Strengths and limitations of Early Warning Scores: a systematic review and narrative synthesis

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Abstract

Background

Early warning scores are widely used to identify deteriorating patients. Whilst their ability to predict clinical outcomes has been extensively reviewed, there has been no attempt to summarise the overall strengths and limitations of these scores for patients, staff and systems. This review aims to address this gap in the literature to guide improvements for the optimization of patient safety.

Methods

A systematic review was conducted of MEDLINE®, PubMed, CINAHL and The Cochrane Library in September 2016. The citations and reference lists of selected studies were reviewed for completeness. Studies were included if they evaluated vital signs monitoring in adult human subjects. Studies regarding the paediatric population were excluded, as were studies describing the development or validation of monitoring models. A narrative synthesis of qualitative, quantitative and mixed-methods studies was undertaken.

Findings

232 studies met the inclusion criteria. Twelve themes were identified from synthesis of the data: Strengths of early warning scores included their prediction value, influence on clinical outcomes, cross-specialty application, international relevance, interaction with other variables, impact on communication and opportunity for automation. Limitations included their sensitivity, the need for practitioner engagement, the need for reaction to escalation and the need for clinical judgment, and the intermittent nature of recording.

Early warning scores are known to have good predictive value for patient deterioration and have been shown to improve patient outcomes across a variety of specialties and international settings. This is partly due to their facilitation of communication between healthcare workers.

There is evidence that the prediction value of generic early warning scores suffers in comparison to specialty-specific scores, and that their sensitivity can be improved by the addition of other variables. They are also prone to inaccurate recording and user error, which can be partly overcome by automation.

Conclusions

Early warning scores provide the right language and environment for the timely escalation of patient care. They are limited by their intermittent and user-dependent nature, which can be partially overcome by automation and new continuous monitoring technologies, although clinical judgment remains paramount.

Contribution of Paper

What is already known about the topic?

- Early warning scores are widely used to identify deteriorating patients
- Early warning scores have strengths and limitations which influence their effectiveness

What this paper adds

- Early warning scores can be used across a range of specialties and international settings
- Early warning scores facilitate communication by providing a common language
- They are limited by their intermittent and user-dependent nature, which must be taken into account when interpreting them.

Introduction

The early warning score system is predicated on the idea that derangements in simple physiological observations can identify hospital inpatients at high risk of deterioration.[1] Prodromal warning signs such as increased respiratory rate or decreased blood pressure precede critical illness,[2] and early recognition of these events presents an opportunity for decreasing mortality.[3] The early warning score system allows the user to record and respond to multiple parameters simultaneously, so that subtle changes in vital signs can be used to initiate early emergency management of the patient to reverse the abnormal physiological decline or prompt admission to a critical care area.[2]

Early warning scores have been widely adopted internationally, and different versions exist. A number of reviews have examined the impact of early warning scores on patient outcomes; however, there exists no formal literature review regarding the overall strengths and limitations of early warning scores for patients, staff and systems. This review aims to address this knowledge gap and provide an overview of current systems, highlighting the benefits and identifying areas for future improvement.

Methods

Study design

A systematic review methodology was adopted for the study, employing the principles and methods provided by the Centre for Reviews and Dissemination guidelines and following the PRISMA statement. A narrative synthesis approach was chosen to synthesise the diverse range of selected studies in a structured manner, following the European Social Research Council Guidance on the Conduct of Narrative Synthesis in Systematic Reviews.[4]

Search strategy

A systematic review of the scientific literature was performed by CD. MEDLINE®, PubMed, CINAHL and The Cochrane Library databases were searched for articles published from the dates of inception of the databases (the earliest being 1947) to September 2016. For on-going trials, Current Controlled Trials and ClinicalTrials.gov were searched.

In order to extract all available data regarding early warning score systems, the search strategy was kept necessarily broad. The search strategy was devised with the help of a Research Support Advisor at the Leeds University Library, using both MeSH and/or keyword search terms according to the database.

The search strategy for PubMed is detailed below and further details are provided in Supplementary Material.

1. “Warning scor*”[tiab] including ("warning score" OR "warning score calculation" OR "warning score levels" OR "warning score system" OR

"warning score systems" OR "warning score value" OR "warning scores" OR "warning scoring" OR "warning scoring system" OR "warning scoring systems")
2. “Monitoring,Physiologic/”[Mesh]
3. #1 AND #2
4. #3 NOT ("Adolescent"[Mesh] OR "Child"[Mesh] OR "Infant"[Mesh])

In addition, citations and reference lists of selected studies were reviewed to identify any missed papers.

Identifying relevant papers

Publications were selected in two phases: first by review of title and abstract and then by full text review by CD. The articles were then independently verified by WT.

Studies were included if they evaluated vital signs monitoring in adult human subjects. Study selection was not limited by the score used or the outcomes measured. Selection was not limited to peer-reviewed publications and included grey literature such as editorials and opinion pieces in order to provide insight into stakeholders’ perspectives of early warning scores. Qualitative, quantitative and mixed-methods studies were included. The search was not limited by year of publication but papers had to be written in English due to lack of translation resources.

Studies regarding the paediatric population were excluded, as were studies describing the development or validation of monitoring models.

Data extraction and analysis

A narrative synthesis approach was chosen to synthesise the diverse range of studies in a structured manner, following the European Social Research Council Guidance on the Conduct of Narrative Synthesis in Systematic Reviews.[4] Briefly, studies were tabulated and grouped by outcome measure, setting and population. Patterns were identified and translated to themes, which were further refined using an iterative process. The evidence was synthesised to provide a meaningful narrative, relevant to the research question.

Full details of selection, data extraction and analysis has been provided as Supplementary Material.

Findings

The search identified 825 papers (285 Medline, 359 PubMed, 176 CINAHL and 5 Cochrane). Duplicates were eliminated. 232 papers met the inclusion criteria. A flow diagram of the search process is shown in Figure 1.

There was 100% inter-rater agreement between CD and WT.

