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Early Warning Scores – Implementation and Impact on Outcomes

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CONTENTS

LIST OF ABBREVIATIONS

AUROC	area under the receiver-operating characteristics
AWTTS	aggregate weighted track and trigger systems
EGDT	early goal-directed therapy
EWS	Early Warning Score
HEWS	Hamilton Early Warning Score
ICU	Intensive Care Unit
IHI	Institute for Healthcare Improvement
NEWS	National Early Warning Score
NICE	National Institute for Health and Care Exelence
NPSA	National Patient Safety Agency
PEWS	Pediatric Early Warning Score
TREWS	Targeted real – time Early Warning Score
ViEWS	Vitalpac Early Warning Score

I. ABSTRACT

Background: Despite the wider use of early warning scores in clinical settings, discussions on low-threshold implementation strategies and emerging studies on outcomes, the topic remains controversial. To date, this field has received little attention compared to other high-risk cardiovascular conditions in a hospital setting.

Objective: The aim of this research is to review the use of early warning scores with regard to the factors affecting implementation and outcomes, as well as their correlation.

Methods: A narrative review, based on recent evidence found in the PubMed database with a scope on clinical data from 2012 – 2022.

Results: Ward patient profit from the use of early warning scores, if implemented correctly and medical staff adheres to the protocol and initiate the proper track and trigger response. Novel innovations could remedy the problem of compliance and protocol adherence without affecting patient comfort. The use of technological support would also reduce the workload of healthcare workers significantly and provide more resources for other neglected tasks.

The sticking point might be the role shift of the healthcare provider from performing routine tasks to becoming the backbone of a standardized decision – making und communication process.

Conclusion: The implementation and acceptance of Early Warning Scores has a significant impact on every measurable outcome parameter. A key role in the near future plays the multi – parameter continuous, non – invasive monitoring with wearable devices that report in real – time to the electronic medical record which calculates a risk score and supports medical staff in their decision – making process.

Keywords: “Early Warning Score”, “implementation” AND “outcome”, “sepsis”, “Covid”

II. INTRODUCTION

Healthcare professionals around the world are demonstrating that patient safety is at the heart of their work and incidents that were once considered unavoidable are now unacceptable. Patients entering a hospital for medical treatment believe they are entering a place where their health is the focus of attention. They rightly trust that they will receive effective treatment and that if their state of health deteriorates, measures to stabilize and improve it will be taken at an early stage. Various international studies show that this is not always the case. (1–5)

A deterioration in a patient's state of health that is noticed too late or even goes unnoticed is becoming increasingly important for patient safety. In-hospital deaths and unplanned ICU transfers are often preceded by a slowly progressive deterioration in the patient that medical staff would need to recognize. Clinical parameters and symptoms of a physiological instability appear several hours before the deterioration and with the help of measurable criteria, changes in the basic parameters and thus a potential risk to the patient can be identified. In most cases, however, an alarm is only triggered when the situation deteriorates, and the patient's life is threatened. A portion of these potentially preventable incidents include acute cardiac arrest, myocardial infarction, pulmonary embolism, stroke, and unplanned ICU admissions for severe sepsis or organ failure.

Most in-hospital cardiac arrests occur in general wards and are associated with a high mortality rate. (6) In most cases, there are significant predictors indicating patients deterioration up to 48 hours prior to the final event, such as changes in physiological parameters, such as pulse, blood pressure, temperature and respiratory rate, and mental status. (7)

For example, 2 out of 3 cardiac arrest patients show abnormal signs and symptoms 6 - 24 hours prior to cardiac arrest, but physicians are only notified or aware 25% of the time. (8)

With an early warning system, patients with a critically deteriorating state of health on a ward can be identified early and appropriate measures can be initiated quickly. Such an early warning system is based on basic parameters of vital functions such as heart rate and respiratory rate, blood pressure, body temperature and level of consciousness. The consistent application of a systematic and standardized early warning system, which creates a scoring system from these parameters, is intended to prevent patients from being unplanned transferred from a ward to the intensive care unit or even dying in the ward due to a delayed or unrecognized acute clinical deterioration. (9)

Patient deterioration is a significant clinical and economic burden for patients and healthcare systems. (10)

The Patient Safety Network Health Grades Report from 2016 stated that 63% of preventable deaths in hospitals are in connection with the to failure to rescue by a nurse or a physician, resulting in over 290 000 deaths a year in the United States alone. (11)

A later detected patients' deterioration, leading to a slower transfer to an intensive care unit, are associated not only with increased mortality and morbidity, but also with increased overall costs by 60%. In absolute numbers a study calculated a median cost increase per case of 10.000 pounds in Great Britain and 23.000 Euros in Germany. (12–14)

