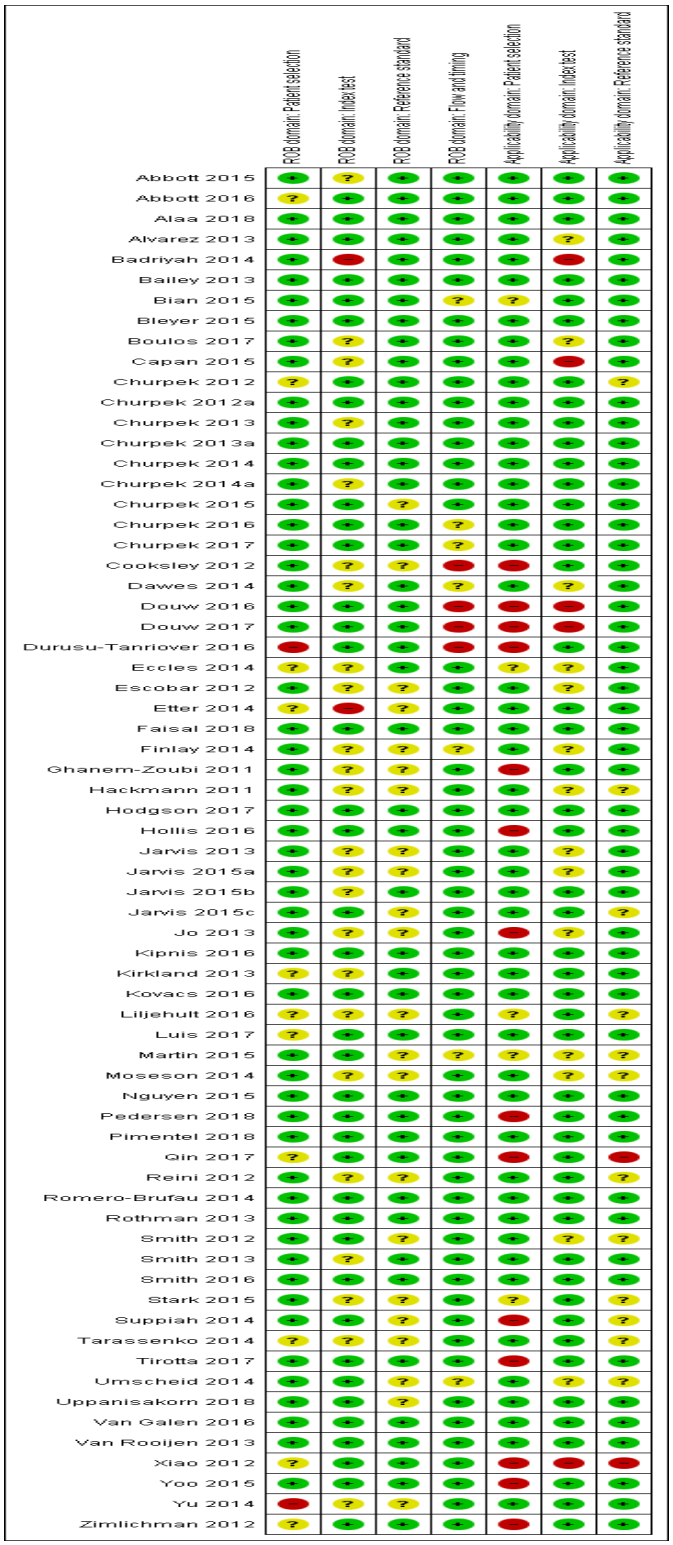
Forty-nine of the 68 studies had a low risk of bias in terms of the index test and its applicability to this review (i.e. there was no concern that the index test, its conduct, or interpretation differ from the review question).[8, 40, 49, 54, 56, 58, 60, 64, 65, 67, 70, 74-78, 84, 87, 89, 90, 94, 100, 101, 103, 105, 106, 110-113, 118, 121-123, 126, 138, 140, 142-146, 149-151, 154-156, 158] Five studies had a high risk of bias.[55, 85, 86, 102, 120] One study developed a decision tree EWS using a database of vital signs and known patient outcomes; and in four studies (one of which used electronic medical record-derived models) it was unclear whether the test results were interpreted without knowledge of the reference standard results. Fourteen studies were classified as having an unclear risk of bias as it was not clear whether the index test was applicable to the NEWS or EWS in this review (i.e. some studies used automated prediction models; others included additional parameters such as co-morbidities, biochemical values and age; others

included EWS tools for specific sub-populations [e.g. CREWS]; others included no vital sign parameters, only lab test results as predictors; others were designed for use in different settings [e.g. the ED], [13, 41, 61, 73, 83, 92, 93, 104, 116, 139, 141, 147, 148, 152].

Applicability domain: Reference standard

Fifty-four of the 68 studies had a low risk of bias for the applicability of the reference standard (i.e. there was no concern that the target condition as defined by the reference standard does not match the review question).[8, 13, 40, 41, 49, 54, 60, 64, 65, 67, 70, 73, 74, 76-78, 84-87, 89, 90, 92-94, 101-105, 110-113, 118, 120, 121, 123, 126, 140-147, 149-152, 154-156] Two studies had a high risk of bias as they included a specific subpopulation of Chinese patients with acute fever or shock.[55, 56] Twelve studies[58, 61, 75, 83, 100, 106, 116, 122, 138, 139, 148, 158] had an unclear risk of bias in terms of the applicability of the reference standard to this review question mainly due to the reference standard not being described or unclear details reported. In six studies [58, 75, 100, 116, 138, 158] there was no reference standard (and so this risk of bias domain was not applicable), (**Figure *7.2***).

Figure 7.2 Risk of bias graph for studies of EWS interventions and deterioration in adults in acute health care settings



7.7 Certainty of the evidence

We assessed the overall certainty of the evidence where appropriate for question 2 of the review (*How predictive are the different EWSs in terms of improving key patient outcomes in adult (non-pregnant) patients in acute healthcare setting?*). A narrative summary of findings table was created using GRADEpro software for the following primary outcomes: Mortality, cardiac arrest, LOS, and transfer or admission to the ICU.

Overall the certainty of the evidence is '*very low*' owing to a high risk of bias due to the various study designs with very few robust designs such as RCTs, a high risk of confounding in the observational studies, small sample sizes and inconsistency in the results. Inconsistency related to the heterogeneous nature of the EWS interventions applied as well as the variety of single centre settings in various countries where the findings may not be applicable to other health care settings (***Table 7.2***).

Table 7.2 Summary of findings table for key outcomes in the predictive ability of EWS interventions (Q2)

EWSs compared to other EWSs, usual care for physiological deterioration

Patient or population: physiological deterioration in adults (aged 16+ years) **Setting**: Acute health care settings
Intervention: EWSs **Comparison**: other EWS, usual care

Outcomes	Impact	№ of participants (studies)	Certainty of the evidence (GRADE)
Mortality	35 different types of EWSs compared in 32/33 of the studies for mortality. These included DTEWS, NEWS, NEWS2 SIRS, qSOFA, Critical vital sign EWS, ViEWS, MEWS, CART, SEWS, MERIT, modified MERIT, e-CART, Worthing PSS EWS, VSS EWS, LDTEWS, APACHE II, CREWS, CROS, S-NEWS, APACHE III, SAPS II, SAPS III, REMS, PEDS, SCS EWS, SOFA, ViEWS-L, HOTEL, RI EWS, Sepsis ERWS, the Shock Index, newly developed electronic medical record-based EWS, a pre-hospital based EWS by Seymour et al., and a centiles-based EWS by Tarassenko et al. In addition, 2/33 studies compared 34+ published EWSs and 36+ published EWSs. The AUCs for the different EWSs ranged from 0.52 (Shock Index) to AUC 0.97 (NEWS minus temperature, followed closely by the standard 7-item NEWS (AUC 0.93), RI EWS (0.93) and eCART (0.93).	1,732,733 (33 studies including 1 RCT, 32 cohort studies) Note: one study did not report a sample size.	⊕◯◯◯ VERY LOW [a,b,c,d]
Cardiac arrest	Eleven different types of EWSs compared in 13/15 studies for cardiac arrest. These included DTEWS, NEWS, NEWS2, MEWS, CART, ViEWS, SEWS, MERIT, eCART and newly developed electronic medical record-based EWS. 1 study out of the 15 compared 36 previously published EWSs and one study compared 44 different sets of MET calling criteria. AUCs ranged from 0.48 (single item max temperature parameter from MEWS) to AUC 0.88 (newly-developed 17-item cardiac arrest model including vital sign parameters, age and laboratory test results). These were closely followed by MEWS in a non-elderly [<65 years] population (AUC 0.85) and CART (AUC 0.84).	1,605,574 (15 studies including 14 retrospective cohort studies and one nested case-control study)	⊕◯◯◯ VERY LOW [b,c,d]
Length of stay (LOS)	1 study including 752 AMU patients assessed the predictive ability of the SCS EWS. When age was added the AUC was 0.70, without age, the AUC was 0.65 for predicting length of stay.	752 (1 prospective cohort)	⊕◯◯◯ VERY LOW [c]
Transfer or admission to the ICU	17/20 studies included 13 different types of EWSs for ICU transfer or admission. These included: MEWS, SOFA, APACHE II, RI, DTEWS, NEWS, NEWS2, CART, MERIT, ViEWS, modified MERIT, eCART, and newly developed electronic medical record–based EWS. In addition, 2/20 studies compared 34+ published EWSs and 36+ published EWSs. One study compared 44 different sets of MET calling criteria. The AUCs ranged from 0.62 (SOFA) to AUC 0.89 (MEWS with blood lactate added). These were closely followed by DTEWS and NEWS (both AUCs 0.86).	1,435,957 (20 studies including 1 RCT, 17 retrospective cohort studies, 1 before-after intervention study and 1 retrospective case-control study) Note: one study did not report a sample size.	⊕◯◯◯ VERY LOW [a,b,d]

***The risk in the intervention group** (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI). **CI:** Confidence interval

EWSs compared to other EWSs, usual care for physiological deterioration

Patient or population: physiological deterioration in adults (aged 16+ years) **Setting**: Acute health care settings
Intervention: EWSs **Comparison**: other EWS, usual care

Outcomes	Impact	№ of participants (studies)	Certainty of the evidence (GRADE)

GRADE Working Group grades of evidence
High certainty: We are very confident that the true effect lies close to that of the estimate of the effect.
Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.
Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect.
Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect .

Explanations
a. High risk of bias in the RCTs and nRCTs , b. Retrospective and prospective cohort studies and case control studies - risk of bias and confounding
c. Small sample size and low event rate d. Inconsistency due to the heterogeneous EWSs predictive models included, varying EWSs (e.g. NEWS, MEWS, modified EWS, etc) and varying patient populations

The predictive ability of the various EWSs included differs across studies and as a result the findings for the primary outcomes for this review are inconsistent. Thirty-three studies examined the ability of EWSs to predict mortality comparing one or more of 35 different named EWSs. Given the different EWSs included, the AUCs ranged from 0.52 (Shock Index) to AUC 0.97 (NEWS minus temperature), followed closely by the standard 7-item NEWS (AUC 0.93), RI EWS (0.93) and eCART (0.93), in a total population of 1,732,733 patients.

Fifteen studies examined the ability of EWSs to predict cardiac arrest, totalling 1,605,574 patients. AUCs ranged from 0.48 (single item max temperature parameter from MEWS) to AUC 0.88 (newly-developed 17-item cardiac arrest model including vital sign parameters, age and laboratory test results). These were closely followed by MEWS in a non-elderly (<65 years) population (AUC 0.85) and CART (AUC 0.84).

One study examined the ability of an EWS to predict LOS including 752 AMU patients and assessed the predictive ability of the SCS EWS. When age was added the AUC was 0.70, without age, the AUC was 0.65 for predicting LOS.

Twenty studies examined the ability of EWSs to predict ICU admission or transfer. The AUCs ranged from 0.62 (SOFA) to AUC 0.89 (MEWS with blood lactate added). These were closely followed by DTEWS and NEWS (both AUCs 0.86).

The lack of high quality evidence to evaluate the predictive ability of EWS interventions on patient outcomes is due to a number of factors. These include small sample size in some studies and low event rates; a wide variation in the EWS interventions used and a wide variation in the definition of the outcomes from study to study (for example mortality may have included death within 24 hours in one study and 30-day mortality in another). The population included also varied.

Future research is needed to address limitations highlighted in this review. Ideally study designs of a more rigorous methodological quality are needed, preferably adequately powered prospective cohort studies or RCTs of alternative scores and systems. A standardised approach to the EWS interventions used and the outcomes included are warranted.

7.9 Conclusion

The findings from the studies included that examine the predictive ability of EWS interventions and their effect on healthcare staff and on improving the detection and management of physiological deterioration in adult patients in acute settings is of poor quality overall. The findings are contrasting owing to the heterogeneous nature of the interventions included making it difficult to draw definitive conclusions to inform policy and clinical practice.

8 Results: The impact of emergency response system interventions on patient outcomes and resource utilisation for the detection of physiological deterioration in adult (non-pregnant) patients in acute health care settings.

8.1 Chapter overview

This chapter in the systematic review update focusses on the literature pertinent to question 2 of the review. "*How effective are the different EWSs in terms of improving key patient outcomes in adult (non-pregnant) patients in acute health care settings?*" This chapter specifically focusses on the efferent limb (i.e. emergency response systems, which are also referred to as Rapid Response Systems [RRS], Rapid Response Teams [RRT], Medical Emergency Teams [MET] or Critical Care Outreach Teams [CCOT]) and their effectiveness in terms of the primary outcomes (mortality, cardiac arrest, length of stay, transfer or admission to the ICU), secondary outcomes (clinical deterioration in sub-populations, PROMs [validated tools]) and outcomes identified post-hoc (including significant adverse events [SAEs], resources utilisation and objective patient-related positive and negative outcomes).

8.2 Overview of studies focussing on the effectiveness of emergency response systems

There were 32 studies which investigated the effectiveness of emergency response systems.[38, 39, 45, 46, 50-53, 62, 63, 71, 72, 80-82, 95, 96, 98, 115, 117, 119, 124, 125, 127-130, 133-136, 157] These included two interrupted time series designs (ITS),[115, 133] 23 uncontrolled before-after observational studies,[38, 39, 45, 46, 50, 51, 53, 62, 63, 71, 72, 80-82, 95, 119, 124, 125, 128, 129, 134, 135, 157] and seven observational cohort studies.[52, 96, 98, 117, 127, 130, 136] All studies were set in hospitals. Sample size ranged from 140 patients[117] to 471,062 patients[134] and was not reported in one study.[129]

8.3 Overview of emergency response systems included

The emergency response systems included varied from study to study in their name or terminology, team composition, escalation plan and response times. This review categorises them as either nurse-led (n=15 studies) or doctor-led (n=16 studies) emergency response systems, and in one study, where multiple hospitals were included, the type of emergency response system varied.

8.3.1 Doctor-led emergency response systems

There were 16 studies which reported on doctor-led emergency response systems (***Table 8.1***), these are described below in terms of team composition, triggering of teams and response times where reported.

Three studies[71, 125, 129] considered an intensivist-led RRT with an ICU fellow or registrar, critical care nurse and a respiratory therapist. For Al-Qahtani et al.,[71] the RRT could be triggered by any HCP when any of the eight triggering criteria (which included vital sign parameters) were met or when staff were concerned. A response time of 15 minutes was reported for the RRT to respond to the deteriorating patient. For Moriarty et al.,[129] any HCP could activate the RRT based on staff concern or physiologically-based criteria. The response time was not reported in this study. In Karpman et al.,[125] the RRT worked in one of the two study ICUs, with calling criteria including derangements in four specific vital signs, staff concern, acute chest pain, and change in conscious state or new onset of symptoms suggestive of stroke. No optimal response time for the RRT was reported in the study.

Karvellas et al.,[52] investigated the effect of an intensivist-led MET (between 8am-4pm Monday to Friday) and a MET outside of these hours which was led by either the resident, nurse or respiratory therapist, who consulted with the on-call consultant intensivist. Any HCP could activate the MET when any of the calling criteria were present including derangements in vital sign parameters, change in level of consciousness or staff concern. A response was expected within 15 minutes by the MET in this study. Moon et al.,[95] reported

on a Critical Care Outreach Service (CCOS) including a consultant intensivist and two senior ICU nurses. The required frequency of measurement of vital signs was increased with higher MEWS scores. The on-call Senior House Officer (SHO), Specialist Registrar (SpR) and team consultant had 30 minutes to respond to the various triggers (different MEWS scores).

Beitler at al.,[119] described a RRT led by a senior medical house officer and the team included an ICU nurse, respiratory therapist and a patient transporter. Clinical judgement or derangements in individual vital signs were triggers for the RRT, which was activated via hospital pager to respond immediately to the bedside.

The Rapid Response System (RRS) team described by Kansal et al.,[38] consisted of an ICU senior resident medical officer, a designated ICU nurse and medical registrar supervised by an ICU consultant or ICU senior registrar. There was a two tier escalation system with early and late calling criteria (***Table 8.1***), where early warning criteria triggered the first tier of clinical review by the ward team, which must be attended to within 30 minutes. Delayed clinical review, progression to or occurrence of late warning criteria at any time triggered the second tier escalation, a RRT call.

The emergency response team reported on in Mathukia et al.,[128] included a hospitalist, a third year medical ICU resident, on-call first and second-year medical residents, and a surgical resident on-call, in addition to a respiratory therapist and an ICU nurse. A MEWS score of six or greater triggered a call to the RRT immediately with transfer to a higher level of care. No response time was reported.

Rothberg et al.,[133] described a hospitalist-led MET comprised of a critical care nurse, a respiratory therapist, intravenous therapist and the patient's physician (either attending or resident). In the hospital, there was a separate code team for cardiac arrests. The MET members carried pagers which were triggered by one or more physiological parameters or staff concern. The response time for the MET was not reported. The RRT based in Iran in the before-after study by Sabahi et al.,[63] included one doctor, one senior ICU nurse and one

staff nurse. The criteria for RRT activation was displayed prominently in each ward and included airway, breathing, circulation, neurologic changes, and other parameters including chest pain and restlessness. The RRT was activated by a pager call and by a public announcement internal communication call. The response time was not reported.

Segon et al.,[135] reported on a RRT which was led by an admitting senior resident in the ICU, an ICU nurse, and a respiratory therapist. The criteria for activation included vital sign parameters, changes in breathing pattern, urine output, seizures, change in mental status and staff or family concern. No specific response time for the RRT was reported, however all activations of the RRT were recorded in a log and reviewed in monthly rapid response meetings.

Two studies by Simmes et al.,[81, 82] described a physician-led RRS comprised of a critical care physician and a critical care nurse and was accessible 24/7. The RRS included a two-tier MET calling protocol. In the first, tier nurses had to call the ward physician immediately if one of the EWS criteria were met (included respiratory rate[RR], Oxygen saturation [SpO_2], heart rate [HR], eye, motor, verbal [EMV] score or staff concern) and the physician was expected to respond within 10 minutes. In the second tier, the ward physician activated the MET immediately if a serious situation existed or if the patient did not stabilise after the initial intervention. Gonçales et al.,[50] describe a 'code yellow' RRT led by an ICU physician. Triggers included worsening in vigilance and cardiac, neurological and respiratory monitoring parameters, or staff concern. The physician had five minutes to respond.

Joshi et al.,[45] reported on a two-tier RRS, which consisted of a pre-call response team (general medicine registrar and an ICU nurse) and for code blue events additional members were included (an anaesthesia registrar/emergency registrar or their consultants from the pre-call team and several other specialist nurses and ward persons/orderlies). The criteria for escalation was based on the Q-ADDS EWS call criteria being met for the pre-response team but immediate escalation of care was expected for code blue events (cardiorespiratory

arrest, threatened airway or altered conscious state). An optimal response time for the RRT was not reported.

Jung et al.,[62] described a 24/7 intensivist–led RRT comprised of an ICU resident and either an ICU fellow or an attending physician. An ICU nurse could be part of the team if requested by the attending physician. Criteria for escalation included derangements in specific vital signs as well as respiratory distress in a tracheotomised patient, respiratory arrest, coma, sudden change in consciousness or seizure. The expected response time for a code blue event was five minutes and 20 minutes in other situations (***Table 8.1***).

8.3.2 Nurse-led emergency response system

In total, 15 studies reported on nurse-led emergency response systems, which are described below.

Davis et al.,[124] described a RRT with a dedicated respiratory therapist and critical care nurse and a configuration where unit charge nurses only respond in their own unit. The RRT was triggered by derangements in a number of vital signs, chest pain, acute blood loss, laboured breathing, an acute decrease in mental status or staff or family concern. A response time to escalation for help was not reported.

Albert et al.,[117] described a nurse-led RRT which included an ICU resident, medical ICU charge nurse and a respiratory therapist. A MEWS score of greater than or equal to three was the trigger for referral to the RRT and no response time for the RRT was reported. Hayani et al.,[51] described the Rapid Assessment of Critical Events (RACE) emergency response team, led by a critical care nurse including a respiratory therapist and medical doctor. A staff intensivist was available during daytime working hours and a senior resident or fellow at night and on weekends. The RACE team could be initiated by any HCP using specific criteria including threatened airway, vital sign derangements, GCS level of consciousness decreased, staff concern or failure to respond to therapy. The RACE team

responded to all urgent calls and provided follow-up care for at least two days after discharge from the ICU.

Howell et al.,[115] described a RRT made up of the patients' usual care providers (the primary nurse, primary house officer, the floor's senior nurse, and a respiratory therapist for patients with respiratory-based triggers). The RRS was triggered by the primary nurse who paged all of the team members when any of the following criteria were met: derangements in vital sign parameters, change in conscious state, urine output or marked nursing concern. The team had to verbally discuss the case with the attending physician within one hour of the event.

Kim et al.,[72] investigated the effectiveness of a part-time RRS during operating and non-operating hours. The RRS operated from 7am to 10pm on weekdays and from 7am to 12pm on Saturdays. The RRS was led by four experienced nurses, a MDT of 12 doctors and during weekday hours one pulmonologist (an intensivist from the ICU) and two RRS nurses were on duty. From 6-10pm weekdays and on Saturdays only, one of 12 staff members (rotating) and two RRS nurses were on RRS duty. The electronic medical record system included ten triggering variables and the response time for the RRS team was not reported.

Kollef et al.,[127] reported on a RRS of a registered nurse, a second or third year internal medicine resident and a respiratory therapist, where from 2012 onwards the RRS team nurse member was established as a dedicated position without other clinical responsibilities. The RRS was activated by nursing staff between 2006 and 2008 and in 2009 could be triggered by real time clinical deterioration alerts as well as by nursing staff based on derangements in a number of vital sign parameters. The RRS nurse carried a pager to which alerts were sent and had a 20 minute response time.

Ludikhuize et al.,[80] described a RRT comprised of an ICU nurse and a physician who was trained in fundamental critical care. A MEWS of greater than or equal to three was the trigger for escalation where the nurse was to directly call the physician using SBAR. The

physician was to respond within 30 minutes, and the RRT was to be triggered after assessment if required. Moroseos et al.,[130] reported on a primary and secondary RRT. The primary RRT included a designated STAT (Latin for 'immediately) or ICU nurse along with the charge respiratory therapist. The secondary response team included a medical ICU fellow from 7.30am until 5.30pm and a medical ICU resident (year three) at other times of the day, seven days a week. The RRT could be activated by staff or the patient's family members by directly calling the STAT page operator when one or more of the clinical criteria to qualify for RRT were met which included staff or family concern as well as physiological criteria. No response time was reported.

Morris et al.,[96] described the feasibility of implementing RRTs in two different hospitals. The Wrexham hospital RRT consisted of two groups of specialist nurses. The first were critical care outreach nurses (working closely with the CCU from 7.30am - 9pm, Monday to Friday) and the second were a group of advanced nurse practitioners who formed part of the hospital night team. The London hospital operated a 24/7 RRT led by a nurse consultant and included nine critical care outreach nurses. The RRT was activated when a MEWS score of greater than or equal to three was reported for a patient. The response time was not reported.

Pattison et al.,[98] described a CCOT which consisted of eight nurses (no other details reported). A MEWS of greater than three was the trigger for referral to the CCOT, and no response time was reported. Scherr et al.,[53] included two hospitals. The RRT in both included a nurse practitioner, an ICU registered nurse and a respiratory therapist. In cases where the nurse practitioner was not available, a clinical associate physician or intensivist was to respond to RRT calls. One hospital operated 24/7 whilst the other hospital's RRT operated 12 hours a day. The triggers for escalation included changes in level of consciousness, breathing issues, BP issues, staff concern, heart rate issues and airway concerns. No response time was reported. Shah et al.,[136] reported on a RRT led by an experienced critical care nurse and respiratory therapist. The triggers for escalation included

derangements in vital sign parameters, change in mental status and staff concern. The response time for the RRT was not reported.

The MET in Mullany et al.,[39] included an ICU nurse, ICU medical officer and a general medical trainee. Three different MEWS criteria (greater than or equal to four, six or eight) triggered three different responses (1-the nurse to contact the nurse unit manager for review, 2-the nurse to contact the nurse unit manager and the registrar and, 3-triggered the MET). Review was necessary within 30 minutes. Massey et al.,[46] examined a two-tier RRS. An after-hours clinical team co-ordinator (service provided by six experienced critical care nurses) was introduced in 2008 to assist clinicians throughout the hospital and was activated by nursing staff in the hospital after-hours (14.00 hours – 07.30 hours, 7 days a week). The second tier of the RRS, the MET was activated by the after-hours clinical team co-ordinator if a patient continued to deteriorate. Criteria for activation of the clinical team co-ordinator service included derangements in vital signs and a response time to escalation was not reported. Sebat et al.,[157] introduced a general ward conventional RRS in 2005, which consisted of a bedside nurse, a critical care trained registered nurse, respiratory therapist, pharmacist and a lab technician. Changes in any two of activation criteria (which included vital signs predominantly as well as some laboratory criteria) activated the RRT. An optimal response time was not reported (***Table 8.1***).

8.3.3 Composite of emergency response systems

One study[134] included ten different hospitals where the composition of the emergency response teams varied. The majority included critical care registered nurses, respiratory therapists, ED registered nurses, and medical doctors. Across the ten hospitals, anyone could activate the emergency response system, and the response time ranged between five minutes and 15 minutes (***Table 8.1***).

8.4 Primary outcomes

8.4.1 Mortality

In total, 26 of the 32 studies examined the effectiveness of emergency response systems on mortality with 13 reporting a significant effect on mortality (In total, 12 out of these 13 studies showed a significant reduction in mortality post intervention whilst one study showed a significant increase in mortality).[125]

Two interrupted time series studies were included and neither showed a significant reduction in mortality. In a study by Howell et al.,[115] the risk of overall in-hospital mortality did not differ significantly between the intervention period and the baseline period. In the intervention period, the mortality rate was 1.95% (95% CI 1.86%–2.04%), compared with 2.08% (95% CI 1.97%–2.19%) in the baseline period (p=0.07). There were no significant differences in adjusted (p=0.09) and time-trend analyses (p=0.2). Rothberg et al.,[133] investigated the effect of a doctor-led MET on mortality. Mortality remained unchanged throughout the study period (2004-2009) at 22 per 1,000 admissions.

24 before-after observational studies were included and 14 reported a significant effect on mortality (13/14 showed a significant reduction in mortality while one study showed a significant increase in mortality).

Seven studies[63, 71, 95, 119, 124, 134, 157] reported a significant reduction in-hospital mortality before-after RRT introduction, with Davis et al.[124] reporting a decrease from (2.1% to 1.7%, [p<0.001]) and Sabahi et al.,[63] reporting a reduction from 73.2% to 66.2%, (a relative risk reduction of 16%, [p=0.004]). A retrospective study by Moon et al.,[95] considered two hospitals (Freeman hospital [FH] and the Royal Victoria Hospital [RVH]). In FH, before the Critical Care Outreach Service (CCOS), the number of in-hospital mortalities was 750 per year compared to 697 per year afterwards, a 7.1% reduction (p<0.0001). In the RVH the number of in-hospital mortalities was 952 per year before and 906 per year afterwards, a 2.3% decrease (no tests for statistical significance reported). In a Beitler et al.,[119] hospital

wide mortality decreased from 15.5 per 1,000 (before) to 13.7 per 1,000 after RRT implementation (p=0.004). In absolute terms, the number of hospital deaths decreased by 139 (95% CI 68-210). In-hospital mortality, in a study by Al-Qahtani et al.,[71] reduced from pre (22.5 per 1,000) to post RRT intervention (20.2 per 1,000), (p<0.0001). Sebat et al.,[157] investigated the effect of a 4-arm RRS intervention on the unadjusted hospital mortality rate in a single US hospital. Pre-intervention the unadjusted hospital mortality rate was 3.7%. Post-intervention this reduced to 3.2% (p<0.001). Salvatierra et al.,[134] investigated in-hospital mortality in a total of ten hospitals including more than 470,000 patients. Six out 10 of the hospitals showed a reduction in mortality post-RRT, while four did not. Overall there was a 24% reduction in risk of in-hospital mortality, (p<0.001).

Six studies[53, 72, 80, 128, 129, 136] reported no significant difference in-hospital mortality, before and after RRT introduction. In Moriarty et al.,[129] before the RRT was introduced, the hospital mortality rate was 1.5% compared to after where it was 1.6% (p=0.30). In a retrospective study by Mathukia et al.,[128] 272 patients were admitted to the medical, telemetry and step-down wards of a community hospital. Before the RRT the inpatient mortality rate was 2.3% compared to 1.2% after (no tests for statistical significance reported). In a prospective multicentre study by Ludikhuize et al.,[80] the death rate in 12 Dutch hospitals before RRT implementation was 20.4 per 1,000 admissions compared to 17.7 per 1,000 admission after RRT implementation (p=0.05). In a study by Scherr et al.,[53] two hospital RRTs were compared. In hospital A, the RRT operated 24 hours a day and was nurse-practitioner-led. In hospital B, the RRT operated 12 hours a day and was intensivist-led. In both hospitals, no significant reduction in hospital mortality was reported before or after the RRT was introduced (Hospital A p=0.17, Hospital B p=0.06). In a study by Kim et al.,[72] in a Korean hospital, before RRT implementation the mean in-hospital mortality rate was 1.38 per 1,000 compared to 1.33 per 1,000 after (p=0.32). Shah et al.,[136] investigated overall hospital mortality before and after a RRS was introduced in two hospitals. Pre-RRT the overall hospital mortality rate was 2.4%, and 2.15% overall post-RRT, (p=0.05).

In a study by Gonçales et al.,[50] a significant reduction in all-cause mortality from 16.3 per 1,000 discharges before the introduction of a physician led code yellow RRT to after 14.3 per 1,000, (p=0.03) was reported. Segon et al.,[135] investigated the effect of a RRT. Before RRT there was a 3.1% mortality rate (439 of 14,013 admissions), and after RRT this dropped to 2.9% (417 of 14,333), (p=0.27). In a retrospective cohort study by Kollef et al.,[127] including over 163,000 patients, the mortality rate before-RRT implementation was 2.87 per 1,000 compared to 2.22 per 1,000 post-RRT (p=0.002).

Jung et al.,[62] investigated the effect of a 24/7 intensivist-led RRT in four French hospitals (one RRT-hospital and three non-RRT hospitals) on unexpected mortality (defined as non-DNR, non-palliative deaths). In the RRT hospital, the unexpected mortality rate pre-intervention was 21.9 per 1000 discharges, post-intervention this reduced significantly to 17.4 per 1,000 discharges (p=0.002). The unexpected mortality rate was not significantly reduced post-intervention in the three non-RRT hospitals (p=0.38, p=0.16, p=0.40). The authors also looked at the overall mortality rates and the findings were similar with a significant reduction in overall mortality in the RRT hospital (p=0.012) post-intervention and no significant reduction in the three non-RRT hospitals (p=0.19, p=0.066, p=0.97). In a retrospective study by Kansal et al.,[38] there was a 20% decrease in unexpected deaths before (0.8 per 1,000) and after (0.6 per 1,000) RRT implementation, however this reduction was not significant (p=0.41).

In a retrospective study by Karpman et al.,[125] the authors compared mortality in patients transferred from the ward to ICU and patients transferred from non-ward locations (e.g. ED, theatre) to ICU. The hospital mortality rate in ward to ICU patients was 19.4% pre-RRT and 20.9% post-RRT (p=0.18). The hospital mortality rate in non-ward to ICU patients was 7.7% pre-RRT and 8.8% post-RRT (p=0.006), which was a significant increase in mortality rates. The ICU mortality rate in ward to ICU patients was 10.5% pre-RRT and 10.2% post-RRT, (p=0.72). The ICU mortality rate in non-ward to ICU patients was 4.3% pre-RRT and 4.9% post-RRT, (p=0.06).

Karvellas et al.,[52] compared three different time periods in a retrospective cohort study, the effect of an intensivist-led (IL) MET which operated 8am-4pm, Monday to Friday and a non-IL MET which operated outside of these hours and the rate of in-hospital mortality. Period one was the control period before a MET was in place and there was no difference between mortality rates between the planned IL-MET hours (30.8%) and non-IL MET hours (30.9%), (p=0.97). Period two was when a partial MET was in place (introduction of MET team covering part of the hospital without a dedicated intensivist) and no significant difference was found between non-IL MET hours (31.4%) and IL-MET hours (34.6%), p=0.44. Period three was when a hospital-wide IL-MET was implemented. No significant difference between non-IL MET hours (35.9%) and IL-MET hours (30.1%) was found in terms of mortality (p=0.10). When comparing period 1 (control, no MET) to period 3 (full MET in place) there was no significant difference for in-hospital mortality (p=0.20).

In a retrospective single centre study by Joshi et al.,[45] the authors investigated the effect of a two-tier RRS on overall hospital mortality. In the before period, the overall hospital mortality rate was 1.56% (95% CI 1.43%-1.69%). After the RRS intervention, this increased to 1.74% (95% CI 1.60%-1.89%), p=0.055. The authors also reported on ICU mortality in ICU-based admissions only and the findings were similar with an insignificant increase in mortality (before 13.7%, after 13.8%, p=0.93).

In a retrospective cohort study by Moroseos et al.,[130] the number of deaths before and after RRT implementation was compared. Before, there were 4.5 per 1,000 admissions compared to 3.3 per 1,000 admissions after the RRT was introduced (p=0.11). Mullany et al.,[39] investigated the all-cause mortality rate before and after the introduction of a RRT in over 300,000 observations from an Australian tertiary referral hospital. Before, the all-cause mortality rate was 14 per 1,000 admissions and after, it reduced to 11.8 per 1,000 admissions (p=0.003). Simmes et al.,[81] investigated the effects of a two-tier MET in a group of 1,376 surgical patients. The reduction in the number of unexpected deaths before and

after the MET was found not to be significant (Before 0.36%, after 0.17%, OR 0.42, 95% CI 0.11-1.59), (**Table 8.1**).

8.4.2 Cardiac arrest

In total, 18 of the 32 studies examined the effectiveness of emergency response systems on cardiac arrest, with 12 of the studies reporting a significant reduction in cardiac arrests.[38, 39, 45, 50, 53, 62, 63, 71, 72, 80, 81, 95, 119, 124, 127, 128, 133, 157]

A single ITS study by Rothberg et al.,[133] which investigated the effect of an intensivist-led MET on cardiac arrests showed it did not change significantly (p=0.98).

Seventeen before-after observational studies were included with eleven reporting a significant reduction in cardiac arrests.

Four studies[71, 119, 128, 160] considered out of ICU cardiopulmonary arrests (CPAs) and all found a significant reduction following the implementation of an RRT. In a study by Beitler et al.,[119] out of ICU CPAs decreased from 3.3 per 1,000 before to 1.6 per 1,000 after RRT implementation (p<0.001). In Davis et al.,[124] non-ICU CPAs were pre 2.7% and post 1.1% RRT introduction, (p<0.0001). Mathukia et al.,[128] in a retrospective study observed that before the RRT the non-ICU code blue cardiac arrest rate was 0.05 per 100 patient days compared to 0.02 per 100 patient days after (p<0.01). A RRT study in Saudi Arabia by Al-Qahtani et al.,[71] yielded a significant reduction in non-ICU CPAs pre (1.4 per 1,000) and post RRT intervention (0.9 per 1,000), p<0.001.

Two studies[45, 50] considered cardiorespiratory arrests (CRAs). In a study by Gonçales et al.,[50] a significant reduction in CRAs per 1,000 discharges was reported from 3.54 per 1,000 before to 1.69 per 1,000 (p<0.0001) after the introduction of a physician-led code yellow RRT. A significant reduction in CRAs per 1,000 deaths was also reported. In a retrospective, single centre study by Joshi et al.,[45] the authors measured the impact of a two-tier RRS, before the rate of CRAs was 1.0 per 1,000 admissions, compared to afterwards where it was 0.7 per 1,000 admissions (p=0.09).

Six studies considered cardiac arrests[38, 39, 80, 81, 95, 157] before and after the introduction of a RRT with four studies showing a significant reduction and two studies showing no change. Sebat et al.,[157] investigated the effect of a RRS, pre-intervention the rate of cardiac arrest was 3.1 per 1,000 discharges which reduced significantly to 2.4 per 1,000 post-intervention (p=0.04). In a prospective multicentre before-after study by Ludikhuize et al.,[80] the cardiac arrest rate in 12 Dutch hospitals was investigated before and after RRT implementation. Before the rate was 1.94 per 1,000 admissions compared to 1.22 per 1,000 admission after RRT implementation (p=0.02). A retrospective study by Moon et al.,[95] compared in two hospitals (Freeman hospital [FH] and the Royal Victoria Hospital [RVH]) before and after the introduction of a Critical Care Outreach Service (CCOS). In FH, before the CCOS, the number of cardiac arrests was 767 per year compared to 584 per year afterwards (p<0.0001). In the RVH the number of cardiac arrests was 723 per year before and 669 per year afterwards, a 7.5% absolute decrease (p<0.0001). Mullany et al.,[39] investigated rates before and after the introduction of a RRT, across a single Australian tertiary referral hospital, in over 300,000 observations. Before the cardiac arrest rate was 5.5 per 1,000 admissions. After the cardiac arrest rate reduced to 3.3 per 1,000 admissions (p<0.001). In a retrospective study by Kansal et al.,[38] there was no significant reduction in cardiac arrests from before RRT implementation (1.3 per 1,000) to after (0.95 per 1,000) (p=0.25). Simmes et al.,[81] investigated the effects of a two-tier MET in a group of 3,786 surgical patients. No significant reduction in the number of cardiac arrests before and after the MET was found (before 0.29%, after 0.12%, OR 0.38, 95% CI [0.09-1.73]).

Three studies[53, 72, 127] considered CPA rates before and after RRT implementation. In a study by Kim et al.,[72] in a Korean hospital. Before RRT implementation the mean CPA rate was 1.60 per 1,000 compared to 1.23 per 1,000 after (p=0.02). They also compared CPA rates during RRS operating times, where a pulmonologist was on duty weekdays, and RRS non-operating times, where one of 12 staff members made up of MDT doctors were on duty for the RRS. During RRS operating times a significant difference was found in CPA rates before (0.82 per 1,000) and after (0.49 per 1,000), (p=0.001). No difference was found during RRS

non-operating time (p=0.73). In a retrospective cohort study by Kollef et al.,[127] including over 163,000 patients, the number of CPAs before-RRT implementation was 57 compared to 35 post-RRT (p=0.006). In a study by Scherr et al.,[53] two hospital RRTs were compared. In hospital A, the RRT operated 24 hours a day and was nurse-practitioner-led. In hospital B, the RRT operated 12 hours a day and was intensivist-led. In both hospitals, no significant reduction in CPAs was reported before and after the RRT was introduced (Hospital A p=0.39, Hospital B p=0.84).

In a study by Jung et al.,[62] the effect of a 24/7 intensivist-led RRT on non-ICU cardiac arrests was compared in four hospitals (one RRT-based hospital and three non-RRT hospitals) in France. Pre-intervention in the RRT hospital the rate of non-ICU cardiac arrests per 1,000 discharges was 2.6, compared to 1.8 per 1,000 afterwards (p=0.09). Two out of the three non-RRT hospitals reported insignificant increases in non-ICU cardiac arrests (Hospital 1: p=0.08; Hospital 2: p=0.044; Hospital 3: p=0.71) post intervention.

Sabahi et al.,[63] investigated the effect of a RRT on unexpected cardiac arrests in a study in Iran. Before the RRT was introduced there were 431 unexpected cardiac arrests compared to after when there was 349 cardiac arrests, a relative risk reduction of 19%, p=0.003, (**Table 8.1**).

8.4.3 Length of stay (LOS)

Seven of the 32 studies examined the effectiveness of emergency response systems on LOS with three reporting a significant reduction in LOS.[39, 45, 52, 62, 72, 125, 127]

Two studies,[62, 127] considered the median LOS before and after the introduction of an RRT. A study by Jung et al.,[62] investigated the effect of a 24/7 intensivist-led RRT in four French hospitals (one RRT-based hospital and three non-RRT hospitals). In the RRT-based hospital, median LOS pre-intervention was 5 days (IQR 2-10 days), remaining unchanged post-intervention (median LOS 5 days, IQR 2-10 days, p=0.09). In a retrospective cohort study by Kollef et al.,[127] including over 163,000 patients, the median hospital LOS before-RRT

implementation was 3.79 days (IQR 2.02-6.81 days) compared to 3.10 days (IQR 1.75-5.82) post-RRT (p=0.001).

In a retrospective before-after observational study by Karpman et al.,[125] the authors compared ICU LOS and hospital LOS in patients transferred from the ward to ICU and patients transferred from non-ward locations (e.g. ED, theatre) to ICU. In patients transferred from ward to ICU, the ICU LOS was a median of three days (IQR 2-5 days) pre-RRT and a median of three days (IQR 2-4 days) post-RRT, (p<0.001). In patients transferred from non-ward to ICU, the ICU LOS was a median of two days (IQR 2-4 days) pre-RRT and a median of two days (IQR 2-3 days) post-RRT, (p<0.001). Hospital LOS was not significantly different in patients transferred from ward to ICU patients (p=0.34) but reduced in patients transferred from non-ward (emergency department, operating room and other hospitals) to ICU from a median of six days pre-RRT to five days post-RRT (p<0.001).

Karvellas et al.,[52] compared three different time periods in a retrospective cohort study, and the effect of an intensivist-led (IL) MET which operated 8am-4pm, Monday to Friday and a non-IL MET which operated outside of these hours and ICU LOS. Period one was the control period before a MET team was in place, there was no difference in median ICU LOS between the planned IL-MET hours (5 days, IQR 2-9 days) and non-IL MET hours (5 days, IQR 2-10 days), (p=0.92). Period two was when a partial MET was in place and no significant difference was found between non-IL MET hours (5 days, IQR 2-9 days) and IL-MET hours (5 days, IQR 3-10 days), (p=0.44). Period three was when a hospital-wide IL-MET was implemented. No significant difference between non-IL MET hours (5 days, IQR 2-11 days) and IL-MET hours (5 days, 3-9 days) was found in terms of ICU LOS (p=0.87), and no significant difference was found between period 1 (control, no MET) and period three (full MET), (p=0.20). The authors also investigated hospital LOS. There was no significant difference between the three time periods for IL-MET hours and non-IL MET hours.

In a study by Kim et al.,[72] the authors compared ICU LOS and hospital LOS before and after RRT implementation in a Korean hospital in patients admitted with CPA. Before, the mean

ICU LOS was 11.3 days, compared to 8.3 days after (p=0.14). No significant difference in-hospital LOS was found before or after the RRT implementation (p=0.59).

Mullany et al.,[39] investigated hospital LOS before and after the introduction of a RRT in over 300,000 observations from an Australian tertiary referral hospital. Before, the average hospital LOS was 5.9 days compared to 4.9 days after the RRT (no statistical test results reported). In a retrospective single centre study by Joshi et al.,[45] the authors investigated the effect of a two-tier RRS on the median ICU LOS and the overall hospital LOS. Post-RRS intervention, the median ICU LOS increased significantly (p=0.02), and the overall hospital LOS reduced significantly from 5.65 days to 4.93 days (p<0.001),(**Table 8.1**).

8.4.4 Transfer or admission to the ICU

In total, 14 of the 32 studies examined the effectiveness of emergency response systems on transfer or admission to the ICU[38, 39, 45, 53, 62, 71, 72, 80, 81, 95, 128-130, 135] with five studies reporting a significant effect on the outcome (two studies reported a significant reduction[71, 130] and three studies reported a significant increase[62, 81, 129] in transfer or admission to the ICU).

Seven studies[38, 39, 45, 53, 62, 81, 129] considered the effect on unplanned ICU admission rates following RRT implementation with three finding a significant increase in the admission rate. Jung et al.,[62] investigated the effect of a 24/7 intensivist-led RRT in four French hospitals (one RRT-based hospital and three non-RRT hospitals) on the rate of unplanned ICU admissions. A significant increase in unplanned ICU admissions was found in the RRT-based hospital (pre: 45.7 per 1,000 discharges, post: 52.8 per 1,000 discharges, p=0.002). No significant changes in unplanned ICU admissions were reported in the three non-RRT hospitals. Moriarty et al.,[129] reported before the RRT was introduced, the unplanned ICU admission rate was 13.7 per 1,000 floor days compared to after where this increased to 15.2 transfers per 1,000 floor days (p<0.001). Simmes et al.,[81] investigated the effects of a two-tier MET in surgical patients. A significant increase in the number of unplanned ICU

admissions before and after the MET was found (before 2.47%, after 4.15%, OR 1.66, 95% CI [1.07-2.55]). In a retrospective, single centre study by Joshi et al.,[45] the authors compared the rate of unplanned ICU admissions before and after a two-tier RRS was introduced. Before the rate was 5.8 per 1,000 admissions, after the rate increased to 6.5 per 1,000 admissions (p=0.11). In a retrospective study by Kansal et al.[38], there was no significant reduction in unplanned ICU or HDU admissions before (2.7 per 1,000) and after (2.5 per 1,000) RRT implementation (p=0.61). Mullany et al.,[39] investigated the introduction of a RRT in over 300,000 observations from an Australian tertiary referral hospital, before the number of unplanned ICU admissions were 41 and after it trebled to 121 admissions per year. In a study by Scherr et al.,[53] two hospital RRTs were compared. In hospital A, the RRT operated 24 hours a day and was nurse-practitioner-led. In hospital B, the RRT operated 12 hours a day and was intensivist-led. In both hospitals, no significant reduction in unplanned ICU admission was reported before and after the RRT was introduced (Hospital A: p=0.21, Hospital B: p=0.10).

Two studies[130, 135] considered the unexpected or unplanned ICU transfer rate, with one reporting a significant decrease. Segon et al.,[135] investigated the effect of a RRT, before RRT there was a 15.8% unexpected ICU transfer rate (295 of 1,866 admissions), after RRT this dropped to 15.5% (258 of 1,663), (p=0.80). In a retrospective cohort study by Moroseos et al.,[130] before, there were 52 per 1,000 unplanned ICU transfers compared to 42 per 1,000 transfers after the RRT was introduced (p=0.01).

Two studies[71, 128] considered all ICU transfers, with one reporting a significant decrease. A RRT study by Al-Qahtani et al.,[71] found a significant reduction in ICU transfers following RRT, pre (8.7 per 1,000) and post RRT intervention (7.3 per 1,000), (p<0.0001). Mathukia et al.,[128] in a retrospective study of 272 patients admitted to the medical, telemetry and step-down wards of a community hospital, reported that before the RRT the ICU transfer rate was 72% compared to 50% after RRT implementation (no statistical tests reported).

Three studies[72, 80, 95] considered all ICU admissions. In a prospective multicentre study by Ludikhuize et al.,[80] the ICU admission rate in 12 Dutch hospitals was investigated before and after RRT implementation. Before, the rate was 19.8 per 1,000 admissions compared to 17.1 per 1,000 admission after RRT implementation (p=0.09). In a study by Kim et al.,[72] in a Korean hospital, no significant difference was in admission to the ICU before and after RRT implementation (p=0.11). In a retrospective study by Moon et al.,[95] that compared in two hospitals (Freeman hospital [FH] and the Royal Victoria Hospital [RVH]) before and after the introduction of a Critical Care Outreach Service (CCOS). In FH, before the CCOS, the number of ICU admissions was 857 per year compared to 1,135 per year afterwards, a 32% increase (statistical test not reported). In the RVH the number of ICU admissions was not reported (**Table 8.1**).

8.5 Secondary outcomes

8.5.1 Clinical deterioration in sub-populations

Two observational studies examined the effectiveness of emergency response systems on clinical deterioration in a sub-population with one reporting a significant reduction in the outcomes as a result of the emergency response system intervention.[51, 98]

Hayani et al.,[51] included 814 hematopoietic stem cell transplant recipients in a before-after observational study where a RACE emergency response team was implemented. The authors looked at the non-relapse mortality by day 100 after transplant which was 10.2% pre-RACE team implementation and 8.8% post-RACE team implementation (p=0.62). The authors looked at the non-relapse mortality by day 100 after transplant in allogeneic recipients only (non-identical donors) which was 22.5% pre-RACE team implementation and 18.2% post-RACE team implementation (p=0.25). The ICU admission rate pre and post implementation was not significantly different in this subpopulation of transplant patients (p=0.44), (**Table 8.1**).

Pattison et al.,[98] investigated three and six month mortality in 407 episodes of CCOT referral in 318 cancer patients. A MEWS greater than three was the trigger for CCOT referral. Three and six-month mortality was significantly associated with a higher MEWS at referral (p=0.02, p=0.01 respectively). The mean MEWS at referral to the CCOT was 3.76 (95% CI 3.49-3.99), with untimely referrals associated with lower survival to discharge (p=0.004) and three and six month mortality (p=0.004, p=0.03 respectively), (**Table 8.1**).

8.5.2 Patient Reported Outcome Measures (PROMs)

One before-after study included a PROMs outcome and reported no significant effect on the outcome (i.e. quality of life was not improved).[82] Simmes et al.,[82] investigated health-related quality of life (HRQOL) which was measured using the EuroQol 5-dimensions (EQ-5D)[161] and EuroQol visual analogue scale (EQ-VAS)[162] questionnaires before and after the introduction of a MET in a group of surgical patients (all patients were included with only 2.8% before and 4.5% after experiencing an unplanned admission to the ICU). There was no difference in HRQOL at three months (p=0.54) or six months (p=0.29) following surgery using the EQ-5D index, nor with the EQ-VAS tool at three (p=0.28) and six months (p=0.80) post surgery (**Table 8.1**).

8.5.3 Post-hoc identified outcomes

8.5.3.1 Composite Outcomes

Three before-after observational studies examined the effectiveness of emergency response systems on a composite of serious events with one reporting a significant reduction.[38, 46, 80]

In a retrospective uncontrolled before-after observational study by Kansal et al.,[38] there was no significant reduction in the composite outcome (defined as unexpected death, cardiac arrest or unplanned admission to the ICU or HDU) before (3.8 per 1,000) and after (3.2 per 1,000) RRT implementation (p=0.28). In a retrospective before-after observational study by Massey et al.,[46] the authors investigated the effect of a two-tier RRS on major events (a composite outcome defined as unplanned admission to the ICU, death, or cardiac

arrest). A significant increase of any major event was found post-intervention (p=0.01). The authors also looked at serious events (a composite outcome defined as myocardial infarction, deep vein thrombosis, pulmonary embolism, cerebral vascular accidents, operating theatre, adverse drug reaction, hospital accident/injury, HCAI/sepsis, other adverse events and major adverse events as defined previously). Pre-intervention the rate of serious events was 32/150 (21.3%). Post-intervention the rate of serious events was 36/150 (24.7%), (p=0.58) In a study by Ludikhuize et al.,[80] a composite outcome of death, cardiac arrest and ICU admission before and after RRT implementation was investigated. Before the rate was 37.14 per 1,000 admissions compared to 32.92 per 1,000 admission after RRT implementation (p=0.04). (**Table 8.1**).

8.5.3.2 Resource utilisation (number of code blue calls or RRT calls)

Eleven of the 32 studies examined the effectiveness of emergency response systems on the number of code blue calls or RRT calls and seven reported a significant effect of the emergency response system intervention.[38, 45, 80, 117, 127, 128, 130, 133, 135, 136, 157] Three out of the seven studies showed a significant reduction in code calls and four of the studies showed a significant increase in RRT calls post intervention.

A single ITS study was included and reported a significant reduction in the number of code calls as a result of the emergency response system intervention. Rothberg et al.,[133] investigated the effect of an intensivist-led MET on the number of code calls. Pre-MET there were 7.3 per 1,000 (95% CI 5.81-9.16). Post-MET this dropped to 4.21 per 1,000 (95% CI 3.42-5.18), (p<0.0001). There was a significant reduction in the number of code calls outside of critical care before and after the MET (p=0.008), in the number of code calls for medical crises (p<0.0001) and in the number of code calls within critical care (**Table 8.1**).

There were ten before- after observational studies of which six reported a significant effect of the emergency response team (three of which reported a significant increase in RRT/MET calls and two of which reported a significant reduction in code calls).

In a retrospective before-after observational study by Kansal et al.,[38] there was a 50% increase in the number of rapid response calls before (14.3 per 1,000) and after (21.2 per 1,000) RRT implementation (p<0.001). Segon et al.,[135] investigated the effect of a RRT. Pre-RRT the number of code blue calls was 3.09 per 1,000 admissions. Post-RRT this dropped to 2.89 per 1,000 admissions, (p=0.14). Sebat et al.,[157] reported the number of RRT calls per 1,000 discharges before and after a four-arm RRS intervention. Pre-intervention there were 10.2 RRT calls per 1,000 discharges, post-intervention this increased significantly to 48.8 RRT calls per 1,000 discharges (p<0.001). In a prospective multicentre study by Ludikhuize et al.,[80] the number of RRT calls in 12 Dutch hospitals was investigated before and after formal RRT implementation. Before the rate was 6.8 per 1,000 admissions (95% CI 6.2-7.5) compared to 7.3 per 1,000 admissions (6.4-8.3) after RRT implementation (statistical test not reported). In a retrospective QIP study by Albert et al.,[117] the authors reported a 33% reduction in the number of code blue calls and a 50% increase in RRT calls six months after implementation of the RRT which included an electronic MEWS system (no statistical tests reported). In a retrospective cohort study by Kollef et al.,[127] which included over 163,000 patients, the number of RRT activations before a formal RRT was implemented was 72 compared to 370 post-RRT, with a significant year on year increase (p<0.001).

The number of RRT calls was reported by Mathukia et al.,[128] in a retrospective before-after observational study of patients admitted to the medical, telemetry and step-down wards of a community hospital. Before the RRT was formally implemented the number of RRT calls was 0.3 per 100 patient days compared to 0.48 per 100 patient days after (p<0.01). In a retrospective study by Moroseos et al.,[130] the number of code blue activations (defined as respiratory arrest or cardiopulmonary arrest) before and after RRT implementation was compared. Before, there were 10 per 1,000 admissions compared to 4 per 1,000 admissions after the RRT was introduced (p=0.04).

Shah et al.,[136] investigated the number of code calls before and after a RRS was introduced in two hospitals. Pre-RRS there were 0.83 code calls per 1,000 admissions. This increased to

0.98 per 1,000 admissions (overall post-RRS), p=0.30. Joshi et al.,[45] reported a significant reduction in RRT calls per 1,000 admissions after a two-tier RRS was introduced (pre: 48/1000, post 11/1000, p<0.001), (**Table 8.1**).

8.5.3.3 Other objective patient-related positive and negative outcomes

Morris et al.,[96] in a retrospective observational cohort study following RRT activation, looked at a number of positive outcomes (timely ICU admission [<4 hours]; alive on the ward and no longer triggering; died with terminal care pathway and had DNAR; alive with DNAR and documented treatment limitations and other [new unrelated RRT trigger, chronic condition leading to continuous trigger, discharged]). They also looked at negative outcomes (delayed ICU admission [>4 hours]; still triggering; CPA; outcome unknown or lost to follow-up). Day one post-RRT 75% of patients had a positive outcome, of the negative outcomes 15.8% were still triggering and 0.7% had a CPA (**Table 8.1**). Day three post RRT activation, 90% of patients had a positive outcome compared to 10% who had a negative outcome. Day seven post RRT activation 88% of patients had a positive outcome compared to 12% of patients having a negative outcome. In this study the absence of a simple tool for auditing and benchmarking was highlighted as hampering development of effective RRTs. This study's matrix of outcomes gives RRTs an opportunity to quantify failure-to-rescue with minimal additional administrative workload. With its ability to classify and measure frequency of clinical outcomes, the tool could facilitate quality initiatives in clinical networks to improve the safety of deteriorating patients on general wards.

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Interrupted time-series					
[115]Howell (2012), Interrupted time-series design.	Urban University Hospital, Boston, USA.	N=171,341 consecutive adult admissions (59-months duration). N=66,496 admissions (baseline), N=14,800 (6-month implementation period), N=90,045 (intervention period)	Nurse led. RRT of usual care providers: patient's primary nurse, primary house officer or licensed independent practitioner, and the floor's senior nurse (usually a nurse educator or specialist); for respiratory criteria, the team includes the respiratory therapist covering the patient.	A. Patient's nurse assembles the team by paging the other providers. Criteria causing team activation included: SBP<90 mmHg: Heart rate <40 or >130; SpO_2 <90% in spite of oxygen; RR<8 or >30; Acute change in conscious state; Oliguria (urine output <50cc in 4 hours); Marked nursing concern. B. No specific therapies were mandated, but the team must verbally discuss the case with the attending physician within 1 hr of the event.	**Primary outcome: Mortality** **Overall In-Hospital Mortality Risk:** Intervention: 1.95% (95% CI 1.86-2.04) Baseline Period: 2.08% (95% CI 1.97-2.19).P=0.07. No significant difference in adjusted (p=0.09) and time-trend analyses (p=0.2).
[133]Rothberg (2012), Interrupted time series design	Tertiary care academic hospital, Boston, USA.	Hospital-led MET was introduced in the 1st and 2nd quarters of 2006, with n=2,717 calls logged through the end of 2009 (out of n=154,382 admissions).	Doctor led. MET: a critical care nurse, a respiratory therapist, intravenous therapist, and the patient's physician (either attending or resident). Separate ''code'' team for cardiovascular arrests which include the ICU medical resident and intern, a critical care nurse, an anaesthesiologist, a respiratory therapist, a staff nurse, and the house supervisor.	A. Baystate staff members carry alpha-numeric pagers, so attendings could be alerted to the fact that the MET had been activated by means of a text page. Anyone could activate the MET with the following: HR (<40 and >130 bpm), SBP (<90 mmHg), RR (<8 or >24 per minute), SpO_2 (<90% despite supplemental oxygen), altered mental status, or simply ''concern that something is wrong''. B. Not reported.	**Primary outcome: Mortality:** remained steady at 22 per 1,000 admissions throughout the study. **Primary outcome: Cardiac arrest:** Cardiac arrests did not change significantly (p=0.98). **Secondary outcome: Post-hoc: No. of code calls** 1,202 codes called Jan 2004 - Dec 2009, case-mix remained constant. Pre-implementation: 7.30 per 1,000 (95% CI 5.81-9.16) Post-implementation: 4.21 per 1,000 (95% CI 3.42-5.18). p<0.0001 **Code calls outside of critical care:** Pre-implementation: 4.70 per 1,000 (95% CI 3.92-5.63) Post-implementation: 3.11 per 1,000 (95% CI 2.44-3.97). p=0.008 **Code calls for medical crises:** Pre-implementation: 3.29 per 1,000 (95% CI 2.70-4.02) Post-implementation: 1.72 per 1,000 (95% CI 1.28-2.31). p<0.0001 **Code calls within critical care:** Pre-implementation: 2.59 per 1,000 (95% CI 1.82-3.69) Post-implementation: 1.24 per 1,000 (95% CI 0.94-1.63).