Themes

Themes identified included: prediction value; influence on clinical outcomes; interaction with other variables; cross-specialty application; international relevance; impact on communication; opportunity for automation; sensitivity; need for practitioner engagement, reaction to escalation and clinical judgment; and intermittent nature of recording. Tables 1 and 2 provide a summary of the most relevant articles within each theme, grouped into 'Strengths' and 'Limitations'. A full list of selected articles is provided in Supplementary Materials.

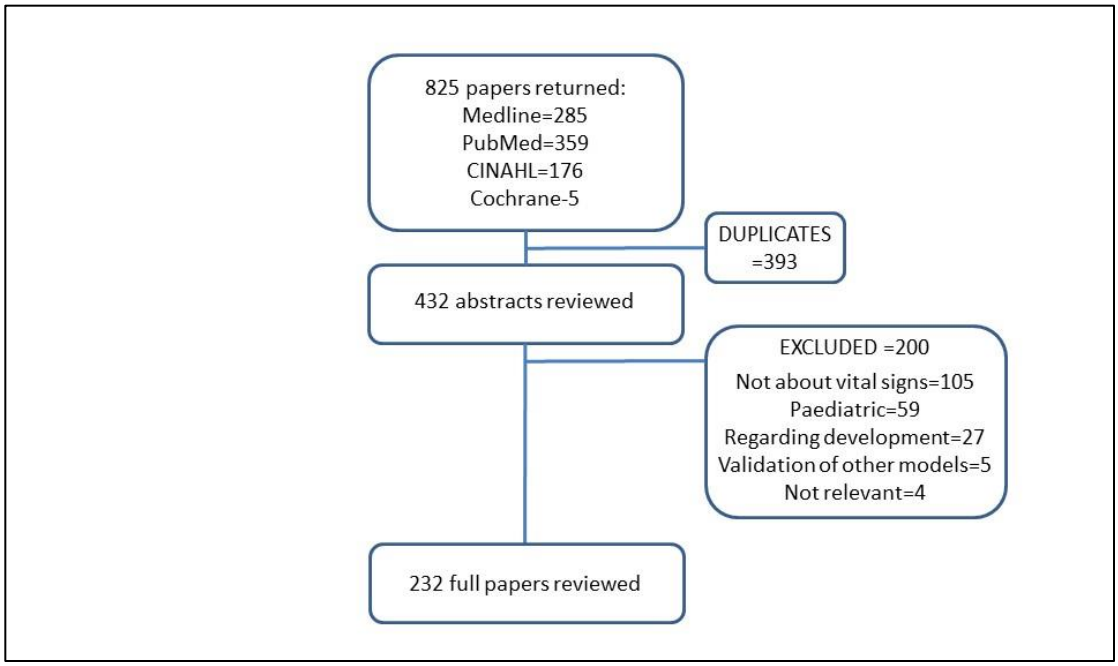

Figure 1: PRISMA diagram summarising selection process

Summary of early warning score systems

Popular scores used internationally include the Modified Early Warning Score (MEWS) and VitalPAC Early Warning Score (VIEWS), which have both been validated as good predictors of mortality during hospitalization.[3] However, individual hospitals have introduced their own local early warning scores, such as the Chelsea Early Warning Score (CEWS), introduced by the Chelsea and Westminster Hospital, UK.[5] This gave rise to variation in the reproducibility of different track-and-trigger warning systems, leading to calls for the adoption of a national system.

In 2012, The Royal College of Physicians developed the National Early Warning Score (NEWS) as a standardised approach to assessment and response to critical illness.[6] The NEWS was shown to be independently valid,[7] and surveys showed that staff found the NEWS was easy to use, did not increase workload and enhanced their ability to identify deteriorating patients.[8]

NEWS has been widely adopted throughout the UK National Health Service.

Strengths of early warning scores

Prediction value

Early warning scores have consistently been found to accurately predict adverse outcomes in a number of different populations. Despite being developed for general medical hospital admissions, a recent retrospective study of 35 174 surgical admissions found that NEWS discriminated deterioration in non-elective surgical patients at least as well as in non-elective medical patients[9].

Theme (Strengths)	Publications identified within theme	Setting	Methodology	Participants	Early warning score	Outcome measure/s	Findings
Prediction value	Kovacs *et al.* (2016) [9]	Hospital inpatients at a single NHS Trust	Real-time observational study	Medical and surgical admissions (n=87 399)	NEWS via VitalPAC	Cardiac arrest, death and unanticipated ICU admission	High prediction rates for death and ICU admission; lower for cardiac arrest
	Churpek *et al.* (2012) [10]	Hospital inpatients at a single centre	Nested case-control study	Ward patients who experienced cardiac arrest (n=88) and matched controls (n=352)	MEWS	Maximum MEWS, individual component vital signs and other predictors	By 48 h prior to cardiac arrest, the MEWS was higher in cases (P= 0.005) than controls
	Lee, Choi (2014) [11]	General wards at a single centre	Retrospective observational study	General ward patients with severe sepsis or septic shock (n=100)	MEWS	ICU transfer	MEWS is an effective predictor of ICU transfer with optimum cutoff value 6
	Reini *et al.* (2012) [13]	A tertiary care general ICU in a single centre	Prospective observational study	Patients admitted to ICU (n=518)	MEWS	Mortality, length of stay, readmission to ICU	MEWS=>6 is an independent predictor of mortality and length of ICU stay, but not readmission.
	Alrawi *et al.* (2013) [14]	Acute Medical Assessment Unit at a single centre	Real-time observational study	Acute medical admissions from nursing homes (n=314)	MEWS	In-patient mortality at 7 days	Admission MEWS of 4-5 was associated with 12 times the odds of death; MEWS >6 had 21 times the odds of death compared with those with a score of <1.
	Armagan *et al.* (2008) [15]	Emergency Department (ED) at a single centre	Prospective observational study	Patients presenting to the Emergency Department (n=309)	MEWS	Death, hospital admission, intensive care unit (ICU) admission	Patients with MEWS>4 were 35 times more likely to die in ED and 14 times more likely to die in hospital than those presenting with a low-risk score. Those with MEWS =>5 were 1.95 times more likely to be admitted to ICU