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Before-after observational studies					
[71]Al-Qahtani (2013), Before (Jan 2006 – Nov 2007), -after (Dec 2007-Dec 2010) RRT uncontrolled observational study	Tertiary care academic hospital (900-bed), Saudi Arabia	N=98,391 patients (pre-RRT) and N=157,804 (post-RRT). All medical-surgical patients	Intensivist-led, ICU fellow or registrar, critical care nurse, respiratory therapist.	A. Triggered by any HCP via an overhead call or pager. Triggers: threatened airway, RR ≤ 8 or ≥ 30, SpO_2 ≤ 90% , FiO_2 ≥ 50% or ≥ 6 L/min), SBP ≤ 90 or ≥ 200, HR ≤40 or ≥130, urine output ≤100 mL over 4 hrs for patients with indwelling urinary catheter, ≥2 points on GCS or repeated seizures, or staff concern. B. Within a max of 15 mins.	**Primary: Total hospital mortality** Pre: 2,214 (22.5 per 1,000) Post: 3,191 (20.2 per 1,000), p<0.0001. **Primary: Ward mortality** Pre: 1,912 (19.4 per 1,000), Post: 2,829 (17.9 per 1,000), p<0.006. **Primary: Non-ICU cardiopulmonary arrests** Pre: 133 (1.4 per 1,000), Post: 144 (0.9 per 1,000), p<0.001. **Primary: ICU transfer** Pre: 856 (8.7 per 1,000), Post: 1158 (7.3 per 1,000), p<0.0001.
Jung et al (2016),[62] Before - after intervention study.	4 hospitals of Montpellier regional health-care centre, France.	N=117,466 patients admitted to the medical-surgical wards between July 2010 and Dec 2011 (pre-RRT) of 3 control hospitals with no RRT and N=43,605 patients admitted from July 2012 to Dec 2013 (post-RRT) in 1 RRT hospital.	24/7 intensivist-led RRT comprised of: an ICU resident and either an ICU fellow or an attending physician. An ICU nurse could be part of the team if requested by the attending physician.	A. Single activation criterion: HR <40/min, >140/min; SBP <80 mmHg; Cardiac arrest; RR <8/min, >30/min, Pulse oximetry <90% with O_2 above 6l/min; Respiratory distress in a tracheotomised patient, Respiratory arrest; Coma; Sudden change in level of consciousness; Seizure B. 5 mins in the case of a code blue and 20 mins in other situations.	**Primary outcome: Unexpected mortality (non-DNR, non-palliative)** RRT hospital: Pre: 21.9 per 1,000 discharges Post: 17.4 per 1,000 discharges (p=0.002) Three control hospitals: Hospital 1: Pre:14.3 per 1,000 discharges Post: 15.4 per 1,000 discharges (p=0.38) Hospital 2: Pre:24.9 per 1,000 discharges Post:22.5 per 1,000 discharges (p=0.16) Hospital 3: Pre: 22.1 per 1,000 discharges Post: 23.8 per 1,000 discharges (p=0.40) **Primary outcome: Overall mortality** RRT hospital: Pre: 39.6 per 1,000 discharges; Post: 34.6 per 1,000 discharges (p=0.012) Three control hospitals: Hospital 1: Pre: 16.7 per 1,000 discharges; Post: 18.4 per 1,000 discharges (p=0.19) Hospital 2: Pre: 28.6 per 1,000 discharges; Post: 25.2 per 1,000 discharges (p=0.066) Hospital 3: Pre: 29.0 per 1,000 discharges; Post: 29.0 per 1,000 discharges (p=0.97)

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Before-after observational studies					
Jung et al. (continued)					**Primary outcome: Non-ICU cardiac arrest (per 1,000 discharges)** RRT hospital: Pre:2.; Post: 1.8 (p=0.093) Three control hospitals: Hospital 1: Pre:3.5; Post: 4.6 (p=0.080) Hospital 2: Pre: 3.3; Post: 2.1 (p=0.044) Hospital 3: Pre:10.2; Post: 10.8 (p=0.71) **Primary outcome: Unplanned ICU admission (per 1,000 discharges)** RRT hospital: Pre:45.7; Post: 52.8 (p=0.002) Three control hospitals: Hospital 1: Pre: 51; Post: 55.3 (p=0.054) Hospital 2: Pre: 60.2 ; Post:55.6 (p=0.34) Hospital 3: Pre: 126.9; Post:122.0 (p=0.24) **Primary outcome: Median hospital LOS (days)** RRT hospital: Pre: 5 (2-10); Post: 5(2-10), (p=0.09) Three control hospitals: Hospital 1: Pre: 4 (2-8), Post: 4 (2-8), (p<0.001) Hospital 2: Pre: 3 (2-7), Post: 3 (2-6), (p<0.001) Hospital 3: Pre: 4 (2-8), Post: 4 (2-8), (p=0.36)

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Before-after observational studies					
[38]Kansal (2012), Retrospective uncontrolled before-after observational study.	John Hunter tertiary Hospital, Australia.	N=375 patients with a RRT call before the intervention (Jun – Oct 2009) and N=582 patients after (Jun – Oct 2010). Adult patients.	Doctor led. An ICU senior resident medical officer, a designated ICU nurse and medical registrar, and supervised by an ICU consultant or ICU senior registrar.	A. Two tier escalation system with early and late calling criteria. **Early warning calling criteria:** RR 5-10 or 25-30 breaths/min; SpO_2 90-95% and/or increase in oxygen requirement; poor peripheral circulation, pulse rate 40-50 or 120-140 beats/min; systolic BP 90-100 or 180-200 mmHg; Decrease in level of consciousness from A (Alert) to V (voice, rousable only by voice) in the AVPU scale; Blood glucose level -4 mmol/L, body temp<35.5 or >38.5, increasing blood loss, anuria, failure to void in 24 hrs or urine output <200ml over 8 hrs; polyuria >200mL/hr for 2 hrs in the absence of diuretics; increasing pain including chest pain. **Late warning calling criteria**; All respiratory and cardiac arrests; airway obstruction; seizures; arterial blood gas: PaO_2 <60 mmHg, $PaCO_2$ > 60 mmHg, pH <7.2 or base excess < - 5mmol/L; venous blood gas $PvCO_2$ >65mmHg, pH <7.2; RR <5 or >30; SpO_2 <90% and or increase in oxygen requirement; pulse rate <40 or > 140/min; systolic BP <90 mmHg or > 200 mmHg; unresponsive to verbal commands or sudden fall in level of consciousness of >= 2 points on the Glasgow Coma Scale; Blood Glucose Level <1 mmol/L; serious concern by any staff member. B. Presence of any 1 of the early warning signs triggered the 1st tier of clinical review by the ward team, which must be attended to within 30 mins. Delayed clinical review, progression to or occurrence of a late warning sign at any time triggered the second-tier escalation, which was a rapid-response call.	**Primary outcome: Unexpected death:** Before: 0.8 per 1,000, After: 0.6 per 1,000, 20% decrease, p=0.41 **Primary outcome: Cardiac Arrest** Before: 1.3 per 1,000, After: 0.95 per 1,000, 26% decrease, p=0.25. **Primary outcome: Unplanned admission to the ICU or HDU:** Before: 2.7 per 1,000, After: 2.5 per 1,000, p=0.61. **Secondary outcome: Post hoc: Rapid response calls**: Before (14.3 per 1,000), After (21.2 per 1,000), 50% increase. p<0.001. **Secondary outcome: Post hoc: Composite rate (unexpected death, cardiac arrest or unplanned admission to ICU or HDU):** Before (3.8 per 1,000), After (3.2 per 1,000), 16% decrease, p=0.28.

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontolled Before-after observational studies					
[125]Karpman (2013), Retrospective before-after observational study.	2 ICUs, Minnesota, USA.	N=4,890 medical/ surgical patients transferred from the hospital ward to 2 ICUs and n=15,855 patients admitted from 'non-ward' locations.	Doctor led.An intensivist, a critical care fellow and nurse, a respiratory therapist, each worked in 1 of the 2 study ICUs.	A. Calling criteria: staff concern, SpO_2 <90%, HR <40 or >130 beats per minute; systolic BP <90 mmHg, RR <10 or >28 breaths per minute; acute chest pain; change in conscious state; new onset of symptoms suggestive of stroke. B. Not reported.	**Primary outcome: Mortality** [WARD TO ICU PATIENTS] **Hospital mortality**: pre-RRT: 478 (19.4%), post-RRT (507 (20.9%), p=0.18 **ICU Mortality**: pre-RRT: 259 (10.5%), post-RRT (247 (10.2%), p=0.72. **Primary outcome: ICU LOS**: pre-RRT median 3 days (IQR 2-5), post-RRT 3 days (IQR 2-4), p<0.001; **Hospital LOS**: pre-RRT median 11 days (IQR 6-22), post-RRT 11 days (IQR 6-21), p=0.34. **Primary outcome: Mortality** [NON-WARD TO ICU PATIENTS, (ED, operating theatre, other hospitals)]. **Hospital mortality**: pre-RRT: 630 (7.7%), post-RRT 674 (8.8%), p=0.006; **ICU Mortality**: pre-RRT: 355 (4.3%), post-RRT 376 (4.9%), p=0.06. **Primary outcome: ICU LOS**: pre-RRT median 2 days (IQR 2-4), post-RRT 2 days (IQR 2-3), p<0.001; **Hospital LOS**: pre-RRT median 6 days (IQR 3-12), post-RRT 5 days (IQR 2-10), p≤0.001.
[80]Ludikhuize (2015), Prospective before-after multi-centre intervention study (COMET)	12 Dutch hospitals, The Nether-lands	N=166,569 patients admitted to medical and surgical wards Apr 2009 and Nov 2011. MEWS and SBAR and RRT implemented	Nurse led. An ICU nurse and a physician who was at least trained in fundamental critical care.	A. MEWS <3: follow local guidelines. MEWS ≥3: nurse to directly call the physician using SBAR. B. Physician responds within 30 mins. After assessment direct activation of RRT or within one hr of assessment determine the effect of treatment.	**Primary outcome: Mortality (per 1,000)**: Before: 20.4 (95% CI 18.7-22.0) After: 17.7 (95% CI 16.2-19.2), p=0.05 **Primary outcome: Cardiac arrest (per 1,000 admissions)**: Before: 1.94 (95% CI 1.43-2.46) After: 1.22 (95% CI 90.82-1.61), p=0.02 **Primary outcome: Admission to the ICU**: Before: 19.8 (95% CI 18.1-21.6) After: 17.1 (95% CI 15.5-18.6), p=0.09 **Secondary outcome: post-hoc: Composite outcome (death, cardiac arrest, ICU admission):** Before: 37.14 (95% CI, 34.94–39.34) After: 32.92 (95% CI, 30.88–34.95), p=0.04 **Secondary outcome: post hoc: RRT calls (per 1,000 admissions):** Before: 6.8 (95% CI 6.2-7.5) After: 7.3 (95% CI 6.4-8.3).

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontolled Before-after observational studies					
[119]Beitler (2011), Before-after observational study	809-bed tertiary referral teaching hospital, USA	N=77,021 before (Jan 2003-Dec 2005), N=79,013 after (Jan 2006-Dec 2008); admitted medical, surgical, paediatric, ICU, obstetric & psychiatric patients	Led by senior resident medical house officer. Team included an ICU nurse, respiratory therapist, and patient transporter.	A. Clinical judgement or derangement in vital signs (pulse oximetry saturation less than 90%, RR <8 or >30 bpm, SBP <90 mmHg, HR <40 or >140 beats per minute, or change in HR >30 bpm. B. Activated via hospital pager to respond immediately to the bedside.	**Primary: Hospital wide mortality:** Decreased from 15.5 to 13.7 per 1,000 discharges after RRT implementation (RR 0.89, 95% CI 0.82, 0.96, p=0.004). Absolute terms, number of hospital deaths decreased by 139 (95% CI 68-210 deaths) after RRT implementation (from 1, 225 expected to 1, 086 observed deaths). **Primary: Out of ICU cardiopulmonary arrest:** Decreased from 3.3 to 1.6 codes per 1,000 discharges after RRT implementation (RR 0.49, 95% CI 0.40, 0.61, p<0.001).
[72]Kim (2017), Before-after study	1360-bed National University Hospital, Seoul, Korea	N=456 patients with CPA admitted to the general ward Jan 2009 to Sept 2015.	Nurse led. N=4 experienced nurses, a MDT of 12 doctors. During weekday hours 1 pulmonologist (an intensivist from the medical ICU), 1 anaesthesiologist (an intensivist from the surgical ICU), and2 RRS nurses were on duty. From 6pm to 10pm weekdays and from 7am to 12pm on Saturdays, one of 12 staff members (rotating) and 2RRS nurses were on RRS duty.	A. The EMR screening system has 10 triggering variables for RRS activation: SBP(< 90 mmHg), HR(<50, >140 /min), RR (<10, >30 /min), temp (>39, <36 ^{o}C), SpO_2 (<90%), pH (< 7.25), $PaCO_2$ (>50 mmHg), PO_2 levels (<55 mmHg), lactic acid level (> 4 mmol/L), and total CO_2 level (<15 mmol/L). B. Not reported.	**Primary outcome: In-hospital mortality:** Before: mean 1.38 (SD 0.23) per 1,000; After: mean 1.33 (SD 0.18) per 1,000, p=0.32 **Primary outcome: CPA incidence per 1,000 admissions**: Before: mean 1.60 (SD 0.82) per 1,000, After: mean 1.23 (SD 0.58) per 1,000, p=0.02. Percentage of CPAs pre-RRS (52%) compared to post-RRS (40.6%), p=0.018. **CPA per 1,000 admissions during RRS operating time**: Before: mean 0.82 (SD 0.50) per 1,000, After: mean 0.49 (SD 0.27) per 1,000, p=0.001 **CPA per 1,000 admissions during non-operating time**: Before: mean 0.77 (SD 0.49) per 1,000, After: mean 0.73 (SD 0.49) per 1,000, p=0.73 **Primary outcome: LOS** ICU LOS: Before: 11.3 (SD 21.2), After: 8.3 (SD 10.8), p=0.14; Hospital LOS: Before: 38.6 (SD 93.5), After: 48.2 (SD 262.2), p=0.59 **Primary outcome: Admission to the ICU:** Before: 176 (69.3), After: 125 (61.9), p=0.11.
[50]Gonçales (2012), Brazil, Before-after observational study	Private 477-bed general hospital, Sáo Paulo, Brazil.	N=82,829 hospital discharges recorded (19 months before RRT n=40,033; 19 months after RRT n=42,796); general acute patients	Code Yellow RRT led by ICU physician implemented in Feb 2007.	A. Triggered by the nursing team via telephone when worsening in vigilance and cardiac, neurological and respiratory monitoring parameters, or when any member of the team is seriously concerned with a patient's general status. B. 5 mins for physician to respond.	**Primary outcome: Mortality:** Mean rate of all-cause mortality/1,000 discharges: Pre-intervention 16.3; post-intervention 14.3; relative variation -12, p=0.029 **Primary outcome: Cardiorespiratory Arrest:** CRA per 1,000 discharges Pre-intervention 3.54; post-intervention 1.69; relative variation -52, p<0.0001 CRA per 1,000 deaths Pre-intervention 2.33; post-intervention 0.78; relative variation -66, p<0.0001

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Before-after observational studies					
[128]Mathukia (2015), Retrospective before-after observational study	Easton comm-unity academic hospital, PA, USA.	N=272 patients admitted to all medical wards, telemetry and step-down units before (2010-2011) and N=454 after (2012-2014) MEWS protocol for escalation added. QIP data used to analyse data.	Doctor led. A hospitalist attending, a third-year medical ICU resident, on-call 1st and 2nd year medical residents, and a surgical resident on-call, in addition to a respiratory therapist, and an ICU nurse.	A. Score 0-2: Continue routine monitoring of vital signs. Score 3: Continue 4 hourly vital sign monitoring and calculate MEWS score. If patient remains at '3' for 3 consecutive readings, call the charge nurse to assess patient. Score 4: Inform charge nurse and patient's physician. The charge nurse assesses the patients and notifies the nurse manager of patient's status. Increase vital sign monitoring to 2-hr intervals and calculate the MEWS score. Measure intake and output and notify charge nurse if urinary output falls below 100 mL every 4 hours. Score 5: Inform physician and request assessment. Increase frequency of vital sign monitoring including pulse oximetry to hourly. If patient remains at '5' for 3 consecutive readings, request transfer to higher level of care. Score '6+': Call RRT and physician immediately. Transfer to higher level of care. B. No time reported.	**Primary outcome: Inpatient mortality**: Before: 2.3%, After: 1.2%. **Primary outcome: Non-ICU code blue cardiac arrest:** Before: 0.05 per 100 patient days, After: 0.02 per 100 patient days, (p<0.01) **Primary outcome: Transfer to ICU:** Before: 72%, After: 50% **Secondary outcome: post hoc: RRT calls:** Before: 0.3 per 100 patient days, After: 0.48 per 100 patient days (p<0.01)
[95]Moon (2011), Retrospective before-after observational study.	Freeman Hospital (FH) and Royal Victoria Hospital (RVH), Newcastle, UK.	N=213,117 before (2002-2005) and N=235,516 after (2006-2009), admitted to the ICU after receiving CPR.	Doctor led. Critical Care Outreach Service (CCOS) established in 2001 consisting of 6 week-day sessions for consultant intensivists, 2 senior ICU nurses (1.5 whole time equivalents or WTEs). Initially the service directly supported geographically separate high dependency unit (HDU) and the hospital's surgical wards. From Aug 2003 (when a new ICU opened) the service expanded to cover other ward areas and with 6.5 WTEs in 2005 became 24/7.	A. MEWS 1: 4-hourly observations, MEWS 2: 1-hourly observations, MEWS 3-5: minimum 1-hourly observations, MEWS>5 OR MEWS 3 in a single category OR MEWS<5 but serious concern: ½ hourly observations. B. MEWS 2: SHO within 30 mins, MEWS 3-5: SHO within 30 mins, continues to trigger: SPR within 30 mins. MEWS>5 OR MEWS 3 in a single category OR MEWS<5 but serious concern: SPR action within 30 mins – continues to trigger – home team consultant and ITU consultants called.	**FH: Primary outcome: hospital deaths** Before: 750/year (n=3,001); After: 697/year (n=2,789), a 7.1% reduction, p<0.0001. **Primary outcome: Cardiac arrest:** Before: 767/year, After: 584, p<0.0001 **Primary outcome: Admissions to the ICU:** Before: 857/year, After: 1,135/year **RVH: Primary outcome: Hospital deaths** Before: 952/year (n=3709), After: 906/year (n=3622), a 2.3% reduction. **Primary outcome: Cardiac arrest:** Before: 723 year, After: 669/year, p<0.0001, 7.5% decrease.

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Before-after observational studies					
[129]Moriarty (2014), Before (Sept 2005-Aug 2006)-after (Mar 2008-Dec 2010) observational study.	2 acute care hospitals: the Mayo Centre, Rochester, the inpatient Mayo Clinic Psychiatry and Psychology Treatment centre, USA	All inpatients discharged between Sept 1st 2005 and 31st Dec 2010. N not reported.	Critical care nurse, critical care fellow and respiratory therapist. Supervised 24/7 by an in-house attending level intensivist.	A. Any care provider may activate the RRT based on concern or physiologically-based criteria. B. Not reported.	**Primary outcome: Hospital mortality rate:** Before: 1.5%, After: 1.6% (p=0.30). **Primary outcome: Unplanned ICU admission rate:** Before: 13.7 transfers per 1,000 floor days, After: 15.2 transfers per 1,000 floor days (p<0.001)
[51]Hayani (2011), Retrospective before-after observational study	Ottawa University teaching hospital, Canada.	N=814 patients with hematopoietic stem cell transplants (HSCT), (n=520 pre-RACE team, n=294 post-RACE team).	Nurse led. A critical care nurse, respiratory therapist and medical doctor. A staff intensivist is available during 0800–1700 and a senior resident or fellow is available at night and on weekends with the support of a staff intensivist.	A. RACE calls were initiated by any HCP using specific criteria: 1) Airway Threatened, stridor, excessive secretions; 2) Breathing RR<=8/min or >=30/min; 3) Circulation systolic BP <90 or >200mmHg, or drop of >40mmHg, HR <40/min or >130/min, 4) Level of Consciousness Decreased or GCS reduced by >2 points; 5) SpO_2 <90% on 50% FiO_2, or patient requires at least 6 l/min supplemental O_2; 6) Urine output <100 c.c. over 4 h (except dialysis patients); 7) Staff 'worried', about patient, needs assistance, failure to respond to therapy. B. The RACE team responds to all urgent ward-based calls and provides follow-up care to all patients previously admitted to ICU for at least 2 days after discharge from ICU.	**Secondary outcome: Clinical deterioration in a sub-population** **Non-relapse mortality by day 100 after transplant:** Pre-RACE: 26 (10.2%); Post-RACE: 53 (8.8%), p=0.62 **Non-relapse mortality by day 100 after transplant in allogeneic recipients (non-identical donors):** Pre-RACE: 22.5% ; Post-RACE: 18.2%, p=0.25 **Admission to the ICU** Pre-RACE: 64 (12.3%);Post-RACE: 42 (14.3%), p=0.44
[39]Mullany (2016), Retrospective observational before-after study.	Prince Charles 630-bed tertiary university referral hospital, Brisbane, Australia.	N=161,153 observations from July 2008- Dec 2012. Pre-MET n=44,505 observations, post-MET n=116,648.	Nurse led. MET team: ICU nurse, ICU medical officer, general medical trainee. CAT team included: 2 clinicians and cardiology trainees.	A. MEWS**≥4** – Nurse to contact nurse unit manager for review; MEWS**≥6** – Nurse to contact nurse unit manager, nurse to contact registrar for review; MEWS **≥8** - Nurse to contact nurse unit manager and MET. B. Review within 30 mins.	**Primary outcome: All-cause hospital mortality rate**: Before: 14/1,000, After 11.8/1,000 (absolute change 2.2/1,000, 95% CI 1-3.5/1,000, p=0.003). **Primary outcome: In-hospital cardiac arrest rate**: Before 5.5/1,000, After 3.3/1,000 (absolute change 2.2/1,000, 95% CI 1.4-3, p≤0.001). **Primary outcome: Hospital LOS:** Before 5.9 days, After: 4.9 overall. **Primary outcome: unplanned ICU admission**: Before: 41 admissions, After 121 admissions However average LOS in the ICU decreased from 140 hours (before) to 95 hours (after).

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Before-after observational studies					
Massey et al (2015),[46] Retrospective before-after observational study.	480-bed Gold Coast Hospital, a tertiary teaching hospital based in Queenslan d, Australia	N=150 adult general medical ward patients admitted Jan –Mar 2008 (pre-RRS intervention) and N=150 randomly selected patients admitted between August – October 2008 (post RRS intervention – introduction of an after-hours Clinical Team Co-ordinator in July 2008)	Nurse led. The after-hours Clinical Team Co-Ordinator (CTC) service was provided by six experienced acute care nurses who supported ward nurses and other members of the multi-disciplinary team A high capability team is physician-led. The Medical Emergency Team (MET)is an example of a high capability team	A. Two-tiered RRS. The after-hours Clinical Team Co-ordinator was introduced in 2008 to provide a rapid response to assist clinicians throughout the hospital. The after-hours Clinical Team Co-ordinator was the first tier of the RRS and was activated by nursing staff in the hospital after-hours (14.00 hrs – 7.30 hrs, 7 days a week). The second tier of the hospital's RRS was the MET. The after-hours Clinical Team Co-ordinator activated the MET if a patient continued to deteriorate and required further escalation of care. The after-hours Clinical Team Co-ordinator service was provided by 6 experienced critical care nurses who supported ward nurses and other members of the multidisciplinary team after hours to respond to patient deterioration. Criteria for activation: Drop of GCS of >2; SpO_2 <90%, SBP <90mmHg, Temp >38.0 or <35.0; Urinary output <0.5ml/kg/h; RR>25 or <10; HR >110 or <50 BPM. B. Not reported.	**Secondary outcome post-hoc:** Major events (including unplanned admission to the ICU, death and cardiac arrest) Unplanned admission to the ICU: Pre: 7 (4.6%) Post: 8 (5.3%) Death: Pre: 0 (0%) Post: 6 (4.0%) Cardiac arrest: Pre: 0 (0%) Post: 4 (2.6%), p=0.01 (of major adverse event) **Secondary outcome post hoc composite outcomes:** defined as myocardial infarction, DVT, PE, cerebral vascular accident, operating theatre, adverse drug reaction, hospital accident/injury, HCAI/sepsis, other adverse event, major adverse event. Pre: 32/150 (21.3%); Post: 36/150 (24.7%), p=0.58
[63]Sabahi (2012), Prospective before-after intervention study.	300-bed private hospital, Tehran, Iran.	N=25,348 admissions before RRT (2008) and N=28,024 after (2010).	Doctor led. 1 doctor, 1 senior intensive care nurse and 1 staff nurse	A. Criteria for RRT activation displayed prominently in each ward. RRT was activated by a pager call and by a public announcement internal communication call *C Code to Ward X*. Criteria: **Airway** Respiratory Distress, Wheezing, Congestion **Breathing** RR > 24 /min, RR < 8 /min, Saturation O2 < 90% on O2, FiO_2 > 50%, **Circulation** Systolic BP < 90 mm-Hg, HR < 40/min, HR > 130/min, Significant Bleeding, **Neurologic** Changes in Consciousness Seizure, **Other** Chest Pain Uncontrolled pain, Restlessness. B. RRT initiated and completed a variety of therapeutic, investigational and procedural interventions. No specific time frame given.	**Primary outcome: In-hospital deaths:** Before: 274 (73.2%) After: 231 deaths (66.2%), Relative Risk Reduction, 16%; p=0.004. **Primary outcome: Unexpected cardiac Arrest:** Before: 431 After: 349, Relative Risk Reduction 19%; *p*=0.003.

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Before-after observational studies					
[134]Salvatierra (2014), Before-after observational study.	Ten acute tertiary care hospitals, Washington, USA.	N=235,718 31-months before RRT and N=235,344 31-months after RRT. Study period Sept 2001 – Dec 2009.	Team compositions varied between the 10 hospitals: including critical care registered nurses, respiratory therapists, ED registered nurses, and medical doctors.	A. Anyone could escalate across all 10 hospitals including staff, carer or family concerns. B. Response times of between 5 mins and 15 mins across the 10 hospitals.	**Primary outcome: In-hospital mortality:** 6/10 hospitals showed a decrease in mortality post RRT, while four hospitals did not. Overall: RR: 0.76 (0.72-0.80), p<0.001.
Sebat et al (2018),[157] prospective single-centre before-after study	Adult general nursing units at a 500-bed community regional hospital, California, USA	N=28,914 medical/surgical patients admitted during the control period consisting of 24 months (Jan 2008– Dec 2009), and N=39,802 patients admitted during the 33-month intervention period (Jan 2011, to Sept 2013).	Nurse led. In 2005 the hospital implemented a general ward conventional RRS, which consisted of the bedside nurse, a critical care trained RN (CCRN), respiratory therapist, pharmacist, and lab technician.	A. Changes in any 2 of the following activated the RRT: SBP<90, RR <6 or >20, altered LOC, pain and SpO_2 <90%, Capillary refill >3 secs, urinary output <30mL/hr or 100mL/4hr or 300 mL/12 hr; Base deficit or lactic acid >-5 meg or LA > 2.0 meq, Temp <36 degrees Celsius. Intervention changed the RRS to a 4-arm RRS including 1) afferent arm [expansion of vital signs, changes in nursing policies for escalation, mandatory education programme]; 2) Efferent arm [expansion of the RRT to include a critical care RN and standardised procedures were developed]; 3) Quality assurance arm: complete data collection and system compliance and improvement implemented; 4) Administrative arm [expanded in personnel and scope] B. Not reported.	**Primary outcome: Cardiac arrest per 1,000 discharges** Pre-intervention: 3.1 per 1,000 Post-intervention: 2.4 per 1,000, p=0.04 **Primary outcome: Unadjusted hospital mortality rate** Pre-intervention: 3.7% Post-intervention: 3.2%, p<0.001 **Secondary outcome post hoc : Resource utilisation RRT calls per 1,000 discharges** Pre-intervention: 10.2 per 1,000 Post-intervention: 48.8 per 1,000, p<0.001
[135]Segon (2014), Before-after intervention study.	367-bed community teaching hospital, USA.	N=213 RRT calls. Medical and surgical patients admitted Jan 2004 to Apr 2006.	Doctor led. An admitting senior resident in the ICU, an ICU nurse, and a respiratory therapist.	A. Criteria for activating RRT: Acute change in HR to <40 beats/min or >130 beats/min, Change in SBP <90 mm Hg, Acute change in RR <6 breaths/min or >30 breaths/min, Change in breathing pattern (regularity/depth), Acute change in pulse oximetry (<90% SpO_2 on oxygen), Acute decrease in urine output, New onset/prolonged seizures, Unexplained change in mental status, Nursing concern or Family concern regarding patient status B. No response time given. Team members carried a dedicated rapid response pager that was signed out before each shift. All activations of the rapid response were recorded in the rapid response log, which was signed by the senior resident and was collected and reviewed in monthly rapid response team meetings.	**Primary outcome: Mortality:** Pre-intervention: 3.1% (439 of 14,013) Post-intervention: 2.9% (417 of 14,333), p=0.27. **Primary outcome: Unexpected ICU transfers** Pre-intervention: 15.8% (295 of 1,866) Post-intervention: 15.5% (258 of 1,663), p=0.80. **Secondary outcome: Post-hoc: Number of code blue calls:** Pre-intervention: 3.09 per 1,000 Post-intervention: 2.89 per 1,000 discharges per year (p=0.14).

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Before-after observational studies					
Davis (2015),[124] Before-after RRT observational study. Jun 2005-2011.	2 urban university hospitals, USA.	N=546 patients with cardiopulmonary arrests. All medical-surgical patients	Nurse led. Dedicated critical care nurse and respiratory therapist. Unit charge nurse only responds in their own unit.	A. Triggered by 90 mmHg>SBP>170 mmHg or decrease >20 mmHg from baseline; 55 beats/min>HR>120 beats/min or rise >20 beats/min from baseline; Chief complaint "chest pain"; Suspected acute blood loss; 12 breaths/min>RR>28 breaths/min or rise >12 breaths/min from baseline; SpO2 <92% or increasing FiO_2; ABG obtained for respiratory concerns; $PetCO_2$ rise by 10 mmHg in 10", 20 mmHg in 20", 30 mmHg in 30"; Increased work-of-breathing; Stridor/noisy breathing; Persistent apneas >20 sec; Acute decrease in mental status/alertness; Acute agitation/confusion; Focal neurological deficit; 35°C>Temp>39.5°C; staff/family concern. B. Not reported.	**Primary: Hospital mortality** Pre: 2.1% , Post: 1.7%, p<0.001 **Primary: Cardiopulmonary arrest (non-ICU)** Pre: 2.7% , Post: 1.1%, p<0.0001 **Primary: Cardiopulmonary arrest (ICU-based)** Pre: 2.7% , Post: 1.7%, p=0.53
Joshi et al (2017),[45] Retrospective single centre before-after observational study.	400+ bed Nambour General Hospital, Australia	N=31,359 patients pre-RRS revision (July 2010 to December 2011) and N=36,489 patients post RRS revision (July 2012-December 2013)	Doctor led. Two tier RRS, divided into a pre-call response team (general medicine registrar and intensive care nurse) and for code blue events additional members(an anaesthesia registrar/emergency registrar or their consultants from the Pre-Call team and several other specialist nurses and ward persons/orderlies)	A. After RRS revision (intervention), the efferent limb was modified to a two-tiered system, divided into a 'Pre-call' (Q–ADDS call criteria met barring cardiorespiratory arrest, airway threat or altered conscious state) and 'Code Blue' (cardiorespiratory arrest, airway threat or altered conscious state) based on the Q-ADDS EWS observation chart. B. Not reported	**ICU-based admissions** **Primary outcome: median ICU LOS** Pre: 3 days (IQR 2 – 6 days); Post: 4 days (IQR 2 – 7 days), p=0.02 **Primary outcome: ICU mortality** Pre: 25/181 (13.7%) ; Post: 33/239 (13.8%), p=0.93 **Hospital admissions** **Primary outcome: unplanned ICU admissions** Pre: 5.8/1000; Post: 6.5/1000, p=0.11 **Primary outcome: Cardiorespiratory arrests** Pre: 1.0/1000; Post: 0.7/1000, p=0.09 **Primary outcome: Overall hospital mortality** Pre: 1.56% (1.43%, 1.69%); Post: 1.74% (1.60%, 1.89%), p=0.055 **Primary outcome: Overall hospital LOS** Pre: 5.65 days; Post: 4.93 days, p<0.001 **Secondary outcome, post hoc: resource utilisation: RRS calls per 1000 admissions** Pre: 48/1000; Post: 11/1000, p<0.001

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes	
Uncontrolled Before-after observational studies						
[53]Scherr (2012), Before-after observational study.	267-bed community general hospital (A) and 259-bed community general hospital (B). Canada	N=255 adults with a RRT call in both hospitals. Included medical, surgical and small sample of obstetric and paediatric patients.	Nurse led. RRT in both hospitals was to include a NP, an ICU RN, and a respiratory therapist. In cases where the NP was absent a clinical associate physician or intensivist was to respond to RRT calls. ICU attending physicians were always available for consultation.	A. Hospital A RRT operated 24 hrs a day whilst Hospital B RRT operated 12 hrs a day. Triggers for RRT call included: change in level of consciousness, breathing issues, blood pressure issues, worried about patient as condition deterioration noted, heart rate issues, and airway concerns B. No response time reported or action plan.	**Hospital A: Primary outcome: CPA:** Before: 2.52 per 1,000, After: 1.68 per 1,000, p=0.39 **Primary outcome: Unplanned ICU admissions:** Before: 6.52 per 1,000, After: 6.13 per 1,000, p=0.21. **Primary outcome: Hospital mortality:** Before: 37.83 per 1,000, After: 41.74 per 1,000, p=0.17.	**Hospital B: Primary outcome: CPA:** Before: 2.7 per 1,000 discharges, After: 2.6 per 1,000, p=0.84 **Primary outcome: Unplanned ICU admissions:** Before: 10.9 per 1,000, After: 7.12 per 1,000, p=0.10. **Primary outcome: Hospital mortality:** Before: 29.43 per 1,000, After: 24.95 per 1,000, p=0.06.
[81]Simmes (2012), Retrospective before-after observational study.	University hospital, The Netherlands.	N=1,376 (before 2-tier MET, Jan to Dec 2006) and n=2,410 (after 2-tier MET, Apr 2007 – Apr 2009), general surgery patients.	Physician-led team including a critical care physician and a critical care nurse and was accessible 24/7.	A. The RRS included a 2-tiered MET calling protocol. In the 1st tier, nurses had to call the ward physician immediately if one of the EWS criteria was met: RR<8 or >30 per minute, SpO_2<90%, SBP<90 or >200 mmHg, HR<40 or >130 per minute, a decrease of 2 points in the eye, motor, verbal (EMV) score or if the nurse felt worried about the patient's condition. B. The ward physician had to evaluate the patient at the bedside within 10 min. In the second tier the ward physicians activated the MET immediately if a serious situation existed or if the patient did not stabilize after an initial intervention.	**Primary outcome: Unexpected deaths**: Before: 0.36% (5/1,376), After: 0.17% (4/2,410), OR 0.42, 95% CI 0.11-1.59. **Primary outcome: Cardiac arrest:** Before: 0.29% (4/1,367), After: 0.12% (3/2,410), OR 0.38, 95% CI 0.09-1.73. **Primary outcome: Unplanned ICU admissions:** Before: 2.47% (34/1,376), After: 4.15% (100/2,410), OR 1.66, 95% CI 1.07-2.55.	

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Before-after observational studies					
[82]Simmes (2013), Prospective before-after observational study	University hospital, The Netherlands	A convenience sample of 518 of 1,376 eligible patients (before MET) was screened for participation and 2,549 of 2,410 patients (after MET). Surgical patients.	The MET included a critical care physician and a critical care nurse. The RRS system was introduced in Jan 2007 and was fully operational by Apr 2007. The system required ward nurses to systematically observe and record patient's vital signs at least three times daily.	A. If nurses felt worried about a patient's condition or observed abnormal vital indicators, and then they were instructed to immediately call the ward physician. Abnormal vital indicators included RR<8 or >30 per minute, SpO_2 <90%, SBP<90 or >200 mm Hg, HR<40 or >130 per minute, and a decrease of 2 points in the eye, motor, and verbal (EMV) score, GCS. B. Once called, the ward physician was required to evaluate the patient at bedside within 10 mins and to immediately call the MET if the patient's condition was serious or if the patient did not stabilise after an initial intervention.	**Secondary outcome: PROMS:** Health-related quality of life (HRQOL) which was measured using the EuroQol 5 dimensions (EQ-5D) and EuroQol visual analogue scale (EQ-VAS) questionnaires. **EQ-5D index** 0.72 versus 0.73, p=0.54 at 3 months following surgery, 0.70 versus 0.72, p=0.29 at 6 months following surgery. **EQ-VAS mean scores** 67 versus 65, p=0.28 at 3 months following surgery 67 versus 67, p=0.80 at 6 months following surgery.

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes	
Uncontrolled Observational cohort studies						
[52]Karvellas (2011), Retrospective cohort study.	University of Alberta Hospital, Canada.	N=1,920 patient admissions between Jul 2002 – Dec 2009 to the ICU.	Intensivist-led (IL) MET implemented Feb 2007, 8am-4pm, Monday-Friday. Outside of these hours, the 24hr non-IL-MET team was led by the resident, nurse or respiratory therapist, who consulted the on-call consultant intensivist.	A. Any HCP could activate MET. Calling criteria included: acute change to RR (<8 or >36 breaths/min), acute change in SpO_2 <90%, HR (<40, >140 beats/min), systolic BP <90 mmHg, change in level of consciousness, staff concern. B. Response expected within 15 mins. MET performs a rapid assessment, orders appropriate diagnostic tests and initiates treatment as necessary. Within 30 mins a decision is to be made on whether the patient should be transferred to ICU or safely managed on the ward.	**Primary outcome: In-hospital mortality:** Period 1 – CONTROL- NO MET TEAM (N=479) Non-IL-MET hours: n=104 (30.9%)IL-MET hours: 44 (30.8%), p=0.97. Period 2 – PARTIAL MET TEAM (N=640) Non-IL-MET hours: n=143 (31.4%) IL-MET hours: N=64 (34.6%), p=0.44. Period 3 – HOSPITAL WIDE IL MET TEAM (N=801) Non-IL-MET hours: n=195 (35.9%) IL-MET hours: N=78 (30.1%), p=0.10. Comparison between Period 1 and 3: p=0.24 **Primary outcome: ICU-LOS** Period 1 – CONTROL- NO MET TEAM (N=479) Non-IL-MET hours: 5 (2-10 days) IL-MET hours: 5 (2-9 days), p=0.92. Period 2 PARTIAL MET TEAM (N=640) Non-IL-MET hours: 5 (2-9 days) IL-MET hours: 5 (3-10 days), p=0.44. Period 3 HOSPITAL WIDE IL-MET TEAM (N=801) Non-IL-MET hours: 5 (2-11 days) IL-MET hours: 5 (3-9 days), p=0.87. Comparison between Period 1 and 3: p=0.20	**Primary outcome: Hospital-LOS:** Period 1 – CONTROL- NO MET TEAM (N=479) Non-IL-MET hours: 25 (13-47 days) IL-MET hours: 26 (13-54 days), p=0.53. Period 2 PARTIAL MET TEAM (N=640) Non-IL-MET hours: 25 (14-51 days) IL-MET hours: 28 (14-52 days), p=0.43. Period 3 HOSPITAL WIDE IL-MET TEAM (N=801) Non-IL-MET hours: 28 (14-55 days) IL-MET hours: 29 (15-55 days), p=0.53. Comparison between Period 1 and 3: p=0.06

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Observational cohort studies					
[127]Kollef (2017), Retrospective observational cohort study.	Barnes-Jewish Hospital, a 1250-bed academic hospital, Missouri, USA.	N=163,311 consecutive patients admitted to 8 adult general wards.	Nurse led. A registered nurse, a 2nd or 3rd-year internal medicine resident, and a respiratory therapist. Prior to 2011, the RRS nurse was pulled from the staff of one of the hospital's ICUs in a rotating manner to respond to RRS calls as they occurred. Starting in 2012, the RRS team nurse member was established as a dedicated position without other clinical responsibilities.	A. RRS activations between 2006 and 2008 were initiated by the nursing staff on the general medicine units as part of routine nursing practice. Starting in 2009, RRS activations could be initiated by the nursing staff as well as by real-time clinical deterioration alerts (RTCDAs). B. The RRS nurse carries a hospital-issued mobile phone to which the RTCDAs were sent and was instructed to respond to all alerts within 20 mins of their receipt. The RRS nurse would initially evaluate the alerted patient using the MEWS and make further clinical and triage decisions based on those criteria and discussions with the RRS physician or the patient's treating physicians.	**Primary outcome: Hospital mortality**: Before (2003): 2.87 per 1,000, After (2014): 2.22 per 1,000. Year-to-year decrease from 2003-2014, (p=0.002). **Primary outcome: Cardiopulmonary arrests (CPAs)**: Before (2005): 57, After (2014): 35. Year-to-year decrease from **2005-2014, (p=0.006). **Primary outcome: Hospital LOS**: 2003 Median LOS: 3.79 days (IQR 2.02, 6.81), 2014 Median LOS: 3.10 days (IQR1.75, 5.82). Year-to-year decrease from 2003-2014, (p=0.001). **Secondary outcomes: post-hoc**: **RRS activations:** Activations 2006: n=72, Activations 2014: n=370. Significant increase year on year (r=0.939, p<0.001).
[130]Moroseos (2014), Retrospective cohort using historical controls study design.	413-bed county teaching hospital, USA.	N=7,092 admissions before RRT (Jan 2000-Dec 2004) and N=9,357 admissions after (Jan 2007-Dec 2011), Burn surgery/acute care ward.	Nurse led. The RRT system comprises primary and secondary response teams. The primary response consists of a designated STAT or ICU nurse along with the charge respiratory therapist. The secondary response team includes a medical ICU fellow from 7:30 am until 5:30 pm and a medical ICU R3 at other times of the day, 7 days a week	A. A patient may exhibit one or more of the clinical symptoms to qualify for RRT activation. When a nurse or a patient's family member was concerned about the condition of a patient or felt that a patient needs immediate intervention secondary to the presence of early warning signs, they could call the RRT by dialling the STAT page operator. Criteria included: Airway: Stridor—noisy airway; Breathing: RR: <12 or >32, Increased effort to breathe; O2: sat <92 with increased O2 Requirements; ABG orders for respiratory concerns; Chest pain; Circulation: HR <55 or >120; SBP <90 or >170 Transfusion >4U PRBC in last 24 hr; Decrease in HCT by more than 6 points in last 24 hr; Temp change <35 or >39.5°C; Conscious state Agitation, restlessness; B. The patient's primary team is notified simultaneously and the RRT members concurrently gather at the patient's bedside.	**Primary outcome: Mortality: Total Deaths per 1,000 admissions** Before RRT: 4.5, After RRT: 3.3 p=0.11 **Primary outcomes: unplanned ICU transfers**: Before RRT: 52 per 1,000, After RRT: 42 per 1,000, p=0.01. **Secondary outcome post-hoc: Code blue activations** (defined as respiratory arrest or cardiopulmonary arrest requiring tracheal intubation and/or chest compressions). Code Blue Activations: Before RRT: 10 per 1,000 admissions, After RRT: 4 per 1,000 admissions p=0.04

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Observational cohort studies					
[96]Morris (2013), UK, Retrospective observational cohort study.	A 457-bed district general hospital and 688-bed University College Hospital, London, UK.	N=146 patients seen by the RRT in the medical and surgical wards of the hospitals (Jan – Mar 2010)	Nurse led. Wrexham hospital: consists of 2 groups of specialist nurses: critical care outreach nurses working closely with the CCU from 07.30 to 21.00 Monday-Friday; and a group of advanced nurse practitioners who form part of the hospital night team. London Hospital: operated 24-7, led by a nurse consultant and included 9 critical care outreach nurses.	A. MEWS score of 3 or more referral to RRT was made according to protocol. B. Not reported.	**Secondary post-hoc outcome: Objective patient-related positive and negative outcomes**: Positive outcomes (i) timely ICU admission (i.e. <4 h); (ii) alive on ward and no longer triggering, (iii) died with terminal care pathway and had DNAR; (iv) alive with DNAR and documented treatment limitations, (v) other (new unrelated RRT trigger, chronic condition leading to continuous trigger, discharged). **Day 1 post-RRT (n=146):** N=109 (75%) of patients had a positive outcome. 69% of patients with MEWS ≥5 had positive outcomes **Day 3 post-RRT (n=86):** 90% (n=77) of patients had a positive outcome **Day 7 post-RRT (n=67):** 88% (n=59) of patients had a positive outcome **Negative outcomes:** (i) delayed ICU admission (i.e. >4 h); (ii) still triggering, (iii) cardiopulmonary arrest; (iv) Outcome unknown or lost to follow-up **Day 1 post-RRT (n=146):** 15.8% (n=23) on wards still triggering MEWS after 24 h. 0.7% (n=1) had a cardiopulmonary arrest. **Day 3 post-RRT (n=86):** 10% (n=9) on wards still triggering MEWS after 24 h. **Day 7 post-RRT (n=67):** 1.5% (n=1) had a cardiopulmonary arrest. 10.5% (n=9) on wards still triggering MEWS after 24 h.
[98]Pattison (2012), Single centre, cohort study.	Single hospital, UK.	N=407 episodes of CCOT referral for 318 cancer patients over an 8-month period.	Nurse led. CCOT included 8 nurses (no other details).	A. A MEWS score >3 would have triggered, or physiological deterioration outside MEWS including documented oxygen saturation (SaO≤90% and ≥35% which was the trigger figure for referral in the trust to CCOT). B. Not reported.	**Secondary outcome: clinical deterioration in a sub-population** **Mortality:** 3- and 6-month mortality associated with a higher MEWS (>3) at referral (p=0.02, p=0.01). Additionally there was a trend towards a higher MEWS at deterioration with 3 month mortality data, significant with 6-month data, (p=0.08, p=0.01). **Mean MEWS at referral (>3)** 3.76 (95% CI 3.49-3.99) **Mean MEWS at deterioration (>3):** 3.96 (95% CI 3.67-4.18)P<0.001. Untimely referrals were associated with lower survival to discharge (p=0.004) and 3 and 6 month mortality (p=0.004, p=0.03).

Table 8.1 Studies of the impact of emergency response system interventions on patient outcomes and resource utilisation [continued]

Author, Study design	Setting, Country	Sample size, Type of patient	RRT composition	A. Escalation B. Response time	Outcomes
Uncontrolled Observational cohort studies					
[136]Shah (2011), Retrospective cohort study.	2 Texan hospitals, USA. Pre-intervention: Jan 2005-Sept 2005; Post intervention-Apr 2006-Dec 2006; Post intervention2 :Jan 2007 – Sept 2007; Post intervention: Oct 2007-Jun 2008	N=231,305 patient days (70,208 pre, 161,097 post), N=16,244 admissions (pre), N=41,145 (post).	Nurse led. Code team is composed of three senior internal medicine residents, an anaesthesiology resident, 2 critical care nurses, and a respiratory therapist. It provides 24-h/7-d assistance for patients with CPA. After reviewing the composition of RRS at different hospitals reported in the literature, the Committee formalised an RRT composed of an experienced critical care nurse and a respiratory therapist.	A. The trigger points for activation were similar to those reported in the literature: RR >24/min, SpO_2 <90%, HR>130/min, SBP<90 mmHg, change in mental status, or a concerned staff member, increase in FiO_2 >50% or threatened airway. Staff members on all inpatient facilities were educated on the triggers for RRT activation. B. Not reported.	**Primary outcome: Overall hospital mortality:** Pre-intervention: 2.4% Post intervention1: 2.06% Post intervention2: 1.94% Post intervention3: 2.46% Total post-intervention: 2.15%, p=0.05 **Secondary outcome: Post-hoc: Codes/1,000 patient days** Pre-intervention: 0.83 per 1,000 Post intervention1: 0.97 Post intervention2: 1.07 Post intervention3: 0.89 Total post-intervention: 0.98, p=0.30
[117]Albert (2011), Retrospective observational cohort QIP study	2 telemetry units, tertiary teaching hospital, USA	N=140 patients with code blue or RRT calls.	Nurse-led RRT including intensive care unit (ICU) resident, the medical ICU (MICU) charge nurse, and the respiratory therapist.	A. An electronic MEWS score of 3 or more was the trigger for action by nursing staff for referral to the RRT. B. Not reported but once reviewed, re-assess within 4 hours again.	**Secondary outcome: post hoc**: **Number of code blue calls and RRT calls**: 33% reduction in code blue calls 6-months after MEWS and RRT and 50% increase in RRT calls.

Key: ABG: Arterial blood gas; **AVPU**: Alert, voice, pain, unresponsive; **CAT**: Cardiac Arrest Team; **CCOS/T**: Critical care outreach service/team; **CCU**: Critical care Unit; **CPA**: Cardio pulmonary arrest; **CPR**: Cardiopulmonary resuscitation; **CRA**: Cardio-respiratory arrest; **DNR**: Do not resuscitate; **ED**: Emergency Department; **EMR**: Electronic medical record; **EMV**: Eye, Motor, Verbal; **FiO_2**: Inspired oxygen; **GCS**: Glasgow coma scale; **HCP**: Healthcare professional; **HDU**: High dependency unit; **HR**: Heart rate; **HRQOL**: Health-Related Quality of Life; **ICU**: Intensive care unit; **IL**: Intensivist-led; **LOS**: Length of stay; **MEWS**: modified early warning score; **MET**: Medical emergency team; **MICU**: medical ICU; **NP**: Nurse practitioner; **PRBC**: Packed red blood cells; **PROMS**: Patient Reported Outcome Measures; **QIP**: Quality improvement project; **RACE**: Rapid assessment clinical evaluation; **RN**: Registered Nurse; **RR**: Respiratory rate; **RR**: Relative risk; **RRT/S:** Rapid response team/system; **RTCDA**: Real-time clinical deterioration alerts; **SAE**: Serious adverse event; **SBAR**: Situation, background, assessment, response; **SBP**: Systolic blood pressure; **SpO_2**: Oxygen saturation; **SPR**: Specialist Registrar; **VAS**: Visual analogue scale; **WTE**: Whole Time Equivalent

8.6 Methodological quality

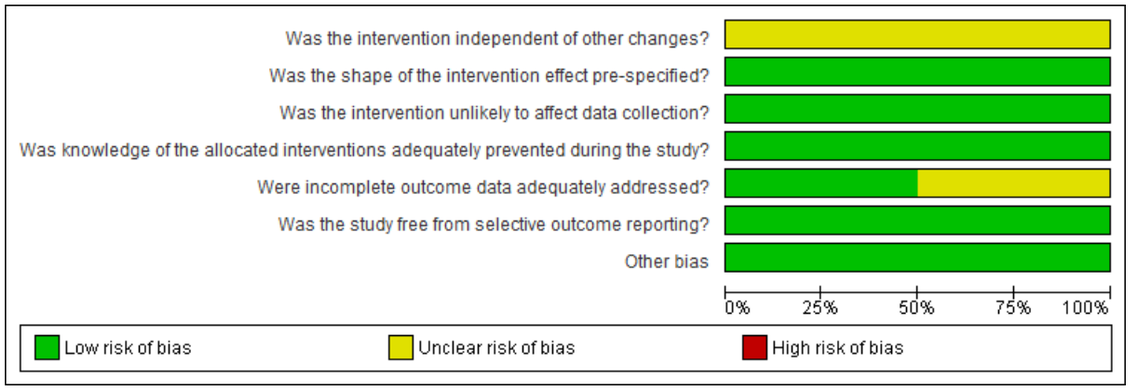
A number of different study designs were included (interrupted time series and before-after observational studies) in this chapter of the systematic review and therefore the methodological quality was appraised using different tools. The quality of included studies is presented according to the different study designs.

8.6.1 Interrupted time series studies

The Cochrane Effective Practice and Organisation of Care (EPOC) tool was used to assess methodological quality of the two interrupted time series (ITS) studies[115, 133] assessing seven risk of bias domains.

The two ITS studies included were deemed to have a low risk of bias overall (in six out of the seven domains), (**Figure *8.1***).[115, 133]

Figure 8.1 Risk of bias summary for ITS studies of EWS interventions and deterioration in adults in acute health care settings



Intervention independent of other changes

Both studies were classified as having an unclear risk of bias in relation to the intervention being independent of other changes.[115, 133] Rothberg et al.[133] acknowledged that it was an observational study and cannot account for other confounders relating to temporal trends in the hospital. However, their long time window of time allowed them to examine trends

over several years and for two years prior to implementation of the MET, there was no decline at all in the rate of code calls, followed by an immediate and sustained drop after implementation. However, other interventions, including ventilator-associated pneumonia bundles, sepsis bundles, and advanced cardiac life support simulation training were also implemented at different times during the study period. Howell et al. [115] stated that there were likely to be unmeasured confounders that influence the risk of death. For example, other patient safety programs undoubtedly contributed to the effect, as confirmed by time-related mortality reductions independent of the intervention. The attempt to control for time trends and other confounders through multivariable methods, and their results suggest an independent effect of the intervention (**Figure *8.2***).

Intervention unlikely to affect data collection

Both studies had a low risk of bias as the intervention was unlikely to affect data collection. Howell et al.[115] used a hospital administrative database and Rothberg et al.[133] used forms which were routinely completed by the nurses after a MET event before and after the intervention was implemented (**Figure *8.2***).

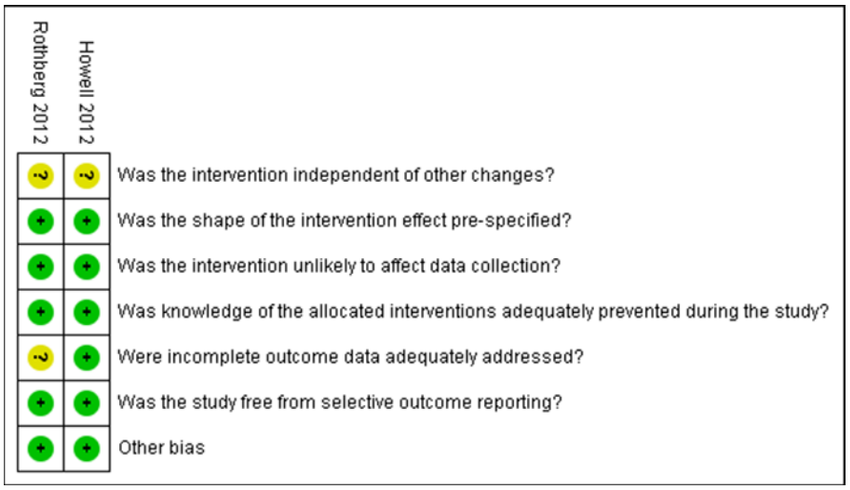
Knowledge of the allocated interventions adequately prevented (blinding)

Both studies had a low risk of bias (even though they were not blinded or randomised) as objective outcome measures such as mortality were used (**Figure *8.2***).[115, 133]

Incomplete outcome data (attrition)

One study had a low risk of bias as all participants were accounted for.[115] The other study made no clear statement of follow-up or missing data and provided no study flow diagram (**Figure *8.2***).[133]

Figure 8.2 Risk of bias graph for included ITS studies of EWS interventions and deterioration in adults in acute health care settings



8.6.2 Before-after studies

The Newcastle Ottawa Scale quality appraisal tool[26] was used for the 23 before-and-after observational studies and the seven observational cohort studies. We rated the quality of the studies (good, fair and poor) by awarding stars in each domain following the guidelines of the Newcastle–Ottawa Scale as described in ***section 2.4.3***.

There were 23 before-after observational studies and seven observational cohort studies.[38, 39, 45, 46, 50-53, 62, 63, 71, 72, 80-82, 95, 96, 98, 117, 119, 124, 125, 127-130, 134-136] Of these, 17 studies were considered 'good quality' overall and received six, seven or eight stars across the different domains of selection, comparability and outcome.[45, 50-52, 62, 63, 71, 72, 80, 95, 119, 125, 127, 129, 130, 134, 136] Three studies were considered 'fair quality' overall and received five stars again across the different domains of selection, comparability and outcome.[38, 53, 81] Ten studies were rated as 'poor quality' overall receiving four or less stars across the domains of selection, comparability and outcome.[39, 46, 82, 96, 98, 117, 124, 128, 135, 157]

Table 8.2 Quality Assessment of before- after observational studies and cohort studies

Study	Selection				Comparability		Outcome			Overall Quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts in analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
Al-Qahanti (2013)[71]	*	*	*	Statement confirming 'no history of CA or ICU admission/ transfer' not provided	*	*	*	*	Prospective data collection but no statement re follow-up	7 stars (GOOD QUALITY)
Albert (2011)[117]	N=150 consecutive inpatients from a single centre	*	*	No. of code blue calls in QIP study	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	6 month duration.	No statement, retrospective review	3 stars (POOR QUALITY)
Beitler (2011)[119]	*	*	*	Statement of 'no history of CA' was not provided	*	*	*	*	No statement of follow-up, retrospective review of patient charts	7 stars (GOOD QUALITY)
Davis (2015)[124]	N=100 patients with CPA in two hospitals	N=147 patients with CPA	*	Included CPA patients only cannot state there was no history of outcome	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	*	No statement of follow-up, retrospective before & after study	3 stars (POOR QUALITY)
Gonçales (2012)[50]	*	*	*	Statement of 'no history of CA' was not provided	*	*	*	*	No statement of follow-up, retrospective review of patient charts	7 stars (GOOD QUALITY)
Hayani (2011)[51]	N=294 transplant recipients, 3 years post-RACE, single centre	*	*	*	*	Does not control for additional factors in analysis phase	*	*	No statement, retrospective review	6 stars (GOOD QUALITY)
Jung et al (2016)[62]	*	Differences in control hospitals e.g. case mix, etc.	*	Statement of 'no history of CA or ICU admission' was not provided	*	*	*	*	No statement of follow-up or flow diagram provided	6 stars (GOOD QUALITY)

Table 8.2 Quality Assessment of before- after observational studies and cohort studies [continued]

Study	Selection				Comparability			Outcome		Overall Quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts in analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
Kansal (2012)[38]	*	*	*	Statement of 'no history of CA or ICU transfer/ admission ' was not provided	*	Does not control for additional factors.	*	5 months before & after RRT	No statement of follow-up, retrospective review of patient charts	5 stars (FAIR QUALITY)
Karpman (2013)[125]	*	*	*	*	*	Does not control for additional factors	*	*	No statement of follow-up, retrospective review of patient charts	7 stars (GOOD QUALITY)
Karvellas (2011)[52]	*	*	*	*	*	Does not control for additional factors	*	*	No statement of follow-up, retrospective review of patient charts	7 stars (GOOD QUALITY
Kim (2017)[72]	*	*	*	Statement of 'no history of ICU transfer/ admission ' was not provided	*	*	*	*	No statement of follow-up, retrospective review of patient charts	7 stars (GOOD QUALITY)
Kollef (2017)[127]	*	*	*	Statement of 'no history of CA' was not provided	*	*	*	*	No statement of follow-up, retrospective review of patient charts	7 stars (GOOD QUALITY)
Ludikhuize (2015)[80]	*	*	*	Statement confirming 'no history of CA or ICU admission/ transfer' not provided	*	*	*	5 months post RRT	*	7 stars (GOOD QUALITY)
Mathukia (2015)[128]	No details provided	No details provided	*	Statement of 'no history of CA or ICU transfer/ admission ' was not provided	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	*	No statement on follow-up. QIP project	3 stars (POOR QUALITY)

Table 8.2 Quality Assessment of before- after observational studies and cohort studies [continued]

Study	Selection				Comparability			Outcome		Overall Quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts in analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
Moon (2011)[95]	*	*	*	Statement of 'no history of CA or ICU transfer/ admission ' was not provided	*	Does not control for additional factors in analysis phase	*	*	Retrospective analysis	6 stars (GOOD QUALITY)
Moriarty (2014)[129]	*	*	*	Statement of 'no history of ICU transfer/ admission ' was not provided	*	Does not control for additional factors in analysis phase	*	*	Retrospective analysis	6 stars (GOOD QUALITY)
Moroseos (2014)[130]	*	*	*	Statement of 'no history of ICU transfer/ admission ' was not provided	*	*	*	*	No statement on follow-up, retrospective review	7 stars (GOOD QUALITY)
Morris (2013)[96]	Snapshot audit of 146 patients	*	*	Composite of positive and negative outcomes	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	7 days for outcome, study 10 weeks	*	4 stars (POOR QUALITY)
Mullany (2016)[39]	*	Massive expansion in hospital post-intervention.	*	Statement of 'no history of CA or ICU transfer/ admission ' was not provided	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	*	No statement of follow-up, retrospective review of patient charts	4 stars (POOR QUALITY)
Pattison (2012)[98]	Small sample of cancer patients, single hospital	No description.	*	*	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	Study 8 months in duration.	*	4 stars (POOR QUALITY)
Sabahi (2012)[63]	*	*	*	Statement confirming 'no history of CA' not provided	*	Does not control for additional factors in analysis phase	*	*	*	7 stars (GOOD QUALITY)

Table 8.2 Quality Assessment of before- after observational studies and cohort studies [continued]

Study	Selection				Comparability			Outcome		Overall Quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts in analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
Salvatierra (2014)[134]	*	*	*	*	*	*	*	*	No statement, retrospective review	8 stars (GOOD QUALITY)
Scherr (2012)[53]	*	N=255 patients from 2 Canadian hospitals	*	Statement of 'no history of CA or ICU transfer/ admission ' was not provided	*	Does not control for additional factors in analysis phase	*	*	No statement, retrospective review – missing data an issue	5 stars (FAIR QUALITY)
Sebat et al (2018)[157]	*	*	No description provided	Statement of 'no history of CA' was not provided	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	No description provided	*	Prospective study however no statement or flow diagram provided	3 stars (POOR QUALITY)
Segon (2014)[135]	N=213 RRT calls	N=213 RRT calls	*	Statement confirming 'no history of ICU admission/ transfer' not provided	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	*	No statement of follow-up, retrospective chart review	3 stars (POOR QUALITY)
Shah (2011)[136]	*	*	*	*	*	Does not control for additional factors in analysis phase	*	*	No statement on follow-up, retrospective review	7 stars (GOOD QUALITY)
Simmes (2012)[81]	*	Different time period and difference in age and gender	*	Statement of 'no history of CA or ICU transfer/ admission ' was not provided	*	Does not control for additional factors in analysis phase	*	*	No statement of follow-up, retrospective before & after study	5 stars (FAIR QUALITY)
Simmes (2013)[82]	Select group of surgical patients	Select group of surgical patients	*	HRQOL	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	Self-reported HRQOL (validated tools)	*	*	3 stars (POOR QUALITY)

Table 8.2 Quality Assessment of before- after observational studies and cohort studies [continued]

Study	Selection				Comparability			Outcome		Overall Quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts in analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
Massey et al (2015)[46]	N=150 consecutive inpatients from a single centre	*	*	Statement of 'no history of CA, etc.' was not provided	Does not control for additional factors in design phase	Does not control for additional factors in analysis phase	*	3 month duration	No statement, retrospective review	3 stars (POOR QUALITY)
Joshi et al (2017)[45]	*	*	*	Statement of 'no history of ICU admission or CA' was not provided	*	Does not control for additional factors in analysis phase	*	*	No statement, retrospective review	6 stars (GOOD QUALITY)

Key: CA: Cardiac Arrest; **HRQOL**: Health Rrelated Quality of Life; **ICU**: Intensive Care Unit.

8.7 Certainty of the evidence

We assessed the overall certainty of the evidence where appropriate for question 2 of the review (*How effective are the emergency response systems in terms of improving key patient outcomes in adult (non-pregnant) patients in acute healthcare setting?*). A narrative summary of findings table was created using GRADEpro software for the following primary outcomes: Mortality, cardiac arrest, LOS, and transfer or admission to the ICU.

Overall, the certainty of the evidence is 'very low' owing to a high risk of bias in the various study designs, a high risk of confounding in the observational studies, imprecision and inconsistency in the results probably owing to the heterogeneous nature of the EWS interventions applied as well as the variety of single centre settings in various countries where the findings may not be applicable to other health care settings (**Table *8.2***).

Table 8.2 Summary of findings table for key outcomes in the effectiveness of emergency response systems

Emergency response systems compared to usual care/ other emergency response systems for physiological deterioration

Patient or population: physiological deterioration
Setting: Acute healthcare settings
Intervention: emergency response systems
Comparison: usual care/ other emergency response systems

Outcomes	Impact	№ of participants (studies)	Certainty of the evidence (GRADE)
Mortality	Mortality was reported in a variety of different ways in the included studies. In addition, the intervention (emergency response systems) also varied in terms of team compositions, triggers for escalation, response times and operating times (full-time or part-time). 14/25 studies included showed a significant effect on mortality after the emergency response system was introduced (13/14 showed a significant reduction in mortality and 1/14 showed a significant increase in mortality). In total, 11/25 studies included showed no reduction in mortality after the emergency response system was introduced.	2,617,122 (26 studies including 24 before-after observational studies, 2 interrupted-time series studies)	⨁◯◯◯ VERY LOW [a,b,c,d]
Cardiac arrest	Cardiac arrest was reported in a variety of different ways in the included studies. In addition, the intervention (emergency response systems) also varied in terms of team compositions, triggers for escalation, response times and operating times (full-time or part-time). 12/18 studies showed a significant reduction in cardiac arrest rates after the emergency response system was introduced, while 6/18 studies reported no reduction in cardiac arrests.	1,878,003 (18 studies including 17 before-after observational studies and 1 interrupted-time series study)	⨁◯◯◯ VERY LOW [a,b,c,d]
Length of stay (LOS)	LOS was included in 7 studies (as ICU-LOS or hospital LOS). 4/7 studies found no reduction in the mean or median LOS, while 3/7 studies reported a significant reduction in LOS after the emergency response system was introduced.	576,504 (7 before-after observational studies)	⨁◯◯◯ VERY LOW [b,c,d]
Transfer or admission to the ICU	In 14 studies the effect of emergency response systems on ICU transfer or ICU admission was examined. Five of these 14 studies reported a significant effect on the outcome (2/5 studies showed a significant reduction in ICU transfer or admission rates and 3/5 studies showed a significant increase in ICU transfer or admission rates). Nine out of the 14 studies reported no significant effect on ICU admission or transfer rates.	1,284,311 (14 before-after observational studies)	⨁◯◯◯ VERY LOW [a,b,c,d]

*__The risk in the intervention group__ (and its 95% confidence interval) is based on the assumed risk in the comparison group and the **relative effect** of the intervention (and its 95% CI).
CI: Confidence interval

Emergency response systems compared to usual care/ other emergency response systems for physiological deterioration

Patient or population: physiological deterioration
Setting: Acute healthcare settings
Intervention: emergency response systems
Comparison: usual care/ other emergency response systems

Outcomes	Impact	№ of participants (studies)	Certainty of the evidence (GRADE)

GRADE Working Group grades of evidence
High certainty: We are very confident that the true effect lies close to that of the estimate of the effect
Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

Explanations
a. High risk of bias in the nRCTs
b. Observational studies (retrospective cohort studies, before-after observational studies) - risk of bias and confounding
c. Inconsistency due to the heterogeneous study designs and systems included (three-level interrupted time series, multilevel and difference-in-means regressions included
d. Imprecision relating small sample sizes including the possibility of a small or no effect

8.8 Discussion

There were 32 studies included in this part of the review investigating the effectiveness of emergency response systems (efferent limb) on patient outcomes and resource utilisation.

The evidence from the review is inconclusive with very low certainty due to the very low methodological quality of the studies included. Twenty-six studies including 2,617,122 patients investigated the effect of various emergency response systems on mortality. Thirteen out of the 26 studies showed a significant effect on mortality after the emergency response system was introduced (12/13 showed a reduction and 1/13 showed an increase in mortality). However, 13 studies showed no change in mortality rates as a result of the emergency response system. Eighteen studies including 1,878,003 patients examined the effectiveness of emergency response systems on cardiac arrest. Twelve out the 18 studies showed a significant reduction in cardiac arrests while six studies showed no change as a result of the emergency response systems. LOS was included in seven studies with a total of 576,504 patients. Four out seven studies found no reduction in the LOS and three reported a significant reduction in mean or median LOS as a result of the emergency response system. Fourteen studies including 1,284,311 patients examined the effectiveness of emergency response systems on ICU transfer or admission. Five studies showed a significant effect on ICU transfers or admissions (two showed a reduction and three showed an

increase in ICU transfers or admissions). The certainty of the evidence overall was deemed to be very low across all the studies.

The lack of high quality evidence to evaluate the effect of EWS interventions on patient outcomes is due to a number of factors. These include a wide variation in the EWS interventions used (for example for the emergency response systems interventions the team composition varied, the parameters to activate the emergency response team varied and the operating times varied from study to study); the definition of the outcomes varied across studies (for example mortality, which was reported as simply 'death', in-hospital mortality, unexpected death and mortality at three months); the population included varied and there were small sample sizes and low event rates in some studies. All of these add significant heterogeneity to the review findings and as a result a meta-analysis was not possible.

Future research is needed to address limitations highlighted in this review. Ideally study designs of a more rigorous methodological quality are needed, preferably RCTs. A standardised approach to the EWS interventions used and the outcomes included are warranted.

8.9 Conclusion

The evidence from the studies which look at EWS interventions in terms of emergency response systems and their effect on improving the detection and management of physiological deterioration in adult patients in acute settings is of poor quality overall. The findings are contrasting owing to the heterogeneous nature of the interventions included and the very low methodological quality of the study designs included.

9 Results: Effectiveness of EWS educational interventions for the identification of physiological deterioration in adult (non-pregnant) patients in acute health care settings (Q3)

9.1 Chapter overview

This chapter in the systematic review update focusses on the literature pertinent to question 3 of the review, "*What education programmes have been established to train HCPs relating to the implementation of EWSs or track and trigger systems for the detection of or timely identification of physiological deterioration in adult (non-pregnant) patients in acute health care settings?*". The characteristics of included studies are described as well as the findings from each study for the effectiveness of EWS educational intervention on the *a priori* defined primary and secondary outcomes as well as any post-hoc identified outcomes. The methodological quality is discussed according to the various study designs and a summary of the evidence for the primary outcomes is presented in a summary of findings table where appropriate.

9.2 Characteristics of included studies

This systematic review is an update of previous work by a team based in UCC[2] who published their findings in 2017 on the effectiveness of educational interventions for the identification of physiological deterioration in adult patients in acute health care settings.[163] The team's systematic search of the literature was until November 2015 and resulted in 10 studies eligible for inclusion.[164-173]

Our systematic review update included 9 of these 10 studies (excluding the study by Kyriacos et al.,[165] as it was conducted in South Africa which is not a very high or high HDI country), and identified a further 14 studies. This resulted in a total of 23 studies eligible for inclusion.

The studies were conducted in Australia,[39, 164, 174, 175] Belgium,[48] the USA,[157, 168, 171, 172, 176] Singapore,[166, 167, 177-181] the Netherlands,[169] France,[62] and the UK.[170, 173, 182, 183] These

included seven RCTs,[166-168, 177-180] one non randomised control trial,[169] fourteen before-and-after studies,[39, 48, 62, 157, 164, 170-174, 176, 181, 183, 184] and one interrupted time series study.[164, 175] The majority of the 23 studies took place in hospitals across one or more wards,[39, 48, 62, 157, 164, 167, 169, 170, 172, 174, 175, 179-183] five studies were based in universities (including simulation labs),[166, 168, 176-178] one study was based between a hospital and adjacent academic simulation suite,[171] and one study was based in a psychiatric in-patient setting.[173]

Sample size varied from 19 participants[173] to 161,153 patient observations [39] and was not reported in one study.[182] Participants were nurses only in 13 studies,[46, 48, 164, 167, 169, 171, 173-176, 179-181, 183] nursing students in four studies,[166, 168, 177, 178] and a mix of staff (including nurses, doctors, healthcare assistants) in six studies.[39, 62, 157, 170, 172, 182] (**Table 9.1**) Data collection methods varied according to study design and included review of patient records (manual or via the hospital information system, prospective and retrospective),[39, 48, 62, 157, 164, 170, 172, 174, 175, 182] administration of pre-test and post-test questionnaires or surveys, [46, 166-168, 171, 173, 176-181, 183] and deteriorating patient case examples.[169]

Education programmes varied and included validated packages such as COMPASS® and FIRST^{2}ACT in three studies,[39, 174, 175] or education programmes specific to the individual hospitals including training on SBAR/ISBAR tools, documentation of vital signs, simulation scenarios, ABCDE training and use of RAPIDS or e-RAPIDS in 20 studies.[48, 62, 157, 164, 166-173, 176-183] Fifteen were delivered face-to-face,[48, 62, 157, 164, 168-170, 172, 173, 175-178, 182, 183] two were online (web-based) only,[180, 181] and six were blended (including online and face-to-face components),[39, 166, 167, 171, 174, 179] (**Table 9.1**).

Table 9.1 Characteristics of studies included in Q3 (Educational interventions)

Study Authors (Year) Country	(a) Sample (b) Setting (c) Data Collection	(d) Education Programme (e) Mode of Delivery (f) Type of Participants (g) Other information
RCTs		
Liaw (2011),[177] Liaw (2012).[178] Singapore RCT	(a) N=31 (65% of eligible population) nursing students. Randomised using fish bowl method after baseline data collection (n=15 intervention, n=16 control group). (b) Simulation lab of the National University of Singapore. (c) Baseline and post-test simulation performances were measured using a validated tool (RAPIDs). Participants completed a pre-test questionnaire followed by a post-test questionnaire a week after the intervention.	(d) RAPIDS simulation-based programme including SBAR and ABCDE. (e) Face-to-face programme. (f) Student nurses in third year. (g) Briefing of RAPIDS simulation programme to begin and study guide given to all students. Followed by a 6-hour session of 4 simulation scenarios (each 1 ½ hours) delivered in a standardised way. A 53 item MCQ to assess knowledge in managing deteriorating patients was completed pre and post-test.
Liaw (2014).[166] Singapore. RCT	(a) N=97 nursing students invited to participate. N=57 recruited (N=31 intervention, N=26 control), randomised using a random number table. (b) Simulation lab of the National University of Singapore. (c) Participants completed baseline assessment and post-test questionnaires at 1-2 days post intervention and 2.5 months post intervention. Simulation videotaped and assessed using RAPIDs tool.	(d) RAPIDS simulation-based programme including SBAR and ABCDE. (e) Blended programme. (f) Student nurses in third year. (g) Baseline evaluation of clinical performance using mannequin simulation. Intervention group received a 2-hour fully automated virtual patient simulation individually. Control group received mannequin-based simulation in groups of 6. Five simulation scenarios (acute coronary syndrome, hypoglycaemia, hypovolemic shock, sepsis and septic shock).
Liaw (2015),[167] Liaw (2016).[179] Singapore. RCT	(a) N=67 registered nurses. N=35 randomised using a computerized random number generator to intervention group, n=32 to control. (b) General ward units of an acute tertiary hospital in Singapore. (c) Research staff observed and rated performance using the RAPIDs validated tool. Conducted Nov to December 2013. A week after pre-test and intervention, participants were re-tested for clinical performance using a validated tool.	(d) RAPIDS simulation-based programme including ISBAR and ABCDE to guide nurses in managing patient deterioration. (e) Blended delivery. (f) Registered nurses with <5 years' experience. (g) Baseline evaluation of all participants' clinical performance in a simulated clinical setting. Followed by 3 hours of web-based simulation for the intervention group only and a survey of their perceptions of the simulation programme.
Liaw (2017)[180] Singapore. RCT	(a) N=64 ENs recruited between Nov 2013 and Jan 2014. Randomised using a computer generated list of random numbers. (b) Centre of Healthcare Simulation at an acute care, tertiary hospital, at the University of Singapore. (c) Following baseline evaluation, experimental group received a web-based educational intervention. Pre-post assessment of skills and knowledge were evaluated with a simulated scenario and a MCQ knowledge questionnaire. Post-tests were 1 week post intervention.	(d) e-RAPIDS with 3 key learning activities: video animation (11 minutes on patient deterioration), multimedia instructional material (using ABCDE and ISBAR) and virtual patient simulation (5 different scenarios of patient deterioration). (e) Online (f) ENs (g) Training lasted 2 ½ to 3 hours.

Table 9.1 Characteristics of studies included in Q3 (Educational interventions) [continued]

Study Authors (Year) Country Study Design	(a) Sample (b) Setting (c) Data Collection	(d) Education Programme (e) Mode of Delivery (f) Type of Participants (g) Other information
RCTs		
Lindsey (2013).[168] USA. RCT	(a) N=79 nursing students. Lab coordinator scheduled students in groups of 3-4 to attend a clinical simulation day. Groups randomly selected (n=40 intervention, n=39 control group). (b) Midwestern Public University, Illinois. (c) An 11-item MCQ used to assess students pre-test and post-test understanding of RRTs. Intervention group completed a 90 minute code blue session.	(d) A rapid response education programme. (e) Face-to-face delivery. (f) Final year nursing students, Caucasian, 20-22 years. (g) A 10 minute lecture by the lead researcher on RRTs and a comparison with code blue, the purpose of rapid response and criteria for activating the system. Hand-out provided to students at the end of lecture and control group post-tested. Intervention group received 90 minute novel rapid response simulation and then were post-tested.
ITS studies		
Kinsman (2012)[175] Australia. Interrupted times series design.	(a) 34 nurses (83% of eligible sample) participated. There were 258 patient records audited before the intervention and 242 afterwards dispersed across 10 2-week periods. (b) Rural hospital in Victoria, Australia. (c) Data obtained retrospectively from patient records 10 weeks before and 10 weeks after the intervention. Data were checked for accuracy by double checking a subset of 10/300 medical records.	(d) FIRST^{2}ACT programme. (e) Face-to-face programme. (f) All registered nurses on acute medical/surgical wards. (g) Involved 1 ½ hours training on the hospital ward including individually completing 2 simulated scenarios (cardiac, respiratory) of patient deterioration, self-review of the videoed scenarios, and feedback from a clinical expert.
nRCTs		
Ludikhuize (2011)[169] The Netherlands. Prospective, nRCT.	(a) N=95 nurses (intervention n=47, control n=48). (b) 3 medical and 3 surgical wards in teaching hospital, Amsterdam. (c) Conducted from Jun - September 2010. Trained (prior MEWS training) and untrained (no prior MEWS training) nurses given a nursing chart documenting a deteriorating patient to work through (1 year post MEWS implementation). This was taped and analysed.	(d) MEWS and SBAR training. (e) Face-to-face delivery. (f) Registered nurses, mean age 28 years. (g) Small interactive training sessions (<15 nurses), 1 hour in duration, facilitated by a senior nurse on MEWS documentation and SBAR. Intervention group received enhanced training through posters, feedback sessions, face-to-face conversations and small posters in each nursing chart. Control group received no training.
Uncontrolled before-after studies		
Cahill (2011)[164] Australia. Prospective before-and-after study (uncontrolled).	(a) 3 wards (Ward A: mixed medical/surgical, Ward B: surgical, Ward C: medical) including n=370 patients (n=104 pre-intervention, n=147 2 weeks post-intervention, n=119 3 months post-intervention). (b) Australian tertiary referral university affiliated teaching hospital between May and Aug 2009. (c) Hospital committee designed and implemented new observation chart, education programme and data collection with 1 nurse appointed to coordinate the system. Patient records examined in hospital information system.	(d) Education programme included an orientation of the new observation chart and basic vital signs assessment using manual techniques. (e) Face-to-face programme. (f) Nurses – mandatory to attend. (g) Old chart plotted vital signs over 2 pages and RR was at the bottom of page 1. New chart added range of values to trigger escalation, all vital signs plotted on 1 page and elevation of RR to top of page and the addition of AVPU.

Table 9.1 Characteristics of studies included in Q3 (Educational interventions) [continued]

Study Authors (Year) Country Study Design	(a) Sample (b) Setting (c) Data Collection	(d) Education Programme (e) Mode of Delivery (f) Type of Participants (g) Other information
Uncontrolled before -after studies		
De Meester (2013)[48] Belgium. Before-and-after study (uncontrolled).	(a) N=425 nurses involved in direct care for patients on medical and surgical wards. (b) Antwerp University tertiary referral hospital between July 2010 and Mar 2012. (c) Pre-intervention was 10 months between July 2010 and Apr 2011. Post-intervention was 10 months between May 2011 - Mar 2012. Participants completed communication tool and hospital information system used to identify cases. MEWS introduced in Nov 2009.	(d) SBAR and ABCDE training. (e) Face-to-face programme. (f) Nurses. (g) 2-hour training session on SBAR and communication-related errors, followed by 4-hour lesson on the ABCDE algorithm, critical thinking for all nurses (delivered by 2 reference nurses from each ward who received advance training).
Hammond (2013)[174] Australia. Prospective before-and-after intervention study (uncontrolled).	(a) N=69 ICU cases before MEWS and n=70 after. 2 groups of hospital observation charts (24 hours post-ICU discharge and 24 hr preceding unplanned admissions to ICU). (b) Tertiary referral teaching hospital in Brisbane with 588 beds and 21 ICU beds. (c) Pre implementation study period (Nov 2009) and post implementation study period (Feb 2010). Data recorded before and after MEWS for 24 hours only from patient records.	(d) COMPASS ®. (e) Blended programme. (f) Nurses – all staff had to complete the education programme. (g) 3 phases to programme: 1) training CD to work through independently, 2) Online quiz, 3) 2-hour face-to-face session including ISBAR.
Jung (2016)[62] France. Before-after study.	(a) N=137,251 patients. Pre-intervention: N=68,086 admitted to the medical-surgical wards July 2010 to Dec 2011 of 3 control hospitals with no RRT. Post-RRT N=69,165 patients admitted July 2012 to Dec 2013 in 1 RRT hospital. Sample of HCPs trained not reported. (b) 4 hospitals of Montpellier regional healthcare centre. (c) RRT intervention in 1 hospital compared to 3 control hospitals (non-RRT). RRT data retrospectively analysed. RRT intervention consisted of an intensivist-led RRT activated by a single criterion along with education.	(d) Education included displaying posters, bedside simulation-based training courses using manikins, practical educational sessions and information through the local hospital newspaper to recognise the listed criteria foe activating the RRT. (e) Face-to-face (f) Ward residents, doctors and nurses (g) During a 6 month period the RRT criterion were presented to the medical and nursing teams.
Liaw (2016)[181] Singapore. Before-after intervention study.	(a)N=99 nurses (85% participation rate) participated (n=64 registered nurses and n=35 ENs) (b) 1 surgical ward and 1 medical ward, acute care 991-bed tertiary hospital at a University. (c) Data collected at the Centre for Healthcare Simulation from June 1 to Aug 14 2014. Nurses and ENs individually brought into a room with a computer to complete the 3 part training. Examination was in the form of a 30-item MCQ before and after the training. Participants completed the Instructional Material Motivational Survey immediately after the training to assess their thoughts on the training. Behavioural change was assessed in a self-reported questionnaire 3-4 months after e-RAPIDS training. Clinical records on cases triggered by nurses from the 2 study wards were checked by an investigator for frequency and type over a period of 6 months pre-(Dec 2013 to May 2014) and 6 months post intervention (Aug 2014 to Feb 2015)	(d) e-RAPIDS web-based training with 3 parts including an animated video focusing on early detection of changes in vital signs; a study guide presented using multimedia instructional materials [text, illustration, audio of lung sounds] on using the ABCDE and ISBAR mnemonics and a virtual simulation with five scenarios on deteriorating patients. (e) Online (f) Registered nurses and enrolled nurses from the surgical and medical wards (g) Training lasted 2 ½ to 3 hours

Table 9.1 Characteristics of studies included in Q3 (Educational interventions) [continued]

Study Authors (Year) Country Study Design	(a) Sample (b) Setting (c) Data Collection	(d) Education Programme (e) Mode of Delivery (f) Type of Participants (g) Other information
Uncontrolled before -after studies		
McDonnell (2012)[183] UK. Before-after intervention study.	(a) N=322 nurses from 12 wards included. (b) 500+ bed District general hospital in the UK. (c) Questionnaire (scale of 1-10) used to examine knowledge and confidence in recognition and management of deteriorating patients 6 weeks before and after an intervention. Data collected in 2009. 84% (271/322) of eligible staff attended training and completed before questionnaires. 77% (247/322) completed after questionnaires. Paired responses was 66% (213/322)	(d) Education programme: information on the recognition/response to deteriorating patients, an overview of the new charts, the new EWS and graded response algorithm. (e) Face-to-face (f) Nurses (RNs and UNs). (g) Delivered by the CCOT nurse, 30-45 minutes.
Ozekcin (2015)[171] USA. Before-and-after study (uncontrolled).	(a) N=35 nurses working on the ward a minimum of 6 months. (b) 3 cardiac surgical universal care units of a university hospital based within the northeast USA, and a medical simulation suite of a medical school adjacent to the hospital. (c) Project included a pre-test post-test descriptive survey (14 –item MCQ). E-learning module and pre-test surveys were assessable on the hospital database to staff. Project took place over 4 weeks with 10 simulation sessions (3-5 nurses in each session).	(d) 2-phase educational programme (e-learning module and simulation scenarios). (e) Blended delivery. (f) Registered nurses. (g) E-learning module, a simulated scenario allowing participants to observe cardiovascular and respiratory changes over a short period and permitted to respond with critical actions. Followed by a group debriefing session. SBAR incorporated to both phases of the education training and a clinical nurse specialist devised the education programme based on the PDSA framework.
Rose (2015)[172] USA. Quality Improvement Project (QIP) before-and-after study (uncontrolled).	(a) N=108 core staff members participated voluntarily. (b) Small 120 bed community hospital with a successfully implemented RRT 2 years prior. (c) QIP ran from Mar – Nov 2013. 3 non-critical care units included. Effectiveness of staff education programme on eMEWS measured in 2 90-day phases (pre- and post-intervention).	(d) One-on-one or small group education related to eMEWS. (e) Face-to-face delivery. (f) Nurses, healthcare assistants and respiratory therapists. (g) 3-minute intense education presentation. Included strategies to rescue the patient, the significance of MEWS a decision support tools and documentation of eMEWS (electronic and manual).
Schubert (2012) [176] USA. Before-and-after intervention study (uncontrolled).	(a) N=58 nurses (b) Simulation lab of a Midwestern U.S University hospital. (c) Failure to rescue knowledge test (comprised of 9 MCQs with a range of scores from 0-9), and the Learning Transfer Tool (LTT), an instrument to assess nurses' skills in overall critical thinking (with 13 self-assess items) were administered before, immediately after and 2 weeks after the simulation. Pre-test demographic data, including level of education, years of experience as a nurse, and any previous simulation exposure, were collected.	(d) Simulation-based intervention. (e) Face-to-face delivery. (f) Nurses attending an annual education day. (g) Groups of 3 nurses with supportive personnel who facilitated the simulation (clinical nurse specialist as the observer/debriefing leader, nurse educator as the mannequin operator, and the project coordinator as the physician). Nurses completed the post-test MCQ and were given a self-addressed, stamped envelope with instructions to complete and return post-test2 in 2 weeks.

Table 9.1 Characteristics of studies included in Q3 (Educational interventions) [continued]

Study Authors (Year) Country Study Design	(a) Sample (b) Setting (c) Data Collection	(d) Education Programme (e) Mode of Delivery (f) Type of Participants (g) Other information
Uncontrolled before -after studies		
Sebat (2018)[157] USA Prospective single-centre before-after study	(a) N=28,914 medical/surgical patients admitted during the control period 24 months (Jan 2008– Dec 2009), and N=39,802 patients admitted during the 33-month intervention period (Jan 2011 - Sept 2013). N=650 nurses on the units completed education. The number of other staff who completed education was not reported. (b) Adult general nursing units at a 500-bed community regional hospital, California (c) Data collected pre-and post-post intervention consisting of: changing the RRS to a 4-arm RRS including 1) expansion of vital signs, changes in nursing policies for escalation, mandatory education programme; 2) expansion of the RRT to include a critical care RN and development of standardised procedures; 3) Complete data collection and system compliance and improvement implemented; 4) expanded in personnel and scope.	(d) Education of nursing assistants on taking and reporting vital signs accurately; 4 hour education programme for RNs on recognising at risk patients earlier using 10 vital signs (including 45 minute video, classroom case study presentations, at risk mock patient simulation scenarios and written examination [required to pass]). RRT ward debriefing sessions post-event. Medical staff education included presentations at staff meetings, grand rounds and at all medical staff committees. RRT received advanced cardiac life support training, ventilation, infusion, pump, pharmacologic and specific invasive intervention (VIPPS) approach training, case studies and mock RRT alerts. (e) Face-to-face (f) Mandatory nurse, physician and nursing assistant training. (g)-
Shaddel (2014)[173] UK. Before-and-after intervention study (uncontrolled).	(a) N=19 psychiatric nurses. (b) The assessment and treatment learning disability unit and in 2 forensic psychiatric units in the UK. (c) Nurses completed a pre-MEWS implementation survey and a post-MEWS implementation survey.	(d) MEWS form introduced to a mental health unit. (e) Face-to-face delivery. (f) Nurses with a minimum of 6 months experience and a max of 20 years nursing experience. (g) Nurses received 15 minutes training on MEWS and then completed the post-intervention questionnaire on 2 case studies of deterioration.
Wood (2015).[182] UK. Prospective before-and-after study (uncontrolled).	(a) Not reported how many staff received training or how many files were audited. (b) Nottingham University Teaching Hospital across 3 sites. (c) A service improvement project commenced in 2013. 3 key phases: 1) Staff engagement and defining the ward culture), 2) 5 multifaceted high impact interventions, 3) Fortnightly case note audit. There were 5 key targets identified for improvement within the hospital.	(d) Multi-faceted education programme including case studies, mock audit and patient scenarios as teaching material. (e) Face-to-face delivery. (f) Doctors (foundation year, core trainees and specialist trainees) and nurses (adult and paediatric nurses) with support from senior nurses. (g) 'EWS focus fortnight': delivered in each area concentrating on poor performing wards first to improve and achieve the 5 key targets. 'Standardised EWS training' and mandatory attendance, followed by personalised clinical feedback to support staff to take ownership of their actions.

Table 9.1 Characteristics of studies included in Q3 (Educational interventions) [continued]

Study Authors (Year) Country Study Design	(a) Sample (b) Setting (c) Data Collection	(d) Education Programme (e) Mode of Delivery (f) Type of Participants (g) Other information
Uncontrolled before -after studies		
Mullany (2016).[39] Australia. Retrospective before-after observational study.	(a) N=161,153 separations and n=1,994 hospital deaths in the study period from July 2008-Dec 2012. Pre-intervention period included 44,505 separations and post-intervention period included 116,648 separations. (b) Prince Charles Hospital, tertiary university-affiliated hospital, Brisbane. (c) Dec 2009 the MET team commenced and a general observation chart incorporating MEWS and MET criteria were introduced. Real audit data of vital signs and escalation used in ward education and meetings pre-intervention (2008-2009) and post-intervention (2010-2012).	(d) COMPASS ® education programme. (e) Blended delivery. (f) Doctors (90% of junior staff trained) and nurses (60% of nursing staff trained). (g) Ward observation chart re-designed with vital sign variables colour-coded to identify variation from the normal range and calculation of MEWS. Minimum frequency of vital sign measurement mandated. COMPASS education package and e-learning package and a 2-hour face-to-face small group format using ISBAR.

Key: AVPU: Alert, Voice, Pain, Unconscious; MEWS: Modified Early Warning System; SBAR: Situation, Background, Assessment, Response; ABCDE: Airway, Breathing, Circulation, Disability, and Exposure; ICU: Intensive Care Unit; ISBAR: Identify, Situation, Background, Assessment, Response; RRT: Rapid Response team; RAPIDS: Rescuing a Patient in Deteriorating Situations; MCQ: Multiple Choice Question; eMEWS: electronic MEWS.

9.3 Findings

The outcomes reported varied from study to study, and were dependent on the aims of the particular study. The findings are discussed according to *a priori* defined primary outcomes (including increase in knowledge and performance; effect on patient outcomes and improved patient rescue strategies) and secondary outcomes (improved documentation of patient observation and improved compliance) as well as any other outcomes reported in the studies and identified post-hoc (communication, collaboration and perception).

9.3.1 Primary outcomes

9.3.1.1 Increase in knowledge and performance

9.3.1.1.1 Knowledge

Eight of the 23 studies looked at an increase in knowledge post-educational intervention, all of which showed a significant effect of the intervention (that is staff knowledge was improved post-intervention).

These included four RCTs (two of these RCTs considered nursing students[168, 178] with the other two investigating the effect on registered or enrolled nurses performance).[167, 179] The interventions consisted of web-based simulation programmes in two of the RCTs,[167, 179] with two considering lab based simulations. [168, 178]

Four uncontrolled before- after studies examined the effectiveness of EWS educational interventions on knowledge. These included a mannequin-based simulation intervention in nurses,[176] a 2-phase educational programme (e-learning module and simulation scenarios) in nurses,[171] a web-based e-RAPIDS simulation intervention tested in 99 registered nurses and enrolled nurses[181] and an educational intervention consisting of the provision of information on detecting deterioration and responding appropriately as well as training on the new observation chart in a group of 322 nurses from 12 different wards,[185] (Appendix 6).

9.3.1.1.2 Performance and confidence

Ten of the 23 studies looked at performance and or confidence post-educational intervention, all of which reported a significant effect of the intervention (i.e. an increase in performance and or confidence).

These included five RCTs of varying interventions: RAPIDS simulation-based training in student nurses,[166, 178] web-based simulation in a group of 67 registered nurses,[167, 179] and a web-based simulation intervention in a group of 64 enrolled nurses.[180] A single nRCT (a quasi experimental trial)[169] measured performance in registered nurses who were trained in the use of a MEWS and SBAR. Four before-after studies examined the effectiveness of EWS educational interventions on performance. Interventions included a 2-phase educational programme (e-learning module and simulation scenarios) in nurses, [171] introducing MEWS to psychiatric nurses in an in-patient mental health setting,[173] registered nurses and enrolled nurses using a web-based simulation educational intervention,[181] and

an educational intervention consisting of the provision of information on detecting deterioration and responding appropriately as well as training on the new observation chart in a group of 322 nurses from 12 different wards,[183] (Appendix 6).

9.3.1.2 Effect on patient outcomes

Eight of the 23 studies looked at the effect on patient outcomes post-educational intervention overall, with five reporting a significant effect of the intervention.

No RCTs were identified.

A single ITS study by Kinsman et al.,[175] reported no significant effect of the intervention on patient outcomes including no change in the administration of oxygen therapy to patients post-mannequin based simulation intervention as well as no difference between MET criteria calls pre-intervention post-intervention.

Seven before- after studies included patient outcomes, of which five reported a significant effect of the intervention (which may include an improvement or worsening of the patient outcomes including serious adverse events [SAEs]).

De Meester et al.[48] investigated SAEs including unexpected deaths, unplanned admission to the ICU, mortality, LOS, and cardiac arrest team calls for ten months before and after SBAR training. There were 4.4 SAEs per 1,000 admissions pre-intervention and 6.7 SAEs per 1,000 admissions post-intervention ($p<0.05$), a worsening of patient outcomes. There were 16 unexpected deaths (0.99 per 1,000 admissions) pre-intervention and five unexpected deaths (0.34 per 1,000 admissions) post-intervention (a relative risk reduction (RRR) of -227%, 95% confidence interval (CI) -793%, -20%), $p<0.001$. Unplanned admission to the ICU increased from 51 (13.1 per 1,000 admissions) pre-intervention to 105 (14.8 per 1,000 admissions) post-intervention (RRR of 50%, 95% CI 30%, 64%), $p=0.001$. There was no significant difference in mortality, LOS or cardiac arrest team calls pre- and post-intervention.

Rose et al.,[172] was an American-based QIP, retrospective uncontrolled before-after study including 108 core staff members. The investigators measured the effect of one-on-one small group education sessions on patient outcomes for 90 days before and after the intervention. The patient RRT survival rate remained unchanged before (23, 100%) and after the intervention (17, 100%). The post RRT transfer rate was 11 (43%) before and 10 (64%) after. The number of RRT calls before (n=23) decreased after the intervention (n=17) (no rates or statistical data provided within the study).

Wood et al.,[182] looked at unscheduled admissions to the ICU before and for 12 months after an educational intervention and found that a mean EWS score of 7 prompted admission to critical care for adults and that consultant involvement was present in 51% of adult cases. These limited data suggest that for the sickest adult patients, observations often improve following initial medical intervention and that early review within working hours may prevent deterioration and need for escalation out of hours. It also shows there was a trend towards more timely admission to critical care for the adult patient when the ward consultant had been involved in the escalation process.

Sebat et al.,[157] compared cardiac arrests, hospital mortality and RRT calls per 1,000 discharges 24 months before and 33 months after a four part RRT-intervention (one component of which was an educational intervention). A significant reduction in cardiac arrests per 1,000 discharges was found (pre intervention: 3.1 per 1,000, post intervention: 2.4 per 1,000, p=0.04); a significant reduction in the unadjusted hospital mortality rate (pre-intervention: 3.7%; post-intervention 3.2%, p<0.001) and a significant increase in the number of RRT calls per 1,000 discharges (pre-intervention: 10.2 per 1,000; post-intervention 48.8 per 1,000, p<0.001) were reported.

Liaw et al.,[181] reported the number of RRT calls before and after a web-based educational intervention on two different wards and found a significant increase on the medical ward (pre: 8.96%, post 14.58%, p<0.001) but not on the surgical ward (pre: 1.97%, post: 1.23%, p=0.15).

Jung et al.,[62] investigated the effect of an educational intervention in four different French hospitals (the RRT intervention hospital and three non-RRT control hospitals) and found significant reductions post-intervention in the RRT hospital for unexpected mortality (p=0.002), overall mortality (p=0.012) and unplanned ICU admissions (p=0.002). No significant difference was found in cardiac arrests (p=0.093) or median hospital LOS (p=0.09).

Mullany et al.,[39] looked at the effect of COMPASS© training on patient outcomes including the all-cause hospital mortality rate which decreased from 14 per 1,000 observations pre intervention to 11.8 per 1,000 post intervention (absolute change 2.2 per 1,000, 95% CI 1-3.5 per 1,000, p=0.003). In addition, the hospital standardised mortality ratio was 95.7 on average for the two year period of 2008 to 2009. It fell 11% in the first six months after implementation and fell again in 2011 and 2012 and by the second half of 2012 was 66 (a 31% total decline over 3 years). The in-hospital cardiac arrest calls rate decreased from 5.5 per 1,000 observations before the introduction of the MET to 3.3 per 1,000 observations after(absolute change 2.2 per 1,000, 95% CI 1.4-3, p=<0.001). Emergency ICU admissions following emergency calls increased from 41 admissions in 2009 to 121 admissions in 2012. However average length of stay in the ICU decreased from 140 hours in 2009 to 95 hours in 2012. Hospital LOS: average decreased from 5.9 days in 2009 to 4.7 days in 2012. Finally, MET calls increased from 8.3 per 1,000 separations in 2010 to 9.1 per 1,000 in 2011 and 11.3 per 1,000 in 2012, an increase of approximately one call per month every two months (Appendix 6).

9.3.1.3 Improved patient rescue strategies

No study looked at improved patient rescue strategies post-educational intervention.

9.3.2 Secondary outcomes

9.3.2.1 Improved documentation of patient observations

Eight of the 23 studies looked at the improvement in documentation of patient observations post-educational intervention with all eight studies reporting a significant effect of the intervention.

Two RCTs[179, 180] (one in a group of registered nurses, the other in a group of 64 enrolled nurses) investigated the effect of a web-based e-RAPIDs educational intervention on documentation of vital signs in a simulation-based assessment one week after training. Both studies found no difference in documentation of BP or SpO_2 post-intervention and a significant improvement in RR and HR documentation.

A single nRCT by Ludikhuize et al.,[169] of 95 registered nurses, investigated the nurse reported measurement of vital signs and a MEWS. Trained nurses were given a patient case chart and asked what vital signs they would request (measure) in reality. Pulse, BP, temperature and SpO_2 were the most requested vital sign parameters (78-84% in both groups). In total, 53% of trained nurses reported that they would request RR, compared to 25% of non-trained nurses, p=0.025). Fifty percent of all nurses reported they would request pain measurement using a visual analogue scale. Of the trained nurses, only 4 (11%) determined and calculated the MEWS correctly.

A single ITS study by Kinsman et al.[175] showed that unsatisfactory pain score charting decreased by -0.179 points (range 0-9 points on a 9-item MCQ test) post-intervention (p=0.003). Unsatisfactory frequency of observations decreased -0.112 points post-intervention, (p=0.009) and observation frequency improved in medical (p=0.003) but not in surgical patients (p=0.403).

Four uncontrolled before- after studies examined the effectiveness of EWS educational interventions on documentation of patient observations, with all four showing a significant effect of the intervention (i.e. an improvement in documentation).

Cahill et al.,[164] and Hammond et al.[174] both looked at the improvement in the documentation of a 'full set' of vital signs. Cahill et al.,[164] reported an improvement from pre-intervention (47.6%) to two weeks post-intervention (96.3%) and remaining at three months post-intervention (96.4%). The documentation of RR (which is consistently the least documented vital sign) improved from 47.8% pre-intervention to 97.8% two weeks post-intervention and remained at 98.5% three months post-intervention. Documentation of BP, SpO_2 and HR remained consistently high pre- and post-intervention. Hammond et al.[174] reported on improvements three months post-intervention in two groups (1, ICU discharge patients, 2, Unplanned ICU admissions). In the ICU discharge patients group there was a statistically significant increase post intervention (210%, 95% CI (148% - 288%), p<0.01). Single parameter documentation significantly increased for temperature (25.5%, 95% CI 8.1%-45.7%, p=0.003) and urine output (which was not on the chart pre-implementation) increased to 103% (95% CI 80.0%-129.7%), p=<0.001). Documentation for systolic and diastolic BP, HR, RR and SpO_2 did not significantly increase. In the unplanned ICU admissions group and the full observation set (7 parameters) post intervention there was a 44% increase in documentation (95% CI 2.6% - 102.1%), p=0.04). When looking at single parameter documentation only urine output significantly increased: 26.9%, (95% CI 2.5%-57.1%), p=<0.03.

In another uncontrolled pre-post intervention study by Rose et al.,[172] undocumented eMEWS scores were reported: pre-intervention (11, 49%), post intervention (0, 0%) and an eMEWS score (with a range of 0-6) mean of 2.3 (SD 1.79) pre-intervention and a mean of 3.2 (SD 1.79) post-intervention.

A study by Merriel et al.,[170] measured documentation of patient observations in a sample of junior doctors and junior and senior nurses. The documentation of individual EWS scores were calculated correctly 93% of the time over six months pre-implementation and 94% of the time over six months post-implementation, Relative Risk 1.01 (95% CI (1.00, 1.03), p=<0.05). At admission all EWS scores were calculated correctly for a patient's admission

pre-implementation 55% of the time and post-implementation 68% of the time, Relative Risk 1.24 (95% CI (1.07, 1.44), p<0.01). There was no significant difference with regard to completion of at least one set of required observations (e.g. at least BP) pre-implementation (68%) and post-implementation (79%), Relative Risk 1.2 (95% CI (1.09, 1.32), p=<0.01). The study also measured how often observations were performed as per the EWS guidelines and found that fewer than half were documented as per the EWS guidelines pre-implementation (46%), increasing post-implementation to 59% , Relative Risk 1.33, (95% CI 1.13, 1.57) (Appendix 6).

9.3.2.2 Improved compliance

Two of the 23 studies looked at improved compliance post-educational intervention with both reporting a significant effect of the intervention (i.e. improved compliance), both were before- after studies.

A study by Wood et al.,[182] looked at compliance with an EWS in a single university hospital in the UK. They had five targets and achieved four out the five in a one year period. 1) Observations done four hourly: Quarter 1 (65%), Quarter 4 (96%) [Target (75%) achieved]; 2) EWS correctly scored and added up: Quarter 1 (88%), Quarter 4 (93%) [Target (95%) not achieved]; 3) Frequency of observations increased appropriately: Quarter 1 (36%), Quarter 4 (50%) [Target (35%) achieved]; 4) NURSING escalation correct: Quarter 1 (22%), Quarter 4 (57%) [Target (35%) achieved]; and 5) Medical escalation correct: Quarter 1 (31%), Quarter 4, (37%) [Target (35%) achieved].

A retrospective observational study with before (two years) and after (three years) intervention comparisons by Mullany et al.,[39] measured compliance with appropriate frequency of vital signs. Following introduction of monthly ward-based audits, compliance with correct frequency of vital signs rapidly rose to above the target of 90%. Completeness of vital signs increased from a mean of 60% in 2010 to 70% in 2011. The intervention resulted in progressive improvement in compliance to 86% in December 2012 and the 90%

target was reached in March 2013. The addition of escalation documentation by nurses to monthly audits in 2011 improved this from 79% to 90% by 2012.

9.3.3 Other post-hoc identified outcomes

9.3.3.1 Communication, collaboration and perception

Four of the 23 studies looked at communication, collaboration or perception, with all four reporting a significant effect of the intervention (i.e. an improvement in communication, collaboration or perception).

Two RCTS were included. An RCT by Liaw et al.,[177] investigated the use of the ABCDE and SBAR tools alongside simulation to improve communication and handover which reported significant effects of the intervention. The intervention group mean total ABCDE domain score (which ranges from 0-36) increased significantly between baseline (mean 10.37, SD 2.48) and one week post-intervention (mean 20.13, SD 3.29, p=0.001). No significant difference was found in the control group (baseline mean 10.22, SD 2.39; post-intervention mean 11.22, SD 2.25). Significant increases were found in the following individual ABCDE domains in the intervention group: Airway; Breathing; and Circulation. No significant increases were found in the other two domains (Disability, Examine). The total SBAR score for communication in the intervention group, in the RCT by Liaw et al.,[177] also significantly increased between baseline (mean 8.47, SD 1.62) and post intervention (mean 11.77, SD 2.83), (p=0.01). However, the intervention group did not show any significant improvement on the post-test scores for individual SBAR subscales except Assessment. The control group showed a significant improvement in the post-test score for the 'global rating performance' (baseline mean 3.34, SD 1.45), post score mean (3.84, SD 1.35), (p=0.05) but not for the rest of the SBAR domains. A further RCT by Liaw et al.,[180] investigating the effect of a web-based simulation tool as well as the use of ISBAR and ABCDE communication tools found a significant improvement in the intervention group in a simulation-based assessment one week after training (p<0.001) and no change in the control group (p>0.05). A significant between group comparison was found (p<0.01).

An nRCT by Ludikhuize et al.,[169] provided SBAR training to the intervention group of registered nurses and reported mixed results. The results showed that only 1 (4%) of the trained nurses used SBAR to communicate with the physician. In addition, measured parameters were only communicated to the physician in 60% of phone calls. Where it was measured, RR was communicated twice as frequently by trained nurses than by non-trained nurses (83% versus 40%). In the four cases where MEWS was calculated (11% of trained nurses), one nurse (2%) followed the protocol correctly and called the physician (but did not mention MEWS). Two nurses took no action and one checked the patient again at a later time. With regards to communicating with and notifying the physician: 24 nurses (67%) in the trained group and 12 (43%) in the non-trained group contacted the physician immediately (p=0.059). When Ward C was excluded (due to demographic differences), 67% of trained nurses and 22% of non-trained nurses notified a physician (p=0.037).

A single before- after study by De Meester et al.,[48] looked at communication, collaboration and perception post-educational intervention using the Communication, Collaboration and Critical Thinking Quality Patient Outcomes Survey Tool (CCCT). This tool provides a transformed score ranging from 0-100. Nurses total score pre-intervention was 58.6 (31-97) and increased to 63.9 (25-97) post-intervention, ($p \leq 0.001$). Collaboration increased from pre-intervention (56.2, 0-100) to post-intervention (62.2, 17-100), $p \leq 0.001$. Communication with the physician significantly increased from pre-intervention (62.9, 20-100) to post-intervention (68.9, 13-100), ($p \leq 0.001$). Overall perception of communication significantly improved between pre-intervention (55.3, 0-89) and post-intervention 58.4, 0-100, p=0.042) among nurses (Appendix 6)

9.4 Methodological quality

A number of different study designs were included (RCTs, non-RCTs, interrupted time series, and before-after observational studies) in this systematic review update and therefore the methodological quality was appraised using different tools. The quality of included studies is presented according to the different study designs.

9.4.1 RCTs

The Cochrane risk of bias tool[23] was used to appraise the methodological quality of the seven RCTs[166-168, 177-180]. Overall, six of the seven trials had a low risk of bias.[166, 167, 177-180] One trial[168] had a high risk of bias due to unclear random sequence generation, lack of allocation concealment, lack of blinding, incomplete outcome data, and other bias (***Figure 9.1, Figure 9.2***).

Figure 9.1 Risk of bias summary for RCTs of educational interventions and deterioration in adults in acute health care settings

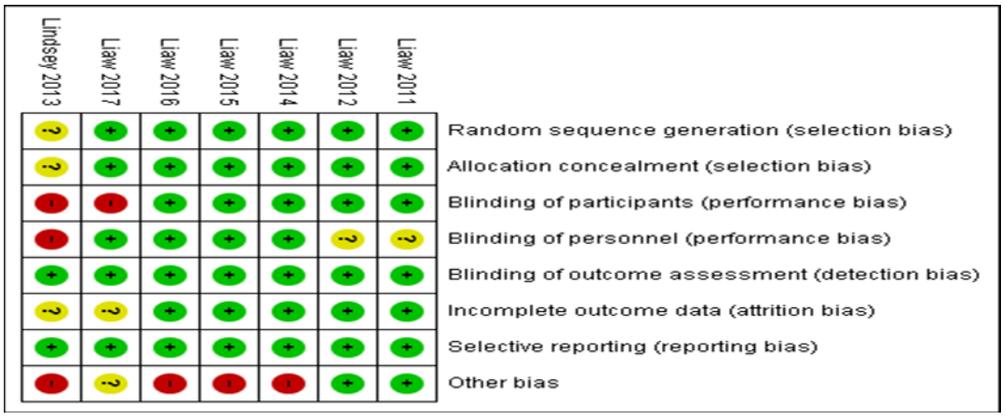
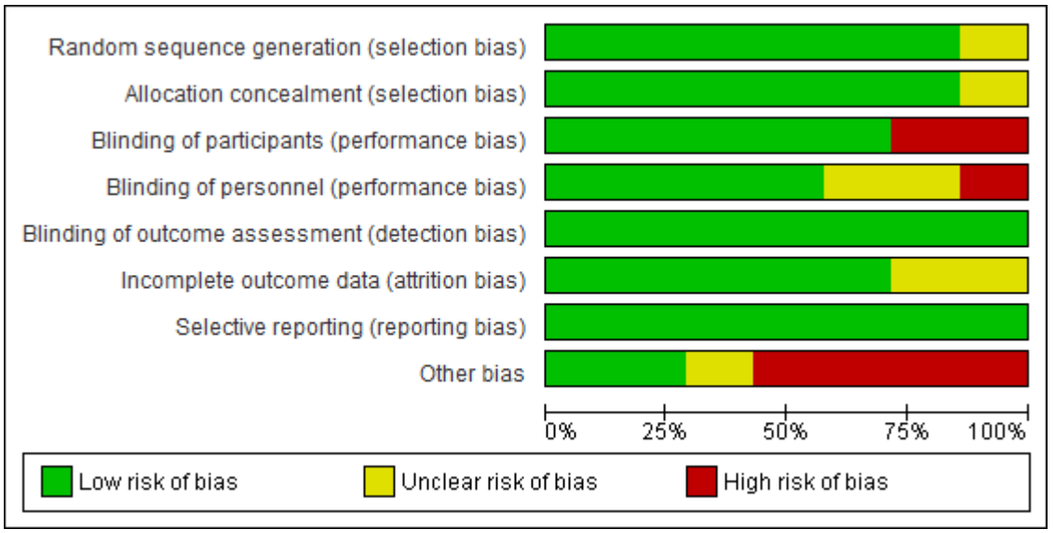


Figure 9.2 Risk of bias graph for included RCTs of educational interventions and deterioration in adults in acute health care settings



9.4.1.1 Allocation

Random sequence generation and allocation concealment

Six of the trials described the method of sequence generation used and allocation concealment and had a low risk of bias.[166, 167, 177-180] One trial did not describe the method sequence generation or allocation concealment and so had an unclear risk of bias.[168]

9.4.1.2 Blinding participants and personnel (performance bias)

Five of the trials had a low risk of bias for blinding of participants.[166, 167, 177-179] Two trials had a high risk of bias as it stated that participants were told they were receiving the intervention.[168, 180] Blinding of personnel was low risk in four trials,[166, 167, 179, 180] two trials had an unclear risk of blinding for personnel as it was not stated,[177, 178] and one trial had a high risk of bias for blinding of personnel (investigators were aware of who received the intervention).

9.4.1.3 Detection bias

All seven trials had a low risk of detection bias (outcomes were scored independently by two assessors using a validated tool and inter-rater reliability was high,[166, 167, 177-180] or pre-test and post-test surveys were scored using a Scantron machine.[168]

9.4.1.4 Incomplete outcome data

Five of the trials described loss to follow-up and accounted for participants.[166, 167, 177-179] Two trials had an unclear risk of bias for attrition as they did not report any details regarding attrition bias[168] or why participants were excluded.[180]

9.4.1.5 Selective reporting

All seven trials had a low risk of bias for selective outcome reporting and provided results for the pre-specified outcomes.[166-168, 177-180]

9.4.1.6 Other potential sources of bias

Two trials had a low risk of bias for 'other potential sources of bias'.[177, 178] Four trials had a high risk of other bias. One trial was unable to control for differences between the comparison (virtual vs. mannequin-based simulation, i.e. comparison confounded) and for confidentially and contamination between the two post-test time points.[166] Another trial reported that the quality of the evidence could be limited by the 'no-intervention control' group but given that the study is looking at the development of a new web-based learning programme for hospital nurses, the no-intervention controlled study is still considered valuable in the early stages of an innovation.[167] In this same trial and another trial[179] the first author was the owner and developer of the simulation software. The trial by Lindsey et al.[168] used a convenience sample and reported that external validity may have been threatened by the interaction of the pre-test and the educational intervention as well as the fact that multiple educational interventions were used sequentially, which may have confounded the results. One trial had an unclear risk of bias as the author developed the e-

RAPIDS tool and there was a potential for contamination amongst participants,[180] (***Figure 9.2***).

9.4.2 Non-RCTs and Interrupted Time Series Studies

The Cochrane Effective Practice and Organisation of Care (EPOC) tool was used to assess methodological quality[24] for the one non-RCT study (a quasi-experimental study by Ludikhuize et al.[169]) and the one interrupted time series study (by Kinsman et al[175]). The tool was modified according to the study design with nine domains assessed in the nRCT and seven domains in the interrupted time series study.

9.4.2.1 nRCT study

The only non-RCT quasi-experimental study included by Ludikhuize et al.,[169] had a low risk of bias overall (low risk across five domains: baseline characteristics; blinding; contamination; selective outcome reporting and other bias). This trial had a high risk of bias for allocation concealment and random sequence generation (the study was not randomised and the intervention and control group were based on a previous study's categorisation). There was an unclear risk of bias for baseline outcome measurements and for attrition (incomplete outcome data) as this was not reported in the study (

Figure 9.3, Figure 9.4*).*

Figure 9.3 Risk of bias summary for nRCTs of educational interventions and deterioration in adults in acute health care settings

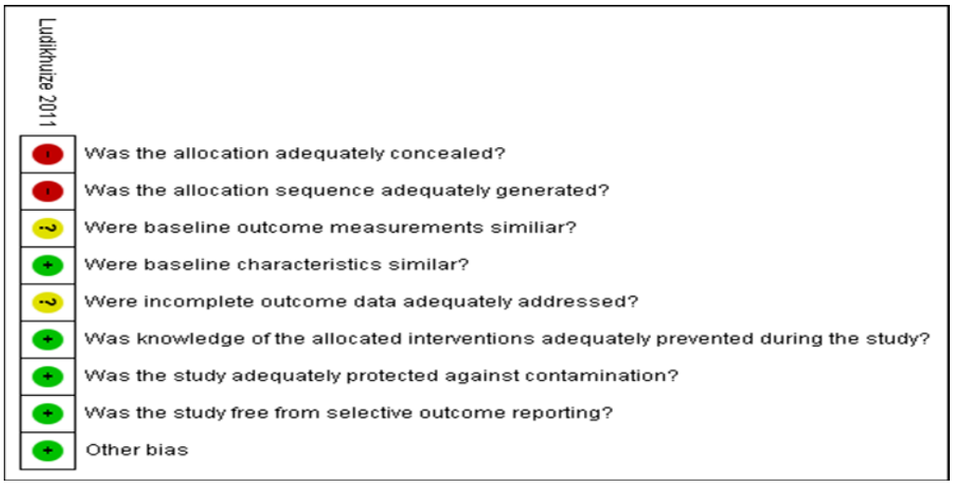
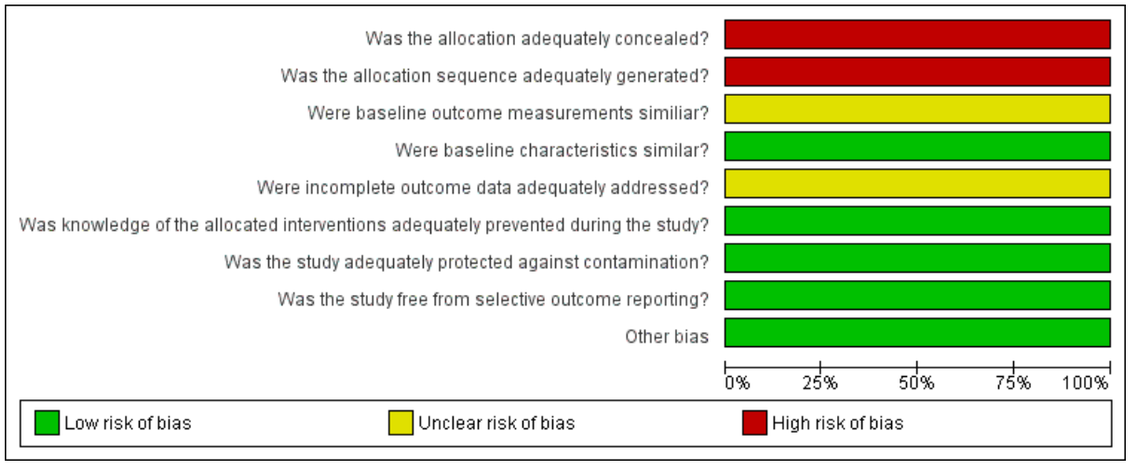


Figure 9.4 Risk of bias graph for included nRCTs of educational interventions and deterioration in adults in acute health care settings



9.4.2.2 ITS study

The single ITS study included by Kinsman et al.,[175] had a low risk of bias overall (low risk for four domains: was the shape of the intervention effect [point of analysis is the point of intervention] pre-specified; was the intervention unlikely to affect data collection; attrition;

and selective outcome reporting). There was a high risk of bias for blinding (study was not blinded or randomised and all nurses received the intervention). There was an unclear risk of bias for the intervention being independent of other changes. However, the authors state that "the issue of contamination of the sample was considered and contributed to our design to invite participation from an entire roster of nurses from a single ward and to encapsulate measurements from medical records to that ward". There was an unclear risk of bias for other bias (seasonality may have been an issue), (***Figure 9.5, Figure 9.6***).

Figure 9.5 Risk of bias summary for ITS studies of educational interventions and deterioration in adults in acute health care settings

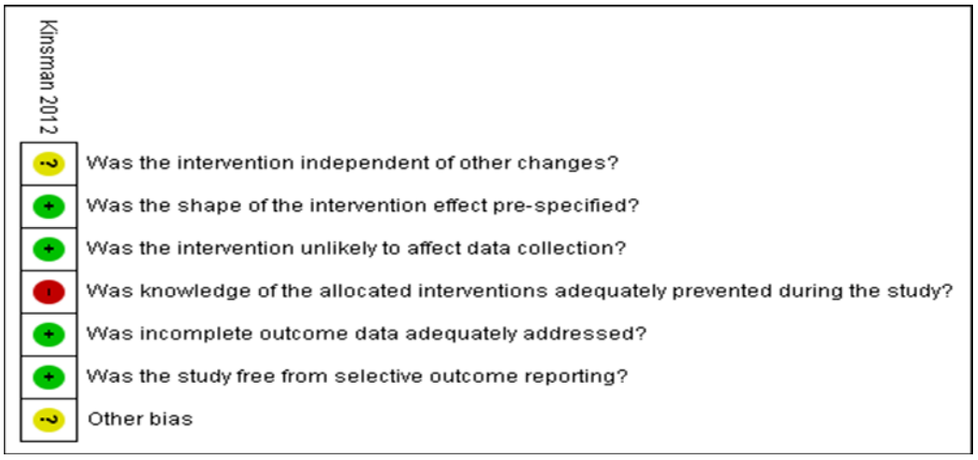
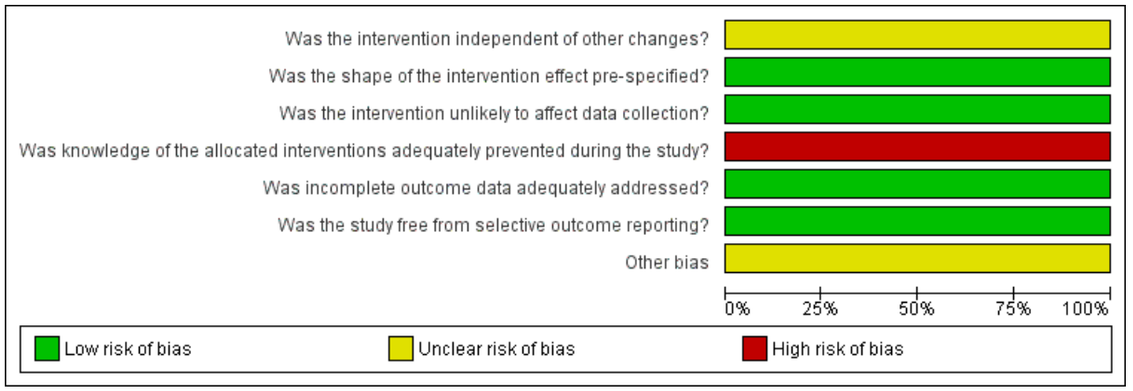


Figure 9.6 Risk of bias graph for included ITS studies of educational interventions and deterioration in adults in acute health care settings



9.4.3 Observational studies uncontrolled before and after studies

The Newcastle Ottawa Scale quality appraisal tool[26] was used for the fourteen before-and-after observational studies.[39, 48, 62, 157, 164, 170-174, 176, 181, 183, 184] We rated the quality of the studies (good, fair and poor) by awarding stars in each domain following the guidelines of the Newcastle–Ottawa Scale as described in ***section 2.4.3***.[31]

Three studies[62, 170, 183] received a 'good quality' rating (6 stars or more). Jung et al.[62] received 8 stars (in all domains except selection – outcome not present at the beginning). McDonnell et al.[183] and Merriel et al.[170] both received 6 stars (in all domains except representativeness of the exposed cohort, outcome not present at the beginning and comparability of cohorts in the analysis phase). Five studies were considered 'fair quality' or '5 stars' in total.[48, 157, 164, 174, 181] The aspects where they scored well were for selection of the non-exposed cohort,[48, 157, 164, 174, 181] ascertainment of exposure,[48, 157, 164, 174, 181] comparability in the design[157, 174] or analysis phase,[164, 174, 181] assessment of the outcome,[48, 157, 164, 174, 181] sufficient follow-up for the outcome to occur,[48, 157, 181] and adequate follow-up.[48, 164] Six were considered 'poor quality' and received 'less than 4 stars' in total.[171-173, 176, 182, 186]

Table 9.3 Quality Assessment of before-and-after studies

Study	Selection				Comparability		Outcome			Overall Quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts in analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
Cahill (2011)[164]	One tertiary hospital, Australia.	*	*	Documentation of vital signs being measured before the intervention.	*	Non-randomised, uncontrolled, study.	*	Only 3 months post intervention.	*	5 * (FAIR QUALITY)
De Meester (2013) [48]	Single hospital, Belgium.	*	*	Cannot say the outcomes of interest did not exist pre-intervention.	Confounding is an issue.	Confounding is an issue.	*	*	*	5 * (FAIR QUALITY)
Hammond (2013)[174]	One tertiary hospital, Australia, ICU patients	*	*	Documentation of vital signs being measured before the intervention.	*	*	*	Only 3 months post intervention, for a period of 24 hours only – small ICU sample size.	Not reported.	5 * (FAIR QUALITY)
Jung et al (2016)[62]	*	*	*	Statement of 'no history of CA or ICU admission' was not provided	*	*	*	*	*	8 * (GOOD QUALITY)
McDonnell et al (2012)[183]	N=247 nurses drawn from a single hospital	*	*	Cannot state this categorically.	*	Does not control for additional factors in analysis phase	*	*	*	6* (GOOD QUALITY)

Table 9.3 Quality Assessment of before-and-after studies [continued]

Study	Selection				Comparability		Outcome			Overall Quality
	S1 Exposed cohort representative	S2 Selection of non-exposed cohort	S3 Ascertainment of exposure	S4 Outcome not present at beginning	C1 Comparability of cohorts in design phase	C2 Comparability of cohorts in analysis phase	O1 Assessment of outcome	O2 Follow-up sufficient for outcome to occur	O3 Adequate follow-up	Total stars
Sebat et al (2018)[157]	One regional hospital	*	*	Statement of 'no history of CA' was not provided	*	Does not control for additional factors in analysis phase	*	*	Prospective study however no flow diagram provided	5 * (FAIR QUALITY)
Shaddel (2014)[173]	Single psychiatric unit, UK.	Nurses completed pre-test survey and post-test survey – no control group.	Self-reported survey post training	*	Confounding is an issue.	Confounding is an issue.	Self-completed post-intervention survey.	Immediately after training.	Not reported.	1 * (POOR QUALITY)
Wood (2015)[182]	Single hospital, UK)	*	*	Cannot say the outcomes of interest did not exist pre-intervention.	Confounding is an issue.	Confounding is an issue.	*	*	Not reported.	4 * (POOR QUALITY)

Key: ICU: Intensive Care Unit; LOS: Length of Stay; MCQ: Multiple Choice Questionnaire; eMEWS; Electronic Modified Early Warning Score

9.5 Certainty of the evidence

The effectiveness of educational interventions in detecting physiological deterioration in adult (non-pregnant) patients in acute health care settings

We assessed the overall certainty of the evidence where appropriate. A narrative summary of findings table was created using GRADEpro software for the following primary outcomes: knowledge and performance/confidence. Patient outcomes were not included as these were reported in very heterogeneous ways (for example as SAEs,[48] oxygen therapy administered,[9] MET calls,[175] all-cause hospital mortality,[39] RRT survival rate,[172] and unscheduled ICU admissions[182]). Overall the certainty of the evidence is very low owing to a high risk of bias in the various study designs, a high risk of confounding and the overall generalisability of the results as all of the studies were conducted in single centre settings in various countries where the findings may not be applicable to other health care settings (

Patient or population: nurses, doctors, other healthcare professionals
Setting: varied (hospital, university simulation lab)
Intervention: educational interventions (including virtual or mannequin-based simulation, validated education programmes such as COMPASS®, hospital specific educational interventions) delivery either face-to-face or blended (online component).
Comparison: another educational intervention, or no educational intervention

Outcomes	Impact	№ of participants (studies)	Certainty of the evidence (GRADE)
Knowledge	All 8 studies demonstrated a significant increase in knowledge post-educational intervention.	755 (8 studies including 4 RCTs, and 4 before and after studies)	⊕◯◯◯ VERY LOW [a,b,c]
Performance/confidence	All 10 studies demonstrated a significant increase in clinical performance or self-confidence post-educational intervention.	789 (10 studies including 5 RCTs, 1 nRCT and 4 before and after studies)	⊕◯◯◯ VERY LOW [a,b,c]

The risk in the intervention group (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).CI: Confidence interval.
GRADE Working Group grades of evidence
High certainty: We are very confident that the true effect lies close to that of the estimate of the effect
Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

).