	Stark *et al.* (2015) [17]	Surgical wards at a single university hospital	Retrospective observational study	All surgical patients who experienced a "Code Blue" event (n=85)	MEWS	Death	Maximum MEWS remained associated with death after multivariate analysis
	Cei *et al.* (2009) [18]	64-bedded medical ward in a public, non-teaching Hospital	Prospective, single centre, cohort study	All patients consecutively admitted over a seven-month period (n=1107)	MEWS	In-hospital mortality , a combined outcome of death and transfer to a higher level of care, length of stay	The risk of death was incremental among all the MEWS categories, as well as the risk of the combined outcome of death and transfer. The difference between length of stay was non-significant.
	Christensen *et al.* (2011) [19]	Emergency Department (ED) at a single centre	Retrospective observational study	A random sample of emergency patients (n=300)	Bispebjerg Early Warning Score (BEWS)	Admission to ICU and death within 48 hours of arrival at the ED	A BEWS > 5 is associated with a significantly increased risk of ICU admission and death within 48 hours of arrival.
	Peris *et al.* (2012) [20]	Surgical unit at a single centre	Retrospective cohort study	Emergency surgical patients admitted before MEWS introduction (controls, n=604) and after MEWS introduction (intervention group, n=478)	MEWS before and after surgical procedure	Admission rates to ICU and HDU (Patients with a MEWS 3 or 4 were transferred to HDU, patients with MEWS >= 5 were admitted to ICU), mortality.	After MEWS introduction, HDU admissions significantly increased and ICU admissions significantly decreased. Mortality rate did not differ.
Influence on clinical outcomes	Bokhari *et al.* (2010) [23]	ICU at a single university hospital	Retrospective cohort study	Patients with haematological malignancies admitted to ICU before (n=27) and after (n=105) use of an early warning score and a critical care outreach nursing team	Unspecified	Survival to ICU discharge	Survival to ICU discharge increased from 44% to 53% after the introduction of the intervention.
	Moon *et al.* (2011) [24]	Single tertiary referral centre	Retrospective audit	Adult hospital admissions before (n=213 117) and after (n=235 516) the introduction of MEWS charts and a critical care outreach service (CCOS)	MEWS	Incidence of cardiac arrest calls, in-hospital mortality, ICU admissions after cardiopulmonary resuscitation (CPR), deaths after CPR	CCOS and MEWS were associated with significant reductions in the incidence of cardiac arrest calls (0.4% to 0.2%) *and* deaths per hospital admission (1.4% to 1.2%). Also reduced were the proportion of patients admitted to ICU after CPR (3% to 2%) and their in-hospital mortality (52% to 42%).

	Bunkenborg *et al.* (2014) [25]	Medical and surgical wards at an urban university hospital	Prospective, non-randomised, before-and-after study	Adult patients admitted with >=24 hours length of hospital stay before (n=1870) and after (n=2234) the introduction of early warning scoring.	MEWS	Incidence of unexpected patient death	The adjusted unexpected patient mortality rate was significantly lower after the intervention (17 versus 61 per 100 adjusted patient years).
	Drower *et al.* (2013) [26]	Single tertiary teaching hospital	Retrospective before-and-after study	Adult patients admitted before (n=21 806) and after (n=22 378) the introduction of an early warning score system	*Adult Deterioration Detection System* (ADDS)	Incidence of in-hospital adult cardiac arrests	The rate of cardiac arrests per 1000 admissions was 4.67 before and 2.91 after the introduction of the intervention.
Interaction with other variables	Heitz *et al.* (2010) [63]	Single tertiary hospital	Retrospective observational study	Patients admitted to hospital from the Emergency Department (n=280)	MEWSMax	All-cause mortality and higher care utilization within 24 hours	The inclusion of additional variables (mode of transport to ED, need for intravenous antibiotics in ED, length of stay in the ED, gender) slightly improved the predictive ability of MEWS.
	Perera *et al.* (2011) [64]	Single tertiary hospital	Prospective observational study	Consecutive admissions to the Acute Medical Unit (n=250)	MEWS	HDU/ICU admission, cardio-respiratory emergency/resuscitation and death	Combining MEWS with biochemical parameters (C-reactive protein, albumin, white cell count, platelet count and haemoglobin) improved the sensitivity of prediction when compared to MEWS alone.
	Alrawi *et al.* (2013) [14]	Acute Medical Assessment Unit at a single centre	Real-time observational study	Acute medical admissions from nursing homes (n=314)	MEWS	In-patient mortality at 7 days	Patients with a MEWS >6 had 21 times the odds of death compared with those with a score of <1. An estimated glomerular filtration rate (eGFR) <30 ml/min/m^2 was associated with a 5-fold increase in the odds of death within 1 week2, compared with eGFR > 60 ml/min/m^2. C-reactive protein (CRP) >100 mg/l was also associated with a 2.5 times higher odds of death.
Cross specialty application	Silcock *et al.* (2015) [48]	Emergency ambulances transporting patients to a single hospital	Retrospective cohort study	Unselected prehospital patients (n=1684)	NEWS	48 hour and 30 day mortality, ICU admission,	All three of the primary endpoints and the combined endpoint were associated with higher NEWS scores.
	Challen and Walter (2010) [49]	Single tertiary hospital	Retrospective, cohort study	Patients presenting with 'shortness of breath' or 'difficulty breathing' transported to the	Physiological social score (PMEWS)	Hospital admission and need for physiologically stabilizing treatment	PMEWS scoring could have diverted 79 patients safely from the emergency department to alternative care providers.