The effectiveness of educational interventions in detecting physiological deterioration in adult (non-pregnant) patients in acute health care settings

Table 9.2 Summary of finding table for the quality of the evidence

Patient or population: nurses, doctors, other healthcare professionals
Setting: varied (hospital, university simulation lab)
Intervention: educational interventions (including virtual or mannequin-based simulation, validated education programmes such as COMPASS®, hospital specific educational interventions) delivery either face-to-face or blended (online component).
Comparison: another educational intervention, or no educational intervention

Outcomes	Impact	№ of participants (studies)	Certainty of the evidence (GRADE)
Knowledge	All 8 studies demonstrated a significant increase in knowledge post-educational intervention.	755 (8 studies including 4 RCTs, and 4 before and after studies)	⊕◯◯◯ VERY LOW [a,b,c]
Performance/confidence	All 10 studies demonstrated a significant increase in clinical performance or self-confidence post-educational intervention.	789 (10 studies including 5 RCTs, 1 nRCT and 4 before and after studies)	⊕◯◯◯ VERY LOW [a,b,c]

The risk in the intervention group (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).CI: Confidence interval.
GRADE Working Group grades of evidence
High certainty: We are very confident that the true effect lies close to that of the estimate of the effect
Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

Explanations

a. Downgraded two levels for risk of bias: High or unclear risk of bias: no blinding of participants and/or personnel in RCTs and risk of confounding in observational studies
b. Downgraded one level for inconsistency: single centre study -may not be generalisable to other settings
c. Downgraded one level for imprecision: small sample size

9.6 Discussion

This systematic review update of the effectiveness of educational interventions to improve the detection of physiological deterioration in adult (non-pregnant) patients in acute health care settings included 23 studies. Evidence from the review suggests that educational interventions (including mannequin- or virtual-based simulation, validated programmes such as COMPASS® or FIRST^{2}ACT, or hospital specific programmes) succeed in increasing healthcare staff (predominantly nursing staff) knowledge, clinical performance and self-confidence to recognise and manage a deteriorating patient, at least in the short term. The evidence also shows improvements in the documentation of vital signs and the use of EWS post-educational intervention, but was mixed for the effect on patient outcomes including ICU admission, length of stay and cardiac arrest. Communication (through the use of standardised tools such as ISBAR, SBAR and ABCDE) between nurses and doctors in relaying a deteriorating patient and escalation improved post-training in the majority of the 23 studies in the short term at least (i.e. immediately post-intervention).

There is however a lack of high quality evidence to evaluate the effect of EWS educational programmes due to a number of factors. These include small sample size, a variation in the educational programmes (interventions) used (validated programmes such as COMPASS®, simulation, local hospital specific educational programmes), differences in how the effect of the intervention is measured (self-reported compared with using a validated tool such as RAPIDs or retrospective review of patient records and observation charts), duration of follow-up of the outcomes (immediately post-intervention, three or six months later), the definition of outcomes, how they were reported and the variety of outcomes examined varied from study to study. The settings varied also (some were in hospitals while others were in simulated non-clinical settings).

Future research is needed to address limitations highlighted in this review. Ideally study designs of a more rigorous methodological quality are needed, preferably further RCTs where blinding is maintained, including a large sample size of a range of HCPs and not just

nurses to minimise bias. A standardised approach to the educational interventions used, the measurement of their effect (using a validated tool) and a core set of outcomes (with standardised definitions, which can be objectively measured with a focus on important clinical outcomes for example length of stay or ICU transfers) are warranted.

9.7 Conclusion

The findings from the studies included which look at educational interventions and their effect on healthcare staff and improving the detection and management of physiological deterioration in adult patients in acute settings are of poor quality overall. However, educational interventions typically resulted in a short term improvement in knowledge, clinical performance, self-confidence, documentation of vital signs and nurse-physician communication.

10 Findings from the economic literature on the implementation of EWSs or track and trigger systems for the detection of acute physiological deterioration in adult (non-pregnant) patients in acute health care settings.

10.1 Chapter overview

This chapter in the systematic review update focusses on the literature relevant to question four of the review, "*What are the findings from the economic literature on cost-effectiveness; cost-impact and resources involved with the implementation of EWSs or track and trigger systems for the detection of or timely identification of physiological deterioration in adult (non-pregnant) patients in acute health care settings?*" The characteristics of the included studies are described as well as the findings from each study reported, and the methodological quality and transferability of the included studies is assessed. In accordance with national health technology assessment (HTA) guidelines, the costs from previous economic evaluations were adjusted and are presented in 2017 euro.[21]

10.2 Characteristics of the economic studies included in the review

In total, three studies were eligible for inclusion. These included one health technology assessment (HTA) on the implementation of an electronic NEWS,[3] one budget impact analysis (BIA) as part of National Clinical Guideline (NCG) No. 1 (The NEWS)[4] and one costing study.[5] Two studies were conducted in Ireland,[3, 4] and one in the Netherlands.[5] Two of the studies included the NEWS, [3, 4] and one included the implementation of a rapid response system (RRS).[5] The populations included acute adult inpatients,[3] acute medical patients,[4] and surgical patients.[5] Hospital or ICU length of stay (LOS) were the key clinical outcomes included (**Table 10.1**).

Table 10.1 Characteristics of studies included in the economic systematic review

Study author (year), country	Intervention	Design (no. of studies)	Condition(s) or population targeted	Type of economic evaluation	Clinical Outcomes
[3] HIQA (2015), Ireland	Electronic NEWS	Systematic review with BIA (n=3)	Acute hospital, adult in-patient services excluding maternity and paediatrics	HTA including a BIA using data from a UK study to estimate costs.	Hospital LOS
[4] NCEC (2013), Ireland	NEWS	Systematic review with BIA (n=2)	Adult acute medical patient	BIA	Reduction in ICU bed days
[5] Simmes (2014), The Netherlands	Implementation of a RRS	Before-after study	Surgical patients >3 days post major surgery	Costing study	ICU LOS

Key: HIQA: Health Information and Quality Authority; **NCEC**: National Clinical Effectiveness Committee; **NEWS**: National Early Warning Score; **NCG**: National Clinical Guideline; **RRS**: Rapid Response System; **BIA**: Budget Impact Analysis; **AMU**: Acute Medical Unit; **HTA**: Health Technology Assessment; **ICU**: Intensive Care Unit; **LOS**: Length of stay.

10.3 Results

A narrative synthesis of the results is presented given the heterogeneous nature of the economic studies included.

10.3.1 HIQA 2015 Health Technology Assessment of the implementation of an electronic EWS

The HTA conducted by HIQA in 2015[3] on the use of information technology for early warning and clinical handover systems evaluated the resources that would be required to introduce an electronic EWS in an Irish hospital (530-bed) setting compared to no EWS, as well as the resources gained (reduced hospital LOS). Data from a UK study by Jones et al.,[88] were used to estimate reductions in LOS by applying them to Irish LOS data. The results showed average LOS on a general ward was reduced by 28.9% (CI 18.6% - 40.3%) and ICU average LOS by 40.3% (4.6% - 76%), leading to additional national hospital capacity of 802,096 bed days per annum relative to a total capacity of 2.8 million acute hospital bed

days per annum and 30,628 ICU bed-days per annum relative to a total capacity of 76,000 ICU bed days per annum (***Table 10.2***). This was considered an efficiency gain rather than a monetary saving as the beds would be used for other patients. The electronic EWS was also found to be 1.6 times faster than a paper EWS leading to a reduction in staff time spent recording vital signs (not included in BIA as opportunity savings). The costs of changing to an electronic EWS were examined over a five year period from a healthcare system perspective. Resources were split into technology-based costs (hardware, software and integration fees) and implementation costs (staff, education, clinical leadership and project management). Two types of license fees were examined (annual fee and once off payment) with the annual licence fee being the best value for money: €1,017,880 (€1,042,614) per site compared to €1,332,272 million euros per site (€1,364,646) over five years. The HTA indicated there is some evidence that the implementation of electronic EWS has contributed to reduced mortality rates and a change in general and ICU LOS (which varied from a minimal relative reduction up to 40.3% and 76% reductions, respectively). Improved efficiency and accuracy of recording vital sign parameters, compliance with escalation protocols and significant user (clinician) satisfaction were also reported. However, as the quality of the included studies of effectiveness was variable and the interventions performed in a range of healthcare jurisdictions with a variety of outcomes measured, the ability to generalise the findings to the Irish healthcare context may be limited (**Table 10.2**).

10.3.2 NCEC 2013 NEWS NCG No.1

A budget impact analysis (BIA) was conducted for the original NEWS NCG No. 1 in 2013,[(1)] to assess the costs of implementing the NEWS and the accompanying multidisciplinary COMPASS™ educational programme. Taking a healthcare perspective initial implementation costs (staff education and material) as well as on-going intervention costs (staff and non-staff costs) were included in the BIA. Initial costs (these were the one off costs incurred during the initial roll out of the COMPASS© education programme nationally) were estimated at 7.47 million euros (most of this was related to staff costs to attend training and

was therefore an opportunity cost, cost year was not reported) with on-going costs estimated at 425,000 euros annually. Additional resources would be required due to the expected increase in response rate triggers, but no cost estimates were provided within the BIA. Annual savings were reported at 4.2 million euros (reduction in ICU bed days from cardiac respiratory arrests based on a single study, estimates not reported in study) in efficiency savings rather than monetary gains (**Table 10.2**).

10.3.3 Simmes 2014 Implementation of a RRS

The costs before and after the introduction of a RRS (which consisted of a clinician-led MET triggered by a single-parameter EWS) on a surgical ward in a Dutch hospital were estimated in a cost analysis study by Simmes et al.[5] The RRS was associated with a significant absolute increase in ICU admissions (from 2.5% – 4.2%) without a decrease in severity of illness (mean APACHE II score 17.5 versus 17.6) and median ICU LOS (3.5 days versus 3 days, *P* = 0.94) and a 0.25% absolute reduction in cardiac arrest. There was no change in-hospital LOS as a result of implementing the RRS. Mean cost per patient of the RRS was €26.87 euros (€28.46), including implementation and maintenance (1%), training (3%), nursing time (8%), MET consults (2%) and extra unplanned ICU days (85%). A scenario analysis was also performed, whereby the APACHE II score was reduced to 14. This reduced the mean daily RRS costs per patient by over 60%, even when MET consults had increased by one third and ICU admissions by one fifth. In this scenario analysis mean RRS costs per patient day were reduced by €16.69 (62%) to €10.18 (€10.78); MET costs increased by €0.19 to €0.76 and costs for extra unplanned ICU days decreased by €16.90 to €5.99. The scenario analysis demonstrated that reducing the APACHE II score to 14, whereby less severely ill patients are referred to ICU, could reduce costs. Overall, RRS costs (including implementation, maintenance, training, nurse time and MET consultations) were considered low by Simmes et al.,[5] but the costs for extra unplanned ICU days after implementation of the RRS were high (**Table 10.2**).

Table 10.2 Results of the economic studies included in the review

Author, country (year)	Population and Interventions	Analysis details	Costs and clinical outcomes	Analysis of uncertainty	Results
[3]HIQA, Ireland (2015)	**Population:** Model 4, 530-bed teaching hospital, adult in-patient services excluding maternity and paediatrics **Intervention:** Electronic NEWS **Comparator:** Paper-based EWS	**Analysis type: BIA** The benefit estimates were based on extrapolated results from a study[88] identified in the systematic review that most closely represented the Irish context and which reported on the impact on LOS. **Perspective:** Health care perspective **Time horizon:** 5 years **Discount rate:** Not applicable	**Currency & cost year:** Irish euro, 2013. **Cost components:** Technology-based costs (hardware, software and integration fees) and implementation costs (staff, education, clinical leadership and project management). Two types of licence fees were examined (annual fee and once off payment). **Clinical outcomes:** Reduction in LOS, from a single study deemed applicable.	The cost of license fees, maintenance and hardware were varied by 20%. Initial cost estimates were derived from an NHS pilot study	**Costs (over five years):** five year national investment requirements have been estimated as €40.1m and €51.4m for Type 1 and Type 2 licenses, respectively. Total costs per site (Type 1 licence): €1,017,880 Total costs per site (Type 2 licence): €1,332,272 Breakdown of costs: Project management: Type 1, €227,453, Type 2: €119,200 Licence fees, hardware and maintenance: Type 1: €767,117 Type 2: €1,189,762 Staff training: Type 1: €23,310 Type 2: €23,310 **Clinical outcomes:** Relative risk reduction in average LOS by 28.9% (95% CI 18.6%-40.3%) and ICU ALOS by 40.3% (4.6% - 76%), leading to additional national hospital capacity of 802,096 bed days per annum and 30,628 ICU bed-days per annum.
[4]NCEC, Ireland (2013)	**Population:** Adult acute medical patients **Intervention:** NEWS and COMPASS™ educational programme **Comparator:** Current practice	**Analysis type:** BIA **Perspective:** Health care perspective **Time horizon:** 12 months **Discount rate:** Not applicable	**Currency & cost year:** Irish euro, not specified. **Cost components:** Initial phase: Staff (Trainees, Trainers), Non-staff (Materials (Manuals, CDs, Sample Observation Charts and ISBAR charts). On-going intervention costs: Non-staff (NEWS charts), Staff (Additional measurements, Charting score, Additional resources to respond to trigger, Ongoing education) **Clinical outcomes:**	Not reported in study.	**Costs:** Total implementation costs (initial phase [These are the one off costs which will be incurred during the initial roll out of the COMPASS© education programme nationally]): €7,490,400 Total on-going intervention costs: €425,000 per annum. Initial phase: Non-staff: €18,000 (once off cost in rolling out COMPASS™) Staff: Trainees (€7.3 million, opportunity costs), Trainers (€172,400) Education initial phase: €18,000 (materials); On-going: €425,000 per annum ALERT™ licence fee: The COMPASS© Education Programme replaced the ALERT™ system which included an annual licence fee of approximately €600 which was being paid by 10 hospitals. Thus moving to COMPASS© resulted in an annual saving of €6,000.

Author, country (year)	Population and Interventions	Analysis details	Costs and clinical outcomes	Analysis of uncertainty	Results
			ICU bed days		**Clinical outcomes:** €4.2 million per annum (reduction in ICU bed days, CRAs)
[5]Simmes, The Netherlands (2014)	**Population:** Surgical patients >3 days post major surgery. There were 1,376 patients in period 1 (before, 1 year) and 2,410 patients in period 2 (after, 2 years). **Intervention:** Implementation of a RRS **Comparator:** 1,376 patients in period 1 (before, 1 year).	**Analysis type:** Costing study. **Perspective:** Health care perspective **Time horizon:** 24 months. **Discount rate:** Not applicable.	**Currency & cost year:** Dutch Euro, 2009 **Cost components:** Training, staff, MET consults, Coordination and continuation costs **Clinical outcomes:** LOS, Unanticipated ICU admissions, ICU LOS	A scenario analysis was performed, where the APACHE II score was reduced to 14, whereby less severely ill patients were referred to ICU. This reduced the mean daily RRS costs per patient by over 60%, even when MET consults had increased by one third and ICU admissions by one fifth. Scenario analysis: mean costs per patient day were €10.18.	**Costs:** Mean RRS costs were €26.87 per patient-day. Which consisted of Implementation: €0.33 (1%) Training: €0.90 (3%) Nursing time spent on extended observation of vital signs: €2.20 (8%) MET consults: €0.57 (2%) Increased number of unplanned ICU days after RRS implementation: €22.87 (85%) Total coordination and continuation cost of RRS: €3,618 per annum. (Additional workload coordination: 1 x nurse hour per week: €1,568; and continuation 20 nurse hours per year and 10 doctor hours per year: €2,050) Training total: €27,291 or €0.90 per patient day (3% of mean RRS cost per day). **Clinical outcomes:** A non-significant decrease in cardiac arrest and/or unexpected death from 0.5% to 0.25% (statistical tests not provided). A significant increase in the number of unplanned ICU admissions after implementation (2.5% versus 4.2%), without a decrease in severity of illness (mean APACHE II score 17.5 versus 17.6) and median ICU LOS (3.5 days versus 3days, *P* = 0.94) Hospital LOS was unchanged

Key: HIQA: Health information and Quality Authority**; NCEC:** National Clinical Effectiveness Committee**; RRS:** Rapid Response System; **MET:** Medical Emergency Team; **LOS:** Length of stay; **ICU:** Intensive Care Unit.

10.4 Methodological quality and transferability

The quality of the included studies was assessed by two reviewers using the CHEC-list tool (The Consensus Health Economic Criteria list)[27] and the transferability of included studies was assessed using the ISPOR tool (International Society for Pharmacoeconomics and Outcomes Research).[28] Where the criteria were applicable to the included studies, the quality of the studies was judged to be good overall. However, given that the studies were not full economic evaluations, a number of the criteria were not relevant or applicable. In addition, some of the costs reported are based on findings from a single hospital or trial which may not be transferable to the Irish setting, given the heterogeneity of such settings.

10.4.1 CHEC-list quality appraisal

The 19-item CHEC-list tool was applied to the three included studies, including two BIAs and one costing study. The majority of the CHEC-list items were adequately described in all three studies. Competing alternatives were not reported in the NCEC BIA (item 2).[1] Important and relevant costs for each alternative were not included in the costing study (Item 7).[5] An incremental analysis of costs and outcomes of alternatives was not performed in any of the studies (Item 13) and discounting was not applicable to any of the three studies (Item 14). Sensitivity analyses were only reported in the HIQA BIA (Item 15).[3] None of the studies discussed the generalisabilty of the results to other settings or patient groups (Item 17). One study did not report on conflicts of interest (Item 18).[5] Ethical issues were not applicable to all three studies (Item 19) (**Table 10.3**).

10.4.2 ISPOR transferability tool

The 11-item ISPOR tool was used to assess the included studies transferability based on the relevance and credibility (validation, model design, data, analysis, reporting, interpretation of results and conflict of interest). For the 'relevance' domain, all three studies were deemed to have suitable and relevant populations (item 1), no missing critical interventions (item 2), no missing outcomes (item 3), and were deemed to be based in an appropriate

setting (item 4). For the 'credibility' domain, as none of the studies included full economic models (there were two BIAs and one costing study) the model specific items on the checklist were not applicable as a result (items 1, 2 and 3 in *validation*). For *design (*item 4), the costing study was not applicable as there was no model included,[5] whilst the two BIAs were judged to be appropriate. For *data* (item 5), and *analysis* (items 6 and 7) the HIQA BIA[3] was deemed appropriate as the data included was based on a systematic review and included an analysis of uncertainty, whilst the two other studies were deemed inappropriate given the data were from a single study which may not be transferable and provided no uncertainty analyses. For *reporting* (item 8) and i*nterpretation* (item 9) all three studies provided adequate information. A conflicts of interest statement (item 10) was not reported in the costing study[5] and item 12 (steps taken to address any conflicts of interests) was not applicable to all three studies (**Table 10.4**).

Table 10.3 CHEC-list quality appraisal of included economic studies

Quality appraisal using the Consensus on Health Economics Criteria (CHEC) Item	HIQA (2015)	NCEC (2013)	Simmes (2014)
1. Is the study population clearly described?	+	+	+
2. Are competing alternatives clearly described?	+	–	+
3. Is a well-designed research question posed in answerable form?	+	+	+
4. Is the economic study design appropriate to the stated objective?	+	+	+
5. Is the chosen time horizon appropriate to include relevant costs and consequences?	+	+	+
6. Is the actual perspective chosen appropriate?	+	+	+
7. Are all important and relevant costs for each alternative identified?	+	+	–
8. Are all costs measured appropriately in physical units?	+	+	+
9. Are costs valued appropriately?	+	+	+
10. Are all important and relevant outcomes for each alternative identified?	+	+	+
11. Are all outcomes measured appropriately?	+	+	+
12. Are outcomes valued appropriately?	+	+	+
13. Is an incremental analysis of costs and outcomes of alternatives performed?	–	●	–
14. Are all future costs and outcomes discounted appropriately?	●	●	●
15. Are all important variables, whose values are uncertain, appropriately subjected to sensitivity analysis?	+	–	–
16. Do the conclusions follow from the data reported?	+	+	+
17. Does the study discuss the generalizability of the results to other settings and patient/ client groups?	–	–	–
18. Does the article indicate that there is no potential conflict of interest of study researcher(s) and funder(s)?	+	+	–
19. Are ethical and distributional issues discussed appropriately?	●	●	●

Key: + = Yes, category considered; – = No, category not considered; ● =Not applicable

Table 10.4 ISPOR Transferability assessment of included economic studies

Transferability using the ISPOR tool	HIQA (2015)	NCEC (2013)	Simmes (2014)
Relevance			
1. Is the population relevant?	Yes	Yes	Yes
2. Are any critical interventions missing?	No	No	No
3. Are any relevant outcomes missing?	No	No	No
4. Is the context (settings and circumstances) applicable?	Yes	Yes	Yes
Credibility			
Validation			
1. Is external validation of the model sufficient to make the results credible for your decision?	NA	NA	NA
2. Is internal verification of the model sufficient to make its results credible for your decision?	NA	NA	NA
3. Does the model have sufficient face validity to make its results credible for your decision?	Yes	Yes	NA
Design			
4. Is the design of your model adequate for your decision problem?	Yes	Yes	No
Data			
5. Are the data used in populating the model suitable for your decision problem?	Yes	No	No
Analysis			
6. Were the analyses performed using the model adequate to inform your decision problem?	Yes	No	No
7. Was there an adequate assessment of the effects of uncertainty?	Yes	No	No
Reporting			
8. Was the reporting of the model adequate to inform your decision problem?	Yes	Yes	Yes
Interpretation			
9. Was the interpretation of results fair and balanced?	Yes	Yes	Yes
Conflict of interest			
10. Were there any potential conflicts of interest?	No	No	NR
11. If there were potential conflicts of interest, were steps taken to address these?	NA	NA	NA

Key: NA=Not applicable (no model); **NR**=Not reported

10.5 Discussion

There is a dearth of economic literature on EWSs in adult non-pregnant patients in the acute health care setting to detect physiological deterioration, as evidenced by this systematic review. Of the three included studies, there were no full economic evaluations of EWSs in adult patients in acute settings. There was however a HTA on electronic EWS, one BIA on EWS, and one costing study (on the implementation of a single parameter-based RRS and the associated costs). In addition, some of the costs and clinical outcomes reported are based on findings from a single hospital or trial, also the currency of the studies may be an issue with no new studies identified during this review update. Thus they may not be transferable to the current Irish setting. The studies included however suggest that EWS have the potential to improve patient outcomes including ICU and hospital LOS and thus reduce health care costs (including potential reduction in cardiac arrests, avoidance of ICU admissions or reduced LOS for example). There is a need to assess the cost-effectiveness of EWSs and a full economic evaluation is warranted. Difficulties in obtaining reliable data however (***Chapters 5-7***), are a significant barrier.

10.6 Conclusion

EWSs, despite the lack of economic data on their cost-effectiveness, have been implemented in many healthcare systems in a number of different countries including Ireland, the UK, America and Australia. Further research is warranted to assess the cost-effectiveness of EWSs given the increasing demands on health systems worldwide.

11 Comparison of the effectiveness of modified EWSs (e.g. CREWS) to the NEWS for the detection of acute physiological deterioration in specific adult subpopulations in acute health care settings

11.1 Chapter overview

This chapter of the systematic review focusses on the literature pertinent to review question five, "*Are modified EWSs [e.g. CREWS] more effective than the NEWS for the detection or timely identification of physiological deterioration in specific adult subpopulations in acute health care settings?*". Two specific sub-populations were eligible for inclusion: 1) Frail older adults (must be defined with a validated frailty scale for inclusion); 2) Adults with chronic respiratory conditions including chronic hypoxia, chronic hypoxaemia, chronic physiological abnormalities, pulmonary fibrosis or chronic obstructive pulmonary disease (COPD). The effectiveness of any modified EWS in these two populations was compared to the NEWS only.

11.2 Characteristics of included studies

Following a systematic search of the literature (please refer to ***Chapter 3, 3.1***), there were four studies eligible for inclusion in this specific review question, all of which included patients with chronic respiratory conditions which compared a modified EWS (NEWS2, CREWS, S-NEWS, and CROS) to the NEWS.[13, 60, 111, 187]

Three studies were conducted in the UK[13, 114, 192] and one in Denmark.[86] All four studies had retrospective cohort designs and all were conducted within hospitals.[13, 60, 111, 187] The sample size ranged from 196 patients[13] to 251,266 patients.[192] One study compared the CREWS modified EWS to the NEWS, [13] the second study compared NEWS2 to the NEWS,[192] the third study compared the CROS, CREWS and S-NEWS to the NEWS,[86] and the fourth study compared the CREWS and S-NEWS to the NEWS.[114] All of the modified EWSs had the same seven parameters as the NEWS and differed only in the weighting assigned to the SpO_2 parameter (***Table 11.1, Table 11.2***).

Table 11.1 Characteristics of EWSs (modified EWSs versus the NEWS) for the detection of acute physiological deterioration in adults with chronic respiratory conditions in acute health care settings

Author, country	No of parameters, Name of EWSs	Parameters included in EWSs								Paper based or electronic	Recording of parameters	Aggregate EWS, score
		RR	SpO_2	FiO_2	SBP	HR	AVPU	Temp	Other –specify modification/ difference in weighting of scores			
Eccles (2014),[13] UK	NEWS vs.	x	x	x	X	x	x	x	Target SpO_2: 94-98%	Paper-based	Not reported	Yes (0-3)
	7-item CREWS	x	x	x	X	x	x	x	Target SpO_2: 88-92%			Yes (0-3)
Hodgson (2017)[111], UK	News vs. CREWS vs. S-NEWS	Parameters not reported within study								Electronic	Not reported	Not reported
Pedersen (2018),[60] Denmark	NEWS vs.	x	x	x	X	x	x	x		Electronic	Semi-automatic	Yes (0-3)
	CROS vs.	x	x	x	X	x	x	x	Option for doctors to apply acceptable chronic value limits to all parameters except temperature for individual patients. NEWS variable values within the acceptable chronic value limits do not generate points. NEWS variable values outside the acceptable chronic limits generate the full NEWS points for that variable value.			
	CREWS vs.	x	x	x	X	x	x	x	Points as in NEWS, except modified score for SpO_2 in patients with chronic hypoxaemia (88-92%)			
	S-NEWS	x	x	x	X	x	x	x	Points as in NEWS, except modified score for SpO_2 based on an individual target range in patients with chronic hypoxaemia. (usually 88-92%)			
Pimental (2018),[187] UK	NEWS vs.	x	x	x	X	x	x	x		Electronic	Time and date stamped	Yes (0-3)
	NEWS2	x	x	x	X	x	x	x	Differs in weights assigned to SpO_2 only (below 88%)			

Key: EWS: Early warning system; **CREWS:** Chronic respiratory EWS; **CROS:** Capital Region of Denmark NEWS Orverride System; **S-NEWS:** Salford NEWS; **NEWS:** National early warning score; **RR:** Respiratory rate; **SpO_2:** Oxygen saturation; **FiO_2:** Inspired oxygen; **SBP:** Systolic blood pressure; **HR:** Heart rate; **AVPU:** Alert, voice, pain, unresponsive; **Temp:** Temperature.

Table 11.2 Comparison of the effectiveness of modified EWSs to the NEWS in adults with chronic respiratory conditions sub-populations

Author, study design	Setting, Country	A. Sample size and details B. Data collection C. Model	AUROC, outcome	Sensitivity, Specificity, Outcome	PPV,NPV, Outcome	Identifying optimal threshold cut-offs, Outcome
Eccles (2014),[13] Retrospective cohort study	2 NHS district general hospitals, UK.	A. N=196 admission to the respiratory ward between Aug - Oct 2012. B. Data obtained from medical notes and observation charts with NEWS scores recorded prospectively. Patients split into 2 groups: CH patients (with target SpO_2 of 88-92%) and oxygen patients (O), those with SpO_2 target saturations of 94-98%. The CREWS score was then retrospectively applied for comparison. C.AUC with 95% CI	**Primary outcome: 30-day mortality** CH patients NEWS: AUC 0.88 (95% CI 0.79-0.96); CH patients CREWS: AUC 0.91 (95% CI 0.85-0.98); All patients NEWS: AUC 0.83 (95% CI 0.70-0.96); O patients NEWS: AUC 0.75 (95% CI 0.52-0.98)			
Hodgson (2017),[111] Observational retrospective cohort study	2 UK hospitals.	A: N=39,470 patients admitted between Mar 2012 and Feb 2014 (n=2,361 admissions in 942 individuals with an acute exacerbation of COPD (AECOPD) and n=37,109 non-COPD admissions in 20,415 comparison patients) B. NEWS calculated automatically using handheld electronic devices and compared to the CREWS and S-NEWS to predict inpatient mortality. C: AUROC analysis	**Primary outcome: Inpatient mortality** **First admissions:** AECOPD cohort: NEWS=AUC 0.74 (95% CI 0.66-0.82) CREWS=AUC 0.72 (95% CI 0.63 to 0.80) S-NEWS=AUC 0.62 (95% CI 0.53 to 0.70). AMU cohort NEWS=AUC 0.77 (95% CI 0.75 to 0.78) **All inpatient episodes** AECOPD cohort NEWS=AUC 0.69 (95% CI 0.64 to 0.75), CREWS=AUC 0.70 (95% CI 0.64 to 0.75) S-NEWS=AUC 0.67 (95% CI 0.61 to 0.72). AMU cohort NEWS=AUC 0.75 (95% CI 0.74 to 0.76)	**Primary outcome: Inpatient mortality** For AECOPD cohort, for their first admission, using Score ≥5 COPD: NEWS: Sen 76% (61 to 88) Spec 57% (54 to 61) CREWS: Sen 48% (32 to 64) Spec 88% (85 to 90) S-NEWS: Sen 24% (12 to 39) Spec 91% (89 to 93) For AMU cohort, for their first admission, using Score ≥5 COPD: NEWS: Sen 43% (40 to 46) Spec 90% (90 to 91) For AECOPD cohort, for their first admission, using Score ≥7 COPD: NEWS: Sen 60% (43 to 74) Spec 80% (77 to 83) CREWS: Sen 13% (6 to 23) Spec 96% (95 to 97) S-NEWS: Sen 14% (5 to 29) Spec 95% (94 to 97) For AMU cohort, for their first admission, using Score ≥7 COPD: NEWS: Sen 25% (23 to 28) Spec 96% (96 to 97)	**Primary outcome: Inpatient mortality** For AECOPD cohort, for their first admission, using Score ≥5 COPD: NEWS: PPV 8% (5 to 11) 98% (97 to 99) CREWS: PPV 15% (10 to 23) NPV 97% (96 to 98) S-NEWS: PPV 11% (5 to 19) NPV 96% (95 to 97) For AMU cohort, for their first admission, using Score ≥5 COPD: NEWS: PPV 17% (16 to 19) NPV 97% (97 to 97) For AECOPD cohort, for their first admission, using Score ≥7 COPD: NEWS: PPV 12% (8 to 18) NPV 98% (96 to 99) CREWS: PPV 21% (10 to 37) NPV 93% (91 to 95) S-NEWS: PPV 12% (5 to 25) NPV 96% (95 to 97) For AMU cohort, for their first admission, using Score ≥7 COPD: 25% (22 to 28) NPV 96% (96 to 97)	-

Table 11.2 Comparison of the effectiveness of modified EWSs to the NEWS in adults with chronic respiratory conditions sub-populations [continued]

Author, study design	Setting, Country	A. Sample size and details B. Data collection C. Model	AUROC, outcome	Sensitivity, Specificity, Outcome	PPV,NPV, Outcome	Identifying optimal threshold cut-offs, Outcome
Pedersen (2018),[60] Retrospective cohort study	Single hospital in Copenhagen, Denmark	A. N=11,266 patients with a diagnosis of chronic respiratory disease (COPD or chronic hypoxaemia) recorded during 2014. B. All complete NEWS records were used in the data analysis and compared to CROS, CREWS and S-NEWS (modified EWS) to predict 48-hour mortality and ICU admission. C: AUROC analysis.	**Outcome: 48-hour mortality** **NEWS:** AUC 0.85 (95% CI 0.85-0.86) **CROS:** AUC 0.82 (95% CI 0.82-0.83) **CREWS:** AUC 0.85 (95% CI 0.84-0.85) **S-NEWS:** AUC 0.84 (95% CI 0.84-0.85) **Outcome: ICU admission** **NEWS:** AUC 0.79 (95% CI 0.78-0.79) **CROS:** AUC 0.81 (95% CI 0.81-0.82) **CREWS:** AUC 0.81 (95% CI 0.80-0.81) **S-NEWS:** AUC 0.79 (95% CI 0.78-0.80)	**Outcome: 48-hour mortality (6+ points)** **NEWS:** Sen: 73.1 (95% CI 71.7-74.4) Spec: 81.8 (95%CI 81.7-81.9) **CROS:** Sen: 53.4%; Spec: 90% **CREWS:** Sen: 60.7%; Spec: 88.4% **S-NEWS:** Sen: 68.3%; Spec: 83.0% (95% CIs not reported for modified EWSs) **Outcome: ICU admission (6+ points)** **NEWS:** Sen: 60.7% (95% CI 59.3-62.1) Spec: 81.7 (95%CI 81.6-81.8) **CROS:** Sen: 52.4%; Spec: 90.1% **CREWS:** Sen: 54.1%; Spec: 88.4% **S-NEWS:** Sen: 59.1%; Spec: 83.0% Applying any of the NEWS modifications resulted in lower sensitivities and NPV, and higher specificities and PPV, when using a total score of **9** as cut-off levels. Only results for scores of 6 presented.	**Outcome: 48-hour mortality (6 + points)** **NEWS:** PPV :4.0 (95%CI 3.9-4.2) NPV: 99.7 (95%CI 99.6-99.7) **CROS:** PPV: 5.3%; NPV: 99.5% **CREWS:** PPV: 5.2%; NPV: 99.5% **S-NEWS:** PPV: 4.0%; NPV: 99.6% **Outcome: ICU admission (6 + points)** **NEWS:** PPV: 3.9% (95%CI 3.7-4.0) NPV: 99.4% (95%CI 99.4-99.4) **CROS:** PPV: 6.0%; NPV: 99.4% **CREWS:** PPV: 5.3%; NPV: 99.4% **S-NEWS:** PPV: 4.0%; NPV: 99.4%	-

Table 11.2 Comparison of the effectiveness of modified EWSs to the NEWS in adults with chronic respiratory conditions sub-populations [continued]

Author, study design	Setting, Country	A. Sample size and details B. Data collection C. Model	AUROC, outcome	Sensitivity, Specificity, Outcome	PPV,NPV, Outcome	Identifying optimal threshold cut-offs, Outcome
Pimentel (2018),[187] Multicentre, retrospective cohort study	5 acute hospitals from 2 UK NHS Trusts, UK.	A.N=251,266 adult acute admissions Jan 2012 and Dec 2016. B. Data were obtained from completed adult admissions who were not fit enough to be discharged alive on the day of admission with at least 1 complete set of vital signs recorded. Divided into 3 groups: 1) Patients with recorded type II respiratory failure (T2RF) [n=1,394], 2) Patients at risk of T2RF (n=48,898), and 3) Patients not at risk of T2RF (n=202,094). C. AUROC analysis	**Primary outcome: in-hospital death with 24-hours** Patients with documented T2RF: NEWS: AUC 0.86 (95% CI 0.85-0.88); NEWS2: AUC 0.84 (95%CI 0.83-0.85) Patients at risk of T2RF: NEWS: AUC 0.88 (95% CI 0.88-0.88); NEWS2: AUC 0.86 (95%CI 0.86-0.86) Patients not at risk of T2RF (control) NEWS: AUC 0.91 (95%CI 0.910-0.91); NEWS2: AUC 0.89 (95% CI 0.89-0.89) **Primary outcome: unanticipated ICU admission** Patients with documented T2RF: NEWS: 0.81 (0.79 - 0.83); NEWS2: 0.82 (0.80 - 0.84) Patients at risk of T2RF: NEWS: 0.81 (0.81 - 0.82); NEWS2: 0.81 (0.81 - 0.82) Patients not at risk of T2RF (control) NEWS: 0.84 (0.84 - 0.84); NEWS2: 0.83 (0.83 - 0.84) **Primary outcome: Cardiac arrest** Patients with documented T2RF: NEWS: 0.70 (0.65 - 0.75); NEWS2: 0.71 (0.66 - 0.75) Patients at risk of T2RF: NEWS: 0.76 (0.74 - 0.77); NEWS2: 0.74 (0.73 - 0.75) Patients not at risk of T2RF (control) NEWS: 0.78 (0.78 - 0.79); NEWS2: 0.77 (0.76 - 0.78) **Secondary outcome post hoc:** SAE (composite of death, ICU admission or cardiac arrest) Documented T2RF NEWS: 0.83 (0.82 - 0.85); NEWS2: 0.83 (0.82 - 0.84) At risk T2RF NEWS: 0.86 (0.85 - 0.86); NEWS2: 0.84 (0.84 - 0.85) Patients not at risk of T2RF (control) NEWS: 0.88 (0.88 - 0.88); NEWS2: 0.87 (0.86 - 0.87)	**Primary outcome: in-hospital death within 24 h** Documented T2RF Score>5 / Score>7 NEWS: Sen 90.7 / 73.9, Spec 57.8 / 88.8 NEWS2: Sen 80.9 / 60.1, Spec 68.8 / 87.3 At risk T2RF Score>5 / Score>7 NEWS: Sen 78.5 / 57.6, Spec 82.4 / 93.9 NEWS2: Sen 73.2 / 51.8, Spec 80.6 / 83.6 Patients not at risk of T2RF (control) Score>5 / Score>7 NEWS: Sen 72.0 / 51.7, Spec 93.6 / 98.1 NEWS2: Sen 73.5 / 54.5, Spec 87.4 / 95.7	**Primary outcome: in-hospital death within 24 h** Documented T2RF Score>5 / Score>7 NEWS: PPV 2.5 / 4.6 NEWS2: PPV 3.0 / 5.3 At risk T2RF Score>5 / Score>7 NEWS: PPV 3.2 / 6.6 NEWS2: PPV 2.7 / 5.7 Patients not at risk of T2RF (control) Score>5 / Score>7 NEWS: PPV 5.0 / 11.2 NEWS2: PPV 2.7 / 5.7	**Outcome: in-hospital death within 24-hours** Patients with documented T2RF: NEWS2 at cut-offs of 5 &7 reduces absolute staff workload by approximately 11% and 5% respectively, reduces sensitivity by approximately 10% and 14%. For patients at risk of T2RF, NEWS2 at cut-offs of 5 and 7 does not significantly decrease staff workload, but reduces sensitivity by 5-6%. Finally, if used in error for patients not at risk of T2RF at the suggested cut-offs, NEWS2 is slightly more sensitive than NEWS but, to achieve this, risks doubling the workload.

Key: AECOPD: Acute exacerbation of chronic obstructive respiratory disease; **AMU:** Acute Medical Unit; **AUC**: Area under the curve; **CH**: Chronic hypoxaemia; **COPD:** Chronic Obstructive Pulmonary Disease; **CREWS**: Chronic respiratory EWS; **CROS**: Capital Region of Denmark NEWS Override System; **ICU**: Intensive Care Unit; **NEWS**: National early warning score; **NHS:** National Health Service; **NPV**: Negative predictive value; **O**: oxygen; **PPV**: Positive predictive value; **SAE:** Serious Adverse Events; **S-NEWS:** Salford NEWS; **Sen:** Sensitivity; **Spec:** Specificity; T2RF: Type 2 Respiratory Failure; **UK:** United Kingdom

11.3 Primary outcomes

11.3.1 Mortality

All four studies compared modified EWSs to the NEWS for the detection of mortality and the findings varied.

Eccles et al.,[13] investigated 30-day mortality in 196 patients who were split into two groups: chronic hypoxaemia (CH) patients (with target SpO_2 of 88-92%) and oxygen patients (O), those with SpO_2 target saturations of 94-98%. For CH patients the CREWS score was retrospectively applied for comparison to the NEWS. The CREWS was superior to the NEWS in CH patients at predicting 30-day mortality (AUC 0.91 versus AUC 0.88, respectively) though confidence intervals for estimates overlapped suggesting the difference may not be statistically significant.

Hodgson et al.,[111] compared the NEWS to the modified CREWS and S-NEWS in 39,470 patient admissions, who were divided into two groups: 2,361 admissions in 942 individuals with an acute exacerbation of COPD (AECOPD) and 37,109 non-COPD admissions in 20,415 comparison patients. The NEWS had a slightly better ability to predict inpatient mortality (AUC 0.74, 95% CI 0.66-0.82) than the CREWS (AUC 0.72, 95% CI 0.63-0.80) and a clearer advantage over the S-NEWS (AUC 0.62, 95% CI 0.53-0.70) in the AECOPD cohort using first admissions only, however the 95% confidence intervals overlap (***Table 11.2***).

Pedersen et al.,[60] compared the NEWS to three modified EWSs (the CREWS, S-NEWS and CROS) in 11,266 patients with a diagnosis of chronic respiratory disease (COPD or chronic hypoxaemia) to predict 48-hour mortality. The NEWS (AUC 0.85, 95% CI 0.85-0.86), modified CREWS (AUC 0.85, 95% CI 0.84-0.85) and the S-NEWS (AUC 0.84, 95% CI 0.84-0.85) had similar predictive ability, and the NEWS was slightly superior to the CROS EWS (AUC 0.82, 95% CI 0.82-0.83) and. In addition, applying any of the NEWS modifications typically resulted in lower sensitivities and NPVs, and higher specificities and PPVs, both when using a total score of 6 or 9.

Pimental et al.,[187] compared the NEWS to NEWS2 in a cohort of 251,266 adult admissions split into three different groups: those with documented type two respiratory failure (T2RF) [n=1,394]; those at risk of T2RF [n=48,898]; and those not at risk of T2RF [n=202,094]. The performance of NEWS and NEWS2 was compared for in-hospital death within 24 hours in each group. The NEWS (AUC 0.86, 95% CI 0.85-0.87) had marginally better discriminatory

ability than the NEWS2 (AUC 0.84, 95% CI 0.83-0.85) in patients with documented T2RF, although the 95% confidence intervals overlap. This was also true for those patients at risk of T2RF (NEWS AUC 0.88 vs. NEWS2 AUC 0.86).

11.3.2 Cardiac arrest

One study by Pimental et al.,[187] compared a modified EWS to the NEWS for the detection of cardiac arrest. The NEWS and NEWS2 had similar discriminatory ability in patients with documented T2RF (AUC 0.701, and 0.706, respectively) and in patients at risk of T2RF (AUC 0.756, and 0.741, respectively (***Table 11.2***).

11.3.3 Length of stay

None of the four studies compared modified EWSs to the NEWS for the detection of LOS.

11.3.4 Transfer or admission to the intensive care unit

Two of the four studies compared modified EWSs to the NEWS for the detection of transfer or admission to the ICU with both showing similar discriminatory ability between the modified EWSs and the NEWS.[60, 187]

Pimental et al.,[187] showed that the NEWS and NEWS2 had similar discriminatory ability in predicting unanticipated ICU admission in patients with documented T2RF (AUC 0.81, and 0.82, respectively) and in patients at risk of T2RF (AUC 0.81, and 0.81, respectively). Pedersen et al.,[60] compared the NEWS, CROS, CREWS and S-NEWS in Danish patients with COPD or chronic hypoaemia. The findings were similar between the NEWS (AUC 0.79) and the modified EWSs (CROS AUC 0.81, CREWS AUC 0.81 and S-NEWS AUC 0.79) in predicting ICU admission.

11.4 Secondary outcomes

11.4.1 Clinical deterioration in a sub-population

None of the four studies reported on this outcome.

11.4.2 Patient reported outcome measures

None of the four studies reported on this outcome.

11.4.3 Post-hoc identified outcomes

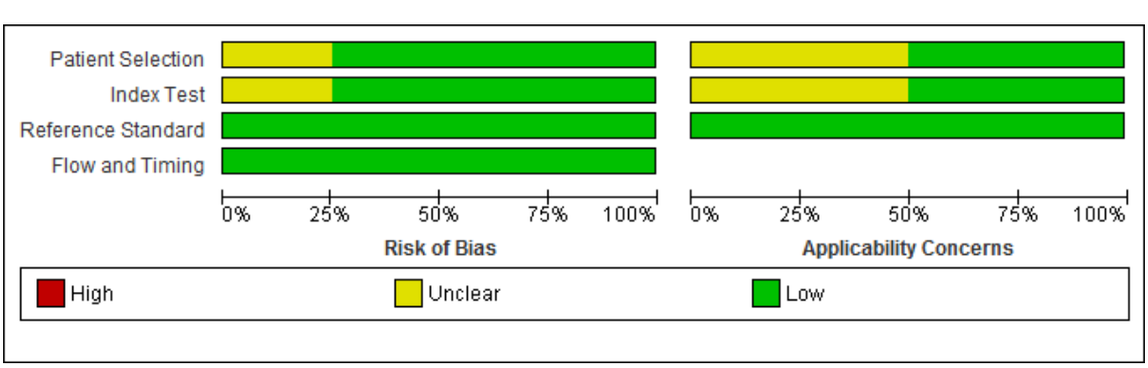
11.4.3.1 Serious adverse events (SAEs)

One study compared a modified EWS to the NEWS for the detection of SAEs. Pimental et al.,[187] defined a composite outcome of in-hospital death within 24 hours, unanticipated ICU admission or cardiac arrest (a combination of the review's primary outcomes). The NEWS and NEWS2 had similar discriminatory ability in predicting SAEs in patients with documented T2RF (AUC 0.83, and 0.83, respectively) and in patients at risk of T2RF (AUC 0.86, and 0.84, respectively).

11.5 Methodological quality

The QUADAS II tool[29] was used to assess the quality of the four retrospective cohort studies included. This tool had four risk of bias domains (patient selection, index test, reference standard and flow and timing) and three applicability domains (patient selection, index test and reference standard). Overall, the studies were classified as having a low risk of bias (**Figure *11.1***).

Figure 11.1 Risk of bias graph for the comparison of the effectiveness of modified EWSs to the NEWS for detecting physiological deterioration in adults with chronic respiratory conditions



Risk of bias domain: Patient selection

Three out of the four included studies had a low risk of bias for patient selection.[60, 111, 187] Eccles et al.,[13] had an unclear risk of bias for patient selection. The study included patients from two respiratory wards but it was unclear from the study whether a case-control design was avoided (which is preferable) as the patients were split into two groups based on oxygen saturations.

Risk of bias domain: Index test

Three out of the four included studies had a low risk of bias for the index test.[60, 111, 187] Eccles et al.,[13] had an unclear risk of bias for the index test. The CREWS was applied retrospectively and it is unclear whether this was done without knowledge of the reference standard test results.

Risk of bias domain: Reference standard

All four studies had a low risk of bias for the reference standard.[13, 86, 114, 192]

Risk of bias domain: Flow and timing

All four studies had a low risk of bias for flow and timing. The patients were all accounted for in the analysis.[13, 86, 114, 192]

Applicability domain: Patient selection

Two out of the four studies had a low risk of bias in the applicability domain.[111, 187] Two studies had an unclear risk of bias,[13,86] for applicability of patient selection. Both included sub-populations of patients with chronic respiratory conditions.

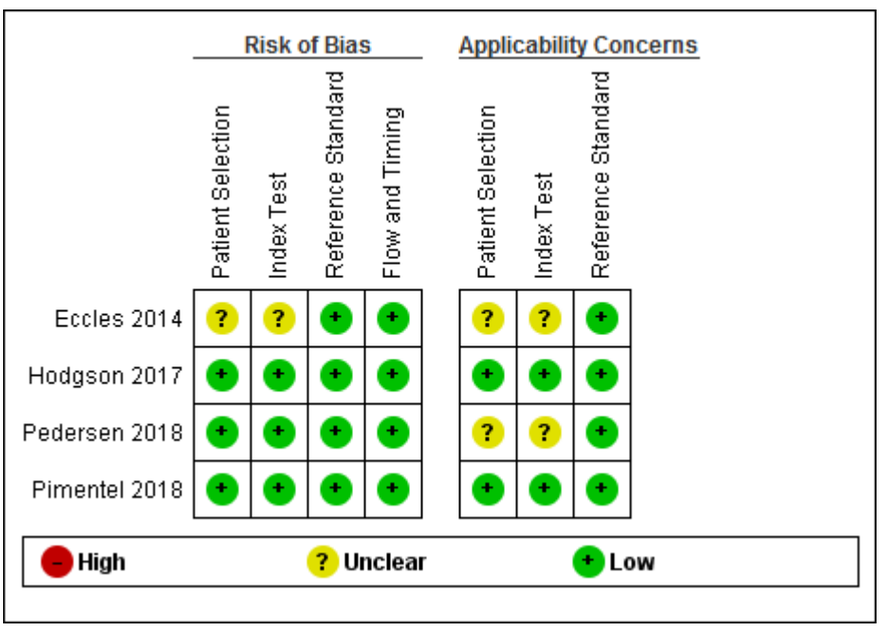
Applicability domain: Index test

Two of the four studies had a low risk of bias for the index test applicability.[111, 187] Two studies had an unclear risk of bias for the applicability of the index test. The modified EWSs were only applied to patients with respiratory conditions and may not be applicable to all adult patients.[13, 86]

Applicability domain: Reference standard

All four studies had a low risk of bias for the applicability of the reference standard (***Figure 11.2***).[13, 60, 111, 187]

Figure 11.2 Risk of bias summary for the comparison of the effectiveness of modified EWSs to the NEWS for detecting physiological deterioration in adults with chronic respiratory conditions



11.6 Certainty of the evidence

We assessed the overall quality of the evidence where appropriate. A narrative summary of findings table was created using GRADEpro software for the primary outcomes included in the four studies: mortality, cardiac arrest and transfer or admission to the ICU. Overall, the certainty of the evidence was very low. This is due to the fact that the evidence was from four observational cohort studies using modified EWSs leading to a higher risk of bias and confounding and further validation in large scale prospective studies is required (**Table *11.3***).

Table 11.3 Summary of findings table for the comparison of the effectiveness of modified EWSs to the NEWS in adults with chronic respiratory conditions

Modified EWSs compared to NEWS for detecting acute physiological deterioration in adults with chronic respiratory conditions

Patient or population: detecting acute physiological deterioration in adults with chronic respiratory conditions

Setting: Acute health care settings

Intervention: Modified EWSs

Comparison: NEWS

Outcomes	Impact	№ of participants (studies)	Certainty of the evidence (GRADE)
Mortality	Four studies included a comparison of modified EWSs to the NEWS in a sub-population of patients with respiratory conditions. These modified EWSs included: the CREWS (3 studies), NEWS2 (1 study), CROS (1 study) and S-NEWS (2 studies). The modified EWSs had similar discriminatory ability to the NEWS and further evaluation of the relationship between SpO_2 values, oxygen therapy and risk should be investigated further before wide-scale adoption of modified EWSs.	302,198 (4 observational cohort studies)	⨁◯◯◯ VERY LOW [a]
Cardiac arrest	One study examined cardiac arrest comparing the ability of the modified EWS NEWS2 to the NEWS in a large UK hospital sample. The NEWS had an AUC of 0.701 and the NEWS2 had an AUC of 0.706 in predicting cardiac arrest in a sample of patients with type 2 respiratory failure. Further evaluation of the relationship between SpO_2 values, oxygen therapy and risk should be investigated further before wide-scale adoption of modified EWSs.	251,266 (1 observational cohort study)	⨁◯◯◯ VERY LOW [a, b]
ICU admission or transfer	Two studies examined ICU admission or transfer when comparing modified EWSs to the NEWS. The NEWS and NEWS2 had similar discriminatory ability in the sample of type 2 respiratory failure patients included in Pimental et al (NEWS AUC 0.81, NEWS2 AUC 0.82) The NEWS (AUC 0.79), CROS (AUC 0.81), CREWS (AUC 0.81) and S-NEWS (AUC 0.79) had similar predictive ability of ICU admission in the sample of patients with chronic respiratory disease included in Pedersen et al. in a Danish hospital.	262,532 (2 observational cohort studies)	⨁◯◯◯ VERY LOW [a]

GRADE Working Group grades of evidence
High certainty: We are very confident that the true effect lies close to that of the estimate of the effect
Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different
Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect
Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

Explanations
a. Downgraded one level for risk of bias - observational cohort studies
b. Downgraded one level for imprecision relating to confidence intervals including the possibility of a small or no effect

11.7 Discussion

For this specific review question assessing the effectiveness of modified EWSs in specific sub-populations (frail elderly patients with chronic respiratory conditions), four observational cohort studies were eligible for inclusion. All four studies included patients with varying respiratory conditions including COPD or chronic hypoxaemia. The studies compared the predictive ability of modified EWSs including NEWS2, S-NEWS, CREWS and the Danish CROS to the NEWS. Modifications were largely in the SpO_2 weighting and cut-offs as this has been associated with excessive triggering and increased workload particularly in patients with chronic respiratory conditions. Overall however, the modified EWSs included were similar to the NEWS in predicting the primary outcomes of interest.

Further large scale, prospective studies are warranted to validate the findings in this sub-population of patients with chronic respiratory conditions included in the four studies. These studies were all observational cohort studies with a greater risk of bias and confounding as a result. The certainty of the evidence was deemed to be very low.

11.8 Conclusion

The NEWS is based on an EWS designed to maximise both sensitivity (the ability to detect patients at risk of dying) and specificity (the minimisation of false alarms) for unselected patients admitted to acute settings. The aim of this review question was to investigate whether modified EWSs (such as CREWS) can improve specificity and maintain sensitivity in specific sub-populations where NEWS has been shown to trigger false alarms. The four included studies of patients with chronic respiratory conditions compared the effectiveness of four modified EWSs (CREWS, S-NEWS, NEWS2 and CROS) to the NEWS and modified EWSs were found to be similar in their ability to predict the outcomes of interest. Further research is warranted to validate the findings from these studies before the widespread adoption of modified EWSs.

12 Why do health care professionals fail to escalate as per the NEWS protocol: a thematic analysis

12.1 Chapter overview

Healthcare professionals (HCPs) may encounter a deteriorating patient on a daily basis. Based on the patient's early warning score, when this passes a certain threshold, the HCP should escalate the level of care that is they should activate the emergency response system (ERS) team. However, we know from previous research that sometimes HCPs do not activate the ERS.[188, 189] This chapter explores the barriers and facilitators to activating ERS from the perspective of HCPs. A thematic analysis was conducted and the key themes which were generated from the literature (categorised into barriers and facilitators of escalation) are presented.

12.2 Characteristics of included studies

Eighteen qualitative studies were eligible for inclusion with three conducted in Australia,[190-192] six in the UK,[98, 185, 193-196] five in the USA,[137, 197-200] and one each in Ireland,[201] Norway,[202] Denmark,[203] and Singapore.[204] To gain an understanding of the barriers and facilitators to escalation, eight studies used face-to-face interviews,[98, 185, 192, 193, 197, 198, 201, 204] and seven studies used focus groups.[137, 190, 191, 196, 199, 202, 203] Three studies[194, 195, 200] used a combination of methods including interviews, observations of interactions, and documentary evidence [protocols and audit data], two of which were conducted in the same hospital and sample.[194, 195] The first study by Mackintosh (2012)[194] contained 150 hours of observations and used thematic analysis while the second study (Mackintosh, 2014)[195] contained 180 hours of observation and the analysis focused on the structural conditions that shape delivery of the rapid response drawing on Bourdieu's logic of practice. Data from both were extracted for this thematic analysis. Ten studies included nurses only (registered, unregistered),[137, 185, 192, 196, 197, 199, 200, 202-204] three studies includes nurses and doctors only,[98, 191, 201] and five studies included a mixture of HCPs and staff [nurses, physicians, administrators, respiratory technicians, health care assistants, safety leads and managers].[190, 193-195, 198] A total of 599 participants were interviewed across the studies with sample sizes ranging from six participants[196] to 218 participants.[190] The key study characteristics are outlined in **Table 12.1**.

Table 12.1 Characteristics of included qualitative studies on why healthcare professionals fail to escalate as per the protocol

Author (year), Country Study setting	Study design (focus group interviews, face-to-face interviews, other) Qualitative methodology (e.g. Ethnography, narrative, phenomenological, grounded theory)	Type of healthcare professional	Outcomes assessed: Data describing the views, experiences and behaviours of HCPs and why there is a failure to escalate as per protocol with NEWS	Type of EWS or RRS in operation
Astroth (2012),[197] USA 3 medical/surgical units, community hospital	Face-to-face interviews Analysis: concept analysis	Nurses (n=15)	Facilitators and barriers to RRT activation	RRT in a 155-bed MidWestern community hospital. No other details provided.
Benin (2012),[198] USA 1 academic hospital	Face-to-face interviews Analysis: thematic analysis and the constant comparative method	49 participants: Nurses (18), primary team senior attending physicians (6), house staff members (6) RRT attending physicians (4), RRT critical care nurses (4), RRT respiratory technicians (3) administrators (8)	To create a comprehensive view of the impact and value of an RRT on a hospital and its staff, the objective of this study was to qualitatively describe the experiences of and attitudes held by nurses, physicians, administrators, and staff regarding RRTs.	Adult RRT implemented in 2005 consisting of a hospitalist physician, a critical care nurse and a respiratory therapist. The RRT was triggered by specific criteria which were not listed in the study.
Braaten (2015),[200] USA Non-teaching, acute care hospital	Cognitive work analysis. Face-to-face interviews, Document review Analysis: Directed content analysis	Nurses (n=12) 11 female, 1 male from the medical-surgical wards	To describe factors within the hospital system that shape medical-surgical nurses RRT activation behaviour	Conducted in the medical-surgical units in a large hospital in Colorado with a well-established RRT system with a standardised policy and calling criteria, developed and implemented in 2005.
Cherry (2015),[196] UK Acute NHS hospital	Focus groups Analysis: Framework analysis technique	Nurses (n=6) 1 focus group 1 band 7, 1 band 6 and 4 staff nurses from the AMU	To understand the attitudes of qualified nursing staff on the AMU concerning the MEWS score chart used to monitor patients.	The MEWS was in use in the AMU and the hospital, including 8 parameters (respiratory rate, oxygen saturation, inspired oxygen, heart rate, systolic blood pressure, central nervous system level using the alert, voice, pain, unresponsive (AVPU) tool, urine output and temperature. Observations were to be measured minimum 12-hourly and more frequently depending on the MEWS score.

Table 12.1 Characteristics of included qualitative studies on why healthcare professionals fail to escalate as per the protocol

Authors, Country Study setting	Study design (focus group interviews, face-to-face interviews, other) Qualitative methodology (e.g. Ethnography, narrative, phenomenological, grounded theory)	Type of Healthcare professional	Outcomes assessed: Data describing the views, experiences and behaviours of HCPs and why there is a failure to escalate as per protocol with NEWS	Type of EWS or RRS in operation
Chua (2013),[204] Singapore 1 acute hospital	Face-to-face interviews with critical incident technique (CIT) Analysis: content analysis	Enrolled nurses (ENs) (n=15) ENs: non-registered nursing staff provide bedside nursing care and routine vital signs monitoring and convey findings to the registered nurses	Experiences of ENs with the deteriorating patient in pre-cardiac arrest situations. Strategies to enhance the role of ENs in detecting and managing ward deteriorating patients	No system reported but vital signs were used to detect deterioration.
Elliott (2015),[190] Australia 8 different hospital sites	Focus groups (44) Analysis: thematic analysis	Staff (n=218) (mainly nurses and doctors)	Experiences and views of staff using ORCs in clinical practice	ORCs based on the ADDS and a RRT with clear protocols for escalation.
Johnston (2014),[193] UK 3 hospitals across London	Semi-structured interviews Analysis: Emergent theme analysis	41 participants: attending/senior resident grade surgeons (16), surgical postgraduate year 1 (11), surgical nurses (6), intensivists (4), critical care outreach team members (4)	The current escalation landscape; When junior doctors and nurses should escalate care; Information required prior to senior review; Barriers to successful escalation of care; Strategies to improve the escalation process.	Escalation of care across the surgical pathway from the specialities of General Surgery, Vascular Surgery, and Urology from 3 London hospitals was examined. No other details provided.

Table 12.1 Characteristics of included qualitative studies on why healthcare professionals fail to escalate as per the protocol

Authors, Country Study setting	Study design (focus group interviews, face-to-face interviews, other) Qualitative methodology (e.g. Ethnography, narrative, phenomenological, grounded theory)	Type of Healthcare professional	Outcomes assessed: Data describing the views, experiences and behaviours of HCPs and why there is a failure to escalate as per protocol with NEWS	Type of EWS or RRS in operation
Kitto (2015),[191] Australia 4 hospitals	Multiple case study (focus groups) Conceptual framework: Collective competence and inter-professional conceptual framework Analysis: Directed content analysis & conventional content analysis	89 participants (10 focus groups): doctors (27), nurses (62)	Medical and nursing staff experiences of RRS Explore the reasons why staff members do not activate the RRS	RRS in 4 different hospitals. No other details provided.
Lydon (2016),[201] Ireland 1 teaching hospital	Mixed Methods, semi-structured interviews Analysis: Deductive content analysis	30 participants: Interns [1st year of postgraduate training](18), Senior NCHDs (2), Nurses (10)	To examine the perceptions of a national PTTS among nurses and doctors and to identify the variables that impact on intention to comply with protocol.	A PTTS using the NEWS and ISBAR communication tool
Mackintosh (2012),[194] UK 2 tertiary teaching hospitals **Same sample as Mackintosh (2014)	Ethnography; Observation of interactions among multi-professional healthcare staff and patient management processes; semi-structured interviews. Analysis: framework approach	150 hours of observations 35 interviews: Doctors (14), Ward and critical care nurses (11), Healthcare assistants (4), Safety leads and managers (6)	To illuminate the different contextual processes which contribute to patients' rescue trajectories and clarify the benefits and limitations of particular safety strategies within a pathway of care for the acutely ill patient.	Five strategies were in use across 2 hospitals. At Westward, an EWS, escalation protocol, communication protocol (SBAR) and CCOT (comprised of nurses, physiotherapists and intensive care

Table 12.1 Characteristics of included qualitative studies on why healthcare professionals fail to escalate as per the protocol

Authors, Country Study setting	Study design (focus group interviews, face-to-face interviews, other) Qualitative methodology (e.g. Ethnography, narrative, phenomenological, grounded theory)	Type of Healthcare professional	Outcomes assessed: Data describing the views, experiences and behaviours of HCPs and why there is a failure to escalate as per protocol with NEWS	Type of EWS or RRS in operation
Mackintosh (2014),[195] UK 2 tertiary teaching hospitals **Same sample as Mackintosh (2012)	Ethnography: - Observations - Documentary evidence-protocols and audit data - Semi-structured interviews Theoretical framework: Bourdieu - logic of practice	180 hours of observations: Interactions between health care staff, recording of patients' vital signs, ward rounds, handovers and multi-disciplinary team meetings. 35 interviews: health care assistants, nurses, physicians, critical care staff and managers	Interviews with staff focused on the management of escalation of care, the role of the RRS, and the influence of organisational contextual factors on its application.	physicians) were in operation. In Eastward, there was an EWS and 2 of the medical wards were piloting an intelligent assessment technology (IAT) which utilised a different scoring system to the EWS already in use in Westward and included a personal digital assistant (PDA).
Massey (2014),[192] Australia 1 public teaching hospital	In-depth semi structured interviews.	Registered ward nurses (n=15)	Nurses' experiences and perceptions of using and activating METs	A large public teaching hospital with a well established MET, using a single parameter system with specific MET calling criteria based on vital sign observations and thresholds.
McDonnell (2013),[185] UK District general hospital	Mixed methods with semi-structured interviews. Interviews before the training and approximately 6 weeks after the introduction of new charts Analysis: thematic framework	Nurses (n=15)	Knowledge and confidence of nursing staff in an acute hospital	A 2 tier track and trigger system using either the standard observation chart or the detailed Patient at Risk (PAR) chart. Patients could be stepped up to the PAR chart (if they triggered) or stepped down to the standard chart. A CCOT was also in place.

Table 12.1 Characteristics of included qualitative studies on why healthcare professionals fail to escalate as per the protocol

Authors, Country Study setting	Study design (focus group interviews, face-to-face interviews, other) Qualitative methodology (e.g. Ethnography, narrative, phenomenological, grounded theory)	Type of Healthcare professional	Outcomes assessed: Data describing the views, experiences and behaviours of HCPs and why there is a failure to escalate as per protocol with NEWS	Type of EWS or RRS in operation
Pattison (2012),[98] UK Specialist hospital	Grounded theory principles. Interviews. Analysis: Constant comparative technique.	9 participants: Nurses (7), Doctors (2)	To explore referrals to CCOT, associated factors around patient management and survival to discharge, and the qualitative exploration of referral characteristics (identifying any areas for service improvement around CCOT).	MEWS and CCOT in a specialist hospital.
Petersen (2017),[203] Denmark University hospital	Focus groups Analysis: Content analysis	Nurses (n=18) 5 focus groups (3-5 participants in each) (2 male, 16 female from the medical and surgical acute care wards)	To identify barriers and facilitators related to three aspects of the EWS protocol: 1) adherence to monitoring frequency; 2) informing doctors of patients with an elevated EWS (≥3), and 3) call for the MET	A modified version of the NEWS has been in use in hospitals in the Capital Region of Denmark since 2013. Parameters included: respiratory rate, oxygen saturation, supplemental oxygen, temperature, systolic blood pressure, heart rate, and level of consciousness. Clear protocol for action based on EWS trigger scores in operation.
Stafseth (2016),[202] Norway University hospital	Semi-structured focus group interviews Analysis: Thematic analysis	Nurses (n=7) 2 focus groups of 3 and 4 nurses.	Registered nurses' experiences with the early detection and recognition of vital function failures and experiences with the use of the MEWS and the MICN.	A track and trigger system comprised of the MEWS and a 24-hour on-call MICU, which was a nurse-led support service (not a team). MICU nurses were registered nurses with two years postgraduate education in critical care nursing and extensive experience in critical care.

Table 12.1 Characteristics of included qualitative studies on why healthcare professionals fail to escalate as per the protocol

Authors, Country Study setting	Study design (focus group interviews, face-to-face interviews, other) Qualitative methodology (e.g. Ethnography, narrative, phenomenological, grounded theory)	Type of Healthcare professional	Outcomes assessed: Data describing the views, experiences and behaviours of HCPs and why there is a failure to escalate as per protocol with NEWS	Type of EWS or RRS in operation
Stewart (2014),[137] USA Acute care hospital	Mixed-methods; Focus groups Analysis: Thematic analysis	Nurses (n=11) 5 focus with between 1 and 4 attendees, providers.	Perceptions of barriers and facilitators to the use of MEWS at the bedside	The MEWS scoring system was implemented in the hospitals electronic medical record system in 2011 where a RRS also exists.
Williams (2011),[199] USA Community hospital	Focus groups Analysis: Content analysis	Nurses (n=14) 6 focus groups Staff nurses (6), Nurse clinicians (2) Supervisor/educators (6)	Thoughts and feelings about shared and "lived" experiences surrounding RRT use.	156-bed community hospital with a nurse-led RRT implemented in 2005. RRT consisted of an ICU registered nurses, an emergency department registered nurse and a respiratory therapist. Hospitalists often responded to RRT calls but were not obliged to according to hospital protocol.

Key: ADDS: Adult Deterioration Detection System; **AMU:** Acute Medical Unit; **CCOT**: Critical Care Outreach Team; **CIT:** Critical Incident Technique; **EN**: Enrolled Nurses; **EWS**: Early Warning System; **HCP**: Health Care Professional; **MEWS**: Modified Early Warning System; **MET:** Medical Emergency Teams; **MICN**: Mobile Intensive Care Nurse; **NCHD**: Non Consultant Hospital Doctor; **ORC**: Observation Response Chart; **PTTS**: Physiological Track and Trigger System; **RRS**: Rapid Response System; **RRT**: Rapid Response Team.

12.3 Methodology

The method used to synthesise the results from each study was based on the technique of thematic analysis or synthesis.[205]

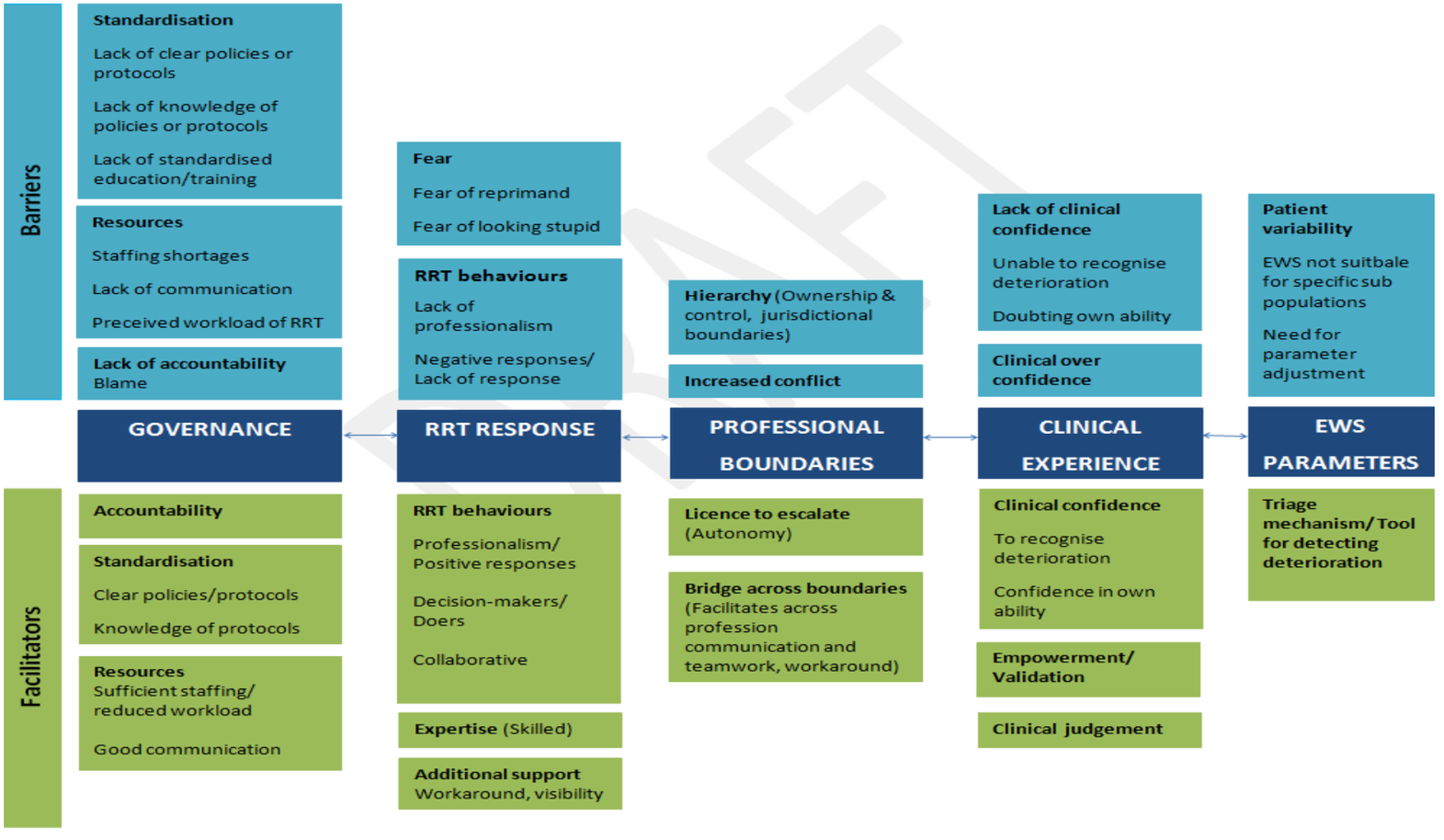
Two review team members read all 18 papers a number of times to achieve absorption of the data. Both review team members manually extracted the text from each study (results section only) and coded line by line in Excel, and developed initial sub-themes and overarching themes independently. Following multiple discussions and re-analysis of the draft themes and sub-themes as well as presentation of the findings to the guideline development group at a meeting in November 2018, the review team members reached consensus on the final overarching themes and sub-themes, presented in **Figure 12.1**.

12.4 Results

Thematic synthesis produced five overarching themes and 22 sub-themes with multiple interdependencies. These are categorised into barriers (twelve sub-themes) and facilitators (ten sub-themes) of escalation. These are described for each of the five overarching themes in ***section 12.5.1*** to ***section 12.5.2***:

- Governance
- Rapid response team Response
- Professional Boundaries
- Clinical Experience
- Early Warning System (EWS) Parameters.

Figure 12.1 Schematic representation of barriers and facilitators to escalation associated with each overarching theme and sub-theme



12.5 Synthesis of results

12.5.1 Barriers to escalation

Table 12.2 provides illustrative quotations from either primary study participants or study authors relating to the 'barriers' for each key theme and sub-theme. There was variation in the relative contribution of each study to the themes and sub-themes.

Governance

'Governance' refers to the overall organisational or institutional specific factors affecting why HCPs fail to escalate, or barriers to escalation. Fourteen papers described governance issues as factors contributing to a failure to escalate care.[98, 190-198, 200, 201, 203, 204] Three sub-themes including *Standardisation*, *Resources* and *Lack of accountability* were identified.

'Standardisation' was an issue reported in twelve studies.[190-194, 196, 197, 200, 201, 204] Standardisation included a lack of clear policies or protocols for action which was reported in four studies[193, 194, 196, 200] and this led to inaction or confusion amongst staff as to who to call or when. In addition to a lack of clear policies or protocols, 'standardisation' included a lack of knowledge of policies or protocols by staff, reported in six studies.[190-193, 197, 200] Where staff were not familiar with the correct protocol for escalation this was a barrier to escalation. Lack of education or training was reported in six studies by participants with no standardised, or regular training in place.[191, 192, 196, 197, 201, 204]

'Resources' were reported as barriers in nine studies[98, 190, 193, 197, 198, 200, 201, 203, 204] whereby staffing shortages, particularly in conducting the required monitoring of patients, (eight studies),[98, 190, 193, 198, 200, 201, 203, 204] poor communication systems/protocols (three studies)[190, 193, 201] and the perceived workload of the RRT (six studies)[98, 190, 193, 197, 201, 204] were all reported as barriers to escalation: "Perceived busyness of the ICU nurses discouraged participants from RRT activation. Participants noted that responding RRT members occasionally talked about how busy they were."

'Lack of accountability' and a blame culture was a reported sub-theme in three papers.[194, 195, 204] This was particularly the case in settings where health care assistants (HCAs) or equivalent staff were involved in documenting patient vital signs. HCAs believed there was often blame put on them by more senior staff when something went wrong. For example, junior staff described situations where a patient deteriorated and they informed senior staff, but the senior staff did not escalate care, and then when the patient collapsed or deteriorated the blame was put on the junior staff member.[194, 195, 204] This lack of accountability of senior staff was a barrier to these staff in raising concerns about deterioration.

RRT Response

'RRT Response' refers to how the RRT responded when a call for help was made. This key theme was apparent in ten papers.[191-193, 196-200, 202, 203] Two sub-themes including *RRT behaviours* and *Fear* were identified.

'RRT behaviours' were a barrier to escalation or future escalation calls when a 'lack of professionalism' was shown by the RRT to the staff who made the call. This was reported in eight papers.[191-193, 197, 199, 200, 202, 203] A 'negative response' or a total 'lack of response' (i.e. the RRT did not come) was also a barrier to escalation or subsequent escalation reported in eight papers.[191-193, 196, 197, 199, 202, 203] Participants reported being questioned as to whether the call to the RRT was necessary, they often reported feeling belittled or criticised and this negative response was a barrier to subsequent escalation.

Participants reported 'fear' was a barrier to escalation in seven papers.[191-193, 197, 198, 200, 203] 'Fear of reprimand' by members of the RRT for activating a call was reported by participants as well as 'fear of looking stupid or dumb' to colleagues, both of which were significant barriers to escalation.

Professional Boundaries

'Professional boundaries' refers to the barriers to escalation that were apparent in the included studies surrounding hierarchy, power, and jurisdictional control. Ten papers described professional boundaries as core contributing factors to not escalating.[98, 191-195, 197, 198, 200, 201] Two sub-themes including *Hierarchy* and *Increased conflict* were identified.

Participants described having to negotiate hierarchical boundaries in order to escalate care in eight papers.[191, 193-198, 200] In some instances, participants described being reprimanded by the patient's primary ward physician for calling the RRT. The primary ward physician often felt it was "their patient and their job to look after them" and that the junior staff had "gone over their head" in calling the RRT.[46, 198] This in turn led to an increase in conflict between nurses and ward physicians. Calling for help (escalation) also led to increased conflict among other staff in a number of papers.[98, 191, 192, 194, 197, 198, 201] In particular, the use of the RRT was often viewed as a jurisdictional shift in responsibility for acutely ill patients by members of the RRT who felt some nurses "washed their hands" of the situation. This may contribute to the negative responses of RRT, as described above.

Clinical Experience

'Clinical experience' refers to the barriers to escalation specifically related to individual staff and their level of confidence and ability to detect deterioration, which was reported in six studies.[98, 192, 193, 197, 200, 203] Two sub-themes including *Clinical over confidence* and *Lack of clinical confidence* were identified.

'Clinical over confidence' reported in five papers,[98, 193, 197, 200, 203] was characterised by participants being overly confident in their clinical ability. Participants expressed confidence that their clinical judgement was a better gauge of when to escalate care, irrespective of the EWS, and also that they were better placed to care for their own patient rather than the RRT.

In contrast, 'lack of clinical confidence', was reported in three studies.[192, 197, 200] Here it was participants inability to detect deterioration or doubting their own skills and ability to detect deterioration that led to a delay in escalation or to no escalation.

Early Warning System Parameters

'EWS Parameters' refers to the system specific barriers to escalation, which were reported in eight studies.[137, 185, 190, 194, 195, 201, 203, 204] One sub-theme, *Patient variability* was identified.

'Patient variability' that is the existence of specific groups of patients, for example, those with chronic obstructive pulmonary disease, was reported as a barrier. For these patients, who by default fall outside the normal range for the various vital signs, participants reported either excessive triggering of the EWS or else staff simply ignored the EWS for these patients. "The inability of the MEWS to tailor alarm settings and limits to accommodate patients whose vital sign measurements normally fell outside predetermined thresholds was cited by focus group participants as a major barrier to effective use of the system".[137] The need for parameter adjustment was also cited within the patient variability sub-theme: Participants reported that parameters were rarely reviewed or adjusted and that this was a continual problem for interns and nurses "If parameters aren't charted you're expected to check the observation and inform the intern more than is necessary" (Nurse 4).[201]

The themes of 'governance', 'professional boundaries', 'RRT Response', 'Clinical Experience', and 'Early Warning System Parameters' are individual but inter-related barriers to escalation of care. Each theme may be its own barrier, but when taken together they create an environment in which escalation of care may occur too late or not occur at all. For example, a lack of governance such as a lack of clear policies or protocols, or lack of knowledge of policies or protocols by all staff creates the potential for conflicts in professional boundaries. This may create a level of 'fear' for junior staff, particular those with less clinical confidence, who experience negative attitudes from both the RRT and primary ward physicians which contribute to a reluctance to activate the RRT in the future.

Table 12.2 Key themes of the barriers of escalation amongst healthcare professionals

Key Themes	Sub-themes	Characteristics of studies from which sub-themes were derived: Type of participant and setting	Illustrative quotations (*Italicised text*= primary quote from a study participant; non-italicised text=secondary quote from study authors)
Governance	**Lack of accountability**[194, 195, 204]	Enrolled nurses (non-registered nurses who assist registered nurses) in 1 Singaporean hospital;[204] HCAs, nurses, physicians, critical care staff and managers in 2 UK hospitals[194, 195]	A few participants strongly reiterated the need for some form of nursing documentation which specified that they had informed the RN-in-charge of patient deterioration. This was to safeguard the ENs from being blamed for not reporting patient deterioration: *"The EN should have charting and documentation that indicates this staff nurse had been informed . . . so then at least we know that we're safe and we don't get into trouble. (P3)"*[204]
	Standardisation -Lack of clear policies/protocols[193, 194, 196, 200] -Lack of knowledge of policies/protocols [190-193, 197, 200] -Lack of standardised education/training[191, 192, 196, 197, 201, 204]	HCAs, nurses, physicians, critical care staff and managers in 2 UK hospitals;[194] Senior resident surgeons, surgical postgraduates year 1, intensivists, and critical care outreach team members from 3 UK hospitals;[193] Nurses in 1 US hospital;[197] Mainly doctors and nurses in 8 Australian hospitals;[190] Doctors and nurses in 4 Australian hospitals;[191] Nurses in 1 Australian hospital;[192] Enrolled nurses (non-registered nurses who assist registered nurses) in 1 Singaporean hospital;[204] Year 1 interns, Senior NCHDs and nurses in 1 Irish hospital;[201] Nurses in 1 US hospital; [200] Nurses in 1 UK hospital[196]	"*On a number of occasions I've had difficulties contacting a senior because there is no fixed framework for doing so".*[193] "*Maybe if we had a clearer-cut criteria on when we do call an RRT and when we wait. You know? . . . People aren't sure. Do we wait until they get this bad . . . or their O2 requirements are at this level? At what point do we need to call them? . . .*" [200] *"I think it's probably a lack of understanding of the MET and how it should be used. People don't see it as an early intervention thing; I am not sure how you go about changing that. I can see that the patient is deteriorating and I can see that poor decisions are being made and it's very frustrating, yet a MET is not called because the patient is not sick enough for a MET; it's amazing".*[192] A few participants stated they had not received any education other than when the RRT was first developed. One nurse indicated she had not attended any RRT educational sessions.[197]

Table 12.2 Key themes of the barriers of escalation amongst healthcare professionals

Key Themes	Sub-themes	Characteristics of studies from which sub-themes were derived: Type of participant and setting	Illustrative quotations (*Italicised text*= primary quote from a study participant; non-italicised text=secondary quote from study authors)
Governance (continued)	**Resources** -Staffing shortages[98, 190, 193, 198, 200, 201, 203, 204] -Poor communication/use of handover tools[190, 193, 201] -Perceived workload of RRT[98, 190, 193, 197, 201, 204]	HCPs from 1 US hospital;[198] Mainly doctors and nurses in 8 Australian hospitals;[190] Year 1 interns, Senior NCHDs and nurses in 1 Irish hospital;[201] Enrolled nurses (non-registered nurses who assist registered nurses) in 1 Singaporean hospital[204] Senior resident surgeons, surgical postgraduates year 1, intensivists, and critical care outreach team members from 3 UK hospitals;[193] Nurses and doctors from 1 UK hospital;[98] Nurses in 1 US hospital[197]	*"Adherence to the NEWS protocol was impaired or impossible due to insufficient staffing levels..."*[206] Communicating actions recommended by the chart to escalate care was also sometimes challenging for participants, especially when attempting to obtain a response from medical officers.[190] Perceived busyness of the ICU nurses discouraged participants from RRT activation. Participants noted that responding RRT members occasionally talked about how busy they were.[197]
RRT Response	**RRT Behaviours** - Lack of professionalism[191-193, 197, 199, 200, 202, 203] -Negative response/Lack of response[191-193, 196, 197, 199, 202, 203]	Nurses in 1 US hospital;[197] HCPs in 3 UK hospitals;[193] Doctors and nurses in 4 Australian hospitals;[191] Nurses in 1 Australian hospital;[192] Nurses in 1 Norwegian hospital;[202] Nurses in 1 US hospital[199]	*"They don't want to listen to our side of the story or what we have to say. They are just more like, "I'm in charge and this is what you have to do," so they're more like barking out orders rather than kind of flowing with whatever we've already been doing and working as a team..."* [200] Sometimes team members complained about the need for the RRT call: "*Why did you call? This wasn't necessary". "Once a nurse gets attitude (from RRT members), they don't want to call again*".[197]
	Fear -Fear of reprimand[191-193, 200, 203]	Nurses in 1 US hospital;[197] HCPs in 1 US hospital;[198] HCPs in 3 UK hospitals;[193] Doctors and nurses in 4 Australian hospitals;[191] Nurses in 1 Australian hospital.[192]	*"Nurses feel like they are going to be told off for wasting the medical emergency team's time. Even though worried or concerned is on the little cards that we all carry around. That message has not been embraced by the nursing staff because people are still frightened I think. Talking to people they still think they are going to get told off or there are going to be repercussions." (Mary).*[46]

Table 12.2 Key themes of the barriers of escalation amongst healthcare professionals

Key Themes	Sub-themes	Characteristics of studies from which sub-themes were derived: Type of participant and setting	Illustrative quotations (*Italicised text*= primary quote from a study participant; non-italicised text=secondary quote from study authors)
RRT Response (continued)	-Fear of looking stupid[191-193, 197, 198]		This theme is understood as either refusing to activate a MET or pausing before activating a MET. Participants said, *"I don't know if it would be the right thing to do", "I don't want to look like an idiot".*[192]
Professional Boundaries	**Increased Conflict**[98, 191, 192, 194, 197, 198, 201]	Nurses and doctors from 1 UK hospital;[98] Doctors and nurses in 4 Australian hospitals;[191]Nurses in 1 Australian hospital;[192] Year 1 interns, Senior NCHDs and nurses in 1 Irish hospital;[201] HCAs, nurses, physicians, critical care staff and managers in 2 UK hospitals;[194] Nurses in 1 US hospital;[197]HCPs in 1 US hospital[198]	RRT improved morale between nurses and RRT but increased conflict between nurses and physicians.[198] Interns frequently cite the NEWS as a source of conflict between doctors and nurses. For example an intern commented that: "*some nurses see NEWS as something where they bring you and then wash their hands - they're rung someone, anyone, so their job is now done*" (Intern 5)[201]
	Hierarchy (ownership and control, jurisdictional boundaries)[191, 193-198, 200]	Doctors & nurses in 4 Australian hospitals;[191] HCPs in 3 UK hospitals;[193] HCAs, nurses, physicians, critical care staff & managers in 2 UK hospitals;[194] Nurses in 1 US hospital;[197] HCPs in 1 US hospital[195, 198]	*"Sometimes they* [primary ward physician]*….have a bit of an attitude thing, oh I can handle this. This is my patient. I know this patient. I didn't want a rapid response to be called. You know we get a fair amount of that, but not as much as we did in the beginning. In the beginning....nurses were being yelled at by the primary team....how dare you call a rapid response on my patient... they seem to be more receptive now [SWAT nurse]".*[198]
Clinical Experience	**Clinical over confidence**[98, 193, 197, 200, 203]	Nurses & doctors from 1 UK hospital;[98] HCPs in 3 UK hospitals;[193] Nurses in 1 US hospital[197]	*"Sometimes it's overconfidence or false confidence that you think you are in control of the situation. . . You could spend slightly less time with a person and then go back to them and realise their condition has changed but not noticed those subtle changes because you haven't seen them for an hour or so."* (R6, Nurse)[98]

Table 12.2 Key themes of the barriers of escalation amongst healthcare professionals [CONTINUED]

Key Themes (Finding)	**Sub-themes**	**Characteristics of studies from which sub-themes were derived**: Type of participant, Setting	Illustrative quotations (*Italicised text*= primary quote from a study participant; non-italicised text=secondary quote from study authors)
Clinical Experience (continued)	**Lack of clinical confidence**[192, 197, 200] -Unable to recognise deterioration -Doubting own ability/skills	Nurses in 1 Australian hospital;[192] Nurses in 1 US hospital[197]	*"Maybe questioning my decisions: Am I over-reacting here? Is this real or am I just panicking?"(Tanya)*[192] *"I think that the main thing is questioning, self-doubt.. Is the patient really sick enough to call? Can I handle this myself?"*[197]
EWS	**Patient variability**[137, 185, 190, 194, 195, 201, 203, 204] -Sub-populations who fall outside the normal vital sign ranges -Need for parameter adjustments	Nurses in 1 US hospital;[137] Doctors & nurses in 8 Australian hospitals;[190] Senior NCHDs & nurses in 1 Irish hospital;[201] ENs in 1 Singaporean hospital;[204] HCAs, nurses, physicians, critical care staff & managers in 2 UK hospitals[194, 195] Nurses in 1 UK hospital[185]	When asked how they would improve the current MEWS, most participants responded that they would customize the preset "normal" vital sign values to account for individual patient variances. Nurses addressed the variance by documenting that the abnormal value represented the patient's baseline or was a desired effect of an intervention, but the system required physician notification added to nursing workload. The inability of the MEWS to tailor alarm settings and limits to accommodate patients whose vital sign measurements normally fell outside predetermined thresholds was cited by focus group participants as a major barrier to effective use of the system.[137] Participants reported that parameters were rarely reviewed or adjusted and that this was a continual problem for interns and nurses *"If parameters aren't charted you're expected to check the observation and inform the intern more than is necessary"* (Nurse 4).[201]

Key: EN: Enrolled nurse; **EWS:** Early warning system; **HCA:** Healthcare assistant; **HCP**: Healthcare Professional; **ICU:** Intensive care unit; **MET:** Medical emergency team; **NCHD**: Non consultant hospital doctor; **NEWS**: National Early warning System; **RRT:** Rapid response team; **UK:** United Kingdom; **US:** United States

12.5.2 Facilitators to escalation

Table 12.3 provides illustrative quotations from primary study participants or study authors relating to the facilitators of escalation for each key theme and sub-theme. There was variation in the relative contribution of each study to each theme and sub-theme.

Governance

'Governance' was a key theme within ten papers.[98, 137, 185, 190, 193-195, 197, 200, 201] Three sub-themes of '*Accountability*', '*Standardisation*' and '*Resources*' as facilitators of escalation among the study participants were identified.

Accountability was a motivating factor in four studies, whereby staff activated the RRT in order to 'cover their own backs' in case something went wrong.[193-195, 201] In this respect, the RRT was viewed as a safety net by the nurses and they valued the extra support it provided.

In addition, 'standardisation' was reported in seven studies, where clear policies or protocols for action[185, 190, 194, 195, 197, 200, 201] and participant knowledge of these policies or protocols for escalation[194, 195, 201] was a key facilitator of escalation. A clear outline of when to call and who to call, that was communicated to and understood by all staff members, was a facilitator of escalation.

Resources (that is sufficient staffing levels and good communication such as use of handover tools) was a key facilitator of escalation in seven studies,[98, 137, 185, 193, 194, 197, 201] as exemplified here: "There is now a single resident who covers the ward for the week and twice daily attending ward rounds. I think this has made things better for juniors because they have a single point of contact who is not going to be off site or in theatre".[193]

RRT Response

The behaviours of RRTs were reported as facilitators of escalation within this key theme in ten studies.[98, 191, 193, 194, 197-200, 202, 203] Three sub-themes of '*RRT behaviours*' (including

professionalism, decision-makers and collaborative), '*Expertise*' and '*Additional support*' were identified.

In terms of RRT behaviours, where there was a 'professional response' or a 'positive reponse' from the RRT, this encouraged staff to escalate in subsequent events.[193, 197, 200, 202, 203] The RRT were seen as 'decision-makers' and 'doers' in emergency situations and these were both facilitators of escalation.[193, 197, 202] The RRT were viewed as collaborative but also of facilitating collaboration between staff, and this was another facilitator of escalation within three studies.[98, 199, 202]

In addition to how the RRT behaved, they were also described as being 'experts'[98, 197, 198, 203] with specific specialised skills and expertise necessary when a patient deteriorated.

They were also seen as providing 'additional support'[98, 191, 194, 197-200, 202] in emergency situations and this was a source of comfort reported by participants.

Professional Boundaries

Professional boundaries as a key theme was included in nine studies.[98, 190-194, 198, 200, 201] This included the sub-themes of a '*Licence to escalate'* and a '*Bridge across boundaries'*.

Licence to escalate was where the staff perceived the EWS as tool to enable escalation across hierarchical and occupational boundaries and was apparent in nine studies,[98, 190-194, 198, 200, 201] as exemplified from the following extracts: "Across both sites the score provided staff with the licence to escalate care across hierarchical and occupational boundaries".[194] *"The nurses actually have something they can do about it versus just kind of watching the patient flounder (hospitalist)".*[198] The EWS was used as tool by nurses to establish a legitimate reason for escalating care to more senior staff without having to seek permission. This licence created a 'Bridge across boundaries'. This refers to the view that the EWS facilitates cross-profession communication and teamwork and is a workaround and means of getting something done, i.e. getting a patient seen to, and was referenced in four studies.

[191, 193, 194, 198] *"We used to actually use them as a way of getting round a resident or whoever who really wasn't doing what you know you needed for your patient (Junior nursing, site 2)".*[191]

Clinical Experience

Clinical experience was a key theme within 12 studies and included sub-themes of '*Clinical confidence*' (to recognise deterioration, confidence in own ability and skills), '*Empowerment/validation'* and '*Clinical judgement*'.[98, 137, 185, 190-194, 197-201, 203]

Where a staff member had clinical confidence in their own skills and ability and were able to recognise deterioration, this was a facilitator of escalation. Staff were confident enough to activate the RRT.[137, 185, 190, 197, 200]

Staff also felt 'empowered' by the EWS and the EWS 'validated' their reasons for escalation and calling for help from the RRT and seniors.[185, 190, 191, 193, 194, 198, 199, 201]

'Clinical judgement' was a facilitator of escalation in seven studies where staff referred to the importance of using clinical judgement when a patient deteriorates and not relying on a score or system alone.[190, 191, 193, 197, 200, 201, 203]

Early Warning System Parameters

The fifth key theme of EWS Parameters included the subtheme of 'Triage mechanism' and a 'Tool for detecting deterioration'.[137, 185, 192, 194, 197, 198, 201, 203]

Staff described using the EWS as a mechanism for triage, to get a patient a higher level of care and to ensure patient safety. In addition, the EWS was seen as valuable tool for picking up patient deterioration by staff and optimising patient outcomes. Doctors described using the system to gauge the severity of a patient's condition for triaging: "*When I'm contacted to review a patient, I use 'NEWS' to prioritise the urgency in which they need to be reviewed* (NCHD 2)".[201]

Just as the themes of 'governance', 'professional boundaries', 'RRT Response', 'Clinical Experience', and 'Early Warning System Parameters' were inter-related in the generation of barriers to escalation of care, the themes are inter-related in creating facilitators to the escalation of care. For example, clear governance in terms of policies or protocols, and knowledge of policies or protocols by all staff decreases the potential for conflicts in professional boundaries and increases role clarity. This in turn may create a more collaborative team based approach that provides reassurance and confidence as opposed to engendering a level of 'fear' in junior staff, particularly those with less clinical confidence. All of which combines to create a climate within which activation of the RRT is more likely to happen.

Table 12.3 Key themes of the facilitators of escalation amongst healthcare professionals

Key Themes (Finding)	Sub-themes and references	Characteristics of studies from which sub-themes were derived: Type of participant and setting (Reference)	Illustrative quotations (*Italicised text*= primary quote from a study participant; non-italicised text=secondary quote from study authors)
Governance	**Accountability**[193-195, 201]	Senior resident surgeons, surgical postgraduates year 1, intensivists, and critical care outreach team members from 3 UK hospitals;[193] Year 1 interns, Senior NCHDs and nurses in 1 Irish hospital;[201] HCAs, nurses, physicians, critical care staff and managers in 2 UK hospitals[194, 195]	"*If you don't follow the NEWS and something goes wrong then the blame rests on you and you've got nothing to back you up…wheras, once you call you're protected*"[201]
	Standardisation -Clear policies or protocols[185, 190, 194, 195, 197, 200, 201] -Knowledge of protocols/policies[194, 195, 201]	Nurses in 1 US hospital;[197] Mainly doctors and nurses in 8 Australian hospitals;[190] Nurses in 1 UK hospital;[185] Year 1 interns, Senior NCHDs and nurses in 1 Irish hospital;[201] HCAs, nurses, physicians, critical care staff and managers in 2 UK hospitals[194, 195]	*"I will continue to use it as I'm currently using it unless the protocol changes as it's a requirement of my job and part of the hospital's policy (Nurse 8)".*[201] Both the escalation protocol and the CCOT at Westward promoted uniformity and standardisation with regards to response to the acutely ill patient.[194] *"As soon as we get a high score we're supposed to go straight to the staff nurse and inform them that this patient's observations have been outside normal. And then the staff nurse will inform the doctor and say, 'this patient's blood pressure is below normal, is x, y, z, so if you could come and review this patient."*[195]
	Resources -Sufficient staffing/reduced workload[98, 193, 197, 201] -Good communication[137, 185, 193, 194, 197, 201]	Nurses in 1 US hospital;[197]Nurses and doctors in 1 UK hospital;[98] HCPs from 3 UK hospitals;[193] HCPs from 1 Irish hospital;[201] HCPs from 2 UK hospitals;[194] Nurses from 1 UK hospital;[185] Nurses from 1 US hospital.[137]	*"There is now a single resident who covers the ward for the week and twice daily attending ward rounds. I think this has made things better for juniors because they have a single point of contact who is not going to be off site or in theatre" (Surgeon)*[193] The team used SBAR, the communication technique approved by the facility…. Standardised language helped participants provide information quickly and accurately.[197]

Table 12.3 Key themes of the facilitators of escalation amongst healthcare professionals

Key Themes (Finding)	Sub-themes and references	Characteristics of studies from which sub-themes were derived: Type of participant and setting (Reference)	Illustrative quotations (*Italicised text*= primary quote from a study participant; non-italicised text=secondary quote from study authors)
RRT Response **RRT Response**	**RRT Behaviours** - Professionalism/Positive responses[193, 197, 200, 202, 203] -Decision-makers/Doers [193, 197, 202] -Collaborative[98, 199, 202]	Nurses in 1 US hospital;[197] HCPs in 3 UK hospitals;[193] Nurses in 1 Norwegian hospital;[202] Nurses and doctors in 1 UK hospital;[98] Nurses in 1 US hospital;[199] HCPs in 1 US hospital;[198] Doctors and nurses in 4 Australian hospitals;[191] HCPs in 2 UK hospitals[194] Nurses in 1 Norwegian hospital;[202] Nurses and doctors in 1 UK hospital;[98] Nurses in 1 US hospital[199]	The approachable style and non-critical attitude of the MICN and their prompt responses in giving advice over the phone or reviewing the situation in person were recurrent comments throughout the interviews.[202] *"ICU nurses' expertise is reassuring. They evaluate the situation. They figure out what is going on and decide what to do".*[197] ''*The MICN did not 'take over' the situation, he only confirmed and asked for collaboration by using skills in communication and support and gave us treatment suggestions. We learned and listened; hopefully I can use this knowledge in other situations too*''.[202]
	Expertise (Skilled)[98, 197, 198, 203]	Nurses and doctors in 1 UK hospital;[98] Nurses in 1 US hospital;[197] HCPs in 1 US hospital[198]	Nurses had a sense of security and of empowerment generated by knowing skilled backup was available immediately through a single phone call.[198]
	Additional Support[98, 191, 194, 197-200, 202]	Nurses and doctors in 1 UK hospital;[98] Doctors and nurses in 4 Australian hospitals;[191] Nurses in 1 Norwegian hospital;[202] HCPs in 2 UK hospitals;[194] Nurses in 1 US hospital;[197] HCPs in 1 US hospital;[198] Nurses in 1 US hospital[199]	*'. . .an extra pair of eyes and ears for patients who are at risk of deteriorating or are in the process of deteriorating; and really able to bring critical care experience to a ward environment, to support the nurses and doctors on the ward to care for deteriorating patients on the ward. It's a very supportive role, bringing that extra degree of knowledge and skills that we may not have on the ward to care for the patient*.' (R7, Nurse)[98]

Table 12.3 Key themes of the facilitators of escalation amongst healthcare professionals [CONTINUED]

Key Themes (Finding)	Sub-themes and references	Characteristics of studies from which sub-themes were derived: Type of participant, Setting (no of references)	Illustrative quotations (*Italicised text*= primary quote from a study participant; non-italicised text=secondary quote from study authors)
Professional Boundaries	**Licence to escalate** (Autonomy)[98, 190-194, 198, 200, 201]	Nurses and doctors in 1 UK hospital;[98] Mainly doctors and nurses in 8 Australian hospitals;[190] Doctors and nurses in 4 Australian hospitals;[191] Nurses in 1 Australian hospital;[192] Year 1 interns, Senior NCHDs and nurses in 1 Irish hospital;[201] HCPs in 3 UK hospitals;[193] HCPs in 2 UK hospitals;[194] HCPs in 1 US hospital[198]	Across both sites the score provided staff with the licence to escalate care across hierarchical and occupational boundaries.[194] *"The nurses actually have something they can do about it versus just kind of watching the patient flounder (hospitalist)"[198]*
	Bridge Across Boundaries (Facilitates cross-profession communication and teamwork, workaround)[191, 193, 194, 198]	Doctors and nurses in 4 Australian hospitals;[191] HCPs in 3 UK hospitals;[193] HCPs in 2 UK hospitals;[194] HCPs in 1 US hospital[198]	*"We used to actually use them as a way of getting round a resident or whoever who really wasn't doing what you know you needed for your patient (Junior nursing, site 2)"[191]* The EWS helped with escalation of care across boundaries: *"The score is useful….if you're handing over the phone in the middle of the night to someone you've never met before….they don't know your judgement and your experience, so it's kind of a physical....this is quite clear" (Nurse, 5, Westward)[194]*
Clinical Experience Clinical	**Clinical Confidence**[137, 185, 190, 197, 200] -To recognise deterioration -Confidence in own ability and skills	Nurses in 1 US hospital;[197] Nurses and doctors in 8 Australian hospitals;[190] Nurses in 1 UK hospital;[185] Nurses in 1 US hospital[137]	*"I'd like to think that it hasn't made any difference to me being able to detect my patient deteriorating (FG I1)" and "I went to nursing school for three years - I know when it is time to ring the doctor" (FG A4)[190]* *"I never hesitate to call an RRS because I'm afraid I'll be criticized or made to feel like I couldn't handle a situation." [137]*

Table 12.3 Key themes of the facilitators of escalation amongst healthcare professionals [CONTINUED]

Key Themes (Finding)	Sub-themes and references	Characteristics of studies from which sub-themes were derived: Type of participant, Setting (no of references)	Illustrative quotations (*Italicised text*= primary quote from a study participant; non-italicised text=secondary quote from study authors)
Clinical Experience (continued)	**Empowerment/validation**[185, 190, 191, 193, 194, 198, 199, 201]	Mainly doctors and nurses in 8 Australian hospitals;[190] Doctors and nurses in 4 Australian hospitals;[191] Year 1 interns, Senior NCHDs and nurses in 1 Irish hospital;[201] HCPs in 3 UK hospitals;[193] HCPs in 2 UK hospitals;[194] Nurses in 1 UK hospital;[185] HCPs in 1 US hospital;[198] Nurses in 1 US hospital[199]	Availability of the RRT empowered nurses who were able to obtain additional help without having to request permission. "*I don't usually hesitate to call. I notify the team of any changes, and if I feel like I need additional nursing support or if I need respiratory support right that minute, I will call an RRT*".[198]
	Clinical judgement[190, 191, 193, 197, 200, 201, 203]	Mainly doctors and nurses in 8 Australian hospitals;[190] Doctors and nurses in 4 Australian hospitals;[191] Year 1 interns, Senior NCHDs and nurses in 1 Irish hospital;[201] HCPs in 3 UK hospitals;[193] Nurses in 1 US hospital[197] Nurses in 1 Australian hospital;[192] Nurses and doctors in 1 UK hospital[203]	Participants referred to the importance of using clinical judgement in tandem with the RRS criteria to guide their assessment and decision-making processes when deliberating whether or not to activate the RRS.[191] "*She just had this sweaty clammy look and just going from previous experience again, it was like there is something really not right here.*" (R1, Nurse)[98]
EWS Parameters	**Triage mechanism/Tool for detecting deterioration**[137, 185, 192, 194, 197, 198, 201, 203]	Nurses in 1 US hospital;[137] Nurses in 1 Australian hospital;[192] Year 1 interns, Senior NCHDs and nurses in 1 Irish hospital;[201] HCPs in 2 UK hospitals;[194] Nurses in 1 UK hospital;[185] HCPs in 1 US hospital;[198] Nurses in 1 US hospital[197]	Doctors described using the system to gauge the severity of a patient's condition for triaging: "*When I'm contacted to review a patient, I use 'NEWS' to prioritise the urgency in which they need to be reviewed* (NCHD 2)"[201] All staff valued the training they had received and reported that the T&T helped identify patient deterioration earlier: *"We now use it on every single patient that we have on the ward and obviously they all get a score at the end of it, so I think it just rings more alarm bells if you like if a patient is unwell or is deteriorating, whereas just recording a patient's observations, you know, you might miss something (15) It does highlight patients that are actually deteriorating quicker than you would".*[185]

Key: CCOT: Critical care outreach team; **EWS:** Early warning system; **HCA:** Healthcare assistant; **HCP**: Healthcare Professional; **MICN:** Mobile intensive care network; **NCHD**: Non consultant hospital doctor; **NEWS**: National Early warning System; **RRT/S:** Rapid response team/system; **SBAR**: Situation, Background, Assessment, Response; **UK:** United Kingdom; **US:** United States

12.6 Quality appraisal

The Critical Appraisal Skills Programme (CASP) tool for qualitative studies was used to appraise the quality of the 18 individual studies by two review team members independently and the overall judgement for each of the 10 CASP questions was agreed by consensus.[30]

All 18 studies reported a clear statement of the aims. All 18 studies were judged to have used an appropriate qualitative methodology [e.g. focus groups or interviews], and were judged to have employed appropriate data collection methods (e.g. interviews or focus groups or observation techniques or document review). All studies had a clear statement of the findings and the research was deemed valuable.

Seven out the 18 studies were judged to have a research design appropriate to the study aims,[98, 191, 192, 195, 200, 201, 204] while in 11 of 18 studies there was insufficient information on the rationale for the chosen qualitative methodology.[137, 185, 190, 193, 194, 196-199, 202, 203] Thirteen out of the 18 studies were judged to have a recruitment strategy appropriate to the study aims (e.g. convenience sampling or purposeful sampling),[98, 185, 190-195, 197, 198, 200, 202, 203] in four studies there was insufficient information provided.[137, 196, 199, 204] In one study the recruitment strategy was deemed inappropriate (the study authors used 'their judgement' and snowball techniques).[201] Six out 18 studies considered the researcher and participant relationship within the study,[137, 192, 194, 196, 199, 203] while 11 out the 18 studies did not consider the researcher-participant relationship and the potential for bias this may introduce.[98, 185, 190, 191, 193, 195, 198, 200-202, 204] In one study insufficient information was provided.[197] Seventeen out of the 18 studies reported having ethical approval while in one study it was unclear.[137] Fifteen out of 18 studies were judged to have rigorous data analysis (e.g. inductively and deductively coded, content analysis),[98, 137, 185, 191, 192, 194-196, 198-201, 203, 204] while in two studies there was insufficient (the authors mentioned triangulation but provided no other details and in the second study no coding framework was provided).[193,

[197] In one study, the analysis was deemed insufficient as there were missing observations which were not reported.[202]

Table 12.4 Methodological quality of the included qualitative studies

Study	CASP Question									
	Clear statement of the aims?	Qualitative methodology appropriate?	Research design appropriate to study aims?	Recruitment strategy appropriate to study aims?	Data collection appropriate?	Researcher & participant relationship considered?	Ethical issues considered?	Rigorous data analysis?	Clear statement of findings?	Is the research valuable?
Astroth (2013)[202]	Yes	Yes	Can't tell	Yes	Yes	Can't tell	Yes	Can't tell	Yes	Yes
Benin (2012)[203]	Yes	Yes	Can't tell	Yes	Yes	No	Yes	Yes	Yes	Yes
Braaten (2015)[205]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Chua (2013)[209]	Yes	Yes	Yes	Can't tell	Yes	No	Yes	Yes	Yes	Yes
Cherry (2015)[201]	Yes	Yes	Can't tell	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes
Elliott (2015)[195]	Yes	Yes	Can't tell	Yes	Yes	No	Yes	Yes	Yes	Yes
Johnston (2014)[198]	Yes	Yes	Can't tell	Yes	Yes	No	Yes	Can't tell	Yes	Yes
Kitto (2015)[196]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Lydon (2016)[206]	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Yes
Mackintosh (2012)[199]	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mackintosh (2014)[200]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Massey (2014)[197]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
McDonnell (2013)[184]	Yes	Yes	Can't tell	Yes	Yes	No	Yes	Yes	Yes	Yes
Pattison (2012)[101]	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Petersen (2017)[208]	Yes	Yes	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Stafseth (2016)[207]	Yes	Yes	Can't tell	Yes	Yes	No	Yes	No	Yes	Yes
Stewart (2014)[60]	Yes	Yes	Can't tell	Can't tell	Yes	Yes	Can't tell	Yes	Yes	Yes
Williams (2011)[204]	Yes	Yes	Can't tell	Can't tell	Yes	Yes	Yes	Yes	Yes	Yes

Key: CASP: Critical analysis skills programme

12.7 Certainty of the evidence

For the 18 included qualitative studies, the GRADE-CERQual (Confidence in the Evidence from Reviews of Qualitative research) approach was used to summarise confidence in the evidence.[37] Four components contribute to an assessment of confidence in the evidence for each key finding (in this review, the key findings are the five key themes generated from the thematic analysis): methodological limitations, relevance, coherence, and adequacy of data. The CERQual components reflect similar concerns to the elements included in the GRADE approach for assessing the certainty of evidence on the effectiveness of interventions in previous chapters, however, CERQual considers these issues from a qualitative perspective. The confidence in the evidence for each key finding (theme) was graded as high (it is highly likely that the review finding is a reasonable representation of the phenomenon of interest), moderate (it is likely that the review finding is a reasonable representation of the phenomenon of interest), low (it is possible that the review finding is a reasonable representation of the phenomenon of interest), or very low (it is not clear whether the review finding is a reasonable representation of the phenomenon of interest).

The certainty of the evidence for the key finding “Governance” was moderate in the 16 studies which contributed. The finding was graded as moderate confidence because of moderate concerns regarding methodological limitations, and minor concerns for both coherence and adequacy. The certainty of the evidence for the key finding “RRT Response” was moderate in the 12 studies which contributed. The finding was graded as moderate confidence because of moderate concerns regarding methodological limitations, and minor concerns for both coherence and adequacy. The certainty of the evidence for the key finding “Professional Boundaries” was judged to be high in the 12 studies which contributed. The finding was graded as high confidence because of moderate concerns regarding methodological limitations (particularly in relation to lack of reflexivity) and minor concerns regarding adequacy (rich descriptions of the data were largely were not always provided). These concerns in the two domains were not strong enough to justify downgrading the

confidence in the finding. The certainty of the evidence for the key finding "Clinical Experience" was deemed to be high also in the 14 studies which contributed. The finding was graded as high confidence because of moderate concerns regarding methodological limitations (particularly in relation to lack of reflexivity) and minor concerns regarding adequacy (rich descriptions of the data were largely were not always provided). As previously, these concerns were not strong enough to justify downgrading the confidence in the finding. The certainty of the evidence for the key finding "EWS Parameters" was judged to be moderate in the 11 studies which contributed. The finding was graded as moderate confidence because of moderate concerns regarding methodological limitations and coherence and minor concerns regarding adequacy.

Therefore, the overall certainty of the evidence was graded as 'moderate'. These assessments are summarised in the summary of qualitative findings (SOQF) table (**Table 12.5**) and in more detail in the evidence profile (***Chapter 14, Section 14.7, Appendix 7***).

Table 12.5 GRADE CERQual Summary of Qualitative Findings Table

Summary of review finding	Studies contributing to the review finding	CERQual assessment of confidence in the evidence	Explanation of CERQual Assessment
Governance: Participants reported clear, standardised policies and protocols; a good knowledge of the policies, sufficient resources including staff and good communication; and ensuring accountability as facilitators to escalation. Where there was no clear standardised policy or protocol; staff didn't know the policies; staffing shortages or competing workloads; and lack of accountability or blame, these were reported as barriers to escalation.	16 studies contributed to this review finding.[98, 137, 185, 190-198, 200, 201, 203, 204]	Moderate confidence ⊕⊕⊕⊖	The finding was graded as moderate confidence because of moderate concerns regarding methodological limitations, and minor concerns for coherence and adequacy.
***RRT Response*:** The behaviour of the RRT was a key barrier or facilitator to escalation. Where the RRT responded negatively (or not at all) or showed a lack of professionalism to those who made the escalation call, this was reported as a barrier to future escalation by participants. Fear of reprimand by senior staff for making the escalation call or fears of looking stupid were reported barriers to escalation. Where the RRT behaved positively, professionally, collaboratively and made key decisions, using their expertise and provided additional support, this was reported as a facilitator to escalation by participants.	12 studies contributed to this review finding.[98, 191-194, 196-200, 202, 203]	Moderate confidence ⊕⊕⊕⊖	The finding was graded as moderate confidence because of moderate concerns regarding methodological limitations, and minor concerns for coherence and adequacy.
***Professional Boundaries*:** The EWS and triggering for help was viewed as a licence to escalate and gave participants increased autonomy. It was also reported to be a bridge across professional boundaries ensuring communication and teamwork across staff levels and a workaround to get a patient seen. Other participants reported including increased conflict among staff (between junior and senior staff) and significant jurisdictional hierarchy as barriers to escalation.	12 studies contributed to this review finding.[98, 190-198, 200, 201]	High confidence ⊕⊕⊕⊕	The finding was graded as high confidence because of moderate concerns regarding methodological limitations and minor concerns regarding adequacy.
Clinical Experience: Clinical confidence to recognise deterioration and confidence in their own ability as well as using one's clinical judgment were all reported as facilitating factors to escalation by participants. The EWS was also a tool which empowered more junior staff to make the call for help and validated their reason for calling. Some participants reported being unable to recognise deterioration or doubting their own ability to detect deterioration as barriers to making a call for help. Clinical 'overconfidence' was also a reported barrier to escalation where staff didn't call for help due to the belief that they could handle the situation themselves.	14 studies contributed to this review finding. [98, 137, 185, 190-194, 197-201, 203]	High confidence ⊕⊕⊕⊕	The finding was graded as high confidence because of moderate concerns regarding methodological limitations and minor concerns regarding adequacy.
Early Warning Systems Parameters: Specific sub-populations (e.g. those with COPD) who resulted in excessive triggering of the EWS and the need for parameter adjustment and modification of the EWS were reported as a deterrent to calling for help by some participants. Others reported that the EWS was an excellent mechanism for triage and ensuring	11 studies contributed to this review finding. [137, 185, 190, 194, 195, 197, 198,	Moderate confidence ⊕⊕⊕⊖	The finding was graded as moderate confidence because of moderate concerns regarding methodological limitations and

patients received the care they needed as well as a valued tool for detecting deterioration	201, 203, 204, 207)		coherence and minor concerns regarding adequacy.

Key: HCP: Healthcare Professional; **RRT:** Rapid Response Team; **RRS:** Rapid Response System; **EWS:** Early Warning System; **COPD:** Chronic Obstructive Pulmonary Disease.

High confidence: It is highly likely that the review finding is a reasonable representation of the phenomenon of interest

Moderate confidence: It is likely that the review finding is a reasonable representation of the phenomenon of interest

Low confidence: It is possible that the review finding is a reasonable representation of the phenomenon of interest

Very low confidence: It is not clear whether the review finding is a reasonable representation of the phenomenon of interest

12.8 Discussion

The aim of this chapter of the review was to explore the qualitative literature to identify the barriers and facilitators to escalation among healthcare professionals (HCPs) and to try and answer the question: "*why do HCPs fail to call for help, to activate the emergency response system when a patient is rapidly deteriorating and why do they not follow the protocol as outlined in the NEWS?"*

The systematic search identified 18 qualitative studies from various countries, all conducted in hospital settings and including nurses only (ten studies), nurses and doctors only (three studies) or a mix of HCPs and staff (including administrators, management, allied health professionals, etc.), (six studies). The studies measured participant's beliefs and opinions on various EWSs or rapid response systems using mainly face-to-face interviews or focus group techniques and the total sample size was 599.

A comprehensive thematic analysis resulted in the generation of five key themes as barriers and facilitators to escalation: *Governance, RRT Response, Professional Boundaries, Clinical Experience* and *Early Warning Systems*. Within these five themes, 22 sub-themes with multiple interdependencies were identified as presented in **Figure 12.1**. The certainty of the evidence using the GRADE CERQual approach was judged to be 'moderate' for governance, RRT response and Early Warning Systems and 'high' for professional boundaries and clinical experience, resulting in a judgement of 'moderate' confidence in the evidence overall.

The findings on the role of the emergency response system as a bridge between the ICU or critical care and the ward is an important one. How the emergency response system is perceived by different staff (some valued it as additional support and expertise, while others felt the emergency response system was intruding on 'their' care of 'their' patient), others reported that the emergency response system led to conflict between staff (senior staff reprimanded junior staff for 'going above their head' and escalating). Lack of confidence among staff to detect and recognise deterioration was another element and barrier to

escalation. Lack of clear protocols and policy as well as regular standardised education (which for the most part did not require clinicians to attend) was cited as a barrier to escalation as it led to confusion and uncertainty. Where clear policies and protocols existed as well as accountability, this was seen as a facilitator to escalation in different organisations. In addition, when the RRT responded positively and professionally, this encourages staff to escalate for help in the future.

12.9 Conclusion

Delays in providing care to deteriorating hospitalised patients may increase the likelihood of adverse events including cardiac arrest and death. Emergency response systems were implemented to improve the quality and safety of hospital care by providing a group of clinical experts from various backgrounds the tools to respond quickly when a patient is escalated to a higher level of care by a member of staff on the ward. This chapter of the review focusses on why HCPs fail to escalate as per the escalation protocol, and aimed to identify the barriers and facilitators to escalation from a thematic analysis of the literature. The five key themes (*Governance, RRT Response, Professional Boundaries, Clinical Experience* and *Early Warning Systems)* and the sub-themes within provide insights to inform policy-makers and HCPs as well as hospital management about emergency response system related issues in practice and the need to incorporate changes as a result of these findings to improve patient care.

13 Overall Review Discussion

13.1 Discussion

A large number of EWSs have been developed internationally and are currently in use in adult (non-pregnant) populations to assist in the detection of physiological deterioration at the bedside. The review included 154 studies with 47 different named EWSs, which investigated the clinical and cost-effectiveness of EWSs on patient outcomes, the predictive performance of EWSs as well as qualitative studies on why health care professionals fail to escalate.

While the certainty of the evidence was low overall positive trends can be seen in relation to the effectiveness of EWSs. For example, of the studies investigating the effectiveness of the afferent limb (recognition and escalation of care) of EWSs on mortality over half found a reduction in mortality as a result of the use of an EWS. Three of seven studies showed a significant reduction in cardiac arrest rates following the introduction of an EWS. Fourteen of 25 studies which investigated the effectiveness of emergency response systems (ERS)(efferent limb) on mortality showed a significant decrease in mortality after introduction of an ERS. Likewise, in those studies which examined the effectiveness of ERS on cardiac arrest rates, two thirds showed a significant reduction in cardiac arrests following ERS introduction.

Studies which explored the effectiveness of EWS educational interventions found that healthcare professionals' knowledge, clinical performance and self-confidence in recognising and managing a deteriorating patient improved at least in the short term.

The review found that there has been no full economic evaluation of EWSs in adult patients in acute hospital settings. However, the three studies which were identified which investigated the cost-effectiveness of elements of EWSs suggest that these systems have the potential to improve patient outcomes including hospital and ICU LOS and thus reduce health care costs.

This updated review contained two new research questions the first focusing on the effectiveness of modified EWSs compared with NEWS in specific adult sub-populations, and the second addressing why health care professionals fail to escalate care as per the NEWS escalation protocol.

The sensitivity and specificity of NEWS in specific sub-populations, in particular in patients with chronic respiratory conditions, is a known problem. The review identified four studies which compared NEWS with a modified EWS for use in respiratory patient cohorts. This limited research shows that these modified EWSs (CREWS, S-NEWS, CROS and NEWS2) are similar to, but not superior to NEWS in predicting mortality, cardiac arrest, LOS or unplanned admissions to ICU. Further research is warranted to validate the findings from these studies before the widespread adoption of modified EWSs in specific sub-populations.

Five themes were identified across the 18 studies which explored why healthcare professionals fail to escalate care in accordance with EWS escalation protocols. Barriers and facilitators to escalation of care were identified in terms of governance, rapid response team (RRT) response, professional boundaries, clinical experience and EWS parameters. Facilitators to escalation of care included standardisation of policies and protocols to provide clarity of action, for example who to call and when, and the availability of resources for the provision of an appropriate response to escalation. A positive response from RRT members encouraged escalation where RRT members were seen as experts who provided additional clinical support to frontline staff when managing deteriorating patients. The EWS was also seen as providing nurses with ‘a license’ to escalate care and thus operated as a kind of ‘bridge across professional boundaries’ through which professional and organisational hierarchies could be negotiated. Barriers were in the main the converse of the facilitators identified and while each included theme described its own barrier, taken together barriers within the five themes had the potential to create an environment in which escalation of care may occur too late or not at all.

Throughout the review questions there was considerable heterogeneity in included EWSs. For instance, with the rapid response systems there was considerable variation in the team composition, the parameters to activate the emergency response team and the operating times. This heterogeneity was found across all domains of the EWSs. The parameters included within EWSs overlapped considerably, with all but one having at least one of the parameters contained within the NEWS. The majority of the 79 studies, where it was reported, included electronic rather than paper based EWSs. The majority of the 123 studies did not report how often parameters were measured (n=83) which can effect performance of an EWS, and where they did, it varied from study to study. The variation across EWSs makes it difficult to compare the systems. While nearly all the included studies suggested that patient outcomes either remained the same or were improved, this must be interpreted in the context of the evidence being of very low certainty due to poor study designs and inadequate sample sizes for some of the rarer outcome events.