				ED by emergency medical services (n=215)		in the emergency department	
	Essam *et al.* (2015) [50]	Ambulance service at a single NHS Trust	Retrospective before-and-after study	Patients attended by 19 volunteer paramedics (n=1932)	MEWS	Percentage of patients transported to hospital or treated at home and revisited in 7 days	MEWS had a minimal effect on transportation or revisit rates. Scores were frequently not calculated or recorded, or incorrectly calculated.
International relevance	Opio *et al.* (2013) [55]	Single resource-poor hospital in Uganda	Retrospective observational study	Acute medical patients admitted to hospital (n=844)	VitalPAC Early Warning Score (ViEWS)	Death within 24 hours of admission	The discrimination of ViEWS in a resource poor sub-Saharan Africa hospital is the same as in the developed world
	Asiimwe *et al.* (2015) [56]	Single resource-poor hospital in Uganda	Retrospective cohort study	Patients admitted to hospital with sepsis (n=317)	MEWS	Probability of in-hospital death	MEWS >=5 predicted mortality and complemented a novel prognostic index
	Baker *et al.* (2015) [57]	Single centre in Tanzania	Prospective, observational cohort study	Patients admitted to ICU (n=269)	NEWS	In-hospital mortality	NEWS >=7 was associated with 2.5 times the odds of death.
	Rylance *et al.* (2009) [58]	Two resource-limited hospitals in Tanzania	Prospective, observational study	Acute medical admissions (n=737)	MEWS	In-hospital mortality	There was a positive correlation between EWS and risk of mortality
	Burch *et al.* (2008) [59]	Single public hospital in South Africa	Prospective, observational study	Medical patients presenting to the emergency department (n=790)	MEWS	Risks of hospital admission and in-hospital death	The proportion of patients admitted and those who died in hospital increased significantly as the MEWS score increased.
	Kyriakos *et al.* (2014) [60]	Single hospital in South Africa	Delphi study for the development of the Cape Town MEWS chart	Validation study	MEWS	Parameters and cut points for the Cape Town MEWS chart	A MEWS for developing countries should record at least seven parameters. Parameters and cut points differed from those in MEWS used in developed countries.

	Rosedale *et al.* (2011) [61]	Single government hospital in rural South Africa	Prospective cross-sectional study	Patients presenting to ED (n=589)	South African Triage Score (SATS) vs MEWS	Outcome in the ED (death, hospital admission or discharge)	SATS was superior to the MEWS as a triage scoring system (4.4% vs 15.1% under-triage rate).
	Wheeler *et al.* (2013) [62]	Single resource-poor hospital in Malawi	A prospective cohort study	Adults admitted to medical wards (n=302)	MEWS vs HOTEL score (Hypotension, Oxygen saturation, Temperature, ECG abnormality, Loss of independence)	Mortality within three days of admission	MEWS and HOTEL lacked sensitivity and specificity within the local population.
Impact on communication	Andrews and Waterman (2005) [65]	Single university hospital	Interviews and observations as part of a grounded-theory approach	44 staff from one surgical and one general medical ward (30 nurses, 7 doctors and 7 health care support workers)	Generic early warning score based on MEWS	Staff opinion on the effectiveness of early warning scores in detecting physiological deterioration	The Early Warning Score improves communication, empowers nurses and increases their confidence when reporting physiological deterioration to doctors.
	Neary *et al.* (2015) [68]	Single university hospital	Questionnaire study	Convenience sample of 40 staff from general surgical wards (27 doctors, 13 nurses)	NEWS	Staff opinion regarding the strengths and pitfalls after NEWS was introduced into surgery	NEWS 'empowers nurses to more easily seek senior medical assistance' and 'avoids conflict'
Opportunity for automation	Prytherch *et al.* (2006) [71]	Single university hospital	Classroom study	21 nurses working on the medical assessment unit, inputting data from fictitious patients either via pen and paper (n=84), or into a handheld personal digital assistant (n=84).	VitalPAC vs a paper-based generic early warning score	Speed and accuracy of data entry, number of hypothetical clinical actions indicated	Incorrect entries/omissions decreased from 29% to 10% using the VitalPAC method. Fewer incorrect clinical actions were indicated (14% to 5%) and mean time taken for participants to calculate and chart the early warning score was 1.6-times faster with VitalPAC.
	Mohammed *et al.* (2009) [72]	Two NHS Trusts	Classroom study	26 nurses from two surgical assessment wards, inputting data from fictitious patients via pen and paper (n=260), or into a handheld	VitalPAC vs a paper-based generic early warning score	Accuracy and efficiency of early warning score calculations	Accuracy improved with the use of the hand-held computers. The mean time to derive an early warning score reduced from 37.9 seconds to 35.1 seconds.

				personal digital assistant (n=260).			
	Schmidt *et al.* (2015) [73]	Two large acute teaching hospitals	Retrospective, observational study	Patients admitted to adult medical, surgical and orthopaedic wards before (n=49 730) and after (n=55 917) the implementation of an electronic physiological surveillance system	VitalPAC vs a paper-based generic early warning score	Mortality	During VitalPAC implementation, crude mortality fell from 7.75% to 6.42% in one hospital, and from 7.57% to 6.15% at the second.
	Bellomo *et al.* (2012) [74]	Ten hospitals in the United States, Europe, and Australia	Before-and-after controlled trial	Patients admitted to 12 general wards before (n= 9617) and after (n=8688) after deployment of electronic automated advisory vital signs monitors	IntelliVue electronic automated advisory vital signs monitors	Frequency of rapid response team calls, survival to hospital discharge or to 90 days for rapid response team call patients; overall type and number of serious adverse events and length of hospital stay	The intervention was associated with an increased proportion of calls secondary to abnormal respiratory vital signs (from 21% to 31%). Survival increased from 86% to 92%. Median length of stay and time to record observations were also significantly reduced.
	Jones *et al.* (2011) [77]	Single university teaching hospital	Historically-controlled cohort study	Consecutive patients admitted to the medical assessment unit and one general medical ward before (n=705) and after (n=776) the implementation of an automated alert system	The Central Manchester University Hospitals NHS Foundation Trust Early Warning Score (CMFT EWS)	Hospital length of stay, compliance with the early warning score protocol, cardiac arrest incidence, critical care utilisation and hospital mortality	Length of stay reduced from 9.7 days to 6.9 days. Clinical attendance to patients with EWS 3, 4 or 5 increased from 29% at baseline to 78% with automated alerts. For patients with EWS >5, clinical attendance increased from 67% at baseline to 96%.