This review included evidence from a range of different study designs (including RCTs, interrupted times series, observation cohorts and case-control studies). There is no suggestion of differing results between those studies with higher quality designs compared to those with poorer quality designs, however the limited number of RCTs included must be acknowledged (eleven in total, with seven of these focusing on educational interventions). The methodological quality of the studies overall across the review questions was poor and there was a high risk of bias, owing to significant heterogeneity in the interventions and populations studied. There was moderate certainty in the evidence which addressed the qualitative question dealing with contextual factors affecting EWS uptake. There was very low certainty in the evidence overall across the review's primary outcomes.

13.2 Strengths and limitations of this systematic review

This systematic review was conducted according to the PRISMA reporting guidelines. It is based on a protocol which was registered on PROSPERO in advance of conducting the review to ensure transparency and minimise bias in the review process. Specific review

questions were formulated based on the PICO approach and *a priori*-defined primary and secondary outcomes. In addition, an extensive search of the published and unpublished (grey literature) was conducted using a detailed search strategy and according to the principles of Boolean logic. Eleven electronic databases, five grey literature databases and over 30 websites relevant to the review topic and clinical guidelines were searched. In addition, two reviewers were involved in all stages of the review (screening, data extraction, quality appraisal and assessing the certainty of the evidence using the GRADE approach), reducing bias.

However, the review has some limitations which include the eligibility of English language only studies and the application of a date restriction (given this was an update of a previous systematic review). As with any systematic review, it is limited by the quality of the studies included which were poor overall leading the review team to judge the certainty of the evidence as very low overall for the review's primary outcomes. Minor deviations from the review's protocol are documented in Appendix 9.

13.3 Recommendations for future research

Further research is warranted of a high methodological quality using standardised definitions of primary outcomes, assessing similar interventions in similar populations in order to truly measure the impact of the NEWS. Research in the Irish setting is imperative.

13.4 Conclusion

While studies included in this review demonstrate considerable heterogeneity a clear trend and direction of findings is evident which supports the use of EWSs for the early recognition, escalation and response to clinical deterioration in adult patients in the acute hospital setting. Interest in EWSs has grown exponentially in the four years since the last review of the literature. Clinical leaders at the frontier of this field are driving the evolution and refinement of EWSs in an attempt to assist healthcare professionals in strengthening frontline patient safety in the increasingly complex environment of acute healthcare. EWSs

are relatively new and emerging systems which, as they develop and evolve are introducing new challenges. EWSs as a field of research is attracting increasing interest which can only serve to further develop and strengthen these adjuncts for clinical practice.

References

1. Health Do. The National Early Warning Score (NCEC National Clinical Gudeline No. 1). 2013.
2. Hegarty J, Drummond FJ, Murphy A, Andrews T, Walshe N, McCarthy B, et al. A systematic review of the clinical & economic literature and a budget impact analysis of any new guideline recommendations to inform the planned update of National Clinical Guideline No. 1 - National Early Warning Score (NEWS) for the Irish health system. Dublin: National Clinical Effectiveness Committee, Department of Health; 2016.
3. HIQA. Health technology assessment of the use of information technology for early warning and clinical handover systems. 2015.
4. Department of Health. National Clinical Guideline No. 1 The National Early Warning Score for Acute Deterioration in Adult (non-pregnant) Populations. 2013.
5. Simmes F, Schoonhoven L, Mintjes J, Adang E, Van Der Hoeven JG. Financial consequences of the implementation of a rapid response system on a surgical ward. Journal of Evaluation in Clinical Practice. 2014;20(4):342-7.
6. Le Lagadec MD, Dwyer T. Scoping review: The use of early warning systems for the identification of in-hospital patients at risk of deterioration. Australian critical care : official journal of the Confederation of Australian Critical Care Nurses. 2017;30(4):211-8.
7. Considine J, Trotter C, Currey J. Nurses' documentation of physiological observations in three acute care settings. Journal of Clinical Nursing. 2016;25(1/2):134-43.
8. Smith GB, Prytherch DR, Meredith P, Schmidt PE, Featherstone PI. The ability of the National Early Warning Score (NEWS) to discriminate patients at risk of early cardiac arrest, unanticipated intensive care unit admission, and death. Resuscitation. 2013;84(4):465-70.
9. Hogan H, Carver C, Zipfel R, Hutchings A, Welch J, Harrison D, et al. Effectiveness of ways to improve detection and rescue of deteriorating patients. British Journal of Hospital Medicine (17508460). 2017;78(3):150-9.
10. Churpek MM, Edelson DP. Moving Beyond Single-Parameter Early Warning Scores for Rapid Response System Activation. Critical Care Medicine. 2016;44(12):2283-5.
11. Health Do. The Irish Paediatric Early Warning System (PEWS) (NCEC National Clinical Guideline No. 12). 2016;2.
12. Health Do. The Irish Maternity Early Warning System (I-MEWS) (NCEC National Clinical Guideline No. 4). 2014.
13. Eccles SR, Subbe C, Hancock D, Thomson N. CREWS: improving specificity whilst maintaining sensitivity of the National Early Warning Score in patients with chronic hypoxaemia. Resuscitation. 2014;85(1):109-11.
14. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Annals of internal medicine. 2009;151(4):264-9, w64.
15. Tong A, Flemming K, McInnes E, Oliver S, Craig J. Enhancing transparency in reporting the synthesis of qualitative research: ENTREQ. BMC medical research methodology. 2012;12(1):181.
16. Caldwell PH, Bennett T, Mellis C. Easy guide to searching for evidence for the busy clinician. Journal of paediatrics and child health. 2012;48(12):1095-100.

17. Glanville J, Fleetwood K, Yellowlees A, Kaunelis D, Mensinkai S. Development and Testing of Search Filters to Identify Economic Evaluations in MEDLINE and EMBASE. Ottawa: Canadian Agency for Drugs and Technologies in Health. 2009.
18. Price LC, Lowe D, Hosker H, Anstey K, Pearson M, Roberts CM. UK National COPD Audit 2003: impact of hospital resources and organisation of care on patient outcome following admission for acute COPD exacerbation. Thorax. 2006;61(10):837-42.
19. UNDP. United Nations Development Programme: Human Development Report. 2015.
20. CADTH. Grey Matters - a practical search tool for evidence-based medicine. Canadian Agency for Drugs and Technologies in Health; 2014.
21. HIQA. Guidelines for the Retrieval and Interpretation of Economic Evaluations of Health Technologies in Ireland. 2014.
22. Higgins JP, Green S. Cochrane Handbook for Systematic Reviews of Interventions The Cochrane Collaboration; 2011. Available from: www.handbook.cochrane.org. .
23. Higgins JP, Altman DG, Gøtzsche PC, Jüni P, Moher D, Oxman AD, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. Bmj. 2011;343:d5928.
24. (EPOC). CEPaOoC. Suggested risk of bias criteria for EPOC reviews. EPOC Resources for review authors. 2017
25. Brouwers MC, Kho ME, Browman GP, Burgers JS, Cluzeau F, Feder G, et al. AGREE II: advancing guideline development, reporting and evaluation in health care. Canadian Medical Association Journal. 2010;182(18):E839-E42.
26. Wells G, Shea B, O'connell D, Peterson J, Welch V, Losos M, et al. The Newcastle-Ottawa Scale (NOS) for assessing the quality if nonrandomized studies in meta-analyses. 2009. Epub Available from: URL: http://www ohri ca/programs/clinical_epidemiology/oxford htm [cited 2009 Oct 19]. 2013.
27. Evers S, Goossens M, De Vet H, Van Tulder M, Ament A. Criteria list for assessment of methodological quality of economic evaluations: Consensus on Health Economic Criteria. International journal of technology assessment in health care. 2005;21(2):240-5.
28. Caro JJ, Eddy DM, Kan H, Kaltz C, Patel B, Eldessouki R, et al. Questionnaire to assess relevance and credibility of modeling studies for informing health care decision making: an ISPOR-AMCP-NPC Good Practice Task Force report. Value in health. 2014;17(2):174-82.
29. Whiting PF, Rutjes AW, Westwood ME, Mallett S, Deeks JJ, Reitsma JB, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. Annals of internal medicine. 2011;155(8):529-36.
30. Critical Appraisal Skills Programme Qualitative Checklist [Internet]. 2017 [cited December 11th 2017]. Available from: Available at: http://www.casp-uk.net/checklists
31. Sharmin S, Kypri K, Khanam M, Wadolowski M, Bruno R, Mattick RP. Parental Supply of Alcohol in Childhood and Risky Drinking in Adolescence: Systematic Review and Meta-Analysis. International journal of environmental research and public health. 2017;14(3).
32. HIQA. Health Information and Quality Authority. Guidelines for Evaluating the Clinical Effectiveness of Health Technologies in Ireland. 2014.
33. Cassell C, Symon G. Essential guide to qualitative methods in organizational research: Sage; 2004.
34. Attride-Stirling J. Thematic networks: an analytic tool for qualitative research. Qualitative research. 2001;1(3):385-405.
35. GRADEpro. GRADEpro Guideline Development Tool [Software]. In: McMaster University (developed by Evidence Prime IAfgo, editor. 2015.

36. Schünemann H BJ, Guyatt G, Oxman A, editors. GRADE handbook for grading quality of evidence and strength of recommendations. The GRADE Working Group, 2013 Available at: guidelinedevelopmentorg/handbook. 2013.
37. Lewin S, Glenton C, Munthe-Kaas H, Carlsen B, Colvin CJ, Gülmezoglu M, et al. Using Qualitative Evidence in Decision Making for Health and Social Interventions: An Approach to Assess Confidence in Findings from Qualitative Evidence Syntheses (GRADE-CERQual). PLOS Medicine. 2015;12(10):e1001895.
38. Kansal A, Havill K. The effects of introduction of new observation charts and calling criteria on call characteristics and outcome of hospitalised patients. Critical care and resuscitation : journal of the Australasian Academy of Critical Care Medicine. 2012;14(1):38-43.
39. Mullany DV, Ziegenfuss M, Goleby MA, Ward HE. Improved hospital mortality with a low MET dose: the importance of a modified early warning score and communication tool.(medical emergency team). Anaesthesia and Intensive Care. 2016;44(6):734.
40. Nguyen MT, Woodman RJ, Hakendorf P, Thompson CH, Faunt J. Can the simple clinical score usefully predict the mortality risk and length of stay for a recently admitted patient? Australian Health Review: A Publication Of The Australian Hospital Association. 2015;39(5):522-7.
41. Boulos D, Shehabi Y, Moghaddas JA, Birrell M, Choy A, Giang V, et al. Predictive value of quick Sepsis-Related Organ Failure Scores following sepsis-related Medical Emergency Team calls: a retrospective cohort study. Anaesthesia & Intensive Care. 2017;45(6):688-94.
42. Christofidis MJ, Hill A, Horswill MS, Watson MO. A human factors approach to observation chart design can trump health professionals' prior chart experience. Resuscitation. 2013;84(5):657-65.
43. Christofidis MJ, Hill A, Horswill MS, Watson MO. Observation charts with overlapping blood pressure and heart rate graphs do not yield the performance advantage that health professionals assume: an experimental study. Journal of advanced nursing. 2014;70(3):610-24.
44. Christofidis MJ, Hill A, Horswill MS, Watson MO. Less is more: the design of early-warning scoring systems affects the speed and accuracy of scoring. Journal of advanced nursing. 2015;71(7):1573-86.
45. Joshi K, Campbell V, Landy M, Anstey CM, Gooch R. The effect of Rapid Response System revision on standard and specific intensive care unit outcomes in a regional hospital. Anaesthesia & Intensive Care. 2017;45(3):369-74.
46. Massey D, Aitken LM, Chaboyer W. The impact of a nurse led rapid response system on adverse, major adverse events and activation of the medical emergency team. Intensive & critical care nursing. 2015;31(2):83-90.
47. Christofidis MJ, Hill A, Horswill MS, Watson MO. Observation chart design features affect the detection of patient deterioration: a systematic experimental evaluation. Journal of advanced nursing. 2015;72(1):158-72.
48. De Meester K, Verspuy M, Monsieurs KG, Van Bogaert P. SBAR improves nurse-physician communication and reduces unexpected death: a pre and post intervention study. Resuscitation. 2013;84(9):1192-6.
49. De Meester K, Das T, Hellemans K, Verbrugghe W, Jorens PG, Verpooten GA, et al. Impact of a standardized nurse observation protocol including MEWS after Intensive Care Unit discharge. Resuscitation. 2013;84(2):184-8.

50. Gonçales PD, Polessi JA, Bass LM, Santos GP, Yokota PK, Laselva CR, et al. Reduced frequency of cardiopulmonary arrests by rapid response teams. Einstein (São Paulo, Brazil). 2012;10(4):442-8.
51. Hayani O, Al-Beihany A, Zarychanski R, Chou A, Kharaba A, Baxter A, et al. Impact of critical care outreach on hematopoietic stem cell transplant recipients: a cohort study. Bone marrow transplantation. 2011;46(8):1138.
52. Karvellas CJ, De Souza IAO, Gibney RTN, Bagshaw SM. Association between implementation of an intensivist-led medical emergency team and mortality. BMJ Quality and Safety. 2012;21(2):152-9.
53. Scherr K, Wilson DM, Wagner J, Haughian M. Evaluating a new rapid response team NP-led versus intensivist-led comparisons. AACN advanced critical care. 2012;23(1):32-42.
54. Bian Y, Xu F, Lv RJ, Wang JL, Cao LJ, Xue L, et al. An early warning scoring system for the prevention of acute heart failure. International journal of cardiology. 2015;183:111-6.
55. Xiao H, Qi H, Wang J, Li X, Ma S, Diao Z, et al. The identification of risk factors for critically ill patients with acute fever and formulation of activation criteria to alert outpatient clinic doctors. Journal of Evaluation in Clinical Practice. 2012;18(4):721-6.
56. Qin Q, Xia Y, Cao Y. Clinical study of a new Modified Early Warning System scoring system for rapidly evaluating shock in adults. Journal of Critical Care. 2017;37:50-5.
57. Bunkenborg G, Samuelson K, Poulsen I, Ladelund S, Akeson J. Lower incidence of unexpected in-hospital death after interprofessional implementation of a bedside track-and-trigger system. Resuscitation. 2014;85(3):424-30.
58. Liljehult J, Christensen T. Early warning score predicts acute mortality in stroke patients. Acta neurologica Scandinavica. 2016;133(4):261-7.
59. Petersen JA, Antonsen K, Rasmussen LS. Frequency of early warning score assessment and clinical deterioration in hospitalized patients: a randomized trial. Resuscitation [Internet]. 2016; 101:[91-6 pp.]. Available from: http://onlinelibrary.wiley.com/o/cochrane/clcentral/articles/284/CN-01264284/frame.html
60. Pedersen NE, Rasmussen LS, Petersen JA, Gerds TA, Østergaard D, Lippert A. Modifications of the National Early Warning Score for patients with chronic respiratory disease. Acta Anaesthesiologica Scandinavica. 2018;62(2):242-52.
61. Martin G, Dupre A, Mulliez A, Prunel F, Slim K, Pezet D. Validation of a score for the early diagnosis of anastomotic leakage following elective colorectal surgery. Journal of visceral surgery. 2015;152(1):5-10.
62. Jung B, Daurat A, De Jong A, Chanques G, Mahul M, Monnin M, et al. Rapid response team and hospital mortality in hospitalized patients. Intensive Care Medicine. 2016;42(4):494-504.
63. Sabahi M, Fanaei SA, Ziaee SA, Falsafi FS. Efficacy of a rapid response team on reducing the incidence and mortality of unexpected cardiac arrests. Trauma Monthly. 2012;17(2):270-4.
64. Zimlichman E, Szyper-Kravitz M, Shinar Z, Klap T, Levkovich S, Unterman A, et al. Early recognition of acutely deteriorating patients in non-intensive care units: Assessment of an innovative monitoring technology. Journal of Hospital Medicine. 2012;7(8):628-33.
65. Ghanem-Zoubi NO, Vardi M, Laor A, Weber G, Bitterman H. Assessment of disease-severity scoring systems for patients with sepsis in general internal medicine departments. Critical Care. 2011;15(2):R95-R.
66. Peris A, Zagli G, Maccarrone N, Batacchi S, Cammelli R, Cecchi A, et al. The use of Modified Early Warning Score may help anesthesists in postoperative level of care selection in emergency abdominal surgery. Minerva anestesiologica. 2012;78(9):1034-8.

67. Tirotta D, Gambacorta M, La Regina M, Attardo T, Lo Gullo A, Panzone F, et al. Evaluation of the threshold value for the modified early warning score (MEWS) in medical septic patients: a secondary analysis of an Italian multicentric prospective cohort (SNOOPII study). QJM: An International Journal of Medicine. 2017;110(6):369-73.
68. Nishijima I, Oyadomari S, Maedomari S, Toma R, Igei C, Kobata S, et al. Use of a modified early warning score system to reduce the rate of in-hospital cardiac arrest. Journal of intensive care. 2016;4(1):12.
69. Drower D, McKeany R, Jogia P, Jull A. Evaluating the impact of implementing an early warning score system on incidence of in-hospital cardiac arrest. The New Zealand medical journal. 2013;126(1385):26-34.
70. Luís L, Nunes C. Short National Early Warning Score — Developing a Modified Early Warning Score. Australian Critical Care. 2017.
71. Al-Qahtani S, Al-Dorzi HM, Tamim HM, Hussain S, Fong L, Taher S, et al. Impact of an intensivist-led multidisciplinary extended rapid response team on hospital-wide cardiopulmonary arrests and mortality. Critical care medicine. 2013;41(2):506-17.
72. Kim Y, Lee DS, Min H, Choi YY, Lee EY, Song I, et al. Effectiveness Analysis of a Part-Time Rapid Response System During Operation Versus Nonoperation. Critical Care Medicine. 2017;45(6):e592-e9.
73. Jo S, Lee JB, Jin YH, Jeong TO, Yoon JC, Jun YK, et al. Modified early warning score with rapid lactate level in critically ill medical patients: the ViEWS-L score. Emergency medicine journal : EMJ. 2013;30(2):123-9.
74. Yoo JW, Lee JR, Jung YK, Choi SH, Son JS, Kang BJ, et al. A combination of early warning score and lactate to predict intensive care unit transfer of inpatients with severe sepsis/septic shock. Korean Journal of Internal Medicine. 2015;30(4):471-7.
75. Reini K, Fredrikson M, Oscarsson A. The prognostic value of the Modified Early Warning Score in critically ill patients: a prospective, observational study. European Journal of Anaesthesiology (EJA). 2012;29(3):152-7.
76. Etter R, Takala J, Merz TM. Intensive care without walls - introduction of a Medical Emergency Team system in a Swiss tertiary care centre. Swiss medical weekly. 2014;144:w14027.
77. Uppanisakorn S, Bhurayanontachai R, Boonyarat J, Kaewpradit J. National Early Warning Score (NEWS) at ICU discharge can predict early clinical deterioration after ICU transfer. Journal of Critical Care. 2018;43:225-9.
78. van Galen LS, Dijkstra CC, Ludikhuize J, Kramer MH, Nanayakkara PW. A protocolised once a day Modified Early Warning Score (MEWS) measurement is an appropriate screening tool for major adverse events in a general hospital population. PloS one. 2016;11(8):e0160811.
79. Ludikhuize J, Borgert M, Binnekade J, Subbe C, Dongelmans D, Goossens A. Standardized measurement of the Modified Early Warning Score results in enhanced implementation of a Rapid Response System: a quasi-experimental study. Resuscitation. 2014;85(5):676-82.
80. Ludikhuize J, Brunsveld-Reinders AH, Dijkgraaf MG, Smorenburg SM, de Rooij SE, Adams R, et al. Outcomes Associated With the Nationwide Introduction of Rapid Response Systems in The Netherlands. Crit Care Med. 2015;43(12):2544-51.
81. Simmes FM, Schoonhoven L, Mintjes J, Fikkers BG, van der Hoeven JG. Incidence of cardiac arrests and unexpected deaths in surgical patients before and after implementation of a rapid response system. Annals of intensive care. 2012;2(1):20.

82. Simmes F, Schoonhoven L, Mintjes J, Fikkers BG, van der Hoeven JG. Effects of a rapid response system on quality of life: a prospective cohort study in surgical patients before and after implementing a rapid response system. Health and quality of life outcomes. 2013;11(1):74.
83. Smith T, Den Hartog D, Moerman T, Patka P, Van Lieshout EM, Schep NW. Accuracy of an expanded early warning score for patients in general and trauma surgery wards. The British journal of surgery. 2012;99(2):192-7.
84. van Rooijen CR, de Ruijter W, van Dam B. Evaluation of the threshold value for the Early Warning Score on general wards. The Netherlands journal of medicine. 2013;71(1):38-43.
85. Douw G, Huisman-de Waal G, van Zanten AR, van der Hoeven JG, Schoonhoven L. Nurses' 'worry' as predictor of deteriorating surgical ward patients: A prospective cohort study of the Dutch-Early-Nurse-Worry-Indicator-Score. International journal of nursing studies. 2016;59:134-40.
86. Douw G, Huisman-de Waal G, van Zanten ARH, van der Hoeven JG, Schoonhoven L. Capturing early signs of deterioration: the dutch-early-nurse-worry-indicator-score and its value in the Rapid Response System. Journal Of Clinical Nursing. 2017;26(17-18):2605-13.
87. Durusu TanriÖVer M, HalaÇLi B, SaİT B, ÖCal S, Topelİ A. Daily surveillance with early warning scores help predict hospital mortality in medical wards. Turkish Journal of Medical Sciences. 2016;46(6):1786-91.
88. Jones S, Mullally M, Ingleby S, Buist M, Bailey M, Eddleston JM. Bedside electronic capture of clinical observations and automated clinical alerts to improve compliance with an Early Warning Score protocol. Critical care and resuscitation : journal of the Australasian Academy of Critical Care Medicine. 2011;13(2):83-8.
89. Hollis RH, Graham LA, Lazenby JP, Brown DM, Taylor BB, Heslin MJ, et al. A Role for the Early Warning Score in Early Identification of Critical Postoperative Complications. Annals Of Surgery. 2016;263(5):918-23.
90. Faisal M, Scally A, Elgaali MA, Richardson Dd, Beatson K, Mohammed MA. The National Early Warning Score and its subcomponents recorded within ±24 h of emergency medical admission are poor predictors of hospital-acquired acute kidney injury. Clinical Medicine. 2018;18(1):47-53.
91. Huddart S, Peden CJ, Swart M, McCormick B, Dickinson M, Mohammed MA, et al. Use of a pathway quality improvement care bundle to reduce mortality after emergency laparotomy. The British journal of surgery. 2015;102(1):57-66.
92. Jarvis SW, Kovacs C, Badriyah T, Briggs J, Mohammed MA, Meredith P, et al. Development and validation of a decision tree early warning score based on routine laboratory test results for the discrimination of hospital mortality in emergency medical admissions. Resuscitation. 2013;84(11):1494-9.
93. Jarvis S, Kovacs C, Briggs J, Meredith P, Schmidt PE, Featherstone PI, et al. Aggregate National Early Warning Score (NEWS) values are more important than high scores for a single vital signs parameter for discriminating the risk of adverse outcomes. Resuscitation. 2015;87:75-80.
94. Kovacs C, Jarvis SW, Prytherch DR, Meredith P, Schmidt PE, Briggs JS, et al. Comparison of the National Early Warning Score in non-elective medical and surgical patients. British Journal of Surgery. 2016;103(10):1385-93.

95. Moon A, Cosgrove JF, Lea D, Fairs A, Cressey DM. An eight year audit before and after the introduction of modified early warning score (MEWS) charts, of patients admitted to a tertiary referral intensive care unit after CPR. Resuscitation. 2011;82(2):150-4.
96. Morris A, Owen HM, Jones K, Hartin J, Welch J, Subbe CP. Objective patient-related outcomes of rapid-response systems - a pilot study to demonstrate feasibility in two hospitals. Critical care and resuscitation : journal of the Australasian Academy of Critical Care Medicine. 2013;15(1):33-9.
97. Patel MS, Jones MA, Jiggins M, Williams SC. Does the use of a "track and trigger" warning system reduce mortality in trauma patients? Injury. 2011;42(12):1455-9.
98. Pattison N, Eastham E. Critical care outreach referrals: a mixed-method investigative study of outcomes and experiences. Nursing in critical care. 2012;17(2):71-82.
99. Schmidt PE, Meredith P, Prytherch DR, Watson D, Watson V, Killen RM, et al. Impact of introducing an electronic physiological surveillance system on hospital mortality. BMJ Quality & Safety. 2014.
100. Suppiah A, Malde D, Arab T, Hamed M, Allgar V, Morris-Stiff G, et al. The Modified Early Warning Score (MEWS): an instant physiological prognostic indicator of poor outcome in acute pancreatitis. JOP : Journal of the pancreas. 2014;15(6):569-76.
101. Abbott TE, Vaid N, Ip D, Cron N, Wells M, Torrance HD, et al. A single-centre observational cohort study of admission National Early Warning Score (NEWS). Resuscitation. 2015;92:89-93.
102. Badriyah T, Briggs JS, Meredith P, Jarvis SW, Schmidt PE, Featherstone PI, et al. Decision-tree early warning score (DTEWS) validates the design of the National Early Warning Score (NEWS). Resuscitation. 2014;85(3):418-23.
103. Cooksley T, Kitlowski E, Haji-Michael P. Effectiveness of Modified Early Warning Score in predicting outcomes in oncology patients. QJM : monthly journal of the Association of Physicians. 2012;105(11):1083-8.
104. Dawes TR, Cheek E, Bewick V, Dennis M, Duckitt RW, Walker J, et al. Introduction of an electronic physiological early warning system: Effects on mortality and length of stay. British Journal of Anaesthesia. 2014;113(4):603-9.
105. Jarvis S, Kovacs C, Briggs J, Meredith P, Schmidt PE, Featherstone PI, et al. Can binary early warning scores perform as well as standard early warning scores for discriminating a patient's risk of cardiac arrest, death or unanticipated intensive care unit admission? Resuscitation. 2015;93:46-52.
106. Jarvis SW, Kovacs C, Briggs J, Meredith P, Schmidt PE, Featherstone PI, et al. Are observation selection methods important when comparing early warning score performance? Resuscitation. 2015;90:1-6.
107. Subbe CP, Duller B, Bellomo R. Effect of an automated notification system for deteriorating ward patients on clinical outcomes. Critical care (London, England) [Internet]. 2017; 21(1) (no pagination). Available from: http://onlinelibrary.wiley.com/o/cochrane/clcentral/articles/602/CN-01367602/frame.html
108. Fung K, Khan F, Dawson J. The introduction of an integrated early warning score observation chart-a picture paints a thousand words. Journal of patient safety. 2014;10(1):13-9.
109. Farenden S, Gamble D, Welch J. Impact of implementation of the National Early Warning Score on patients and staff. British Journal of Hospital Medicine (17508460). 2017;78(3):132-6.

110. Abbott TEF, Torrance HDT, Cron N, Vaid N, Emmanuel J. A single-centre cohort study of National Early Warning Score (NEWS) and near patient testing in acute medical admissions. European Journal of Internal Medicine. 2016;35:78-82.
111. Hodgson LE, Dimitrov BD, Congleton J, Venn R, Forni LG, Roderick PJ. A validation of the National Early Warning Score to predict outcome in patients with COPD exacerbation. Thorax. 2017;72(1):23-30.
112. Pimentel MA, Redfern OC, Gerry S, Collins GS, Malycha J, Prytherch D, et al. A comparison of the ability of the National Early Warning Score and the National Early Warning Score 2 to identify patients at risk of in-hospital mortality: A multi-centre database study. Resuscitation. 2018.
113. Smith GB, Prytherch DR, Jarvis S, Kovacs C, Meredith P, Schmidt PE, et al. A Comparison of the Ability of the Physiologic Components of Medical Emergency Team Criteria and the U.K. National Early Warning Score to Discriminate Patients at Risk of a Range of Adverse Clinical Outcomes. Critical Care Medicine. 2016;44(12):2171-81.
114. Jones B. Developing a Vital Sign Alert System. American Journal of Nursing. 2013;113(8):36-46.
115. Howell MD, Ngo L, Folcarelli P, Yang J, Mottley L, Marcantonio ER, et al. Sustained effectiveness of a primary-team–based rapid response system. Critical care medicine. 2012;40(9):2562.
116. Hackmann G, Chen M, Chipara O, Lu C, Chen Y, Kollef M, et al. Toward a Two-Tier Clinical Warning System for Hospitalized Patients. AMIA Annual Symposium Proceedings. 2011;2011:511-9.
117. Albert BL, Huesman L. Development of a modified early warning score using the electronic medical record. Dimensions of Critical Care Nursing. 2011;30(5):283-92.
118. Bailey TC, Chen Y, Mao Y, Lu C, Hackmann G, Micek ST, et al. A trial of a real-time Alert for clinical deterioration in Patients hospitalized on general medical wards. Journal of hospital medicine. 2013;8(5):236-42.
119. Beitler JR, Link N, Bails DB, Hurdle K, Chong DH. Reduction in hospital-wide mortality following implementation of a rapid response team: A long-term cohort study. Critical Care. 2011:R269.
120. Capan M, Ivy JS, Rohleder T, Hickman J, Huddleston JM. Individualizing and optimizing the use of early warning scores in acute medical care for deteriorating hospitalized patients. Resuscitation. 2015;93:107-12.
121. Churpek MM, Yuen TC, Edelson DP. Predicting clinical deterioration in the hospital: The impact of outcome selection. Resuscitation. 2013;84(5):564-8.
122. Churpek MM, Yuen TC, Huber MT, Park SY, Hall JB, Edelson DP. Predicting cardiac arrest on the wards: a nested case-control study. Chest. 2012;141(5):1170-6.
123. Churpek MM, Yuen TC, Winslow C, Hall J, Edelson DP. Differences in vital signs between elderly and nonelderly patients prior to ward cardiac arrest. Crit Care Med. 2015;43(4):816-22.
124. Davis DP, Aguilar SA, Graham PG, Lawrence B, Sell RE, Minokadeh A, et al. A novel configuration of a traditional rapid response team decreases non–intensive care unit arrests and overall hospital mortality. Journal of hospital medicine. 2015;10(6):352-7.
125. Karpman C, Keegan MT, Jensen JB, Bauer PR, Brown DR, Afessa B. The impact of rapid response team on outcome of patients transferred from the ward to the ICU: A single-center study. Critical Care Medicine. 2013;41(10):2284-91.

126. Kirkland LL, Malinchoc M, O'Byrne M, Benson JT, Kashiwagi DT, Burton MC, et al. A clinical deterioration prediction tool for internal medicine patients. American journal of medical quality : the official journal of the American College of Medical Quality. 2013;28(2):135-42.
127. Kollef MH, Heard K, Chen Y, Lu C, Martin N, Bailey T. Mortality and Length of Stay Trends Following Implementation of a Rapid Response System and Real-Time Automated Clinical Deterioration Alerts. American journal of medical quality : the official journal of the American College of Medical Quality. 2017;32(1):12-8.
128. Mathukia C, Fan W, Vadyak K, Biege C, Krishnamurthy M. Modified Early Warning System improves patient safety and clinical outcomes in an academic community hospital. Journal of Community Hospital Internal Medicine Perspectives. 2015;5(2):10.3402/jchimp.v5.26716.
129. Moriarty JP, Schiebel NE, Johnson MG, Jensen JB, Caples SM, Morlan BW, et al. Evaluating implementation of a rapid response team: Considering alternative outcome measures. International Journal for Quality in Health Care. 2014;26(1):49-57.
130. Moroseos T, Bidwell K, Rui L, Fuhrman L, Gibran NS, Honari S, et al. Rapid response team implementation on a burn surgery/acute care ward. Journal of Burn Care and Research. 2014;35(1):21-7.
131. Parrish WM, Hravnak M, Dudjak L, Guttendorf J. Impact of a modified early warning score on rapid response and cardiopulmonary arrest calls in telemetry and medical-surgical units.(Continuous Quality Improvement). MedSurg Nursing. 2017;26(1):15.
132. Picker D, Dans M, Heard K, Bailey T, Chen Y, Lu C, et al. A Randomized Trial of Palliative Care Discussions Linked to an Automated Early Warning System Alert. Critical care medicine [Internet]. 2017; 45(2):[234-40 pp.]. Available from: http://onlinelibrary.wiley.com/o/cochrane/clcentral/articles/529/CN-01298529/frame.html.
133. Rothberg MB, Belforti R, Fitzgerald J, Friderici J, Keyes M. Four years' experience with a hospitalist-led medical emergency team: An interrupted time series. Journal of hospital medicine. 2012;7(2):98-103.
134. Salvatierra G, Bindler RC, Corbett C, Roll J, Daratha KB. Rapid response team implementation and in-hospital mortality. Critical Care Medicine. 2014;42(9):2001-6.
135. Segon A, Ahmad S, Segon Y, Kumar V, Friedman H, Ali M. Effect of a rapid response team on patient outcomes in a community-based teaching hospital. Journal of Graduate Medical Education. 2014;6(1):61-4.
136. Shah SK, Cardenas Jr VJ, Kuo YF, Sharma G. Rapid response team in an academic institution: Does it make a difference? Chest. 2011;139(6):1361-7.
137. Stewart J, Carman M, Spegman A, Sabol VK. Evaluation of the effect of the modified early warning system on the nurse-led activation of the rapid response system. Journal of nursing care quality. 2014;29(3):223-9.
138. Stark AP, Maciel RC, Sheppard W, Sacks G, Hines OJ. An Early Warning Score Predicts Risk of Death after In-hospital Cardiopulmonary Arrest in Surgical Patients. The American surgeon. 2015;81(10):916-21.
139. Umscheid CA, Betesh J, VanZandbergen C, Hanish A, Tait G, Mikkelsen ME, et al. Development, implementation, and impact of an automated early warning and response system for sepsis. J Hosp Med. 2015;10(1):26-31.
140. Alaa AM, Yoon J, Hu S, van der Schaar M. Personalized Risk Scoring for Critical Care Prognosis Using Mixtures of Gaussian Processes. IEEE Transactions on Biomedical Engineering. 2018;65(1):207-18.

141. Alvarez CA, Clark CA, Zhang S, Halm EA, Shannon JJ, Girod CE, et al. Predicting out of intensive care unit cardiopulmonary arrest or death using electronic medical record data. BMC medical informatics and decision making. 2013;13:28.
142. Bleyer AJ, Vidya S, Russell GB, Jones CM, Sujata L, Daeihagh P, et al. Longitudinal analysis of one million vital signs in patients in an academic medical center. Resuscitation. 2011;82(11):1387-92.
143. Churpek MM, Yuen TC, Park SY, Meltzer DO, Hall JB, Edelson DP. Derivation of a cardiac arrest prediction model using ward vital signs*. Crit Care Med. 2012;40(7):2102-8.
144. Churpek MM, Yuen TC, Edelson DP. Risk stratification of hospitalized patients on the wards. Chest. 2013;143(6):1758-65.
145. Churpek MM, Yuen TC, Park SY, Gibbons R, Edelson DP. Using electronic health record data to develop and validate a prediction model for adverse outcomes in the wards*. Crit Care Med. 2014;42(4):841-8.
146. Churpek MM, Yuen TC, Winslow C, Robicsek AA, Meltzer DO, Gibbons RD, et al. Multicenter development and validation of a risk stratification tool for ward patients. American Journal of Respiratory and Critical Care Medicine. 2014;190(6):649-55.
147. Escobar GJ, Laguardia JC, Turk BJ, Ragins A, Kipnis P, Draper D. Early detection of impending physiologic deterioration among patients who are not in intensive care: Development of predictive models using data from an automated electronic medical record. Journal of Hospital Medicine. 2012;7(5):388-95.
148. Moseson EM, Zhuo H, Chu J, Stein JC, Matthay MA, Kangelaris KN, et al. Intensive care unit scoring systems outperform emergency department scoring systems for mortality prediction in critically ill patients: A prospective cohort study. Journal of Intensive Care. 2014;2(1).
149. Romero-Brufau S, Huddleston JM, Naessens JM, Johnson MG, Hickman J, Morlan BW, et al. Widely used track and trigger scores: are they ready for automation in practice? Resuscitation. 2014;85(4):549-52.
150. Rothman MJ, Rothman SI, Beals IV J. Development and validation of a continuous measure of patient condition using the Electronic Medical Record. Journal of biomedical informatics. 2013;46(5):837-48.
151. Yu S, Leung S, Heo M, Soto GJ, Shah RT, Gunda S, et al. Comparison of risk prediction scoring systems for ward patients: a retrospective nested case-control study. Critical care (London, England). 2014;18(3):R132.
152. Finlay GD, Rothman MJ, Smith RA. Measuring the modified early warning score and the Rothman index: advantages of utilizing the electronic medical record in an early warning system. J Hosp Med. 2014;9(2):116-9.
153. Young RS, Gobel BH, Schumacher M, Lee J, Weaver C, Weitzman S. Use of the modified early warning score and serum lactate to prevent cardiopulmonary arrest in hematology-oncology patients: a quality improvement study. American journal of medical quality : the official journal of the American College of Medical Quality. 2014;29(6):530-7.
154. Churpek MM, Yuen TC, Winslow C, Meltzer DO, Kattan MW, Edelson DP. Multicenter Comparison of Machine Learning Methods and Conventional Regression for Predicting Clinical Deterioration on the Wards. Critical Care Medicine. 2016;44(2):368-74.
155. Churpek MM, Snyder A, Han X, Sokol S, Pettit N, Howell MD, et al. Quick Sepsis-related Organ Failure Assessment, Systemic Inflammatory Response Syndrome, and Early Warning Scores for Detecting Clinical Deterioration in Infected Patients outside the Intensive Care Unit. American Journal Of Respiratory And Critical Care Medicine. 2017;195(7):906-11.

156. Kipnis P, Turk BJ, Wulf DA, LaGuardia JC, Liu V, Churpek MM, et al. Development and validation of an electronic medical record-based alert score for detection of inpatient deterioration outside the ICU. Journal Of Biomedical Informatics. 2016;64:10-9.
157. Sebat F, Vandegrift MA, Childers S, Lighthall GK. A Novel Bedside-Focused Ward Surveillance and Response System. Joint Commission Journal on Quality & Patient Safety. 2018;44(2):94-100.
158. Tarassenko L, Clifton DA, Pinsky MR, Hravnak MT, Woods JR, Watkinson PJ. Centile-based early warning scores derived from statistical distributions of vital signs. Resuscitation. 2011;82(8):1013-8.
159. Seymour CW, Kahn JM, Cooke CR, Watkins TR, Heckbert SR, Rea TD. Prediction of Critical Illness During Out-of-Hospital Emergency Care. JAMA : the journal of the American Medical Association. 2010;304(7):747-54.
160. Davies O, DeVita MA, Ayinla R, Perez X. Barriers to activation of the rapid response system. Resuscitation. 2014;85(11):1557-61.
161. Balestroni G, Bertolotti G. [EuroQol-5D (EQ-5D): an instrument for measuring quality of life]. Monaldi archives for chest disease = Archivio Monaldi per le malattie del torace. 2012;78(3):155-9.
162. Sach T, Barton G, Doherty M, Muir K, Jenkinson C, Avery A. The relationship between body mass index and health-related quality of life: comparing the EQ-5D, EuroQol VAS and SF-6D. International journal of obesity. 2007;31(1):189.
163. Saab MM, McCarthy B, Andrews T, Savage E, Drummond FJ, Walshe N, et al. The effect of adult Early Warning Systems education on nurses' knowledge, confidence and clinical performance: A systematic review. Journal of advanced nursing. 2017;73(11):2506-21.
164. Cahill H, Jones A, Herkes R, Cook K, Stirling A, Halbert T, et al. Introduction of a new observation chart and education programme is associated with higher rates of vital-sign ascertainment in hospital wards. BMJ Quality and Safety. 2011;20(9):791-6.
165. Kyriacos U, Jelsma J, James M, Jordan S. Early warning scoring systems versus standard observations charts for wards in South Africa: a cluster randomized controlled trial. Trials. 2015;16:103.
166. Liaw SY, Chan SW, Chen FG, Hooi SC, Siau C. Comparison of virtual patient simulation with mannequin-based simulation for improving clinical performances in assessing and managing clinical deterioration: randomized controlled trial. Journal of medical Internet research. 2014;16(9):e214.
167. Liaw SY, Wong LF, Chan SW, Ho JT, Mordiffi SZ, Ang SB, et al. Designing and evaluating an interactive multimedia Web-based simulation for developing nurses' competencies in acute nursing care: randomized controlled trial. Journal of medical Internet research. 2015;17(1):e5.
168. Lindsey PL, Jenkins S. Nursing students' clinical judgment regarding rapid response: the influence of a clinical simulation education intervention. Nursing forum. 2013;48(1):61-70.
169. Ludikhuize J, de Jonge E, Goossens A. Measuring adherence among nurses one year after training in applying the Modified Early Warning Score and Situation-Background-Assessment-Recommendation instruments. Resuscitation. 2011;82(11):1428-33.
170. Merriel A, Nelson Hvd, Merriel S, Bennett J, Donald F, Draycott T, et al. Identifying Deteriorating Patients Through Multidisciplinary Team Training. American Journal of Medical Quality. 2016;31(6):589-95.

171. Ozekcin LR, Tuite P, Willner K, Hravnak M. Simulation education: early identification of patient physiologic deterioration by acute care nurses. Clinical nurse specialist CNS. 2015;29(3):166-73.
172. Rose MA, Hanna LA, Nur SA, Johnson CM. Utilization of electronic modified early warning score to engage rapid response team early in clinical deterioration. Journal for nurses in professional development. 2015;31(3):E1-7.
173. Shaddel F, Khosla V, Banerjee S. Effects of introducing MEWS on nursing staff in mental health inpatient settings. Progress in Neurology and Psychiatry. 2014;18(2):24-7.
174. Hammond NE, Spooner AJ, Barnett AG, Corley A, Brown P, Fraser JF. The effect of implementing a modified early warning scoring (MEWS) system on the adequacy of vital sign documentation. Australian critical care : official journal of the Confederation of Australian Critical Care Nurses. 2013;26(1):18-22.
175. Kinsman L, Buykx P, Cant R, Champion R, Cooper S, Endacott R, et al. The FIRST(2)ACT simulation program improves nursing practice in a rural Australian hospital. The Australian journal of rural health. 2012;20(5):270-4.
176. Schubert CR. Effect of simulation on nursing knowledge and critical thinking in failure to rescue events. Journal of continuing education in nursing. 2012;43(10):467-71.
177. Liaw SY, Scherpbier A, Klainin-Yobas P, Rethans JJ. Rescuing A Patient In Deteriorating Situations (RAPIDS): An evaluation tool for assessing simulation performance on clinical deterioration. Resuscitation. 2011;82(11):1434-9.
178. Liaw SY, Scherpbier A, Rethans JJ, Klainin-Yobas P. Assessment for simulation learning outcomes: a comparison of knowledge and self-reported confidence with observed clinical performance. Nurse education today. 2012;32(6):e35-9.
179. Liaw SY, Wong LF, Ang SB, Ho JT, Siau C, Ang EN. Strengthening the afferent limb of rapid response systems: an educational intervention using web-based learning for early recognition and responding to deteriorating patients. BMJ quality & safety. 2016;25(6):448-56.
180. Liaw SY, Chng DYJ, Wong LF, Ho JTY, Mordiffi SZ, Cooper S, et al. The impact of a Web-based educational program on the recognition and management of deteriorating patients. Journal of Clinical Nursing. 2017;26(23/24):4848-56.
181. Liaw SY, Wong LF, Lim EY, Ang SB, Mujumdar S, Ho JT, et al. Effectiveness of a Web-Based Simulation in Improving Nurses' Workplace Practice With Deteriorating Ward Patients: A Pre- and Postintervention Study. Journal of medical Internet research. 2016;18(2):e37.
182. Wood SD, Candeland JL, Dinning A, Dow S, Hunkin H, McHale S, et al. Our approach to changing the culture of caring for the acutely unwell patient at a large UK teaching hospital: A service improvement focus on Early Warning Scoring tools. Intensive Crit Care Nurs. 2015;31(2):106-15.
183. McDonnell A, Tod A, Bray K, Bainbridge D, Adsetts D, Walters S. A before and after study assessing the impact of a new model for recognizing and responding to early signs of deterioration in an acute hospital. Journal of advanced nursing. 2013;69(1):41-52.
184. Wood SD, Candeland JL, Dinning A, Dow S, Hunkin H, McHale S, et al. Our approach to changing the culture of caring for the acutely unwell patient at a large UK teaching hospital: A service improvement focus on Early Warning Scoring tools. Intensive & critical care nursing. 2015;31(2):106-15.

185. McDonnell A, Tod A, Bray K, Bainbridge D, Adsetts D, Walters S. A before and after study assessing the impact of a new model for recognizing and responding to early signs of deterioration in an acute hospital. Journal of advanced nursing. 2012;69(1):41-52.
186. Mullany DV, Ziegenfuss M, Goleby MA, Ward HE. Improved hospital mortality with a low MET dose: the importance of a modified early warning score and communication tool. Anaesthesia & Intensive Care. 2016;44(6):734-41.
187. Pimentel MAF, Redfern OC, Gerry S, Collins GS, Malycha J, Prytherch D, et al. A comparison of the ability of the National Early Warning Score and the National Early Warning Score 2 to identify patients at risk of in-hospital mortality: A multi-centre database study. Resuscitation. 2018;134:147-56.
188. Trinkle RM, Flabouris A. Documenting Rapid Response System afferent limb failure and associated patient outcomes. Resuscitation. 2011;82(7):810-4.
189. Johnston MJ, Arora S, King D, Bouras G, Almoudaris AM, Davis R, et al. A systematic review to identify the factors that affect failure to rescue and escalation of care in surgery. Surgery. 2015;157(4):752-63.
190. Elliott D, Allen E, Perry L, Fry M, Duffield C, Gallagher R, et al. Clinical user experiences of observation and response charts: focus group findings of using a new format chart incorporating a track and trigger system. BMJ quality & safety. 2015;24(1):65-75.
191. Kitto S, Marshall SD, McMillan SE, Shearer B, Buist M, Grant R, et al. Rapid response systems and collective (in) competence: An exploratory analysis of intraprofessional and interprofessional activation factors. Journal of interprofessional care. 2015;29(4):340-6.
192. Massey D, Chaboyer W, Aitken L. Nurses' perceptions of accessing a Medical Emergency Team: a qualitative study. Australian critical care : official journal of the Confederation of Australian Critical Care Nurses. 2014;27(3):133-8.
193. Johnston M, Arora S, King D, Stroman L, Darzi A. Escalation of care and failure to rescue: a multicenter, multiprofessional qualitative study. Surgery. 2014;155(6):989-94.
194. Mackintosh N, Rainey H, Sandall J. Understanding how rapid response systems may improve safety for the acutely ill patient: learning from the frontline. BMJ quality & safety. 2012;21(2):135-44.
195. Mackintosh N, Humphrey C, Sandall J. The habitus of 'rescue' and its significance for implementation of rapid response systems in acute health care. Social science & medicine (1982). 2014;120:233-42.
196. Cherry PG, Jones CP. Attitudes of nursing staff towards a Modified Early Warning System. British Journal Of Nursing (Mark Allen Publishing). 2015;24(16):812-8.
197. Astroth K, M Woith W, Stapleton SJ, Degitz RJ, Jenkins SH. Qualitative exploration of nurses' decisions to activate rapid response teams. Journal of Clinical Nursing. 2013;22(19-20):2876-82.
198. Benin AL, Borgstrom CP, Jenq GY, Roumanis SA, Horwitz LI, Benin AL, et al. Republished: Defining impact of a rapid response team: qualitative study with nurses, physicians and hospital administrators. Postgraduate Medical Journal. 2012;88(1044):575-82.
199. Williams DJ, Newman A, Jones C, Woodard B. Nurses' perceptions of how rapid response teams affect the nurse, team, and system. Journal of nursing care quality. 2011;26(3):265-72.
200. Braaten JS. Hospital System Barriers to Rapid Response Team Activation: A Cognitive Work Analysis. AJN American Journal of Nursing. 2015;115(2):22-33.

201. Lydon S, Byrne D, Offiah G, Gleeson L, O'Connor P. A mixed-methods investigation of health professionals' perceptions of a physiological track and trigger system. BMJ Quality & Safety. 2016;25(9):688-95.
202. Stafseth SK, Grønbeck S, Lien T, Randen I, Lerdal A. The experiences of nurses implementing the Modified Early Warning Score and a 24-hour on-call Mobile Intensive Care Nurse: An exploratory study. Intensive and Critical Care Nursing. 2016;34:33-41.
203. Petersen JA, Rasmussen LS, Rydahl-Hansen S. Barriers and facilitating factors related to use of early warning score among acute care nurses: a qualitative study. BMC Emergency Medicine. 2017;17:1-9.
204. Chua WL, Liaw SY, Ng EKC, Mackey SJ. Frontline nurses' experiences in recognising and responding to clinical deterioration. Annals of the Academy of Medicine Singapore. 2012;41(9):S40.
205. Braun V, Clarke V, Terry G. Thematic analysis. Qual Res Clin Health Psychol. 2014;24:95-114.
206. Lydon S, Byrne D, O'Connor P, Gleeson L, Offiah G. A mixed-methods investigation of health professionals' perceptions of a physiological track and trigger system. 2016.
207. Massey D, Chaboyer W, Anderson V. What factors influence ward nurses' recognition of and response to patient deterioration? An integrative review of the literature. Nursing Open. 2017;4(1):6-23.
208. Ford DW, Goodwin AJ, Simpson AN, Johnson E, Nadig N, Simpson KN. A Severe Sepsis Mortality Prediction Model and Score for Use With Administrative Data. Critical Care Medicine. 2016;44(2):319-27.
209. Alam N, Vegting IL, Houben E, van Berkel B, Vaughan L, Kramer MH, et al. Exploring the performance of the National Early Warning Score (NEWS) in a European emergency department. Resuscitation. 2015;90:111-5.
210. Brown RT. Facilitating adoption of NEWS tool to develop clinical decision making. US: ProQuest Information & Learning; 2018.
211. Bulut M, Cebicci H, Sigirli D, Sak A, Durmus O, Top AA, et al. The comparison of modified early warning score with rapid emergency medicine score: a prospective multicentre observational cohort study on medical and surgical patients presenting to emergency department. Emergency medicine journal : EMJ. 2014;31(6):476-81.
212. Cattermole GN, Mak SK, Liow CH, Ho MF, Hung KY, Keung KM, et al. Derivation of a prognostic score for identifying critically ill patients in an emergency department resuscitation room. Resuscitation. 2009;80(9):1000-5.
213. Christensen D, Jensen NM, Maaloe R, Rudolph SS, Belhage B, Perrild H. Nurse-administered early warning score system can be used for emergency department triage. Danish medical bulletin. 2011;58(6):A4221.
214. Considine J, Jones D, Pilcher D, Currey J. Physiological status during emergency department care: relationship with inhospital death after clinical deterioration. Critical care and resuscitation : journal of the Australasian Academy of Critical Care Medicine. 2015;17(4):257-62.
215. Dundar ZD, Ergin M, Karamercan MA, Ayranci K, Colak T, Tuncar A, et al. Modified Early Warning Score and VitalPac Early Warning Score in geriatric patients admitted to emergency department. European journal of emergency medicine : official journal of the European Society for Emergency Medicine. 2016;23(6):406-12.
216. Flôr da Rocha T, Gibbon Neves J, Viegas K. Modified early warning score: evaluation of trauma patients. Revista Brasileira de Enfermagem. 2016;69(5):850-5.

217. Geier F, Popp S, Greve Y, Achterberg A, Glockner E, Ziegler R, et al. Severity illness scoring systems for early identification and prediction of in-hospital mortality in patients with suspected sepsis presenting to the emergency department. Wiener klinische Wochenschrift. 2013;125(17-18):508-15.
218. Ho le O, Li H, Shahidah N, Koh ZX, Sultana P, Hock Ong ME. Poor performance of the modified early warning score for predicting mortality in critically ill patients presenting to an emergency department. World journal of emergency medicine. 2013;4(4):273-8.
219. Huggan PJ, Akram F, Er BH, Christen LS, Weixian L, Lim V, et al. Measures of acute physiology, comorbidity and functional status to differentiate illness severity and length of stay among acute general medical admissions: a prospective cohort study. Internal medicine journal. 2015;45(7):732-40.
220. Jain A, Palta S, Saroa R, Palta A, Sama S, Gombar S. Sequential organ failure assessment scoring and prediction of patient's outcome in Intensive Care Unit of a tertiary care hospital. Journal of Anaesthesiology Clinical Pharmacology. 2016;32(3):364-8.
221. Kaufman EJ, Earl-Royal E, Barie PS, Holena DN. Failure to Rescue after Infectious Complications in a Statewide Trauma System. Surgical Infections. 2017;18(2):89-98.
222. Keep JW, Messmer AS, Sladden R, Burrell N, Pinate R, Tunnicliff M, et al. National early warning score at Emergency Department triage may allow earlier identification of patients with severe sepsis and septic shock: a retrospective observational study. Emergency medicine journal : EMJ. 2016;33(1):37-41.
223. Kellett J, Murray A. Should predictive scores based on vital signs be used in the same way as those based on laboratory data? A hypothesis generating retrospective evaluation of in-hospital mortality by four different scoring systems. Resuscitation. 2016;102:94-7.
224. Liu N, Koh ZX, Chua EC, Tan LM, Lin Z, Mirza B, et al. Risk scoring for prediction of acute cardiac complications from imbalanced clinical data. IEEE journal of biomedical and health informatics. 2014;18(6):1894-902.
225. Liu N, Koh ZX, Goh J, Lin Z, Haaland B, Ting BP, et al. Prediction of adverse cardiac events in emergency department patients with chest pain using machine learning for variable selection. BMC medical informatics and decision making. 2014;14(1):75.
226. Ong ME, Lee Ng CH, Goh K, Liu N, Koh ZX, Shahidah N, et al. Prediction of cardiac arrest in critically ill patients presenting to the emergency department using a machine learning score incorporating heart rate variability compared with the modified early warning score. Critical care (London, England). 2012;16(3):R108.
227. Park HO, Kim JW, Kim SH, Moon SH, Byun JH, Kim KN, et al. Usability verification of the Emergency Trauma Score (EMTRAS) and Rapid Emergency Medicine Score (REMS) in patients with trauma: A retrospective cohort study. Medicine. 2017;96(44):e8449-e.
228. Sbiti-Rohr D, Kutz A, Christ-Crain M, Thomann R, Zimmerli W, Hoess C, et al. The National Early Warning Score (NEWS) for outcome prediction in emergency department patients with community-acquired pneumonia: results from a 6-year prospective cohort study. BMJ open. 2016;6(9):e011021.
229. So SN, Ong CW, Wong LY, Chung JY, Graham CA. Is the Modified Early Warning Score able to enhance clinical observation to detect deteriorating patients earlier in an Accident & Emergency Department? Australasian emergency nursing journal : AENJ. 2015;18(1):24-32.
230. Urban RW, Mumba M, Martin SD, Glowicz J, Cipher DJ. Modified Early Warning System as a Predictor for Hospital Admissions and Previous Visits in Emergency Departments. Advanced emergency nursing journal. 2015;37(4):281-9.

231. Wong J, Taljaard M, Forster AJ, Escobar GJ, van Walraven C. Derivation and validation of a model to predict daily risk of death in hospital. Medical Care. 2011;49(8):734-43.
232. Calvert J, Hoffman J, Barton C, Shimabukuro D, Ries M, Chettipally U, et al. Cost and mortality impact of an algorithm-driven sepsis prediction system. Journal of medical economics. 2017;20(6):646-51.
233. Bunkenborg G, Poulsen I, Samuelson K, Ladelund S, Akeson J. Mandatory early warning scoring-implementation evaluated with a mixed-methods approach. Applied Nursing Research. 2016;29(1):168-76.
234. Churpek MM, Snyder A, Sokol S, Pettit NN, Edelson DP. Investigating the Impact of Different Suspicion of Infection Criteria on the Accuracy of Quick Sepsis-Related Organ Failure Assessment, Systemic Inflammatory Response Syndrome, and Early Warning Scores. Critical Care Medicine. 2017;45(11):1805-12.
235. Colombo F, Taurino L, Colombo G, Amato M, Rizzo S, Murolo M, et al. The Niguarda MEWS, a new and refined tool to determine criticality and instability in Internal Medicine Ward and Emergency Medicine Unit. Italian Journal of Medicine. 2017;11(3):310-7.
236. Jones M, Neal C, Ngu W, Dennison A, Garcea G. Early warning score independently predicts adverse outcome and mortality in patients with acute pancreatitis. Langenbeck's Archives of Surgery. 2017;402(5):811-9.
237. Badreldin AMA, Doerr F, Bender EM, Bayer O, Brehm BR, Wahlers T, et al. Rapid clinical evaluation: An early warning cardiac surgical scoring system for hand-held digital devices*. European Journal of Cardio-thoracic Surgery. 2013;44(6):992-8.
238. Barbosa V, Gomes E, Vaz S, Azevedo G, Fernandes G, Ferreira A, et al. Failure to activate the in-hospital emergency team: causes and outcomes. Revista Brasileira De Terapia Intensiva. 2016;28(4):420-6.
239. Chen J, Bellomo R, Flabouris A, Hillman K, Assareh H, Ou L. Delayed emergency team calls and associated hospital mortality: A multicenter study. Critical Care Medicine. 2015;43(10):2059-65.
240. Cheung W. Outcomes following changing from a two-tiered to a three-tiered hospital rapid response system. Australian health review: a publication of the Australian Hospital Association. 2017.
241. Clifton L, Clifton DA, Pimentel MA, Watkinson PJ, Tarassenko L. Predictive monitoring of mobile patients by combining clinical observations with data from wearable sensors. IEEE journal of biomedical and health informatics. 2014;18(3):722-30.
242. Despins LA. Factors influencing when intensive care unit nurses go to the bedside to investigate patient related alarms: A descriptive qualitative study. Intensive & Critical Care Nursing. 2017;43:101-7.
243. Edelson DP, Retzer E, Weidman EK, Woodruff J, Davis AM, Minsky BD, et al. Patient acuity rating: quantifying clinical judgment regarding inpatient stability. J Hosp Med. 2011;6(8):475-9.
244. Hoikka M, Lankimaki S, Silfvast T, Ala-Kokko TI. Medical priority dispatch codes--comparison with National Early Warning Score.(Report). Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine. 2016;24(1).
245. Hravnak M, Chen L, Dubrawski A, Bose E, Clermont G, Pinsky MR. Real alerts and artifact classification in archived multi-signal vital sign monitoring data: implications for mining big data. Journal Of Clinical Monitoring And Computing. 2016;30(6):875-88.

246. Kabrhel C, Rosovsky R, Channick R, Jaff MR, Weinberg I, Sundt T, et al. A Multidisciplinary Pulmonary Embolism Response Team: Initial 30-Month Experience With a Novel Approach to Delivery of Care to Patients With Submassive and Massive Pulmonary Embolism. Chest. 2016;150(2):384-93.
247. Kvande M, Delmar C, Lykkeslet E, Storli SL. Foresight and awareness of incipient changes in a patient' clinical conditions -- Perspectives of intensive care nurses. Intensive & Critical Care Nursing. 2015;31(5):261-8.
248. Law BY-S, Chan EA. The experience of learning to speak up: a narrative inquiry on newly graduated registered nurses. Journal of Clinical Nursing. 2015;24(13/14):1837-48.
249. Paredes S, Rocha T, Mendes D, Carvalho P, Henriques J, Morais J, et al. New approaches for improving cardiovascular risk assessment. Revista Portuguesa De Cardiologia: Orgao Oficial Da Sociedade Portuguesa De Cardiologia = Portuguese Journal Of Cardiology: An Official Journal Of The Portuguese Society Of Cardiology. 2016;35(1):5-13.
250. Rosenberg DJ, Press A, Fishbein J, Lesser M, McCullagh L, McGinn T, et al. External validation of the IMPROVE Bleeding Risk Assessment Model in medical patients. Thrombosis And Haemostasis. 2016;116(3):530-6.
251. Schoenfeld AJ, Le HV, Marjoua Y, Leonard DA, Belmont PJ, Jr., Bono CM, et al. Assessing the utility of a clinical prediction score regarding 30-day morbidity and mortality following metastatic spinal surgery: the New England Spinal Metastasis Score (NESMS). The Spine Journal: Official Journal Of The North American Spine Society. 2016;16(4):482-90.
252. Suh E-S, Mandal S, Harding R, Ramsay M, Kamalanathan M, Henderson K, et al. Neural respiratory drive predicts clinical deterioration and safe discharge in exacerbations of COPD. Thorax. 2015:thoraxjnl-2015-207188.
253. Thompson JE, Collett LW, Langbart MJ, Purcell NJ, Boyd SM, Yuminaga Y, et al. Using the ISBAR handover tool in junior medical officer handover: A study in an Australian tertiary hospital. Postgraduate Medical Journal. 2011;87(1027):340-4.
254. Timóteo AT, Aguiar Rosa S, Nogueira MA, Belo A, Cruz Ferreira R. External validation of the ProACS score for risk stratification of patients with acute coronary syndromes. Revista Portuguesa De Cardiologia: Orgao Oficial Da Sociedade Portuguesa De Cardiologia = Portuguese Journal Of Cardiology: An Official Journal Of The Portuguese Society Of Cardiology. 2016;35(6):323-8.
255. Won Young K, Yu Jung S, Jin Mi L, Jin Won H, Younsuck K, Chae-Man L, et al. Modified Early Warning Score Changes Prior to Cardiac Arrest in General Wards. PLoS ONE. 2015;10(6):e0130523.
256. Bellomo R, Ackerman M, Bailey M, Beale R, Clancy G, Danesh V, et al. A controlled trial of electronic automated advisory vital signs monitoring in general hospital wards. Critical Care Medicine. 2012;40(8):2349-61.
257. Subbe CP, Kellett J, Whitaker CJ, Jishi F, White A, Price S, et al. A pragmatic triage system to reduce length of stay in medical emergency admission: feasibility study and health economic analysis. Eur J Intern Med. 2014;25(9):815-20.
258. Kostiuk S. Can Learning the ISBARR Framework Help to Address Nursing Students' Perceived Anxiety and Confidence Levels Associated With Handover Reports? The Journal Of Nursing Education. 2015;54(10):583-7.
259. Adelstein BA, Piza MA, Nayyar V, Mudaliar Y, Klineberg PL, Rubin G. Rapid response systems: A prospective study of response times. Journal of Critical Care. 2011;26(6):635.e11-.e18.

260. Barwise A, Thongprayoon C, Gajic O, Jensen J, Herasevich V, Pickering BW. Delayed rapid response team activation is associated with increased hospital mortality, morbidity, and length of stay in a tertiary care institution. Critical Care Medicine. 2016;44(1):54-63.
261. Brown C, Drosdowsky A, Krishnasamy M. An exploration of medical emergency team intervention at the end of life for people with advanced cancer. European Journal of Oncology Nursing. 2017;31:77-83.
262. Capan M, Ivy JS, Wilson JR, Huddleston JM. A stochastic model of acute-care decisions based on patient and provider heterogeneity. Health Care Management Science. 2017;20(2):187-206.
263. Chen L, Dubrawski A, Wang D, Fiterau M, Guillame-Bert M, Bose E, et al. Using Supervised Machine Learning to Classify Real Alerts and Artifact in Online Multisignal Vital Sign Monitoring Data. Critical Care Medicine. 2016;44(7):e456-e63.
264. Cheung W, Sahai V, Mann-Farrar J, Skylas K, Uy J, Doyle B. Incidents resulting from staff leaving normal duties to attend medical emergency team calls. The Medical Journal Of Australia. 2014;201(9):528-31.
265. Considine J, Charlesworth D, Currey J. Characteristics and outcomes of patients requiring rapid response system activation within hours of emergency admission. Critical care and resuscitation : journal of the Australasian Academy of Critical Care Medicine. 2014;16(3):184-9.
266. De Freitas GF, Hoga LAK, Fernandes MdFP, GonzÁLez JS, Ruiz MCS, Bonini BB. Brazilian registered nurses' perceptions and attitudes towards adverse events in nursing care: a phenomenological study. Journal of Nursing Management. 2011;19(3):331-8.
267. Clifton DA, Clifton L, Sandu D-M, Smith GB, Tarassenko L, Vollam SA, et al. 'Errors' and omissions in paper-based early warning scores: the association with changes in vital signs—a database analysis. BMJ Open. 2015;5(7).
268. Downar J, Barua R, Rodin D, Lejnieks B, Gudimella R, McCredie V, et al. Changes in end of life care 5 years after the introduction of a rapid response team: A multicentre retrospective study. Resuscitation. 2013;84(10):1339-44.
269. Downar J, Rodin D, Barua R, Lejnieks B, Gudimella R, McCredie V, et al. Rapid response teams, do not resuscitate orders, and potential opportunities to improve end-of-life care: a multicentre retrospective study. Journal of Critical Care. 2013;28(4):498-503.
270. Hands C, Reid E, Meredith P, Smith GB, Prytherch DR, Schmidt PE, et al. Patterns in the recording of vital signs and early warning scores: compliance with a clinical escalation protocol. BMJ Quality & Safety. 2013;22(9):719-26.
271. Harris P. Early warning scores in cardiac arrest patients. British Journal of Cardiac Nursing. 2013;8(9):432-7.
272. Oglesby KJ, Durham L, Welch J, Subbe CP. 'Score to Door Time', a benchmarking tool for rapid response systems: a pilot multi-centre service evaluation. Critical Care. 2011;15(4):R180-R.
273. Pedersen N, Rasmussen L, Petersen J, Gerds T, Østergaard D, Lippert A. A critical assessment of early warning score records in 168,000 patients. Including a Specialty Section on Surgical Neuromonitoring. 2018;32(1):109-16.
274. Peebles E, Subbe CP, Hughes P, Gemmell L. Timing and teamwork--an observational pilot study of patients referred to a Rapid Response Team with the aim of identifying factors amenable to re-design of a Rapid Response System. Resuscitation. 2012;83(6):782-7.

275. Petersen JA, Mackel R, Antonsen K, Rasmussen LS. Serious adverse events in a hospital using early warning score - what went wrong? Resuscitation. 2014;85(12):1699-703.
276. Tan LH, Delaney A. Medical emergency teams and end-of-life care: a systematic review. Critical care and resuscitation : journal of the Australasian Academy of Critical Care Medicine. 2014;16(1):62-8.
277. Aligawesa M, Marks-Maran D. Meeting physical health needs: The Modified Early Warning Score (MEWS) project. British Journal of Mental Health Nursing. 2017;6(2):73-80.
278. Alrawi YA, Parker RA, Harvey RC, Sultanzadeh SJ, Patel J, Mallinson R, et al. Predictors of early mortality among hospitalized nursing home residents. QJM : monthly journal of the Association of Physicians. 2013;106(1):51-7.
279. Arulvarathan C, Yuting D. A retrospective pilot study on patients who deteriorated while admitted to a neurovascular ward. British Journal of Neuroscience Nursing. 2017;13(6):282-7.
280. Austen C, Patterson C, Poots A, Green S, Weldring T, Bell D. Using a local early warning scoring system as a model for the introduction of a national system. Acute Medicine. 2012;11(2):66-73.
281. Ballangrud R, Hall-Lord ML, Persenius M, Hedelin B. Intensive care nurses' perceptions of simulation-based team training for building patient safety in intensive care: A descriptive qualitative study. Intensive & Critical Care Nursing. 2013;30(4):179-87.
282. Bardwell KD. Evaluation of the early warning system at banner desert medical center. https://arizona.openrepository.com/arizona/bitstream/10150/621108/1/azu_etd_14943_sip1_m.pdf, editor: The University of Arizona; 2016.
283. Brown S, Anderson MA, Hill PD. Rapid response team in a rural hospital. Clinical nurse specialist CNS. 2012;26(2):95-102.
284. Chalwin RP, Flabouris A. Utility and assessment of non-technical skills for rapid response systems and medical emergency teams. Internal medicine journal. 2013;43(9):962-9.
285. Christian Peter S, John Robert W. Failure to rescue: using rapid response systems to improve care of the deteriorating patient in hospital. Clinical Risk. 2013;19(1):6-11.
286. Churpek MM, Adhikari R, Edelson DP. The value of vital sign trends for detecting clinical deterioration on the wards. Resuscitation. 2016;102:1-5.
287. Cooper S, Beauchamp A, Bogossian F, Bucknall T, Cant R, DeVries B, et al. Managing patient deterioration: a protocol for enhancing undergraduate nursing students' competence through web-based simulation and feedback techniques. BMC Nursing. 2012;11(1):18-24.
288. Cooper SJ, Cant RP. Measuring non-technical skills of medical emergency teams: An update on the validity and reliability of the team emergency assessment measure (TEAM). Resuscitation. 2014;85(1):31-3.
289. De Silva AP, Sujeewa JA, De Silva N, Danapala Rathnayake RM, Vithanage L, Sigera PC, et al. A Retrospective Study of Physiological Observation-reporting Practices and the Recognition, Response, and Outcomes Following Cardiopulmonary Arrest in a Low-to-middle-income Country. Indian Journal of Critical Care Medicine. 2017;21(6):343-5.
290. Khurana HS, Groves RH, Jr., Simons MP, Martin M, Stoffer B, Kou S, et al. Real-Time Automated Sampling of Electronic Medical Records Predicts Hospital Mortality. The American Journal Of Medicine. 2016;129(7):688-98.e2.
291. Kolic I, Crane S, McCartney S, Perkins Z, Taylor A. Factors affecting response to national early warning score (NEWS). Resuscitation. 2015;90:85-90.

292. LeGuen M, Ballueer Y, McKay R, Eastwood G, Bellomo R, Jones D, et al. Frequency and significance of qSOFA criteria during adult rapid response team reviews: A prospective cohort study. Resuscitation. 2018;122:13-8.
293. Lobo R, Lynch K, Casserly LF. Cross-sectional audit on the relevance of Elevated National Early Warning Score in medical patients at a Model 2 hospital in Ireland. Irish journal of medical science. 2015;184(4):893-8.
294. Ludikhuize J, Dongelmans DA, Smorenburg SM, Gans-Langelaar M, Jonge E, Rooij SE. How nurses and physicians judge their own quality of care for deteriorating patients on medical wards: Self-assessment of quality of care is suboptimal*. Critical Care Medicine. 2012;40(11):2982-6.
295. Maharaj R, Stelfox H, Stelfox HT. Rapid response teams improve outcomes: no. Intensive Care Medicine. 2016;42(4):596-8.
296. McClelland G. A retrospective observational study to explore the introduction of the National Early Warning Score in NEAS. Journal of Paramedic Practice. 2015;7(2):80-9.
297. McGinley A, Pearse RM. A national early warning score for acutely ill patients. BMJ (Online). 2012;345(7869).
298. Mok W, Wang W, Cooper S, Ang EN, Liaw SY. Attitudes towards vital signs monitoring in the detection of clinical deterioration: scale development and survey of ward nurses. International journal for quality in health care : journal of the International Society for Quality in Health Care. 2015;27(3):207-13.
299. Mora JC, Schneider A, Robbins R, Bailey M, Bebee B, Hsiao Y-FF, et al. Epidemiology of early Rapid Response Team activation after Emergency Department admission. Australasian Emergency Nursing Journal. 2016;19(1):54-61.
300. Nagammal S, Nashwan AJ, Nair SLK, Susmitha A. Nurses' perceptions regarding using the SBAR tool for handoff communication in a tertiary cancer center in Qatar. Journal of Nursing Education & Practice. 2017;7(4):103-10.
301. Nwulu U, Westwood D, Edwards D, Kelliher F, Coleman JJ. Adoption of an electronic observation chart with an integrated early warning scoring system on pilot wards: a descriptive report. Computers, informatics, nursing : CIN. 2012;30(7):371-9.
302. Parham G. Recognition and response to the clinically deteriorating patient. Australian Medical Student Journal. 2012;3:18-22.
303. Patel AR, Zadravecz FJ, Young RS, Williams MV, Churpek MM, Edelson DP. The value of clinical judgment in the detection of clinical deterioration. JAMA internal medicine. 2015;175(3):456-8.
304. Patel A, Hassan S, Ullah A, Hamid T, Kirk H. Early triaging using the Modified Early Warning Score (MEWS) and dedicated emergency teams leads to improved clinical outcomes in acute emergencies. Clinical medicine (London, England). 2015;15 Suppl 3:s3.
305. Psirides A, Hill J, Hurford S. A review of rapid response team activation parameters in New Zealand hospitals. Resuscitation. 2013;84(8):1040-4.
306. Purling A, King L. A literature review: Graduate nurses' preparedness for recognising and responding to the deteriorating patient. Journal of Clinical Nursing. 2012;21(23-24):3451-65.
307. Roasio A, Costanzo E, Cardellino S. The impact of rapid response team on epidemiology of in-hospital cardiac arrest: A 5-years observational study. Intensive Care Medicine Experimental. 2016;4.

308. Romero-Brufau S, Huddleston JM, Escobar GJ, Liebow M. Why the C-statistic is not informative to evaluate early warning scores and what metrics to use. Critical Care. 2015;19(1):285.
309. Royal College of Physicians. National Early Warning Score (NEWS) 2: Standardising the assessment of acute-illness severity in the NHS. Updated report of a working party. London: RCP2017.
310. Ruiz Izquierdo J, Simón Pascua L, Martínez Pujol L, Sánchez González B, Figueras Solé G, Muñoz Gamito G, et al. The National Early Warning Score (NEWS) for outcome prediction in medical patients in emergency department with medical criteria of admission in medical ward: A pilot study. Intensive Care Medicine Experimental. 2017;5(2).
311. Sarani B. Accuracy of an expanded early warning score for patients in general and trauma surgery wards (Br J Surg 2012; 99: 192-197). The British journal of surgery. 2012;99(2):197-8.
312. Tirkkonen J, Olkkola KT, Huhtala H, Tenhunen J, Hoppu S. Medical emergency team activation: performance of conventional dichotomised criteria versus national early warning score. Acta Anaesthesiol Scand. 2014;58(4):411-9.
313. White K, Scott IA, Vaux A, Sullivan CM. Rapid response teams in adult hospitals: time for another look? Internal medicine journal. 2015;45(12):1211-20.
314. Yoder JC, Yuen TC, Churpek MM, Arora VM, Edelson DP. A prospective study of nighttime vital sign monitoring frequency and risk of clinical deterioration. JAMA internal medicine. 2013;173(16):1554-5.
315. Shearer B, Marshall S, Buist MD. What stops hospital clinical staff from following protocols? an analysis of the incidence and factors behind the failure of bedside clinical staff to activate the rapid response system in a multi-campus Australian metropolitan healthcare service. 2012.
316. Buykx P, Kinsman L, Cooper S, McConnell-Henry T, Cant R, Endacott R, et al. FIRST2ACT: educating nurses to identify patient deterioration - a theory-based model for best practice simulation education. Nurse education today. 2011;31(7):687-93.
317. Preece MH, Hill A, Horswill MS, Watson MO. Supporting the detection of patient deterioration: observation chart design affects the recognition of abnormal vital signs. Resuscitation. 2012;83(9):1111-8.
318. Alam N, Hobbelink EL, van Tienhoven AJ, van de Ven PM, Jansma EP, Nanayakkara PW. The impact of the use of the Early Warning Score (EWS) on patient outcomes: a systematic review. Resuscitation. 2014;85(5):587-94.
319. Jo S, Jeong T, Lee JB, Jin Y, Yoon J, Park B. Validation of modified early warning score using serum lactate level in community-acquired pneumonia patients. The National Early Warning Score–Lactate score. American Journal of Emergency Medicine. 2016;34(3):536-41.
320. Jong A, Jung B, Daurat A, Chanques G, Mahul M, Monnin M, et al. Effect of rapid response systems on hospital mortality: a systematic review and meta-analysis. Intensive Care Medicine. 2016;42(4):615-7.
321. Mapp ID, Davis LL, Krowchuk H. Prevention of unplanned intensive care unit admissions and hospital mortality by early warning systems. Dimensions of critical care nursing : DCCN. 2013;32(6):300-9.
322. McNeill G, Bryden D. Do either early warning systems or emergency response teams improve hospital patient survival? A systematic review. Resuscitation. 2013;84(12):1652-67.

323. Roney JK, Whitley BE, Maples JC, Futrell LS, Stunkard KA, Long JD. Modified early warning scoring (MEWS): evaluating the evidence for tool inclusion of sepsis screening criteria and impact on mortality and failure to rescue. J Clin Nurs. 2015;24(23-24):3343-54.
324. Smith MEB, Chiovaro J, O'Neil M, Kansagara D, Quinones A, Freeman M, et al. Early Warning Scoring Systems: A Systematic Review VA-ESP Project #05-225: 2013.
325. Smith MEB, Chiovaro JC, O'Neil M, Kansagara D, Quiñones AR, Freeman M, et al. Early warning system scores for clinical deterioration in hospitalized patients: A systematic review. Annals of the American Thoracic Society. 2014;11(9):1454-65.
326. Solomon RS, Corwin GS, Barclay DC, Quddusi SF, Dannenberg MD. Effectiveness of rapid response teams on rates of in-hospital cardiopulmonary arrest and mortality: A systematic review and meta-analysis. Journal of Hospital Medicine. 2016;11(6):438-45.
327. Winters BD, Weaver SJ, Pfoh ER, Yang T, Pham JC, Dy SM. Rapid-response systems as a patient safety strategy: a systematic review. Annals of internal medicine. 2013;158(5 Pt 2):417-25.
328. Cardona-Morrell M, Prgomet M, Turner RM, Nicholson M, Hillman K. Effectiveness of continuous or intermittent vital signs monitoring in preventing adverse events on general wards: a systematic review and meta-analysis. International journal of clinical practice. 2016;70(10):806-24.
329. Maharaj R, Raffaele I, Wendon J. Rapid response systems: a systematic review and meta-analysis. Critical care (London, England). 2015;19:254.
330. Downey CL, Tahir W, Randell R, Brown JM, Jayne DG. Strengths and limitations of early warning scores: A systematic review and narrative synthesis. Int J Nurs Stud. 2017;76:106-19.
331. Leach LS, Mayo AM. Rapid response teams: qualitative analysis of their effectiveness. American Journal Of Critical Care: An Official Publication, American Association Of Critical-Care Nurses. 2013;22(3):198-210.
332. Smith DJ, Aitken LM. Use of a single parameter track and trigger chart and the perceived barriers and facilitators to escalation of a deteriorating ward patient: a mixed methods study. Journal of Clinical Nursing. 2016;25(1/2):175-85.
333. Stolldorf DP. The Benefits of Rapid Response Teams: Exploring Perceptions of Nurse Leaders, Team Members, and End Users. AJN American Journal of Nursing. 2016;116(3):38-47.
334. Vaughn JL, Kline D, Denlinger NM, Andritsos LA, Exline MC, Walker AR. Predictive performance of early warning scores in acute leukemia patients receiving induction chemotherapy. Leukemia and Lymphoma. 2017:1-3.
335. Beebe P, Bawel-Brinkley K, O'Leary-Kelley C. Observed and self-perceived teamwork in a rapid response team. Journal for nurses in staff development : JNSD : official journal of the National Nursing Staff Development Organization. 2012;28(4):191-7.
336. Boniatti MM, Azzolini N, Viana MV, Ribeiro BSP, Coelho RS, Castilho RK, et al. Delayed medical emergency team calls and associated outcomes. Critical Care Medicine. 2014;42(1):26-30.
337. Bucknall TK, Jones D, Bellomo R, Staples M. Responding to medical emergencies: System characteristics under examination (RESCUE). A prospective multi-site point prevalence study. Resuscitation. 2013;84(2):179-83.
338. Cabrini L, Monti G, Plumari VP, Landoni G, Turi S, Laura P, et al. Observed versus predicted hospital mortality in general wards patients assisted by a medical emergency team. Signa Vitae. 2012;7(1):38-42.

339. Carmichael HA, Robertson E, Austin J, McCruden D, Messow CM, Belcher PR. A new approach to scoring systems to improve identification of acute medical admissions that will require critical care. Scottish Medical Journal. 2011;56(4):195-202.
340. Corfield AR, Lees F, Zealley I, Houston G, Dickie S, Ward K, et al. Utility of a single early warning score in patients with sepsis in the emergency department. Emergency Medicine Journal. 2013.
341. Correia N, Rodrigues RP, Sá MC, Dias P, Lopes L, Paiva A. Improving recognition of patients at risk in a Portuguese general hospital: results from a preliminary study on the early warning score. International Journal of Emergency Medicine. 2014;7(1).
342. Coventry C, Flabouris A, Sundararajan K, Cramey T. Rapid response team calls to patients with a pre-existing not for resuscitation order. Resuscitation. 2013;84(8):1035-9.
343. De Meester K, Haegdorens F, Monsieurs KG, Verpooten GA, Holvoet A, Van Bogaert P. Six-day postoperative impact of a standardized nurse observation and escalation protocol: A preintervention and postintervention study. Journal of Critical Care. 2013;28(6):1068-74.
344. Gordon CF, Beckett DJ. Significant deficiencies in the overnight use of a Standardised Early Warning Scoring system in a teaching hospital. Scott Med J. 2011;56(1):15-8.
345. Hammer JA, Jones TL, Brown SA. Rapid response teams and failure to rescue: One community's experience. Journal of nursing care quality. 2012;27(4):352-8.
346. Herrod PJJ, Barclay C, Blakey JD. Can mobile technology improve response times of junior doctors to urgent out-of-hours calls? A prospective observational study. QJM : monthly journal of the Association of Physicians. 2014;107(4):271-6.
347. Hughes C, Pain C, Braithwaite J, Hillman K. 'Between the flags': Implementing a rapid response system at scale. BMJ Quality and Safety. 2014;23(9):714-7.
348. Huh JW, Lim CM, Koh Y, Lee J, Jung YK, Seo HS, et al. Activation of a medical emergency team using an electronic medical recording-based screening system. Critical Care Medicine. 2014;42(4):801-8.
349. Jäderling G, Bell M, Martling CR, Ekbom A, Bottai M, Konrad D. ICU admittance by a rapid response team versus conventional admittance, characteristics, and outcome. Critical Care Medicine. 2013;41(3):725-31.
350. Jäderling G, Bell M, Martling CR, Ekbom A, Konrad D. Limitations of medical treatment among patients attended by the rapid response team. Acta Anaesthesiologica Scandinavica. 2013;57(10):1268-74.
351. Jäderling G, Calzavacca P, Bell M, Martling CR, Jones D, Bellomo R, et al. The deteriorating ward patient: A Swedish-Australian comparison. Intensive Care Medicine. 2011;37(6):1000-5.
352. Jenkins PF, Thompson CH, Barton LL. Clinical deterioration in the condition of patients with acute medical illness in Australian hospitals: Improving detection and response. Medical Journal of Australia. 2011;194(11):596-8.
353. Jonsson T, Jonsdottir H, Möller AD, Baldursdottir L. Nursing documentation prior to emergency admissions to the intensive care unit. Nursing in critical care. 2011;16(4):164-9.
354. Johnson M, Jefferies D, Nicholls D. Developing a minimum data set for electronic nursing handover. Journal of Clinical Nursing. 2012;21(3-4):331-43.
355. Jones D, Drennan K, Hart GK, Bellomo R, Steven AR. Rapid Response Team composition, resourcing and calling criteria in Australia. Resuscitation. 2012;83(5):563-7.
356. Jones D, Moran J, Winters B, Welch J. The rapid response system and end-of-life care. Current Opinion in Critical Care. 2013;19(6):616-23.

357. Jones DA, Drennan K, Bailey M, Hart GK, Bellomo R, Webb SAR, et al. Mortality of rapid response team patients in Australia: A multicentre study. Critical Care and Resuscitation. 2013;15(4):273-8.
358. Kabrhel C, Okechukwu I, Hariharan P, Takayesu JK, MacMahon P, Haddad F, et al. Factors associated with clinical deterioration shortly after PE. Thorax. 2014;69(9):835-42.
359. Karra V, Papathanassoglou ED, Lemonidou C, Sourtzi P, Giannakopoulou M. Exploration and classification of intensive care nurses' clinical decisions: a Greek perspective. Nursing in critical care. 2014;19(2):87-97.
360. Kaufman M, Bebee B, Bailey J, Robbins R, Hart GK, Bellomo R. Laboratory tests to identify patients at risk of early major adverse events: A prospective pilot study. Internal medicine journal. 2014;44(10):1005-12.
361. Kegler AL, Dale BD, McCarthy AJ. The use of high-fidelity simulation for rapid response team training: a community hospital's story. Journal for nurses in staff development : JNSD : official journal of the National Nursing Staff Development Organization. 2012;28(2):50-2.
362. Kellett J, Kim A. Validation of an abbreviated Vitalpac™ Early Warning Score (ViEWS) in 75,419 consecutive admissions to a Canadian Regional Hospital. Resuscitation. 2012;83(3):297-302.
363. Kellett J, Murray A. How to follow the NEWS. Acute Medicine. 2014;13(3):104-7.
364. Kellett J, Wang F, Woodworth S, Huang W. Changes and their prognostic implications in the abbreviated VitalPAC™ Early Warning Score (ViEWS) after admission to hospital of 18,827 surgical patients. Resuscitation. 2013;84(4):471-6.
365. Khalid I, Qabajah MR, Hamad WJ, Khalid TJ, DiGiovine B. Outcome of hypotensive ward patients who re-deteriorate after initial stabilization by the Medical Emergency Team. Journal of Critical Care. 2014;29(1):54-9.
366. Kollef MH, Chen Y, Heard K, Larossa GN, Lu C, Martin NR, et al. A randomized trial of real-time automated clinical deterioration alerts sent to a rapid response team. Journal of Hospital Medicine. 2014;9(7):424-9.
367. Kwak HJ, Yun I, Kim SH, Sohn JW, Shin DH, Yoon HJ, et al. The extended rapid response system: 1-year experience in a university hospital. Journal of Korean medical science. 2014;29(3):423-30.
368. Kyriacos U, Jelsma J, Jordan S. Monitoring vital signs using early warning scoring systems: A review of the literature. Journal of Nursing Management. 2011;19(3):311-30.
369. Laurens N, Dwyer T. The impact of medical emergency teams on ICU admission rates, cardiopulmonary arrests and mortality in a regional hospital. Resuscitation. 2011;82(6):707-12.
370. Lim SY, Park SY, Park HK, Kim M, Park HY, Lee B, et al. Early impact of medical emergency team implementation in a country with limited medical resources: A before-and-after study. Journal of Critical Care. 2011;26(4):373-8.
371. Lin LC, Lee TH, Chang CH, Chang YJ, Liou CW, Chang KC, et al. Predictors of clinical deterioration during hospitalization following acute ischemic stroke. European Neurology. 2012;67(3):186-92.
372. Lin LC, Yang JT, Weng HH, Hsiao CT, Lai SL, Fann WC. Predictors of early clinical deterioration after acute ischemic stroke. American Journal of Emergency Medicine. 2011;29(6):577-81.
373. Lovett PB, Massone RJ, Holmes MN, Hall RV, Lopez BL. Rapid response team activations within 24 hours of admission from the emergency department: An innovative approach for performance improvement. Academic Emergency Medicine. 2014;21(6):667-72.

374. Ludikhuize J, Smorenburg SM, de Rooij SE, de Jonge E. Identification of deteriorating patients on general wards; measurement of vital parameters and potential effectiveness of the Modified Early Warning Score. J Crit Care. 2012;27(4):424.e7-13.
375. Ludikhuize J, Hamming A, de Jonge E, Fikkers BG. Rapid response systems in The Netherlands. Joint Commission journal on quality and patient safety / Joint Commission Resources. 2011;37(3):138-44, 97.
376. Medical Emergency Team End-of-Life Care i. The timing of Rapid-Response Team activations: a multicentre international study. Critical care and resuscitation : journal of the Australasian Academy of Critical Care Medicine. 2013;15(1):15-20.
377. Menees SB, Elliott E, Govani S, Anastassiades C, Schoenfeld P. Adherence to recommended intervals for surveillance colonoscopy in average-risk patients with 1 to 2 small (<1 cm) polyps on screening colonoscopy. Gastrointestinal Endoscopy. 2014;79(4):551-7.
378. Mitchell IA, Kulh M, McKay H. Use of the modified early warning score in emergency medical units. Medical Journal of Australia. 2011;195(8):448.
379. Mohammed MA, Rudge G, Watson D, Wood G, Smith GB, Prytherch DR, et al. Index Blood Tests and National Early Warning Scores within 24 Hours of Emergency Admission Can Predict the Risk of In-Hospital Mortality: A Model Development and Validation Study. PLoS ONE. 2013;8(5).
380. Morris DS, Schweickert W, Holena D, Handzel R, Sims C, Pascual JL, et al. Differences in outcomes between ICU attending and senior resident physician led medical emergency team responses. Resuscitation. 2012;83(12):1434-7.
381. Neary PM, Regan M, Joyce MJ, McAnena OJ, Callanan I. National early warning score (NEWS) – evaluation in surgery. International Journal of Health Care Quality Assurance. 2015;28(3):245-52.
382. Nelson JL, Smith BL, Jared JD, Younger JG. Prospective trial of real-time electronic surveillance to expedite early care of severe sepsis. Annals of emergency medicine. 2011;57(5):500-4.
383. Niegsch M, Fabritius ML, Anhøj J. Imperfect Implementation of an Early Warning Scoring System in a Danish Teaching Hospital: A Cross-Sectional Study. PLoS ONE. 2013;8(7).
384. Omar Y. Avoiding medical emergencies. British Dental Journal. 2013;214(5):255-9.
385. Orosz J, Bailey M, Bohensky M, Gold M, Zalstein S, Pilcher D. Deteriorating patients managed with end-of-life care following Medical Emergency Team calls. Internal medicine journal. 2014;44(3):246-54.
386. Patterson C, Maclean F, Bell C, Mukherjee E, Bryan L, Woodcock T, et al. Early warning systems in the UK: Variation in content and implementation strategy has implications for a NHS early warning system. Clinical Medicine, Journal of the Royal College of Physicians of London. 2011;11(5):424-7.
387. Randmaa M, Mårtensson G, Leo Swenne C, Engström M. SBAR improves communication and safety climate and decreases incident reports due to communication errors in an anaesthetic clinic: a prospective intervention study. BMJ Open. 2014;4(1):e004268-e.
388. Ritter G, Johnson T, Walden H, Sharma C, Corley A, Ravikumar TS, et al. Comparison of Two Rapid Response Teams Models: Reduction of Rapid Response Triggers and Cardiac Arrests by the Continuum of Care Model Compared With Traditional Rapid Response Team. ICU Director. 2013;4(1):6-10.
389. Smith RJ, Santamaria JD, Reid DA, Faraone EE. The mortality associated with review by the rapid response team for non-arrest deterioration: a cohort study of acute hospital adult

patients. Critical care and resuscitation : journal of the Australasian Academy of Critical Care Medicine. 2014;16(2):119-26.

390. Smith RL, Hayashi VN, Lee YI, Navarro-Mariazeta L, Felner K. The medical emergency team call: A sentinel event that triggers goals of care discussion. Critical Care Medicine. 2014;42(2):322-7.
391. Subbe CP, Welch JR. Failure to rescue : using rapid response systems to improve care of the deteriorating patient in hospital. 2013.
392. Westphal GA, Koenig Á, Caldeira Filho M, Feijó J, de Oliveira LT, Nunes F, et al. Reduced mortality after the implementation of a protocol for the early detection of severe sepsis. Journal of Critical Care. 2011;26(1):76-81.
393. Burger D, Jordan S, Kyriacos U. Validation of a modified early warning score-linked Situation-Background-Assessment-Recommendation communication tool: A mixed methods study. Journal of Clinical Nursing. 2017;26(17/18):2794-806.
394. D. K T, M. R S, I L. Correlation of Coagulopathy of Trauma and Revised Trauma Score in Predicting Outcome in Trauma Patients. Journal of Institute of Medicine. 2016;38(2/3):105-11.
395. Kyriacos U, Jelsma J, Jordan S. Record review to explore the adequacy of post-operative vital signs monitoring using a local modified early warning score (mews) chart to evaluate outcomes. PLoS One. 2014;9(1):e87320.
396. Naidoo DK, Rangiah S, Naidoo SS. An evaluation of the Triage Early Warning Score in an urban accident and emergency department in KwaZulu-Natal. South African Family Practice. 2014;56(1):69-73.
397. Kim WY, Shin YJ, Lee JM, Huh JW, Koh Y, Lim C-M, et al. Modified Early Warning Score Changes Prior to Cardiac Arrest in General Wards. PLoS ONE. 2015;10(6):e0130523.
398. Sok Ying L, Lai Fun W, Bee Leng Ang S, Tze Yin Ho J, Chiang S, Neo Kim Ang E. Strengthening the afferent limb of rapid response systems: an educational intervention using web-based learning for early recognition and responding to deteriorating patients. BMJ quality & safety. 2016;25(6):448-56.
399. Lee JR, Choi HR. Validation of a modified early warning score to predict ICU transfer for patients with severe sepsis or septic shock on general wards. Journal of Korean Academy of Nursing. 2014;44(2):219-27.
400. Manozzo Boniatti M. Advances in performance, more benefits... the perspectives of rapid response teams. Avanços na atuação, mais benefícios as perspectivas dos times de resposta rápida. 2016;28(3):217-9.
401. Taguti Pd.a S, Dotti AZ, de Araujo KP, de Pariz PS, Dias GF, Kauss IA, et al. The performance of a rapid response team in the management of code yellow events at a university hospital. Revista Brasileira de terapia intensiva. 2013;25(2):99-105.

14 Appendices

14.1 Appendix 1 National Early Warning Score (NEWS) 2013 Patient Observation Chart

FRONT PAGE

NATIONAL EARLY WARNING SCORE
ADULT PATIENT OBSERVATION CHART

Escalation Protocol Flow Chart

Total Score	Minimum Observation Frequency	ALERT	RESPONSE
1	12 Hourly	Nurse in charge	Nurse in charge to review if new score1
2	6 Hourly	Nurse in charge	Nurse in charge to review
3	4 Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review within 1 hour
4-6	1 Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review within½ hour 2. Screen for Sepsis 3. If no response to treatment within 1 hour contact Registrar 4. Consider continuous patient monitoring 6. Consider transfer to higher level of care
≥ 7	½ Hourly	Nurse in charge & Team/On-Call Registrar Inform Team/On-Call Consultant	1. Registrar to review immediately 2. Continuous patient monitoring recommended 3. Plan to transfer to higher level of care 4. Activate Emergency Response System (ERS) *(as appropriate to hospital model)*
Note: Single Score triggers			
Score of 2 HR ≤ 40 (Bradycardia)	½ Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review immediately
*Score of 3 in any single parameter	½ Hourly or as indicated by patient's condition	Nurse in charge & Team/On-call SHO	1. SHO to review immediately 2. If no response to treatment or still concerned contact Registrar 3. Consider activating ERS

*In certain circumstances a score of 3 in a single parameter may not require ½ hourly observations i.e. some patients on O_2.

- When communicating patients score inform relevant personnel if patient is charted for supplemental oxygen e.g. post-op.
- Document all communication and management plans at each escalation point in medical and nursing notes.
- Escalation protocol may be stepped down as appropriate and documented in management plan.

IMPORTANT:
1. If response is not carried out as above CNM/Nurse in charge must contact the Registrar or Consultant.
2. If you are concerned about a patient escalate care regardless of score.

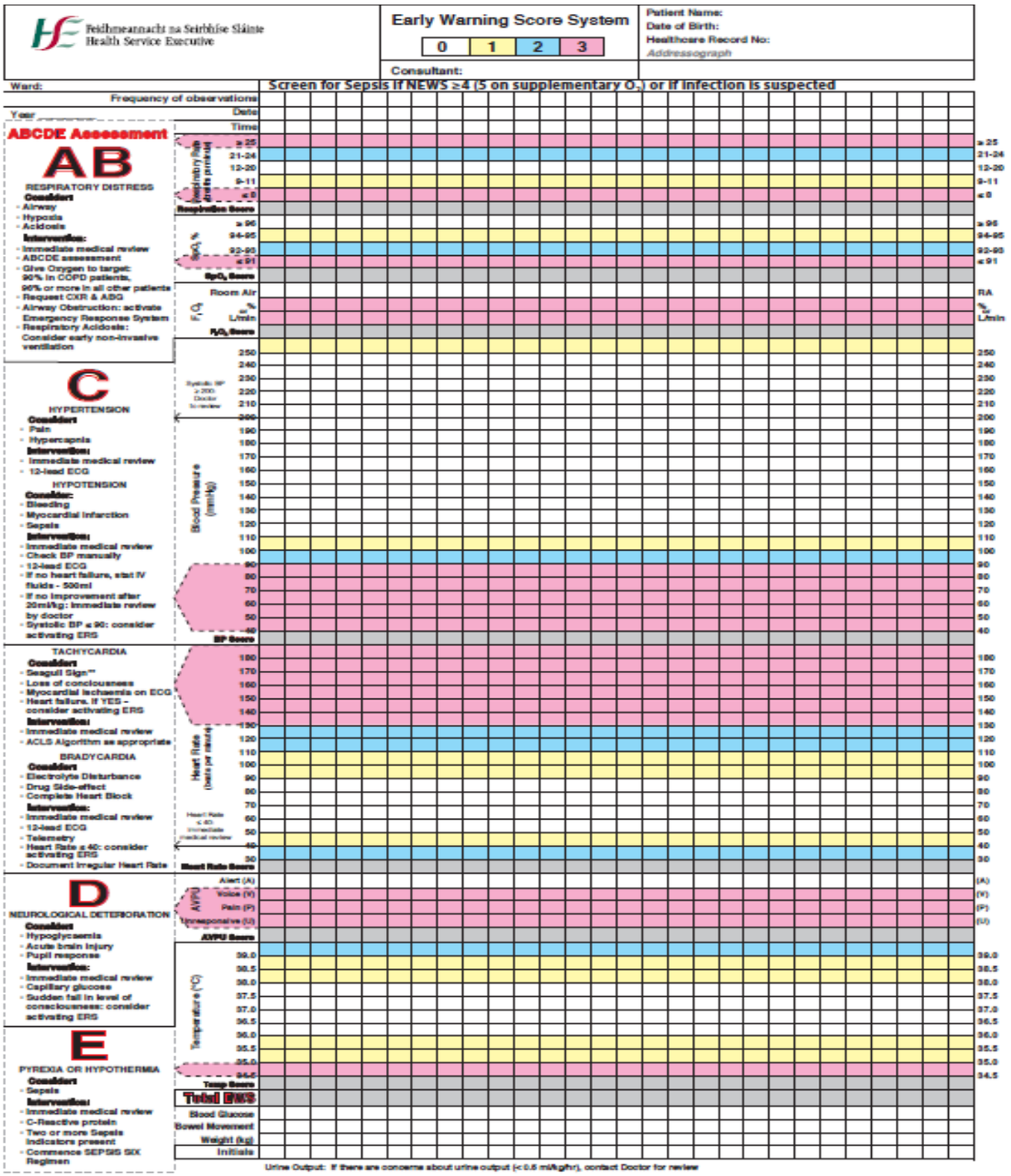
National Early Warning Score (NEWS) Key

SCORE	3	2	1	0	1	2	3
Respiratory Rate (bpm)	≤ 8		9 - 11	12 - 20		21 - 24	≥ 25
SpO_2 (%)	≤ 91	92 - 93	94 - 95	≥ 96			
Inspired O_2 (FiO_2)				Air			Any O_2
Systolic BP (mmHg)	≤ 90	91 - 100	101 - 110	111 - 249	≥ 250		
Heart Rate (BPM)		≤ 40	41 - 50	51 - 90	91 - 110	111 - 130	≥ 131
AVPU/CNS Response				Alert (A)			Voice (V), Pain (P), Unresponsive (U)
Temp (°C)	≤ 35.0		35.1 - 36.0	36.1 - 38.0	38.1 - 39.0	≥ 39.1	

Note: Where systolic blood pressure is ≥ 200mmHg, request Doctor to review.

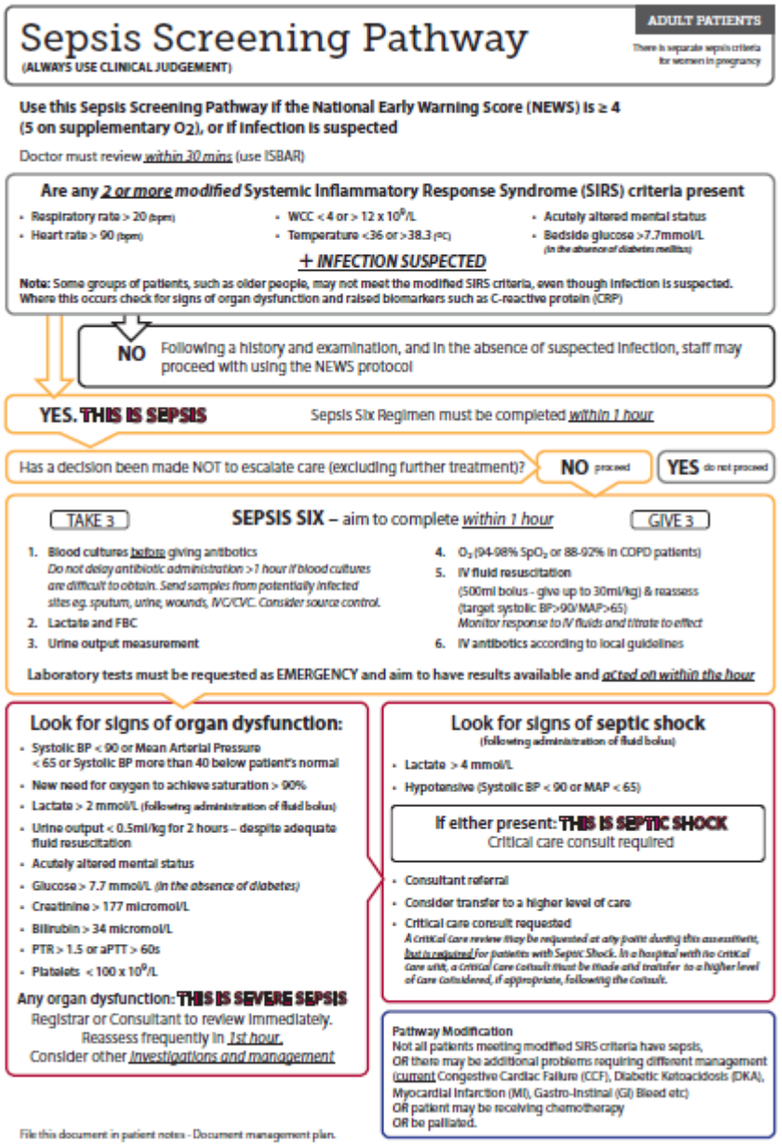
14.1 Appendix 1 National Early Warning Score (NEWS) 2013 Patient Observation Chart (continued)

MIDDLE PAGES



14.1 Appendix 1 National Early Warning Score (NEWS) 2013 Patient Observation Chart (continued)

BACK PAGE



Sepsis Screening Pathway

(ALWAYS USE CLINICAL JUDGEMENT)

ADULT PATIENTS

There is separate sepsis criteria for women in pregnancy

Use this Sepsis Screening Pathway if the National Early Warning Score (NEWS) is ≥ 4 (5 on supplementary O_2), or if infection is suspected

Doctor must review *within 30 mins* (use ISBAR)

Are any *2 or more modified* Systemic Inflammatory Response Syndrome (SIRS) criteria present

- Respiratory rate > 20 (bpm)
- Heart rate > 90 (bpm)
- WCC < 4 or > 12 x 10^9/L
- Temperature <36 or >38.3 (°C)
- Acutely altered mental status
- Bedside glucose >7.7mmol/L (in the absence of diabetes mellitus)

+ INFECTION SUSPECTED

Note: Some groups of patients, such as older people, may not meet the modified SIRS criteria, even though infection is suspected. Where this occurs check for signs of organ dysfunction and raised biomarkers such as C-reactive protein (CRP)

NO Following a history and examination, and in the absence of suspected infection, staff may proceed with using the NEWS protocol

YES. THIS IS SEPSIS Sepsis Six Regimen must be completed *within 1 hour*

Has a decision been made NOT to escalate care (excluding further treatment)? **NO** proceed **YES** do not proceed

TAKE 3 **SEPSIS SIX** – aim to complete *within 1 hour* GIVE 3

1. Blood cultures *before* giving antibiotics
   Do not delay antibiotic administration >1 hour if blood cultures are difficult to obtain. Send samples from potentially infected sites eg. sputum, urine, wounds, IVC/CVC. Consider source control.
2. Lactate and FBC
3. Urine output measurement
4. O_2 (94-98% SpO_2 or 88-92% in COPD patients)
5. IV fluid resuscitation
   (500ml bolus - give up to 30ml/kg) & reassess (target systolic BP>90/MAP>65)
   Monitor response to IV fluids and titrate to effect
6. IV antibiotics according to local guidelines

Laboratory tests must be requested as EMERGENCY and aim to have results available and *acted on within the hour*

Look for signs of organ dysfunction:

- Systolic BP < 90 or Mean Arterial Pressure < 65 or Systolic BP more than 40 below patient's normal
- New need for oxygen to achieve saturation > 90%
- Lactate > 2 mmol/L (following administration of fluid bolus)
- Urine output < 0.5ml/kg for 2 hours – despite adequate fluid resuscitation
- Acutely altered mental status
- Glucose > 7.7 mmol/L *(in the absence of diabetes)*
- Creatinine > 177 micromol/L
- Bilirubin > 34 micromol/L
- PTR > 1.5 or aPTT > 60s
- Platelets < 100 x 10^9/L

Any organ dysfunction: **THIS IS SEVERE SEPSIS**
Registrar or Consultant to review immediately.
Reassess frequently in *1st hour.*
Consider other *investigations and management*

Look for signs of septic shock
(following administration of fluid bolus)

- Lactate > 4 mmol/L
- Hypotensive (Systolic BP < 90 or MAP < 65)

If either present: **THIS IS SEPTIC SHOCK**
Critical care consult required

- Consultant referral
- Consider transfer to a higher level of care
- Critical care consult requested
  A critical care review may be requested at any point during this assessment, but is required for patients with Septic Shock. In a hospital with no Critical Care unit, a Critical Care Consult must be made and transfer to a higher level of care considered, if appropriate, following the consult.

Pathway Modification
Not all patients meeting modified SIRS criteria have sepsis,
OR there may be additional problems requiring different management (current Congestive Cardiac Failure (CCF), Diabetic Ketoacidosis (DKA), Myocardial Infarction (MI), Gastro-Instinal (GI) Bleed etc)
OR patient may be receiving chemotherapy
OR be palliated.

File this document in patient notes - Document management plan.

NOTE: The vital signs section, should not be amended as colour coding and scoring parameters are integral to the National Patient Observation Chart The scoring parameters for the physiological signs identified in the nationally agreed National Early Warning Score (using ViEWS parameters) should be strictly adhered to in the event that an acute hospital decides to design other aspects of their own observation chart.

14.2 Appendix 2 Search Strategy for Systematic Review

PICO Framework	Broad Areas	Specific search terms	Inclusion criteria	Exclusion criteria
Population	Adult patient. Specific sub-populations for Q5	No specifically applied search terms. *"chronic respiratory conditions" OR "chronic hypoxia" OR "chronic hypoxaemia" OR "chronic hypoxemia" OR "chronic physiological abnormalities" OR "chronic obstructive pulmonary disease" OR "COPD" OR "pulmonary fibrosis" or "frail elderly" OR "frail elderly or aged or elderly" OR "frailty in elderly people" OR "frail older adult".*	Adult acute patient (i.e. ≥16 years of age) (cared for within an acute hospital).	Pre-hospital settings, Community Settings, Patients with intellectual disability or psychiatric disorders cared for outside of the acute hospital setting, Acute Care (paediatric patients, obstetric patients, emergency department patients, DNR patients).
Intervention	Early Warning Scoring System(s).	*"Detection of deterioration" OR "clinical deterioration" OR "identification of deterioration" OR "physiological scoring system" OR "risk assessment report" OR "emergency response system" OR "early warning" OR "warning system" OR "warning scor*" OR "failure to rescue" OR "vital sign" OR "electronic system" OR "tablet" OR "iPad" OR "escalation protocol" OR "communication" OR "response" OR "VIEWS" OR "NEWS" OR "medical emergency team" OR "rapid response team" OR "rapid response system" OR "emergency response system" OR "emergency response team".* *CINAHL BP "detection of deterioration" SH "patient safety", "nursing assessment, "critical care".* *MEDLINE "risk assessment/methods") OR "point-of care systems") OR "monitoring, Physiologic/ methods"[208].* **Named Systems (in)** *"Early warning system" OR "early warning score" OR "modified early warning score" OR "MEWS" OR "VitalPAC" OR "track and trigger system" OR "Worthing" OR "SBAR" OR "situation, background, assessment, recommendation" OR "situation, background, assessment and recommendation" OR "ISBAR" OR "Identify, Situation, Background, Assessment and Recommendation" OR "Identify, Situation, Background, Assessment, Recommendation" OR "Manchester triage system" OR "biosignTM", "Patient at Risk" OR "PAR score" OR "Physiological Scoring System" OR "Vital Sign Score" OR "Physiological Observation Track and Trigger System" OR "Between the flags".*	Studies which address the effectiveness of EWSs or track and trigger systems that have been developed to facilitate early detection of deterioration and escalation of care. Papers will be included if the principal focus of the paper and its results is on evaluating the effectiveness of the NEWS or validating the use of the NEWS in the clinical context.	EWSs or track and trigger system not suitable for measurement and reporting of acute clinical deterioration in the acute health care context. Studies which deal exclusively with the early development of an EWS or track and trigger system. Clinical studies which examine health care professionals' responses to fictional/hypothe-tical cases e.g. vignettes.
	Education program.	**Education program (in Title/Abstract)** *"ALERT™" OR "COMPASS©" OR "Education" OR "Program*" OR "Training" OR "Course" OR "Mode of delivery" or "Online delivery" Or "face-to-face delivery"*	Studies which address the effectiveness of education programmes that are used to educate/train registered healthcare professionals in relation to EWSs or track and trigger systems.	Studies which describe the development of education programmes used to educate/train healthcare professionals in relation to EWSs, with no outcome evaluation

				presented.
	Economic literature	*"economics" or "cost* and benefit" OR "cost analysis" OR "cost management" OR "cost saving" OR "escalation cost*" OR "additional resources" OR "cost effectiveness" OR "education" OR "resources"*	Economic evaluation studies, costing studies and systematic reviews relating to EWSs.	
	Parameter adjustment in specific sub-populations	*"Physiological parameter adjustment" OR "parameter adjustment" OR "parameter variance" OR "parameter amendment" OR "medical variance" OR "medical escalation suspension" OR "triggering thresholds" OR "activation thresholds" OR "EWS thresholds" OR "CREWS" OR "Chronic Respiratory Early Warning Score"*	Studies which address the effectiveness of EWSs or track and trigger systems that have been developed to facilitate early detection of deterioration and escalation of care in specific sub-populations including frail older adults and patients with COPD with an emphasis on parameter adjustment.	EWS or track and trigger system not suitable for measurement and reporting of acute clinical deterioration in the acute health care context. Studies which deal exclusively with the early development of an EWS or track and trigger system. Clinical studies which examine health care professionals' responses to fictional/hypothetical cases e.g. vignettes.
	Why HCPs fail to escalate as per EWS protocol	*"Failure to escalate" OR "fail to escalate" OR "non-adherence to EWS escalation protocol" OR "qualitative" OR "ethnography" OR "phenomenology" OR "grounded theory" OR "mixed methods" OR "study design" OR "interview" OR "attitudes" OR "themes".*	Qualitative studies which address why HCPs fail to escalate as per the NEWS protocol	Qualitative studies (e.g. open-ended survey questions) where the responses are analysed using descriptive statistics.
Comparison	Comparison against another intervention or with no intervention	No specific search terms.	Studies looking at early warning systems and their implementation, clinical validation.	
Outcome		No specific search criteria		If no outcome data are presented studies will not be included.
Setting	No specific terms.	No specific search criteria.	Acute hospital setting in countries categorised as either very high or high human development index (UNDP 2015).	Non-acute settings, Acute hospital setting in countries categorised as either medium or low Human Development Index (UNDP 2015)
Publication type/level of evidence		**Databases searched** We will search relevant health and psychosocial databases including Academic Search Complete, CINAHL (the	**Time:** Publication date within timeframe of Nov 2015.	**Publication quality**: Publication of

		Cumulative Index to Nursing and Allied Health Literature), Medline, PsycINFO, PsycARTICLES, Psychology and Behavioral Science Collection, SocINDEX, and UK/Eire Reference Centre, Embase and the Trip database. Detailed outline in the methods section of the protocol. **Grey Literature**: Guideline Websites will be searched. As different study designs will be required to meet the different objectives of this review, no study design limits will be applied thus ensuring that the likelihood of finding relevant studies irrespective of design will be increased.	*New review questions – Jan 2011 **Publication types:** Studies which include analysis of data prospectively/ retrospectively. Data were pre- and post-critical adverse clinical event(s) or pre-post EWS intervention. However, the analysis must help to explicate the following: 1) Clinical effectiveness (harm/benefit) of EWSs or track and trigger systems, 2) Clinical validation of EWSs or track and trigger systems, 3) In addition studies which evaluated the effectiveness of education programmes preparing HCPs for the implementation of EWS.	study did not contain sufficient detail regarding intervention or outcome measures. **Publication types:** Literature reviews, discussion papers, integrative reviews and opinion pieces, oral/poster conference abstracts (as limited data available for data extraction).

14.3 Appendix 3 Grey Literature Databases Searched

Databases:

- OpenGrey System for Information on Grey Literature in Europe (http://www.opengrey.eu/)
- Open University Dedicated Grey Literature site (http://www.open.ac.uk/library/)
- Education Resources Information Center (ERIC) database (https://eric.ed.gov/)
- GrayLit Network (via Science.Gov as it was discontinued in 2007 and archived in Science.Gov) (https://www.science.gov/)
- Networked Digital Library of Theses. (http://www.ndltd.org/)

Websites:

- Agency for Healthcare Research and Quality (https://www.ahrq.gov/)
- Andalusian Agency for Health Technology Assessment (AETSA) (http://www.inahta.org/)
- Association of Anaesthetists of Great Britain and Ireland (https://www.aagbi.org/)
- Australian National Health and Medical Research Council Clinical Practice Guidelines (https://www.nhmrc.gov.au/)
- Belgian Health Care Knowledge Centre (https://kce.fgov.be/en)
- Canadian Medical Association InfoBase of Clinical Practice Guidelines (https://www.cma.ca/En/Pages/clinical-practice-guidelines.aspx)
- eGuidelines (UK) (https://www.guidelines.co.uk/)
- Danish Health Authority/Danish Secretariat for Clinical Guidelines (https://www.sst.dk/en/national-clinical-guidelines)
- European Society of Intensive Care Medicine (https://www.esicm.org/)
- Finnish Medical Society Duodecim (https://www.duodecim.fi/english/)
- Geneva Foundation for Medical Education and Research (https://www.gfmer.ch/)
- Guidelines International Network (GIN) (http://www.g-i-n.net/)
- German Institute of Medical Documentation and Information

(https://www.dimdi.de/static/en/index.html)

- Haute Autorité de santé (https://www.has-sante.fr/portail/jcms/r_1455081/Home-page)
- Institute for Healthcare Improvement (USA) (http://www.ihi.org/)
- Intensive Care Society (https://www.ics.ac.uk/)
- Intensive Care Society of Ireland (http://www.intensivecare.ie/)
- Intensive Care National Audit & Research Centre (https://www.icnarc.org/)
- Japan Council for Quality Health Care (https://jcqhc.or.jp/en/)
- National Institute for Health and Clinical Excellence (NICE) (https://www.nice.org.uk/)
- National Library for Health (NLH) Guidelines Finder/National Library for Health (NLH) Protocols and Care Pathways database (archived 2008) (http://webarchive.nationalarchives.gov.uk/20081113053157/https://www.library.nhs.uk/GuidelinesFinder/AboutUs.aspx)
- National Guideline Clearinghouse (USA) (https://www.guideline.gov/)
- NCEC (National Clinical Effectiveness Committee, Ireland) (http://health.gov.ie/national-patient-safety-office/ncec/national-clinical-guidelines/)
- New Zealand Guidelines Group (https://www.health.govt.nz/)
- NHS Evidence database (UK) (https://www.evidence.nhs.uk/)
- NHS Institute for Innovation and Improvement (ceased in 2013) (https://www.gov.uk/government/organisations/nhs-institute-for-innovation-and-improvement)
- Royal College of Physicians (https://www.rcplondon.ac.uk/)
- Royal College of Surgeons (https://www.rcseng.ac.uk/)
- The Royal College of Anaesthetists (https://www.rcoa.ac.uk/)
- Royal College of Nursing (https://www.rcn.org.uk/)
- Scottish Intensive Care Society (https://www.scottishintensivecare.org.uk/)
- Singapore Ministry of Health (https://www.moh.gov.sg/content/moh_web/home.html)

- Socialstyrelsen (Health and Medical Care and Social Services, Sweden) (http://www.socialstyrelsen.se)
- Society of Critical Care Medicine (USA) (http://www.sccm.org/)
- TRIP Database (https://www.tripdatabase.com/)
- World Health Organization (http://www.who.int/en/).

14.4 Appendix 4 Studies excluded after full text review

Reason for exclusion	Study reference
Irrelevant population (n=28)	(209) (210-217) (218-236)
Irrelevant intervention (n=23)	(208, 237-258)
Irrelevant outcome (n=18)	(259-276)
Irrelevant study design (n=62)	(6, 9, 160, 232, 277-334)
Published prior to 2015 (n=62)	(130, 134, 177, 188, 335-392)
Medium or low HDI country (n=4)	(393-396)
Duplicate (n=3)	(172, 397, 398)
Foreign language (n=3)	(399-401)

14.5 Appendix 5 EWS weightings and scores according to study

Study (Year)	EWS	Score							Trigger score
		3	2	1	0	1	2	3	
Abbott (2015)	**NEWS**								
	Temperature	<35.0		35.1-36.0	36.1-38.0	38.1-39.0	>39.0		Scores of greater than 5 (or 3 in any one parameter) trigger an urgent medical review. A score of over 7 triggers a review by a CCOT.
	HR	<41		41-50	51-90	91-110	111-130	>130	
	SBP	<91	91-100	101-110	111-219			>219	
	RR	<9		9-11	12-20		21-24	>25	
	SpO_2	<92	92-93	94-95	>96				
	FiO_2		YES		NO				
	AVPU				A			V,P,U	
	PARS								
	Temperature		<35.0	35-35.9	36-37.4	37.5-38.4	>38.5		Scores of 3 and 5 trigger reviews by the medical team or CCOT respectively.
	HR	<40		40-49	50-99	100-114	115-129	>130	
	SBP	<70	70-79	80-89	100-179		>180		
	RR		<10		10-19	20-29	30-39	>40	
	SpO_2	<85	85-89	90-94	>95				
	AVPU			Confused	A	V	P	U	
	Urine output	Nil	<0.5	Dialysis	<0.5-3	>3			
Albert (2011)	**MEWS**								
	HR		<40	41-50	51-120	121-139	>140		A MEWS score of 3 or more triggered staff referral to the RRT.
	SBP	<75	75-79	80-89	90-140	141-160	161-180		
	RR		<8	9-11	12-20	21-25	26-30	>30	
	Temperature			<96.1	97.1-97.9	96.1-97	>100.9		
	SpO_2	≤85	86-89	90-91	≥92				
	Urine output		<20	20-30	31-199	>200			
	Other	Difficulty breathing, increased supplemental oxygen, altered level of consciousness, WBC, new focal weakness and staff/family concerns also criteria included in the electronic health record.							
Badriyah (2014)	**DTEWS**								
	RR				<18	19-20	21-24	≥25	Not reported.
	SpO_2	≤89	90-92	93-94	95-99	100			
	FiO_2				No			Yes	
	Temperature	≤35.8	35.9-36.0	36.1-36.4	36.5-37.1	37.2-37.9	≥38.0		
	SBP	≤89		90-116	117-272			≥273	
	HR	≤38		39-46	47-89	90-100	≥101		
	AVPU				A			V, P, U	
	NEWS								
	RR	<8		9-11	12-20		21-24	≥25	Not reported.
	SpO_2	≤91	92-93	94-95	≥96				
	FiO_2				No		Yes		
	Temperature	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1		
	SBP	≤90	91-100	101-110	111-219			≥220	
	HR	≤40		41-50	51-90	91-110	111-130	≥131	
	AVPU				A			V, P, U	
Bian (2015)	**Super Score**								
	SpO_2				99-100	95-98	≤94		0–1 point, low-risk; 2–3 points, intermediate risk; 4–5 points, high risk; 6–10 points, extremely high risk.
	Urine volume				>50	30-50	≤30		
	HR		>140	90-140	<90				
	Emotion				0	- / --	+		
	RR		≥30	20-30	<20				
	MEWS								
	SBP	<70	71-80	81-100	101-199		≥200		Not reported in this study.
	HR		<40	41-50	51-100	101-110	111-129	≥130	
	RR		<9		9-14	15-20	21-29	≥30	
	Temperature		<35		35-38.4		≥38.5		
	AVPU				A	V	P	U	

14.5 Appendix 5 – EWS weightings and scores according to study

Study (Year)	EWS	Score							Trigger score
		3	2	1	0	1	2	3	
Bleyer (2011)	**Critical vital sign scoring EWS**								
	SBP			<85					The occurrence of any critical vital sign derangement or HCP concern that patients were unstable.
	HR			>120					
	Temperature			<35 or >38.9					
	SpO_2			<91%					
	RR			≤12 or ≥24					
	AVPU			V, P, U	A				
	Age	>80	70-80	60-69					
Bunkenborg (2014)	**MEWS**								
	RR		<9		9-14	15-20	21-29	≥30	MEWs score ≥5: follow algorithm for bedside action, call physician on-call, re-observe and re-score, call MET.
	HR		<40	41-50	51-100	101-110	111-129	≥130	
	BP	<70	71-80	81-100	101-199		≥200		
	AVPU				A	V	P	U	
	Temperature		<35		35-38.4		≥38.5		
	SpO_2	≤95: supply oxygen to patient; ≤ 90: despite oxygen supply call MET and physician on-call							
Capan (2015)	**NEWS**								
	RR	≤8		9-11	12-20		21-24	≥25	A score of 7 initiates RRT activation.
	SpO_2	≤91	92-93	94-95	≥96				
	FiO_2				No		Yes		
	Temperature	<35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1		
	SBP	≤90	91-100	101-110	111-219			≥220	
	HR	≤40		41-50	51-90	91-110	111-130	≥131	
	AVPU				A			V, P, U	
Churpek (2013)	**MEWS**								
	RR		<9		9-14	15-20	21-29	>29	Not reported in paper.
	HR		<40	41-50	51-100	101-110	111-129	>129	
	SBP	<70	71-80	81-100	101-199		>199		
	Temperature		<35		35-38.4		>38.4		
	AVPU				A	V	P	U	
	ViEWS								
	RR	<9		9-11	12-20		21-24	>24	Not reported in paper.
	SpO_2	<92	92-93	94-95	96-100				
	FiO_2				No			Yes	
	HR		<41	41-50	51-90	91-110	111-130	>130	
	SBP	<90	91-100	101-110	111-249	>249			
	Temperature	<35.1		35.1-36	36.1-38	38.1-39	>39		
	AVPU				A			V, P, U	
	SEWS								
	RR	<9			9-20	21-30	31-35	>35	Not reported in paper.
	SpO_2	<85	85-89	90-92	93-100				
	HR	<30	30-39	40-49	50-99	100-109	110-129	>129	
	SBP	<70	70-79	80-99	100-199		>199		
	Temperature	<34	34-34.9	35-35.9	36-37.9	38-38.9	>38.9		
	AVPU				A	V	P	U	
	CART (score in parentheses)								
	RR	<21 (0)	21-23 (8)	24-25 (12)	26-29 (15)	>29 (22)			Not reported in paper.
	HR	<100 (0)	110-139 (4)	>139 (13)					
	DBP	>49 (0)	40-49 (4)	35-39 (6)	<35 (13)				
	Age, years	<55 (0)	55-69 (4)	>69 (9)					
Churpek (2012)	**MEWS**								
	RR		≤8		9-14	15-20	21-29	>29	Not reported in paper.
	HR		≤40	41-50	51-100	101-110	111-129	>129	
	SBP	≤70	71-80	81-100	101-199		≥200		
	Temperature		≤35	35.1-36	36.1-38	38.1-38.5	≥38.6		
	AVPU				A	V	P	U	

14.5 Appendix 5 – EWS weightings and scores according to study

Study (Year)	EWS	Score							Trigger score
		3	2	1	0	1	2	3	
Churpek (2012a)	**MEWS**								
	RR		≤8		9-14	15-20	21-29	>29	Not reported.
	HR		≤40	41-50	51-100		111-129	>129	
	SBP	≤70	71-80	81-100	101-199		≥200		
	Temperature		≤35	35.1-36	36.1-38	38.1-38.5	≥38.6		
	AVPU				A	V	P	U	
	CART								
	RR	Not reported in this study – max and min vital signs were used in the CART model derivation.							Not reported.
	HR								
	DBP								
	Age								
Cooksley (2012)	**MEWS**								
	RR		5-9	10-13	14-19	20-24	25-29	>30	Not reported.
	SBP	30-69	70-79	80-109	110-159	160-199	>200		
	HR		30-39	40-49	50-99	100-119	120-129	>130	
	Temperature		34-34.9	35-35.9	36-37.9	38-38.9	>39		
	Urine output	<10		10-29	30-200		201-300	>300	
	AVPU				A	V	P	U	
	SpO_2				>96	95-92	91-88	<88	
	NEWS								
	RR	<8		9-11	12-20		21-24	>25	Not reported.
	SpO_2				>96	94-95	92-93	<91	
	FiO_2				No		Yes		
	Temperature	<35		35.1-35.9	36-37.9	38-38.9	>39		
	SBP	<90	90-99	100-109	110-219			>220	
	HR	<40		40-49	50-89	90-109	110-129	>130	
	AVPU				A			V, P, U	
Dawes (2014)	**Worthing PSS**								
	RR				≤19	20-21	≥22		Not reported.
	HR				≤101	≥102			
	SBP		≤99		≥100				
	Temperature	<35.3			≥35.3				
	SpO_2	<92	62-64	64 -95	96-100				
	AVPU				A			V, P, U	
Drower (2013)	**ADDS**								
	AVPU				A	V		P	'U' in AVPU call CAT immediately. 'RR' <6 or >40 call CAT immediately. 'SBP<70' call CAT immediately.
	RR	36-39	25-35	21-24	12-20	9-11		6-8	
	SpO_2				≥93	90-92	85-80	<85	
	FiO_2				≤2, room air	3-6	>6		
	HR	<30	30-39	40-49	50-109	110-119	120-129	≥130	
	SBP	70-79	80-89	90-99	100-179	180-199		≥200	
	Temperature	<35		35-35.9	36-37.9	38-38.9	≥39		
	Urine output	<110		110-159	160-800	>800			
Durusu Tanriover (2016)	**MEWS**								
	HR		<44	45-54	55-100	101-110	111-130	150	Not reported.
	SBP	<70	71-80	81-100	101-199		>200		
	RR		<8	9-12	12-20	20-24	24-29	30	
	Temperature			<36	36-37.4	37.5-37.0	>38		
	AVPU				A	V	P	U	
Eccles (2014)	**NEWS**								
	Temperature	<35.0		35.1-36.0	36.1-38.0	38.1-39.0	>39.0		Not reported.
	HR	<41		41-50	51-90	91-110	111-130	>130	
	SBP	<91	91-100	101-110	111-219			>219	
	RR	<9		9-11	12-20		21-24	>25	
	SpO_2	≤91	92-93	94-95	≥96				
	FiO_2		YES		NO				
	AVPU				A			V,P,U	
	CREWS (identical to NEWS apart from SpO_2 weightings)								
	SpO_2	≤85	86-87	88-89	≥90				Not reported.