Table 1: Summary of relevant articles within each 'Strength' theme

Theme (Limitations)	Publications identified within theme	Setting	Methodology	Participants	Early warning score	Outcome measure/s	Findings
Sensitivity and specificity, including comparisons to specialty-specific scores	Shuk-Ngor *et al*. (2015) [79]	Single tertiary university teaching hospital	Prospective observational study	ED patients awaiting admission to medicine, general surgery, neurosurgery or clinical oncology. Intervention group: MEWS monitoring (n= 269) Control group: 4 hourly observations with no protocolised escalation plan (n=275)	MEWS	Change in ED management, p adverse events within 24 hours (active resuscitation, ICU admission, cardiac arrest and death)	MEWS had a 100% sensitivity and a 98.3% specificity in detecting patient deterioration, while there was also a high sensitivity and a high specificity (100% and 97.8%) in the comparison group.
	Barlow *et al*. (2007) [80]	Two hospitals: a 1000-bed teaching hospital and a 500-bed district general hospital	Retrospective analysis of data prospectively collected for a different study	Patients with community-acquired pneumonia (CAP) (n=419)	Standardised early warning score (SEWS) vs CURB65 (a pneumonia-specific risk score)	Mortality	The sensitivity and specificity of CURB65 were 71% and 69% respectively. The sensitivity and specificity of SEWS were 52% and 67% respectively.
	Bayer *et al*. (2015) [81]	Single tertiary hospital	Retrospective observational analysis	Consecutive patients admitted to the emergency department (n=375) including those with sepsis (n=93), severe sepsis (n=60) and septic shock (n=12)	MEWS vs Prehospital Early Sepsis Detection (PRESEP) score	Sepsis	The sensitivity and specificity of PRESEP were 85% and 86% respectively. The sensitivity and specificity of MEWS were 74% and 75% respectively.
	Bulut *et al*. (2014) [82]	Three university teaching hospitals	Prospective, observational cohort study	General medical and surgical patients admitted to the ED (n=2000)	MEWS vs Rapid Emergency Medicine Score (REMS)	In-hospital mortality and escalation of care	REMS was a better predictor of both in-hospital mortality and escalation of care that MEWS.
	Lobo *et al*. (2014) [86]	Single acute hospital	Cross-sectional audit	Medical admissions with NEWS score >=7 (n=87)	NEWS vs CREWS (Chronic Respiratory Early Warning Score)	Change in clinical management (indicating clinical deterioration)	NEWS had a low positive predictive value (35.4%) to detect clinical deterioration. Application of the CREWS score in chronic hypoxaemic patients safely lowered the trigger threshold.
Need for practitioner engagement	Simmes *et al*. (2012) [41]	Single university medical centre	Retrospective before-after study	Surgical patients before (n= 1376) and after (n=2410) the introduction of a rapid response system (RRS) which includes an early warning score	Generic early warning score	Incidence of cardiac arrests and unexpected deaths	Introduction of an RRS resulted in a 50% reduction in cardiac arrest rates and/or unexpected death. However, in 16% (15/91 events) activation was delayed for one or two days.

	Clifton *et al*. (2015) [102]	Single large university teaching hospital	Retrospective database analysis	Post-surgical patients (n=200)	Generic paper-based early warning score	Incidence of errors in observation sets	Missed alerts were common in incomplete observation sets (15.1% vs 7.6%) and when a patient first became unstable. Incorrect observation sets are highly predictive of the next observation set.
	Niegsch *et al*. (2013) [105]	Single teaching hospital	Prospective, observational study	Hospitalised patients on 12 wards (n=132)	MEWS	Adherence to early warning score guidelines	58% of patients had been observed and managed correctly. 77% had all MEWS elements recorded. 38% of patients with abnormal MEWS were correctly escalated by nursing staff.
	Peterson *et al*. (2014) [107]	Single large tertiary centre	Observational study of prospectively collected data	Inpatients who suffered an adverse event (unexpected death, cardiac arrest or unanticipated ICU admission) (n=144)	NEWS-based early warning score	Compliance with escalation protocol in the 24 hours preceding the event	The escalation protocol was followed in 13% of ICU admissions, 31% of cardiac arrests and 13% of unexpected deaths. Senior staff were involved in 53% and 36% of cases of ICU admission and cardiac arrest, respectively.
Need for reaction to escalation	Cherry and Jones (2015) [103]	Single acute Trust	Mixed methods study using questionnaires and focus groups	Acute Medical Unit nursing staff (n=9)	MEWS	Attitudes of nursing staff towards an early warning score	The colour of the nurse's uniform, showing seniority, has an effect on a medic's attitude to review a patient with a high MEWS score.
	Day (2003) [112]	Single acute general hospital	Prospective audit	Calls for medical assistance triggered by the early warning score on the surgical 'step down unit' (SDU) (n=45)	Derby Modified Early Warning System (DMEWS)	Response times to early warning scores	The average response time to calls from SDU staff was 46·1 minutes (guidelines suggest 30 minutes).
	Beckett *et al*. (2009) [113]	Single large teaching hospital	Prospective observational study	Patients requiring medical review overnight on 18 wards (n=136) and 4 critical care areas (n=159)	Standardised Early Warning Score (SEWS)	Response times to early warning scores overnight	The median response time was 5 minutes for SEWS>4 and 10 minutes if SEWS<4
Need for clinical judgment	Martin (2015) [115]	Single large tertiary teaching hospital	Grounded theory study using semi-structured interviews	Midwives working on the labour ward (n=6)	Modified early obstetric warning score (MEOWS)	Midwives' experiences of using the early warning score	Midwives experienced the tool as a threat to autonomy, undermining clinical judgement and were concerned about task orientation among junior colleagues.
	Neary *et al*. (2015) [68]	Single university hospital	Questionnaire study	Convenience sample of 40 staff from general surgical wards (27 doctors, 13 nurses)	NEWS	Staff opinion regarding the strengths and pitfalls after NEWS was introduced into surgery	Staff felt the NEWS did not correlate well clinically with patients within the first 24 hours post-operatively.
Intermittent nature of recording	Taenzer *et al*. (2014) [117]	Single large tertiary hospital	Comparative study between oxygen saturation recordings using automatic continuous monitoring and intermittent manual monitoring	Patients from 3 surgical units and 2 medical units who suffered an adverse evert (n=36) matched controls (n=176). 16 of these patients were classified as having 'prolonged desaturations.'	Unspecified manual vital signs chart	Accuracy of intermittent, manual SpO_2 data collection	Manually recorded data were on average 6.5% higher and did not reflect the high-risk patients' physiological state as well as continuous automated sampling

Table 2: Summary of relevant articles within each 'Limitations' theme

Early warning scores have been found to be excellent predictors of cardiac arrest [10], ICU transfer[11] and death on ICU[12], as well as 30-day mortality and length of stay on ICU.[13]

In nursing home residents admitted to hospital, MEWS was found to be an important predictor of 7-day mortality.[14] Patients with a MEWS of 4-5 on admission had 12 times the odds of death, and those with a score of >6 had 21 times the odds of death, compared with those with a score of <1.

In the Emergency Department (ED), an early warning score can be used as a triage instrument. One prospective study examined the MEWS of 309 patients presenting to a Turkish ED and found that patients with a MEWS of 5 or more were 1.95 times more likely to be admitted to ICU than those with a MEWS < 5, and 35 times more likely to die in the ED and 14 times more likely to die in hospital.[15]

A group in Amsterdam retrospectively analysed the MEWS of 204 medical and surgical patients who had experienced a 'severe adverse event,' including cardiopulmonary arrest, unplanned ICU admission, emergency surgery or unexpected death. Eighty one percent of patients had an MEWS value of 3 or more at least once during the 48 hours before their event.[16] Similarly, in an exclusively surgical population, MEWS has been found to predict the risk of death after cardiopulmonary arrest.[17]

An Italian prospective single-centre cohort study concluded that MEWS, even when calculated once on admission, is a 'simple but highly useful tool to predict in-hospital outcome,' in terms of mortality, critical care admission and length of hospital stay.[18] Similar results have been published from Denmark.[19]

The prediction value of early warning scores is important. They have been found to prevent ICU admissions by aiding decision making for anaesthetists,[20] and can be used to help capacity planning by predicting the number of days a patient will spend in hospital.[21] However, they cannot be used in isolation nor can they replace clinical judgment.[22]

Influence on clinical outcomes

The introduction of early warning scores has been found to improve patient outcomes. However, the introduction of early warning scores is often accompanied by that of a critical care outreach team, making the individual impact of the early warning score difficult to assess.

A 2010 study reported that the introduction of an early warning score and a critical care outreach team improved survival to ICU discharge in haematology patients.[23] The introduction of an outreach service and MEWS at a tertiary referral centre was associated with significant reductions in the incidence of cardiac arrest calls, the proportion of patients admitted to ICU having undergone in-hospital CPR and their in-hospital mortality.[24]

A large Danish prospective, non-randomized, controlled study investigated unexpected in-hospital death before and after implementation of a clinical intervention comprising systematic monitoring practice, early warning scoring, an

observation chart and an algorithm for bedside management.[25] The adjusted unexpected patient mortality rate was significantly lower after the intervention (17 versus 61 per 100 adjusted patient years). In a New Zealand tertiary hospital, the introduction of an early warning score system in addition to an existing cardiac arrest team decreased the incidence of in-hospital cardiac arrests from an average of 8.5 per month to 5.5 per month.[26]

Cross specialty application

Most of the studies evaluating early warning scores involve inpatients, and come from a wide range of specialties. These include stroke,[27] oncology, [28, 29] general medicine [30-34] and surgery. [17, 20, 35-42] [36-40] [17, 41, 42]

The use of early warning scores in the ED has been described above.

Early warning scores have also been implemented in the community. Ammitzboll and Maarslet describe how an early warning score can be used to identify elderly patients in need of medical assistance. At a score </= 2, 24% were visited by a doctor or admitted directly. At a score >/= 5, this number increased to 45%. At a score </= 5, 11% were admitted to hospital and at a score >/= 5, 31% were admitted to hospital.[43]

Studies have described the use of early warning scores in private care homes.[44] the army [45] and dentists.[46] The system has also proved valuable in the prehospital setting.[47, 48] Challen and Walter describe how early warning scores can help to safely divert patients from the ED to alternative care providers.[49] However, another study amongst the ambulance service showed no effect of MEWS implementation on transportation or revisit rates.[50]

Comprehensive implementation of the same early warning score allows a universal language to be spoken across specialties. However, it is important to recognize the limitations of early warning scores in certain patient groups. Vital signs have been shown to be more accurate in detecting cardiac arrest in nonelderly patients compared with elderly patients.[51] Generic early warning scores cannot be used in the maternity or paediatric populations;[52,53] instead, specialized charts need to be used for these groups.[54]

International relevance

A number of studies have shown that early warning scores can be used in countries with limited healthcare resources, such as Uganda,[55,56], Tanzania[57, 58] and South Africa.[59,60,61] However, disease and population differences may strongly influence the performance of early warning scores. A Malawi study showed that MEWS had only a 58.8% sensitivity and 56.2% specificity for mortality within three days. The authors advised local validation and impact assessment before the adoption of early warning scores adoption in resource-limited settings.[62]