14.5 Appendix 5 – EWS weightings and scores according to study

Study (Year)	EWS	Score							Trigger score
		3	2	1	0	1	2	3	
Etter (2014)	**VSS – each parameter is given 1 point where an abnormality occurs. VSS=total sum of all VSS points at one point in time**								
	HR			<40 or >140					Any HCP could trigger the MET using a set of calling criteria including Airway, Breathing, Circulation, Neurology and Staff Concern-based criteria.
	SBP			<90					
	RR			<6 or >36					
	SpO_2			<90%					
	GCS			<13, decrease ≤2 points					
	Peripheral perfusion			>3 seconds					
Fung (2014)	**PARS**								
	RR	<11			11-20	21-25	26-30	>30	PARS score 5 and above: ITU Junior doctor and PARS nurse (3 point).
	SpO_2		<86	86-91	92-100				
	SBP	<71	71-80	81-99	100-180	181-200	>200		
	HR	<41	40-41		51-100	101-110	111-130	>130	
	AVPU				A	V	P	U	
	Temperature	<33	33-35		35.1-38	38.1-39	>39		
	Urine output							<30ml	
Jarvis (2013)	**LDT-EWS (Males)**								
	Hb		≤11.1	11.2-12.8	≥12.9				Not reported.
	WBC				≤9.3	9.4-16.6	≥16.7		
	U				≤9.4	9.5-13.7		≥13.8	
	Cr				≤114	115-179	≥180		
	Na		≤132		133-140	≥141			
	K			≤3.7	3.8-4.4	4.5-4.7	≥4.8		
	AIB		≤30	31-34	≥35				
	LDT-EWS (Females)								
	Hb			≤12.0	12.1-14.8	≥14.9			Not reported.
	WBC				≤12.6	12.7-14.8	≥14.9		
	U				≤8.4	8.5-13.8		≥13.9	
	Cr				≤91	92-157	≥158		
	Na			≤134	135-140	≥141			
	K			≤3.3	3.4-4.5	≥4.6			
	AIB		≤28	29-34	≥35				
Jarvis (2015a)	**NEWS**								
	RR	≤8		9-11	12-20		21-24	≥25	NEWS score ≥6.
	SpO_2	≤91	92-93	94-95	≥96				
	FiO_2				No		Yes		
	Temperature	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1		
	SBP	≤90	91-100	101-110	111-219			≥220	
	HR	≤3		41-50	51-90	91-110	111-130	≥131	
	AVPU				A			V, P, U	
Jarvis (2015b)	**NEWS**								
	RR	≤8		9-11	12-20		21-24	≥25	Not reported.
	SpO_2	≤91	92-93	94-95	≥96				
	FiO_2				No		Yes		
	Temperature	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1		
	SBP	≤90	91-100	101-110	111-219			≥220	
	HR	≤3		41-50	51-90	91-110	111-130	≥131	
	AVPU				A			V, P, U	
	Binary NEWS								
	RR			<12	12-20	>20			Not reported.
	SpO_2			<96	≥96				
	FiO_2				No	Yes			
	Temperature			<36.1	36.1-38.0	>38.0			
	SBP			<111	111-219	>219			
	HR			<51	51-90	>90			
	AVPU				A	V, P, U			

14.5 Appendix 5 – EWS weightings and scores according to study

Study (Year)	EWS	Score							Trigger score
		3	2	1	0	1	2	3	
Jo (2013)	**VIEWS-L**								
	SBP	≤90	91-100	101-110	111-249	≥250			Not reported.
	HR		≤40	41-50	51-90	91-110	111-130	≥131	
	RR	≤8		9-11	11-20		21-24	≥25	
	Temperature	≤35.0		35.1-36.0	36.1-38.0		38.1-39.0	≥39	
	SpO_2	≤84	85-89	90-94	≥95				
	FiO_2				Room air			Any O_2	
	AVPU				A			V, P, U	
Jones (2013)	**VSA**								
	HR		≤49	50-59	60-100	101-119	≥120		Score 5-8: Notify charge nurse and medical doctor. Consider calling MET.
	RR		≤10	11-15	16-20	21-29	≥30		
	SBP		≤89	90-99	100-140	141-180	≥181		
	SpO_2		≤89	90-94	95-100				
Jones (2011)	**Patientrack EWS**								
	HR		<40	41-50	51-100	101-110	111-130	>130	EWS ≥6 or EWS ≥3 5 times within 24 hours – senior doctor must be contacted. EWS 3-5: inform nurse in charge and consider nursing intervention. Recheck score in one hour. If EWS ≥3 call junior doctor.
	SBP	<70	71-80	81-100	101-199		>200		
	RR		<8		9-14	15-20	21-29	>30	
	Temperature		<35.0	35.1-36.0	36.1-37.9	38.0-38.9	>39.0		
	AVPU				A	V	P	U	
Liljehult (2016)	**ViEWS**								
	SBP	≤90	91-100	101-110	111-219			≥220	Not reported.
	HR	≤40		41-50	51-90	91-110	111-130	≥131	
	RR	≤8		9-11	12-20		21-24	≥25	
	SaO_2	≤91	92-93	94-95	≤96				
	FiO_2				No		Yes		
	Temperature	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1		
	AVPU				A			V, P, U	
Van Galen (2016)	**MEWS**								
	RR		<9		9-14	15-20	21-30	>30	A score of 3 or more was considered a critical score and nurses were requested to contact a doctor immediately.
	SpO_2	<90							
	HR		<40	40-50	51-100	101-110	111-130	>130	
	SBP	<70	70-80	81-100	101-200				
	Temperature		<35.1	35.1-36.5	36.5-37.5	>37.5			
	AVPU				A	V	P	U	
	Urine output	<75ml/4hrs							
	Staff concern	1 point							
Ludikhuize (2014)	**MEWS**								
	HR		<40	40-50	51-100	101-110	111-130	>130	A score of 3 or more was considered a critical score and nurses were requested to contact a doctor immediately.
	SBP	<70	70-80	81-100	101-200		>200		
	SpO_2	<90							
	RR		<9		9-14	15-20	21-30	>30	
	Temperature		<35.1	35.1-36.5	36.6-37.5	>37.5			
	AVPU				A	V	P	U	
	Staff concern	1 point							
	Urine output	<75ml/4hrs 1 point							
Luis (2017)	**Short NEWS (NEWS excluding temperature)**								
	RR	<8		9-11	12-20		21-24	>25	Not reported.
	SpO_2	<91	92-93	94-95	>96				
	FiO_2		Yes		No				
	SBP	<90	91-100	101-110	111-219			>220	
	HR	<40		41-50	51-90	91-110	111-130	>131	
	AVPU				A			V, P, U	
	NEWS (as above with temperature)								
	Temperature	Not reported in paper.							

14.5 Appendix 5 – EWS weightings and scores according to study

Study (Year)	EWS	Score							Trigger score
		3	2	1	0	1	2	3	
Mathukia (2015)	**MEWS**								
	RR		<8	8	9-17	18-20	21-29	≥30	Score 6+: Call RRT and physician immediately.
	HR		<40	40-50	51-100	101-110	111-129	≥130	
	SBP	≤70	71-80	81-100	101-159	160-199	200-220	>220	
	AVPU		New onset agitation, confusion	agitation, confusion	A	V	P	U	
	Temperature		<35.0	35.0-36	36.05-38	38.05-38.5	≥38.55		
Moon (2011)	**MEWS**								
	RR	<8			8-20	21-30		>30	MEWS >5 or MEWS=3 in a single category or serious concern.
	HR	<40		40-50	51-100	101-110	111-130	>130	
	SBP	<70	71-80	81-100	101-180	181-200	201-220	>220	
	Temperature	<34	34.0-35.0		35.1-37.5	37.6-38.5	38.6-40.2	>40	
	SpO_2	<90	91-93		94-100				
	Urine output							<30ml over 2 hours	
	AVPU		Confused, Agitated		A	V	P	U	
Martin (2015)	**DULK**								
	Temperature	>38◦C – 1 point							<3 points: Surveillance 4-7 points: Clinical re-evaluation (vital signs), Laboratory re-evaluation, standard imaging >8 points: Within 12 hours, abdomino-pelvic CT scan ± with intra-colonic contrast.
	HR	> 100 – 1 point							
	RR	> 30/min							
	Oliguria	Diuresis < 700 mL/d – 1 point							
	Agitation or lethargy	2 points							
	Clinical deterioration	2 points							
	Gastroparesia	2 points							
	Evisceration	2 points							
	Abdominal or parietal pain	2 points							
	Elevated WBC count, CRP	103/mL) or CRP (mg/L) > 5% - 1 point							
	Blood creatinine, urea	>5% - 1 point							
	Enteral nutrition tube/ Parenteral nutrition	1 point 2 points							
	Ileus	2 points							
Nishijima (2016)	**SCS**								
	SBP	<70	71-80	81-100	101-199		>200		An alert is automatically generated if the MEWS score is 7 or more. Nurse then contacts ICU nurses and attending physician for immediate treatment response.
	HR		<40	41-50	51-100	101-110	111-129	>130	
	RR		≤8		9-14	15-20	21-29	≥30	
	Temperature		≤35.0	35.1-38.4		≥38.5			
	AVPU				A	V	P	U	
	Staff concern				No	Yes			
Parrish (2017)	**MEWS**								
	HR		<40	40-50	21-100	101-110	111-130	>130	A score of 4 or more triggers a pop up notification on the electronic system.
	SBP	<70	70-80	81-100	101-159	160-199	200-220	>220	
	RR		<8	8	9-17	18-20	21-29	>30	
	Temperature		<95F		95-100.4	100.5-101	>101		
	AVPU			Confusion	A	V	P	U	
	SpO_2	<85	85-89	90-94	>94				
	O_s delivery		Trach collar	Cannula	Room air	Face tent	Venturi mask		

14.5 Appendix 5 – EWS weightings and scores according to study

Study (Year)	EWS	Score							Trigger score
		3	2	1	0	1	2	3	
Patel (2011)	**MEWS**								
	HR		<40	40-50	51-100	101-110	111-129	≥130	Score 1-3: observations 4-hourly. A MEWS >4 prompts staff to seek senior medical advice. If necessary a referral to the CCOT is made.
	RR		≤8		9-14	15-20	21-29	≥30	
	Temperature		<35.0	35.1-36	36.1-37.9	38-38.4	≥38.5		
	AVPU				A	V	P	U	
	Urine catheterised	Nil	<0.5ml/2hours	<0.5ml/1hour		>3ml/2hours			
	Non-catheterised	P/U in 12 hours: No			P/U in 12 hours: Yes				
	BP	Not reported.							
Peris (2012)	**MEWS**								
	SBP	<70	71-80	81-100	101-199		≥200		MEWS of 3 or 4 in the preoperative evaluation or at operating room discharge: transferred to HDU, whereas a MEWS score of 5 or more was considered criteria for ICU admission.
	HR		<40	41-50	51-100	101-110	111-129	≥130	
	RR		<9		9-14	15-20	21-29	≥30	
	Temperature		<35		35.1-38.4		≥38.5		
	AVPU				A	V	P	U	
Petersen (2016)	**NEWS**								
	RR	<9		9-11	12-20	21-24		>24	Not reported.
	SpO_2	<92	92-93	94-95	>95				
	HR	<41		41-50	51-90	91-110	111-130	>130	
	SBP	<91	91-100	101-110	111-219			>219	
	AVPU				A			V, P, U	
	Temperature	<35.1		35.1-36.0	36.1-38.0	38.1-39.0	>39		
	FiO_2		Yes		No				
Reini (2012)	**MEWS**								
	SBP	≤70	71-80	81-100	101-199		≥200		A MEWS of 5 or more triggered referral to the CCOS.
	RR		<9		9-14	15-20	21-29	≥30	
	HR		≤40	41-50	51-100	101-110	111-129	≥130	
	Temperature	≤35		35.1-36	36.1-38	38.1-38.5	>38.5		
	AVPU			Confused.	A	V	P	U	
Smith (2012)	**MEWS**								
	HR		<40	40-50	51-100	101-110	111-130	>130	MEWS of 3 or more: call the attending physician.
	SBP	<70	70-80	81-100	101-200		>200		
	RR		<9		9-14	15-20	21-30	>30	
	Temperature		<35.1	35.1-36.5	36.6-37.5	>37.5			
	AVPU				A	V	P	U	
	Urine output	<75 mL during last 4 hours: 1 point							
	Staff concern	Uneasy about patient's condition: 1 point							
	SpO_2	<90							
Smith (2013)	**NEWS**								
	RR	<8		9-11	12-20		21-24	≥25	Not reported in the paper.
	SpO_2	≤91	92-93	94-95	≥96				
	FiO_2		Yes		No				
	Temperature	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1		
	SBP	≤90	91-100	101-110	111-219			≥220	
	HR	≤40		41-50	51-90	91-110	111-130	≥131	
	AVPU				A			V, P, U	
Stark (2015)	**MEWS**								
	SBP	<70	71-80	81-100	101-199		≥200		Not reported.
	HR		<40	41-50	51-100	101-110	111-129	>130	
	RR		<9		9-14	15-20	21-29	≥30	
	Temperature		<35		35-38.4		≥38.5		
	AVPU				A	V	P	U	

14.5 Appendix 5 – EWS weightings and scores according to study

Study (Year)	EWS	Score							Trigger score
		3	2	1	0	1	2	3	
Suppiah (2014)	**MEWS**								
	HR	Not reported.							MEWS 3-4: 2-hourly observations and junior doctor to review within 30 minutes. MEWS ≥5 or a score of 3 in a single parameter: Senior medical review within 30 mins and CCOT
	Temperature	≤35.0	35.0-35.9	35.0-35.9	36.0-37.9	38.0-38.9	39.0-39.9	≥40.0	
	SBP	≤70	70-79	80-99	100-180	180-199	200-219	≥220	
	RR	<8		8-11	12-20	21-25	26-30	>30	
	SpO_2	<85	85-89	90-93	≥94				
	FiO_2				No	O_2	>60% O_2		
	AVPU				A	V	P	U	
	Urine output	<80	80-119	120-199	>200 ml	>800			
Van Rooijen (2013)	**Unnamed EWS**								
	HR				51-100	101-110	111-130	>130	EWS ≥3: Electronic programme generated an alert to call the doctor.
	SBP	<70	70-80	81-100	101-200		>200		
	RR		<9		9-14	15-20	21-30	>30	
	Temperature		<35.1	35.1-36.5	36.6-37.5	>37.5			
	AVPU				A	V	P	U	
	Staff concern	1 point							
	Urine output	<75ml in 4 hours: 1 point							
	SpO_2	<90							
Xiao (2012)	**AFSS EWS**								
	Age				18-30	31-45	46-65	>65	A score of 8 alert doctors to patients of a severe fever state.
	Past history				Yes		No		
	Fever course				≤3	4-7	8-14	>14	
	Temperature				<38	38-38.9	39-39.9	≥40	
	RR		<10		11-19		20-29	≥30	
	HR		≤50		51-100	101-110	111-129	≥130	
	MAP	≤49	50-74		75-119		≥120		
	WBC count	≤2.9	3-3.9		4-10	10.1-24.9	≥25		
Abbott (2016)	**NEWS**								
	Temperature	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	>39.0		A score of over 7 triggers review by the CCOT or medical response team
	HR	<41		41-50	51-90	91-110	111-130	>130	
	SBP	<91	91-100	101-110	111-219			>219	
	RR	<9		9-11	12-20		21-24	>25	
	SpO_2	<92	92-93	94-95	>96				
	FiO_2		Yes		No				
	AVPU				A			V,P,U	
Hollis (2016)	**ViEWS**								
	HR		≤40	41-50	51-90	91-110	111-130	≥131	Institutional criteria for MET activation include nurse triggered recognition of single vital parameter abnormalities
	SBP	≤90	91-100	101-110	111-249	≥250			
	RR	≤8		9-11	12-20		21-24	≥25	
	Temperature	≤95		95.1-96.8	96.9-100.4	100.5-102.2	≥102.3		
	SpO_2								
	Alertness				Alert			Altered	
Pedersen 2018	**NEWS**								
	RR	≤8		9-11	12-20		21-24	≥25	Total score 5 or more, or 3 in one variable: Registered nurse to urgently inform the medical team caring for the patient; Total: 7 or more: Registered nurse to immediately inform the medical team caring for the patient – this should be at least at Specialist Registrar level
	SpO_2	≤91	92-93	94-95	≥96				
	FiO_2	0	>0						
	Pulse rate	≤40		41-50	51-90	91-110	111-130	≥131	
	SBP	≤90	91-100	101-110	111-219			≥220	
	Mental state	V,P,U			A				
	Temperature	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1		
	CREWS SpO_2	≤85	86-87	88-89	≥90				
	S-NEWS SpO_2	≤83	84-85	86-87	88-92, or ≥93 without oxygen supplementation		≥93 with oxygen supplementation		

14.5 Appendix 5 – EWS weightings and scores according to study

Study (Year)	EWS	Score							Trigger score
		3	2	1	0	1	2	3	
Smith (2016)	**NEWS**								
	RR	≤8		9-11	12-20		21-24	≥25	NEWS score ≥7
	SpO_2	≤91	92-93	94-95	≥96				
	FiO_2		Yes		No				
	Temperature	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1		
	SBP	≤90	91-100	101-110	111-219			≥220	
	HR	≤40		41-50	51-90	91-110	111-130	≥131	
	Level of consciousness				A			V, P, U	
Uppanisakorn (2018)	**NEWS**								
	RR	≤8		9-11	12-20		21-24	≥25	NEWS score ≥7
	SpO_2	≤91	92-93	94-95	≥96				
	FiO_2		Yes		No				
	Temperature	≤35.0		35.1-36.0	36.1-38.0	38.1-39.0	≥39.1		
	SBP	≤90	91-100	101-110	111-219			≥220	
	HR	≤40		41-50	51-90	91-110	111-130	≥131	
	Level of consciousness				A			V, P, U	
Young (2014)	**MEWS**								
	SBP	<81	81-90	91-100	101-160	161-170	171-180	>180	
	HR		<41	41-50	51-100	101-110	111-129	>129	
	RR	<10			10-20	21-24	25-28	>28	
	Temperature		<36		36-38		>38		
	SpO_2	<91		91-94	95-100				
	Dyspnea	Observed shortness of breath	Verbal						
	Mental status	Any new mental status							

14.6 Appendix 6: Findings of the studies included in Q3 (Educational interventions)

Study Authors (Year)	Outcomes	Conclusion
RCTs		
Liaw (2011)[177]	**Other outcomes post-hoc: communication** Total ABCDE domain (score ranges from 0-36): Intervention group baseline mean 10.37 (SD 2.48), post-intervention mean 20.13 (SD 3.29), p=0.001). Control group baseline mean 10.22 (SD 2.39), post-intervention mean 11.22 (SD 2.25). Individual ABCDE domains: Airway: intervention group pre-intervention mean 0.77(SD 0.73) post-intervention 2.60 (SD 0.93) (p=0.001). Control group pre-intervention mean 0.66 (SD 0.96), post-intervention mean 0.50 (SD0.61). Breathing: intervention group pre-intervention mean 2.63 (SD 0.79), post-intervention 4.67 (SD 0.49) (p=0.001). Control group pre-intervention mean 3.13 (SD 0.74), post-intervention mean 3.13 (SD 0.62). Circulation: intervention group pre-intervention mean 1.80 (SD 0.84), post-intervention mean 5.03 (SD 1.08), (p=0.001). Control group pre-intervention mean 1.69 (SD 1.00), post-intervention mean 2.03 (0.74).Disability: intervention group pre-intervention mean 1.30 (SD 1.00), post-intervention 1.77 (SD1.31). Control group pre-intervention mean 1.13 (SD 1.15), post-intervention mean 1.44 (SD 1.03).Examine: intervention group pre-intervention mean 0.53 (SD 0.40), post-intervention 0.87 (SD 0.69). Control group pre-intervention mean 1.13 (SD 1.15), post-intervention mean 1.44 (SD 1.03). Total SBAR: intervention group baseline mean 8.47 (SD 1.62), post-score mean 11.77 (SD 2.83) (p=0.01). The intervention group did not show any significant improvement on the post-test scores for individual SBAR subscales except Assessment. Baseline mean 0.10 (SD 0.28), post score mean 0.40 (SD 0.47) (p=0.05). The control group showed a significant improvement in the post-test score for the 'global rating performance' not for the rest of the SBAR domains. Baseline mean 3.34 (SD 1.45), post score mean 3.84 (SD 1.35), (p=0.05).	The nursing students' competency in assessing, managing and reporting of deteriorating patient can be enhanced through a systematic development and implementation of a simulation-based educational program that utilized mnemonics including ABCDE and SBAR to help students to remember key tasks.
Liaw (2012)[178]	**Primary outcome: increase in knowledge and performance** Performance: Intervention group pre-test mean 10.37 (SD 2.48), post-test 20.13 (SD 3.29), (p≤0.001), Control group: pre-test 10.22 (SD 2.39), post-test 11.22 (SD 2.25) (p=0.15) Knowledge: Intervention group pre-test mean 35.72 (SD 2.90), post-test 43.48 (SD 2.89), (p≤0.001). Control group pre-test mean 36.8 (SD 3.95), post-test 36.81 (SD 2.99), (p=0.99). Self-confidence: Intervention group pre-test mean 18.73 (SD 7.69), post-test mean 24.53 (SD 6.56), (p≤0.001). Control group pre-test mean 14.63 (SD 5.90), post-test mean 20.63 (SD 6.05), (p≤0.001). Between group tests showed that the intervention group scored significantly better than the controls for knowledge (p≤0.001) and performance (p≤0.001). No difference between groups for self-confidence (p=0.32).	Significantly improved knowledge and performance scores in intervention group post-test compared to control group but not for self-confidence. Possible explanation for this is that the control group received a 15 minute pre-test simulation that could have altered their post-test confidence score.
Liaw (2014)[166]	**Primary outcome: increase in knowledge and performance** Clinical performance mean score (max score 54): mean score of participants 30.58 (SD 5.78) or 'average' clinical performance. Intervention: pre-test (38.52, SD 4.82) post-test1 (36.65, SD 5.59) post-test2 (33.58, SD 6.78) Control: pre-test (29.46, SD 6.67) post-test1 (33.27, SD 7.50) post-test2 (33.38, SD 6.49) Significant increases in the post-test1 scores (1 day later) for the intervention group (p<0.001) and the control group (p<0.05). Post-test2 scores (2.5 months) decreased significantly for the intervention group (p<0.05), there was no significant decrease for the controls at post-test2.	Both virtual-simulation and mannequin-simulation resulted in improved clinical performance immediately post intervention. Only mannequin-based simulation yielded an increase in clinical performance in the longer term (2.5 months). Suggests hands-on learning provided deeper learning.

Appendix 6: Findings of the studies included in Q3 (Educational interventions) [continued]

Study Authors (Year)	Outcomes	Conclusion
RCTs		
Liaw (2017),[180]	**Primary outcome: Knowledge** Pre-test Intervention: mean 16.66 (SD 3.73) Post-test intervention: mean 18.66 (SD 3.824) (p<0.001) Pre-test control: mean 16.38 (SD 3.64) Post-test control: mean 16.50 (SD 3.742) (p=0.75) Between group comparison: p<0.01 **Primary outcome: Performance (measurement of vital signs, assessing and managing clinical deterioration)** Pre-test Intervention: mean 12.19 (SD 2.40) Post-test intervention: mean 19.44 (SD 0.69) (p<0.001) Pre-test control: mean 12.88 (SD 2.45) Post-test control: mean 14.09 (SD 0.44) (p=0.05) Between group comparison: p<0.001 **Secondary outcome: Improved documentation of patient observations** No statistical difference pre-test in the measurement of vital signs between the experimental and control group. Post-test, experimental group were significantly more likely to monitor RR (59.4% vs 21.9%, p<0.001) and HR (68.8% vs. 43.4%, p<0.05). No difference between groups for temperature, BP and SpO_2 **Other outcomes post-hoc: Communication, collaboration and perception: Improved documentation of patient observations (reporting clinical deterioration ISBAR and ABCDE)** Pre-test Intervention: mean 8.03 (SD 1.74) Post-test intervention: mean 10.00 (SD 1.48) (p<0.001) Pre-test control: mean 8.41 (SD 2.01) Post-test control: mean 8.75 (SD 1.67) (p>0.05) Between group comparison: p<0.01	Using a web-based educational programme, EN's in the intervention group had improved knowledge and skills in recognising, responding (performance) and reporting (SBAR, ABCDE) of a patient deteriorating in a simulated setting. Limited by small sample size, non-clinical setting, ENs – may not be applicable to other settings or countries.
Lindsey (2013)[168]	**Primary outcome: increase in knowledge and performance** Changes in knowledge and clinical judgement: Both control (mean 57.05, SD 16.47), intervention (mean 61.07, SD 17.19) groups scored lowest on the pre-test scores. Nursing students who received the rapid response educational intervention had significantly higher post-test scores (mean 90.91, SD 19.69) compared to controls (mean 64.80, SD 19.69), p <0.001. 11-items survey (1,5, 6, 8 and 9 looked at knowledge of RRTs; 2, 3, 4, 7, and 10 looked at clinical judgement in activating RRTs and 11 looked at prior exposure to RRTs). The intervention group scored higher on all post-test items compared to the controls, except for Question 3 on clinical judgement.	The findings demonstrate that clinical simulation is effective in improving students' knowledge and clinical judgment, specifically concerning rapid response systems.

Appendix 6: Findings of the studies included in Q3 (Educational interventions) [continued]

Study Authors (Year)	Outcomes	Conclusion
nRCTs		
Ludikhuize (2011),[169]	**Primary outcome: increase in knowledge and performance** Taking action after reading nursing chart (performance): After reading the patient case description, 77% (36) of trained nurses and 58% (28) of non-trained nurses said they would review the patient immediately (p=0.056). At ward level, differences were observed between the wards and the range of nurses taking action varied from 37% to 88%. Post hoc analyses removing Ward C (included older and more experienced nurses), showed a statistically significant difference between trained and non-trained nurses (77% vs. 53%, p=0.026). **Secondary outcome: improved documentation of observations** Measurement of vital signs and MEWS: Pulse, BP, temperature and SpO_2 were the most requested vital sign parameters (78-84% in both groups). 53% of trained nurses requested RR, compared to 25% of non-trained nurses, p=0.025. Pain measurement using a VAS was requested by 50% of all nurses. Of the trained nurses, only 4 (11%) determined and calculated the MEWS correctly. **Other outcomes post-hoc: communication** Use of SBAR: Only 1 (4%) of trained nurses used SBAR to communicate with the physician. Measured parameters were only communicated to the physician in 60% of phone calls. Where measured, RR was relayed twice as frequently by trained nurses than by non-trained nurses (83% versus 40%). In the 4 cases where MEWS was calculated (11% of trained nurses), 1 nurse (2%) followed the protocol correctly and called the physician (but did not mention MEWS). 2 nurses took no action and 1 checked the patient again at a later time. Notifying the physician: 24 nurses (67%) in the trained group and 12 (43%) in the non-trained group contacted the physician immediately (p=0.059). When Ward C was excluded (due to demographic differences), 67% of trained nurses and 22% of non-trained nurses notified a physician (p=0.037).	**"**Overall no difference between trained and non-trained nurses in the number of vital signs "measured", although trained nurses measured RR more often". Feedback session identified barriers to MEWS including that its use was voluntary, physicians were not trained in MEWS or SBAR, and an established culture within the hospital hampered immediate physician notification. Suggestions for improvement included: electronic MEWS system, bedside consultation with the physician rather than by telephone, making MEWS mandatory and getting physicians to use MEWS.
ITS		
Kinsman (2012),[175]	**Primary outcome: effect on patient outcomes** Administration of oxygen therapy: improved but no significant difference pre- and post-intervention (p=0.143). MET criteria calls: pre-intervention (n=30 calls), post intervention (25 calls). **Secondary outcome: improved documentation of observations** Unsatisfactory pain score charting: decreased (-0.179 points, p=0.003) Unsatisfactory frequency of observations: decreased (-0.112 points, p=0.009) Observation frequency: improved in medical (p=0.003) but not in surgical patients (p=0.403).	$FIRST^2ACT$ programme is associated with improved assessment of pain score and documentation of observations in medical patients.
Before-after observational studies		
Cahill (2011),[164]	**Secondary outcome: improvement in documentation of patient observations:** Full observation set: pre-intervention (47.6%), post-intervention two weeks (96.3%), post-intervention three months (96.4%), p≤0.001. RR: pre-intervention (47.8%), post-intervention two weeks (97.8%), post-intervention three months (98.5%), p≤0.001. BP: pre-intervention (97.9%), post-intervention two weeks (99.4%), post-intervention three months (99.3%), p≤0.001. HR: pre-intervention (99.7%), post-intervention two weeks (99.7%), post-intervention three months (99.9%), p=0.19. SpO_2: pre-intervention (97.0%), post-intervention two weeks (98.4%), post-intervention three months (98.1%), p≤0.002.	Re-design of the observation chart to 1 page with colour coding and banding, elevation of RR to the top of the chart and the additional of physiological triggers for escalation resulted in an increase in documentation of patient observations, sustained at three months post-intervention.

Appendix 6: Findings of the studies included in Q3 (Educational interventions) [continued]

Study Authors (Year)	Outcomes	Conclusion
Before-after observational studies		
De Meester (2013),[48]	**Primary outcome: effect on patient outcomes** SAEs: n=207 in total, of which 81 (4.4/1,000 admissions) were pre-intervention and 126 (6.7/1,000 admissions) were post-intervention (p=<0.05). Unexpected deaths: n=16 unexpected deaths (0.99/1,000 admissions) pre-intervention and 5 unexpected deaths (0.34/1,000 admissions) post-intervention (RRR -227%, 95% CI -793%, -20%), p≤0.001. Unplanned admission to the ICU: increased from 51 (13.1/1,000 admissions) pre-intervention to 105 (14.8/1,000 admissions) post intervention (RRR 50%, 95% CI 30%, 64%), p=0.001). Mortality; 10.29/1,000 (pre-intervention), 10.60 (post-intervention). LOS: mean 5.7 days (pre-intervention), 5.54 days (post-intervention) Cardiac arrest team calls: 3.15/1,000 admissions (pre-intervention), 14.85/1,000 post-intervention. **Other outcomes post-hoc: communication, collaboration and perception:** Nurses total score**:** pre-intervention 58.6 (31-97), increased to 63.9 (25-97) post-intervention, p≤0.001). Collaboration: pre-intervention (56.2, 0-100) to post-intervention (62.2, 17-100), p≤0.001. Communication with the physician: pre-intervention (62.9, 20-100), post-intervention (68.9, 13-100), p≤0.001). Overall perception of communication: pre-intervention (55.3, 0-89), post-intervention 58.4, 0-100, p=0.042).	A significant reduction in SAEs following SBAR intervention training. An increase in unplanned ICU admissions but a reduction in unexpected deaths, possibly due to earlier deterioration. In addition SBAR improved communication and collaboration between nurses and physicians.
Hammond (2013),[174]	**Secondary outcome: improvement in documentation of patient observations:** *ICU-Discharge Patients group* Full observation set (7 parameters): increase post intervention (210%, 95% CI 148% - 288%), p≤0.0001). Six vital parameters (excluding urine output): 30% increase (95% CI 10.6%-52.8%). Single parameter documentation: Temperature: 25.5%, 95% CI 8.1%-45.7%, p=0.003. Urine output: 103%, 95% CI 80.0%-129.7%, p≤0.001. Systolic BP: 1.4%, 95% CI -11.5%-16.1%; Diastolic BP: 0.9%, 95% CI -11.9%-15.6%. HR: 4.8%, 95% CI -8.8%-20.3%. RR: 10.0%, 95% CI 4.2%-26.2%. SpO_2: -0.8%, 95% CI -13.3%-13.36%. *Unplanned ICU admissions group* Full observation set (7 parameters): post intervention (44%, 95% CI 2.6% - 102.1%), p=0.04). Six vital parameters (excluding urine output): -3.9% (95% CI -28.3%-28.9%). Single parameter documentation: Temperature: 6.1%, 95% CI -18.8%-38.6%, p=0.7. Urine output: 26.9%, 95% CI 2.5%-57.1%, p≤0.03. Systolic BP and diastolic BP: -13.3%, 95% CI -31.6% - 9.9%, p=0.2. HR: -17.0%, 95% CI -34.5%-5.2%. RR: -11.3%, 95% CI -30%-12.4%. SpO_2: -14.2%, 95% CI -32%-8.36%.	Implementation of a new MEWS observation chart and supporting educational programme was associated with statistically significant increases in frequency of combined and individual vital sign set recordings during the first 24 h post-ICU discharge. There were no significant changes to frequency of individual vital sign recordings in unplanned admissions to ICU after the MEWS observation chart was implemented, except for urine output. Overall increases in the frequency of full vital sign sets were seen.

Appendix 6: Findings of the studies included in Q3 (Educational interventions) [continued]

Study Authors (Year)	Outcomes	Conclusion
Before-after observational studies		
Jung (2016),[62]	**Primary outcome: effect on patient outcomes:** **Unexpected mortality (non-DNR, non-palliative)** RRT hospital: Pre: 21.9 per 1,000 discharges Post: 17.4 per 1,000 discharges (p=0.002) Three control hospitals: Hospital 1: Pre:14.3 per 1,000 discharges Post: 15.4 per 1,000 discharges (p=0.38) Hospital 2: Pre:24.9 per 1,000 discharges Post:22.5 per 1,000 discharges (p=0.16) Hospital 3: Pre: 22.1 per 1,000 discharges Post: 23.8 per 1,000 discharges (p=0.40) **Overall mortality** RRT hospital:Pre: 39.6 per 1,000 discharges Post: 34.6 per 1,000 discharges (p=0.012) Three control hospitals: Hospital 1: Pre: 16.7 per 1,000 discharges Post: 18.4 per 1,000 discharges (p=0.19) Hospital 2: Pre: 28.6 per 1,000 discharges Post: 25.2 per 1,000 discharges (p=0.066) Hospital 3: Pre: 29.0 per 1,000 discharges Post: 29.0 per 1,000 discharges (p=0.97) **Non-ICU cardiac arrest** RRT hospital: Pre:2.6 per 1,000 discharges Post: 1.8 per 1,000 discharges (p=0.093) Three control hospitals: Hospital 1: Pre:3.5 per 1,000 discharges Post: 4.6 per 1,000 discharges (p=0.080) Hospital 2: Pre: 3.3 per 1,000 discharges Post: 2.1per 1,000 discharges (p=0.044) Hospital 3: Pre:10.2 per 1,000 discharges Post: 10.8 per 1,000 discharges (p=0.71) **Unplanned ICU admission** RRT hospital: Pre:45.7 per 1,000 discharges Post: 52.8 per 1,000 discharges (p=0.002) Three control hospitals: Hospital 1: Pre: 51 per 1,000 discharges Post: 55.3 per 1,000 discharges (p=0.054) Hospital 2: Pre:60.2 per 1,000 discharges Post: 55.6 per 1,000 discharges (p=0.34) Hospital 3: Pre: 126.9 per 1,000 discharges Post: 122.0 per 1,000 discharges (p=0.24) **Median hospital LOS (days)** RRT hospital: Pre:5 (2-10) Post: 5(2-10), (p=0.09) Three control hospitals: Hospital 1: Pre: 4 (2-8) Post: 4 (2-8), (p<0.001) Hospital 2: Pre:3 (2-7) Post: 3 (2-6), (p<0.001) Hospital 3: Pre: 4 (2-8) Post: 4 (2-8), (p=0.36)	In the present study, implementation of an intensivist-led RRT along with educational modules, publicity and bedside simulation-based training was associated with a significant decrease in unexpected and overall mortality of inpatients.
Liaw (2016),[181]	**Primary outcome: Increase in knowledge** RNs pre-test: mean 18.80, SD 3.05. RNs post test: mean 22.47, SD 2.99, p<0.001 ENs pre-test: mean 16.57, SD 3.99. ENs post test: mean 19.57, SD 3.97, p<0.001 **Primary outcome: Performance (Training transfer at workplace, 5 point Likert scale), self-reported 3-4 months post training** Participants demonstrated positive attitudes (mean 3.89, SD 0.49) towards the transfer of learning to clinical practice mean scores on each item ranged from 3.39 (peers have said my performance has improved since the training) to 4.13 (putting what I have learned into practice to benefit the patient). No significant difference between nurses (mean 3.82, SD, 0.52) and ENs (mean 4.06, SD 0.39). **Work with more confidence after the training:** mean 3.95, SD 0.64 **Work performance improved after the training**: mean 3.88, SD 0.65 **Primary outcome: Effect on patient outcomes**: Trigger cases (RRT calls) pre and post intervention: Medical ward: pre: 8.96%, post 14.58% (p<0.001) Surgical ward: pre: 1.97%, post 1.23%, (p=0.15)	Authors measured the outcomes across the levels of an existing adaptation of Kirpatrick's model during a 14-month period to evaluate the impact of e-RAPIDs. Found changes in practice (more trigger cases of the RRT post intervention) in the medical ward only. Changes in practice self-reported 3-4 months later by nurses and ENs after the educational intervention. Only focusses on the afferent limb, did not look at RRT effectiveness. Limited by lack of control group (which did not receive the intervention).

Appendix 6: Findings of the studies included in Q3 (Educational interventions) [continued]

Study Authors (Year)	Outcomes	Conclusion
Before-after observational studies		
McDonnell (2012),[185]	**Primary outcome: Knowledge (Scale of 1 to 10)** **Level of knowledge** Before: mean 7.3 (SD 1.8); After: mean 8.0 (SD 1.5), p<0.001 **Primary outcome: Performance and confidence** **Confidence to recognise** Before: mean 7.5 (SD 1.8); After 8.2 (SD 1.4), p<0.001 **Confidence when to react:** Before: mean 8.8 (SD 1.3); After 9.0 (SD 1.2), p=0.01 **Confidence who to contact:** Before: mean 8.9 (SD 1.3); After 9.2 (SD 1.1), p<0.001 **Confidence to report abnormal observations:** Before: mean 9.0 (SD 1.3); After 9.3 (SD 1.1), p<0.0001 **Confidence to ask senior staff to come:** Before: mean 9.3 (SD 1.1); After 9.4 (SD 0.9), p=0.16 **Level of experience:** Before: mean 7.5 (SD 1.8); After 8.1 (SD 1.4), p≤0.001 Also looked at differences between RNs and UNs and found significantly improved mean differences (greater change in score after the intervention) in UNs for change for **level of experience** (p=0.008); change in **level of knowledge** (p=0.008) and change **in confidence to recognise** (p=0.006) only.	The new model and educational intervention had a positive impact on the self-assessed knowledge and confidence of registered and unregistered nurses.
Mullany (2016),[186]	**Primary outcome: effect on patient outcomes** All-cause hospital mortality rate: decreased from 14/1,000 to 11.8/1,000 separations (absolute change 2.2/1,000, 95% CI 1-3.5/1,000, p=0.003). Hospital standardised mortality ratio: 95.7 for 2008/2009. Fell 11% in the first 6 months after implementation. Fell again in 2011 and 2012 and by the second half of 2012 was 66 and below the 3 SD control limit (a 31% total decline over 3 years). In-hospital cardiac arrest rate: from before and after the introduction of the MET, cardiac arrest calls decreased from 5.5/1,000 to 3.3/1,000 separations (absolute change 2.2/1,000, 95% CI 1.4-3, p≤0.001). Emergency ICU admissions following emergency calls: increased from 41 admissions in 2009 to 121 admissions in 2012 and in total, 383 admissions overall. Average length of stay in the ICU decreased from 140 hours in 2009 to 95 hours in 2012, and 92 hours overall. Hospital LOS: average 5.9 days in 2009, 4.7 days in 2012, and 4.9 overall. Escalation: MET calls 8.3/1,000 separations in 2010, 9.1/1,000 in 2011 and 11.3/1,000 in 2012. An increase of approximately 1 per month call every 2 months. **Secondary outcome: Improved compliance** Compliance with appropriate frequency of vital signs: Following introduction of monthly ward-based audits, compliance with correct frequency of vital signs rapidly rose to above the target of 90%. Completeness of vital signs increased from a mean of 60% in 2010 to 70% in 2011. The intervention resulted in progressive improvement in compliance to 86% in December 2012 and the 90% target was reached in Mar 2013. The addition of documentation of escalation by nurses to monthly audits in 2011 improved this from 79% to 90% by 2012.	A low MET dose may be associated with improved hospital mortality when combined with a MEWS and an intervention to improve communication. There was a fall in cardiac arrest calls, all-cause mortality and improved hospital standardised mortality ratio – however causation cannot be established.

Appendix 6: Findings of the studies included in Q3 (Educational interventions) [continued]

Study Authors (Year)	Outcomes	Conclusion
Before-after observational studies		
Merriel (2016),[170]	**Secondary outcome: improved documentation of observations** Individual EWS scores calculated correctly: pre-implementation (3,786/4,082, 92.7%); post-implementation (2,602/2,769, 93.97%), Relative Risk 1.01 (95% CI 1.00, 1.03), p=<0.05) All EWS scores calculated correctly for a patient's admission: pre-implementation (140/254, 55.12%); post-implementation (134/197, 68.02%), Relative Risk 1.24 (95% CI 1.07, 1.44), p=<0.01). Completion of at least 1 set of required observations (e.g. at least BP): pre-implementation (192/282, 68.09%); post-implementation (165/210, 78.57%), Relative Risk 1.2 (95% CI 1.09, 1.32), p=<0.01). Observations performed as per the EWS guidelines: fewer than half documented as per the EWS guidelines pre-implementation (130/282, 46.10%), increasing post-implementation to 58.57% (123/210), Relative Risk 1.33 (95% CI 1.13, 1.57).	Regular, ward-based training of shorter duration (similar to the 1 hour training sessions in this study) should become a regular feature in every clinical area.
Ozekcin (2015),[171]	**Primary outcome: increase in knowledge and performance** Knowledge: pre-test (mean 56.9%, SD 16.9%), post-test (mean 84.6%, SD 10.3%), mean difference (27.6%, SD 15.9%, p≤0.0001). Performance: Likert scale survey - responses of the participants in responding to clinical deterioration post simulation training. Included: Confident to recognise patient deterioration: before simulation mean (4.06, SD 0.44), after simulation mean (4.45, SD 0.51), p=0.001. Confident in responding to an unstable patient and using a systematic assessment tool: before simulation mean (4.00, SD 0.52), after simulation mean (4.48, SD 0.51), p≤0.0001). Confident to coordinate responders using an escalation protocol: before simulation mean (3.80, SD 0.79), post simulation mean (4.39, SD 0.62), p=0.001. Comfortable using the SBAR tool: pre-simulation mean (4.48, SD 0.57), post simulation mean (4.71, SD 0.46), p=0.04).	After completion of education and simulation scenarios, the goal is to reduce the number of code blue events by 50% in this hospital. Use of SBAR and e-learning simulation and debriefing can improve instability recognition resulting in an increase in knowledge and decreased time to critical actions.
Rose (2015),[172]	**Primary outcome: effect on patient outcomes** Patient RRT survival rate: pre (23, 100%), post (17, 100%) Post RRT transfer rate: pre intervention (11, 43%) post (10, 64%). Number of RRT calls: pre-intervention (n=23), post-intervention (17) **Secondary outcome: improved documentation of observations** Undocumented eMEWS scores: pre-intervention (11, 49%), post intervention (0, 0%) eMEWS score range: pre (0-6, mean 2.3,SD 1.79), post (mean 3.2, SD 1.79).	A brief educational intervention (3 minutes duration) resulted in an increase in eMEWS documentation and more focused identification of patient deterioration.
Schubert (2012),[176]	**Primary outcome: increase in knowledge and performance** Knowledge: average increase in knowledge scores overall between pre-test and post-test of 0.73 points (*t*=3.16, *df*=110, p=0.002, 95% CI 0.27, 1.19). Mean knowledge scores increased between pre-test and 2-weeks post-test by 1.76 points (*t*=4.08, *df*=68, p<0.001, *95%* CI 0.90, 2.62). Mean scores also increased between immediate and 2-week post-tests with an increase of 1.03 points (*t*=3.16, *df*=64, p<0.001, *95%* CI 0.44, 1.61). Mean score for knowledge (out of 9) was 6.66 pre-test, 7.39 post-test and 8.42 2-weeks post-test. Critical thinking: significant change in critical thinking between pre-test and 2-weeks post-test results overall (p=0.001). No significant change occurred between pre-test and 2-week post-test measures (p=0.468) or between post-test (immediate) and 2-week post-test measures (p=0.058).	Nursing knowledge and critical thinking improved after the simulation and showed the effectiveness of simulation as a teaching strategy to address nursing knowledge and critical skills thinking.

Appendix 6: Findings of the studies included in Q3 (Educational interventions) [continued]

Study Authors (Year)	Outcomes	Conclusion
Before-after observational studies		
Sebat (2018),[157]	**Primary outcome: effect on patient outcomes** **Cardiac arrest per 1,000 discharges** Before-intervention: 3.1 per 1,000 After-intervention: 2.4 per 1,000, p=0.04 **Unadjusted hospital mortality rate** Before-intervention: 3.7% After-intervention: 3.2%, p<0.001 **Resource utilisation RRT calls per 1,000 discharges** Before-intervention: 10.2 per 1,000 After-intervention: 48.8 per 1,000, p<0.001	Although the 4-part RRT intervention reduced the number of cardiac arrests and hospital mortality, we cannot be certain which aspect of the intervention is most responsible for the improved outcomes or whether unknown confounding played a role. We cannot be certain that the educational component of the intervention was responsible.
Shaddel (2014),[173]	**Primary outcome: increase in knowledge and performance** Mean confidence in clinical judgement: (pre) 3.73, post 4.63, p=0.0001. Correct MEWS score and decision made: pre-test: 42.1%, post-test: 92.1% (p<0.00001)	Limited research into the use of MEWS in psychiatric in-patient settings and small sample size but demonstrated the usefulness of MEWS to increase nurse's knowledge and confidence.
Wood (2015),[182]	**Primary outcome: effect on patient outcomes** Unscheduled admissions to the ICU: Mean EWS score of 7 prompting admission to critical care for adults. Consultant involvement in 51% of adult cases. **Secondary outcome: Improved compliance** Observations done 4 hourly: Quarter 1(65%), Quarter 4(96%) [Mar 2014 Target (75%) achieved] EWS correctly scored and added up: Quarter 1(88%), Quarter 4(93%) [Mar 2014 Target (95%) not achieved] Frequency of observations increased appropriately: Quarter 1 (36%), Quarter 4 (50%) [Mar 2014 Target (35%) achieved]. NURSING escalation correct: Quarter 1 (22%), Quarter 4 (57%) [Mar 2014 Target (35%) achieved]. Medical escalation correct: Quarter 1 (31%), Quarter 4 (37%) [Mar 2014 Target (35%) achieved].	Limited data to date suggests for the sickest adult patients, observations often improve following initial medical intervention and that early review within working hours may prevent patient deterioration and need for escalation out of hours. Suggests ascertaining compliance and culture with regards to EWS.

Key: RR: Respiratory Rate; BP: Blood Pressure; HR: Heart Rate; SpO_2: Oxygen Saturation; SAE: Serious Adverse Event; RRR: Relative Risk Reduction; CI: Confidence Interval; ICU: Intensive Care Unit; LOS: Length of Stay; SBAR: Situation, Background, Assessment, Recommendation; MEWS: Modified Early Warning Score; MET: Medical Emergency Team; ABCDE: Airway, Breathing, Circulation, Disability, Examine; SD: Standard Deviation; RRT: rapid Response team; EWS: Early Warning Score; eMEWS: Electronic MEWS; VAS - visual analogue scale

14.7 Appendix 7 GRADE CERQual Qualitative Evidence Profile

Summary of review finding	Studies contributing to the review finding	Methodological limitations	Coherence	Adequacy	Relevance	CERQual assessment of confidence in the evidence	Explanation of CERQual assessment
Governance: refers to the overall organisational or institutional specific factors affecting why HCPs fail to escalate, or barriers to escalation. Participants reported clear, standardised policies and protocols; a good knowledge of the policies, sufficient resources including staff and good communication; and ensuring accountability as facilitators to escalation. Where there was no clear standardised policy or protocol; staff didn't know the policies; staffing shortages or competing workloads; and lack of accountability or blame, these were reported as barriers to escalation.	16 studies contributed to this review finding. [98, 137, 185, 190-198, 200, 201, 203, 204]	There were *moderate concerns regarding methodological limitations* (3 studies with moderate limitations, 5 studies with minor limitations, 7 studies with very minor limitations and 1 study with no limitations [no rationale for research design (7 studies), unclear recruitment strategy (3 studies), no reflexivity considered (10 studies), unclear ethical issues (1 study), insufficiently rigorous data analysis (2 studies])	There were *minor concerns regarding coherence.* The data were fairly consistent within and across studies but there was variation and the sub-themes within the governance finding were more pronounced in some studies than others.	*There were minor concerns regarding data adequacy*. The studies for the most part offered data that were moderately rich, although data were limited in some studies, sample size small in one study using focus groups.	*No or very minor concerns regarding relevance.* All studies were conducted in hospital settings and included healthcare professionals. The EWS and RRS varied however from study to study.	Moderate confidence ⊕⊕⊕⊖	The finding was graded as moderate confidence because of moderate concerns regarding methodological limitations, and minor concerns for coherence and adequacy.
***RRT Response*:** refers to how the RRT responded when a call for help was made. The behaviour of the RRT was a key barrier or facilitator to escalation. Where the RRT responded negatively (or not at all) or showed a lack of professionalism to those who made the escalation call, this was reported as a barrier to future escalation by participants. Fear of reprimand by senior staff for making the escalation call or fears of looking stupid were reported barriers to escalation. Where the RRT behaved positively, professionally, collaboratively and made key decisions, using their expertise and provided additional support, this was reported as a facilitator to escalation by participants.	12 studies contributed to this review finding. [98, 191-194, 196-200, 202, 203]	There were *moderate concerns regarding methodological limitations* (3 studies with moderate limitations, 2 studies with minor limitations, 6 studies with very minor limitations and 1 study with no limitations [no rationale for research design (6 studies), unclear recruitment strategy (1 study), no reflexivity considered (6 studies), and insufficiently rigorous data analysis (3 studies)])	There were *minor concerns regarding coherence.* The data were varied and the sub-themes within the RRT Response finding were more pronounced in some studies than others. However there was agreement overall.	*There were minor concerns regarding data adequacy*. The studies for the most part offered data that were moderately rich, although data were limited in some studies, sample size small in two studies using focus groups.	*No or very minor concerns regarding relevance.* All studies were conducted in hospital settings and included healthcare professionals. The EWS and RRS interventions varied however from study to study.	Moderate confidence ⊕⊕⊕⊖	The finding was graded as moderate confidence because of moderate concerns regarding methodological limitations, and minor concerns for coherence and adequacy.

Summary of review finding	Studies contributing to the review finding	Methodological limitations	Coherence	Adequacy	Relevance	CERQual assessment of confidence in the evidence	Explanation of CERQual assessment
Professional Boundaries: refers to the barriers to escalation that were endemic in the included studies surrounding hierarchy, power, and jurisdictional control. The EWS and triggering for help was viewed as a licence to escalate and gave participants increased autonomy. It was also reported to be a bridge across professional boundaries ensuring communication and teamwork across staff levels and a workaround to get a patient seen. Other participants reported including increased conflict among staff (between junior and senior staff) and significant jurisdictional hierarchy as barriers to escalation.	12 studies contributed to this review finding.[98, 190-198, 200, 201]	*There were moderate methodological limitations overall* (2 studies with moderate limitations, 3 studies with minor limitations, 6 studies with very minor limitations and 1 study with no limitations [no rationale for research design (5 studies), unclear recruitment strategy (1 study), no reflexivity considered (8 studies), and insufficiently rigorous data analysis (2 studies)])	There were *no or very minor concerns* regarding coherence.	There were *minor concerns* regarding adequacy (data were largely superficial and a rich description was not provided).	There were *no or very minor concerns* regarding relevance.	High Confidence ⊕⊕⊕⊕	The finding was graded as high confidence because of moderate concerns regarding methodological limitations and minor concerns regarding adequacy.
Clinical Experience: refers to the barriers to escalation specifically related to individual staff and their level of confidence and ability to detect deterioration. Clinical confidence to recognise deterioration and confidence in their own ability as well as using one's clinical judgment were all reported as facilitating factors to escalation by participants. The EWS was also a tool which empowered more junior staff to make the call for help and validated their reason for calling. Some participants reported being unable to recognise deterioration or doubting their own ability to detect deterioration as barriers to making a call for help. Clinical 'overconfidence' was also a reported barrier to escalation where staff didn't call for help due to the belief that they could handle the situation themselves.	14 studies contributed to this review finding. [98, 137, 185, 190-194, 197-201, 203]	There were *moderate methodological limitations overall* (3 studies with moderate limitations, 7 studies with minor limitations, 3 studies with very minor limitations and 1 study with no limitations [no rationale for research design (8 studies), unclear recruitment strategy (3 studies), no reflexivity considered (8 studies), unclear ethical issues (1 study), and insufficiently rigorous data analysis (2 studies)])	There were *no or very minor concerns* regarding coherence.	There were *minor concerns* regarding adequacy (data were largely superficial and a rich description was not provided).	There were *no or very minor concerns* regarding relevance.	High Confidence ⊕⊕⊕⊕	The finding was graded as high confidence because of moderate concerns regarding methodological limitations and minor concerns regarding adequacy.

Summary of review finding	Studies contributing to the review finding	Methodological limitations	Coherence	Adequacy	Relevance	CERQual assessment of confidence in the evidence	Explanation of CERQual assessment
Early Warning Systems: refers to the system specific barriers to escalation. Specific sub-populations (e.g. those with COPD) who resulted in excessive triggering of the EWS and the need for parameter adjustment and modification of the EWS were reported as a deterrent to calling for help by some participants. Others reported that the EWS was an excellent mechanism for triage and ensuring patients received the care they needed as well as a valued tool for detecting deterioration.	11 studies contributed to this review finding. (137, 185, 190, 194, 195, 197, 198, 201, 203, 204, 207)	There were *moderate methodological limitations* overall (2 studies with moderate limitations, 2 studies with minor limitations, 6 studies with very minor limitations and 1 study with no limitations [no rationale for research design (6 studies), unclear recruitment strategy (3 studies), no reflexivity considered (7 studies), unclear ethical issues (1 study), insufficiently rigorous data analysis (1 study)])	There were *moderate concerns* regarding coherence. Due to the varying nature of the EWS and RRS included there was variation in the data as a result.	There were *minor concerns* regarding adequacy (data were largely superficial and a rich description was not provided).	There were *no or very minor concerns* regarding relevance.	Moderate confidence ⊕⊕⊕⊖	The finding was graded as moderate confidence because of moderate concerns regarding methodological limitations and coherence and minor concerns regarding adequacy.

Key: HCP: Healthcare Professional; **RRT:** Rapid Response Team; **RRS:** Rapid Response System; **EWS:** Early Warning System; **COPD:** Chronic Obstructive Pulmonary Disease.

14.8 Appendix 8 Deviations from the systematic review protocol

Addition of search terms
List of search terms added to search string for Q5 in sub populations for 'frail older adults'. These include: *"frail elderly" OR "frail elderly or aged or elderly" OR "frailty in elderly people" OR "frail older adult".*
Economic search terms added to the protocol (based on the last review update): *"economics" or "cost* and benefit" OR "cost analysis" OR "cost management" OR "cost saving" OR "escalation cost*" OR "additional resources" OR "cost effectiveness" OR "education" OR "resources".*
Qualitative search terms added to review question 6 on why do HCPs fail to escalate as the proposed search terms were not capturing qualitative studies on the subject area: "*qualitative" OR "ethnography" OR "phenomenology" OR "grounded theory" OR "mixed methods" OR "study design" OR "interview" OR "attitudes" OR "themes"* .
Change in databases/websites searched
• **ASSIA** searched (rather than **Social Sciences Full Texts**, and **Social Sciences Abstracts** individually). • **Global Health** not searched individually as it is indexed within **Academic Search Complete**. • **UK & Ireland Reference Centre Database** not searched. This database includes newspapers (including tabloids) and magazines and has no date limiting function and was deemed irrelevant overall to this search. • **The Cochrane Database of Systematic Reviews** is indexed within **Medline** and so was not searched individually. • **The Cochrane Central Register of Controlled Trials (CENTRAL)** was searched within the **Cochrane Library** (www.cochranelibrary.com) as pre-specified. • The **Cochrane Methodology Register (CMR);** the **Database of Abstracts of Reviews of Effects (DARE);** the **Health Technology Assessment Database (HTA)** and the **National Health Service Economic Evaluation Database (NHS EED)** were not searched after discussion with a librarian as all of these databases have ceased at various times and are not currently up to date. • **TRIP** database or the **WHO Global Index Medicus** were not searched for main detailed search strategy, only for the more basic grey literature searching. • **GrayLit Network** – database discontinued in 2007. Searchable via Science.Gov (https://www.science.gov/) for the current review update. • Due to changes in Google's API, **OpenDOAR** Search has been retired and was not searched as a result. • The **Scottish Intercollegiate Guidelines Network** (SIGN) website (http://www.sign.ac.uk/) could not be searched – the website was down.
Additional items added to data extraction form as requested by the GDG
• **Manual vs. elective recording of vital signs** (e.g. physically feeling for a pulse versus using an electronic monitor • **Oxygen parameters** (range versus score) • **Minimum standard for assessment of vital signs** (e.g. 6hrs versus 12hours threshold)
Study design
• Systematic reviews not to be included as a separate evidence source, rather eligible studies from within any systematic reviews identified will be individually appraised within this current review

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