Interaction with other variables

There is good correlation between early warning scores and other risk indicators. A study of an early warning score in the ED[63] found that adding specialty-specific parameters (such as mode of transport to hospital) to the score provided more accurate prediction of their risk. Alrawi has described how CRP and eGFR levels on admission can be used in conjunction with MEWS to allow decision making on the appropriate level of care at the point of hospital admission.[14] A Sri Lankan study showed that adding biochemical parameters to the early warning score improved the sensitivity of predicted length of hospital stay and adverse outcomes.[64]

Impact on communication

A qualitative study in 2005 interviewed 30 nurses, 7 doctors and 7 health care support workers with regard to the detection of physiological deterioration.[65] Participants reported that quantifiable evidence is the most effective means of referring patients to doctors, and that early warning scores achieve this by packaging individual vital signs together, providing a 'precise, concise and unambiguous means of communicating deterioration, and confidence in using medical language.' This sentiment is echoed in other publications. Early warning scores help to facilitate nurses' communication with doctors[66] by providing 'ammunition' when referring patients.[67] A questionnaire study of surgical ward staff found that NEWS 'empowers nurses to more easily seek senior medical assistance' and 'avoids conflict.'[68]

Opportunity for automation

The detection of deteriorating patients is often later than it should be. One solution could be the electronic charting of early warning scores to improve the accuracy, reliability and availability of patients' vital signs. There is a drive within healthcare systems to improve the efficiency of information management in hospitals, through integration and intelligent use of new technology.[69]

A number of software packages have become available to address this need. NHS Education for Scotland has made the NEWS available as a smartphone app.[70] Another such package, VitalPAC, was shown by Prytherch *et al.* to offer significant advantages both in speed and accuracy of recording early warning scores.[71] These findings were echoed in a later study which found that a hand-held computer is acceptable to nurses and helps to improve the accuracy and efficiency of early warning scores in acute hospital care.[72] Schmidt *et al.* associated the use of such technology with reduced patient mortality.[73] A before-and-after controlled trial of 18 305 patients investigated the effects of automated vital signs monitors[74] and found their introduction to be associated with increased survival to discharge from 86% to 92% in patients receiving rapid response team calls. The same study noted that there was also a decrease in the time required for vital signs measurement and recording, from 4.1 minutes to 2.5 minutes.

However, the accuracy of electronic early warning score systems is still user-dependent. One study of electronic observations found that levels of completeness of observations differed between wards from 69% to 92%, with traditional gaps in observations, such as recording of respiratory rate, still apparent.[75]

Several technologies could provide the basis of a solution. Bonnici *et al.* suggest the use of unobtrusive wearable monitors that track the patient's physiology continuously.[76]

A number of studies have investigated the use of automated clinical alerts in an attempt to deliver timely clinical responses to acutely deteriorating patients. An historically-controlled study from 2011 found that automatic alerts significantly improved clinical attendance to unstable general medical patients.[77] However, the potential of these technologies depends strongly on implementation, with poor-quality deployment likely to worsen patient care.[76]

Limitations of early warning scores

Sensitivity, especially compared to specialty-specific scores

In 2003, Boyle reported that early warning scoring systems were largely unproven and could prove to be over-sensitive and unspecific.[78] However, the evidence base has grown and a recent study from Hong Kong found that MEWS has a 100% sensitivity and a 98.3% specificity in detecting patient deterioration.[79]

Nevertheless, early warning scores are generic tools which should be used to complement, but not necessarily replace, existing prediction tools.[80]

A retrospective analysis of 419 patients with community-acquired pneumonia (CAP) tested the performance of CURB65 (a mortality predictor in CAP) against generic early warning scores. The study reported that CURB65 has a better sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) compared to the early warning score, and advised that it should not be supplanted for the initial prognostic assessment in CAP.

Similarly, in the prehospital patient, the PRESEP score surpassed MEWS for sensitivity, specificity, PPV and NPV.[81] The same findings have been reported for the REMS (Rapid Emergency Medicine Score),[82] MEDS (modified mortality in emergency department sepsis)[83] and THERM (The Resuscitation Management Score)[84] scores in the ED, the PREEMPT-2 (PRE-critical Emergency Medical Patient Triage) and PREAMBLE-2 (PRE-Admission Medical Blue-Light Emergency) scores in acute medical admissions[85] and CREWS (Chronic Respiratory Early Warning Score) for respiratory disease.[86]

Care must be taken when using early warning scores in certain subspecialties. Teasdale notes the limitations of most early warning scores in patients with brain injury.[87] Similarly, patients prone to hypercapnia are at risk of inaccurate oxygen monitoring when using early warning scores.[88] Scores are also difficult to use in end-of-life care.[52,53,89]

Need for practitioner engagement

The introduction of early warning scores has been shown to help improve the monitoring of vital signs, especially respiratory rate[90, 91,92]. However, these systems

are highly user-dependent. A retrospective study of surgical patients before and after the implementation of a rapid response system found that early warning score recordings were 'frequently incomplete.'[41]

Indeed, a number of studies into the implementation of early warning scores have highlighted poor compliance as an issue.[93,94, 95, 68, 96-100 101] User error can occur in recording vital signs, calculating the score and escalating appropriately.

In the Amsterdam study, the authors retrospectively analysed the MEWS of patients who had experienced a severe adverse event, and found that, even when the MEWS was 3 or more, respiratory rate, diuresis, and oxygen saturation were documented in only 30% to 66% of assessments.[16] This is concerning, as missed alerts are particularly common in incomplete observation sets.[102]

Even when observations are complete, the aggregate scores can be miscalculated.[103, 104] This is important, as Austen et al.[5] found that calculation errors were eleven times more likely to result in under-scoring than over-scoring, resulting in the potential failure to recognise deteriorating patients. In addition, Clifton *et al.* found that incorrect scores are highly predictive of the next observation set, suggesting that clinical staff detect patient status in advance of the EWS system 'by using information not currently encoded within it.'[102]

Crucial to the success of early warning systems is the escalation of abnormal scores. A Danish study found that only 38% of patients with abnormal MEWS were correctly escalated by nursing staff,[105] a finding echoed throughout the literature.[106] Poor compliance with the escalation protocol is commonly found when serious adverse events occur.[107]

In particular, there have been concerns raised about compliance with early warning scores overnight [108, 109] and at weekends [110] when, arguably, these scores could be of most use. As such, a number of competency frameworks and audit systems have been introduced, which show significant benefits in terms of patient safety.[111]

Need for reaction after escalation

A crucial step for the success of early warning scores is timely response to escalation. Qualitative studies into the attitudes of nursing staff towards early warning scores highlight concerns about difficulty in getting medical staff to review the patient.[103] In a UK NHS Trust, anecdotal evidence from nursing staff indicated that response times by doctors were outside the established timescale, prompting an audit which confirmed their concerns.[112] A study by Beckett *et al.* showed a significant inter-specialty variation in median response times and seniority of responding staff, particularly within critical care, which recorded the slowest times.[113]

Need for clinical judgment

There is concern that early warning scores add to the de-skilling of practitioners. Editorials stress that scores do not place importance on knowing individual patients, nor the background to the observations being recorded. This may prevent nursing students from 'fully developing professional judgement as an aspect of decision

making when faced with a deteriorating patient.'[114] Indeed, a study amongst midwives found that this group experienced early warning scores as a 'threat to autonomy, undermining clinical judgement' [115] and highlighted their concerns about the delegation of vital signs monitoring to support staff, opposing holistic care.

To counteract this, some studies have suggested adding a measure of biological capacity to the early warning score, such as mobility or frailty.[116] However, it might be simpler to acknowledge that early warning scores cannot replace clinical judgement. [22] Neary *et al.*[68] found that NEWS correlated poorly with the patient's clinical status within the first 24 hours post-operatively, and suggested that 'nursing acumen' should dictate escalation parameters in certain scenarios.

Intermittent nature of recording

A significant limitation of early warning score systems is their intermittent nature. In a cohort of patients with prolonged desaturations, manual recordings of SpO_2 did not reflect the patient's physiological state when compared with continuous automated sampling.[117]

Ideally, every patient would receive ICU-style continuous monitoring, but this is limited by bulky equipment, which would limit the patient's mobility and potentially hinder recovery. Indeed, when ICU-style monitoring was implemented on a general ward, only 16% of patients remained connected in a 72-hour period.[76] A number of wearable wireless devices are in the early stages of evaluation to address this problem.

Discussion

This systematic review and narrative synthesis was conducted to explore the literature regarding the strengths and limitations of early warning score vital signs monitoring systems, for both patients and clinical teams. To our knowledge, this is the first literature review to systematically assess the extent of the evidence around these tools.

Early warning scores have become ubiquitous with the recognition of the deteriorating patient. This review confirms that early warning scores have excellent predictive value and have been found to influence patient outcomes in the inpatient setting. However, it is important to recognize that they are more effective in certain patient groups, and care must be taken in the elderly, pregnant, paediatric, palliative and head-injured populations. Specialist tools should continue to be used in these groups.

Early warning scores are also used in a number of ways outside their original remit. Studies investigating the use of early warning scores as a pre-hospital triage tool show conflicting results. This can also be attributed to the mixed patient population in pre-hospital care. Whilst some papers report that the universal language of early warning scores improves communication between healthcare professionals, this is

not always reflected in the reaction to the escalation. Training may improve staff engagement and the response to poor scores.

Limitations in the design of this review are acknowledged. The search criteria were intentionally broad to capture a wide range of studies and optimize the generalizability of the findings. This is a heterogeneous area of investigation and, by including a range of early warning scores, settings and outcome measures, some of the subtleties of individual systems may have been lost. In addition, the use of key word searching can result in the omission of important papers. However, the search strategy was checked for completeness by combining it with more specific terms (such as EWS, MEWS) and this did not produce any additional references. Citations and reference lists were also checked to optimise the search strategy.

The inclusion of a number of study types outside of randomised controlled trials precluded traditional meta-analysis. Selected articles included qualitative, quantitative and mixed-methods studies, alongside grey literature. The value of other study designs in complex interventions is well recognised, but the wide range sources necessitated the adoption of a narrative synthesis approach, which has several limitations. Appraisal of quality is difficult with such variety of study design, and data extraction relies heavily on the reviewers' interpretation of the literature, which may introduce bias. However, a narrative approach allows the synthesis of diverse literature into common themes relevant to the research question.

Two interventions could improve the success of early warning scores to the benefit of patients. Firstly, the introduction of automated early warning score systems can minimize the risk of user error. Using a handheld computer device to document vital signs can highlight erroneous data, improve accuracy of calculations and prompt escalation. Scores can also be accessed remotely, which aids communication between healthcare professionals. A number of UK NHS hospitals have begun to adopt such systems.

In addition, new remote monitoring technologies, aided by wireless data transmission, have the potential to overcome the intermittent nature of current early warning score systems. A number of devices are emerging that promise to convey the advantages of continuous vital signs monitoring to general ward patients. Whilst it seems intuitive that continuous monitoring is safer than intermittent observations, no large controlled trials have yet been conducted and this remains an exciting area for future development.

Conclusion

This review has shown that early warning scores are successful in predicting and improving patient outcomes across a range of settings and populations. The most important advantage of early warning scores is that they are easy to use and interpret, and so provide a common language across healthcare providers and specialties. However, inaccurate recordings or inappropriate reactions to abnormal scores can undermine the benefits of these systems.

Harnessing their strengths and recognizing their limitations can improve early warning scores to the benefit of patients and healthcare professionals alike.

However, it is important to highlight the recurrent theme from the literature: whilst early warning score systems are a useful tool, they can never replace clinical judgment and experience in the management of the unwell patient.

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