This clinical, economical, and humanitarian burden of undetected patient deterioration has pushed clinicians and researchers to find solutions for early identification and proactive interventions of patients with worsening conditions. (15)
Prior to the codification of early warning scoring systems, single-parameter alterations in key physiological measures were used to identify at-risks patients to trigger an intervention.
The first iteration of such a system to come up with standardized and reproducible values to calculate a probability of cardiac arrest and deterioration was presented to the scientific community in 1997. (16,17)
Different hospitals used locals scores without sufficient scientific data before, so in 2012 the British National Health Service rolled out the National Early Warning Score (NEWS) on a nation-wide scale. (18,19)
The aim of this research work is to analyse and review current evidence on the use of early warning scores regarding the factors affecting implementation and outcomes, as well as their correlation.
After giving a brief overview on current knowledge and defining different scores and adherent principles, various levels of implementation, compliance, increased workload, and the measurement of short and long-term outcome will be individually discussed for a possible positive or negative correlation.
The paper intends to close with an outlook into future fields of research and utilisation of early warning scores in the advent of digitalisation, artificial intelligence, and machine learning.

III. METHODS

A search on the PubMed website was conducted with the keywords "implementation", "outcome", "sepsis", "Covid" each separate in combination with the term "Early Warning Score" and all together. To receive only the most recent scientific work and obtain the latest data, parameters for the PubMed search were set to include articles with a publication date within the last 10 years.
The search for "implementation" and "Early Warning Score" yielded 174 results, the search 'outcome' and 'Early Warning Scores' 682 results and the search for 'sepsis' and 'Early Warning Scores' yielded 230 results. Only displaying results from 2012 to 2022, the search for 'Covid' and 'Early Warning Score' showed 192 matches.
Yielding over 1000 articles to choose from, the actual number was potentially lower due to a considerably high number of cross - matches in the results for the different keywords.

Inclusion and exclusion criteria were defined, additional to the publication date, to create a relevant literature review on the given research topic.
Only articles published in English were included. Furthermore, only studies focusing on Early Warning Scores for the general population were considered. Articles not focusing on the general score, but certain medical products implementing a kind of Early Warning Score were excluded. Also, a study about the benefits of the implementation of Early Warning Scores into a monitoring device by the company Mindray Ltd. was excluded, on the basis that the authors declaration of conflict of interest stated: "No conflict of interest declared. The wifes of both authors hold stock and stock options of Shenzhen Mindray Bio-Medical Electronics Corp."
Forms of implementation (paper based, electronic, algorithm, trends, Threshold Trigger Responds, AWTTS) and outcomes (measurement, cardiac arrest, ICU stays, 1-year-survival, short-term, long-term) had to be put at least in association to the topic of Early Warning Scores by an article to get involved in that research work.
Additional papers discovered by reviewing the reference list of the articles that were deemed to provide new information and perspective as well as meeting the inclusion criteria have been included in this work.
To avoid the risk of a preconceived opinion, reviews on this topic were neglected on the first search attempt. In later stages of the process, systematic reviews on the broader scope of the topic and narrative reviews on certain aspects and details were included.
To gain a general knowledge about early warning scores and in order to understand certain aspects of the papers read, a PubMed search for 'Early Warning Scores' in general and particular with special keywords was conducted.
In the process of this research, the 2021 Surviving Sepsis Campaign guidelines, the modified National Early Warning Score 2 for Covid-19 detection and the revised 2021 European Resuscitation Council Guidelines for basic and advanced life support were included.

IV. DISCUSSION

4.1 Definition of Early Warning Scores, an overview, variants, differences, similarities

The British Journal of Anaesthesia defines the concept of Early Warning Scores as follows: "Early warning scores using physiological measurements may help identify ward patients who are, or who may become, critically ill. They award an increasing number of points to worsening physiological values until a trigger score is reached." (20,21)

Abnormal values identify patients with greater mortality risk. Patients with abnormal values had a 90-day mortality of 20%, compared with 1.6% overall. (16,21,22)
Multiple studies show that abnormal vital signs predict critical events such as sudden death, cardiac arrest or unplanned transfer to an intensive care unit. (23–27)
Also, preceding abnormal vital signs seem to reduce the physiological reserve capacity and therefore decrease survival rate after a cardiac arrest. (7)
Early Warning Scores are intended to use vital signs and clinical observation that are recorded during the daily patient`s ward routine and try to avoid tasks added to the healthcare professionals workload. (20) It is intended not to replace, but to supplement the patients assessment, add structure and comparability. (28)
Physiological instabilities show up in the patient through changed clinical parameters and symptoms, which often appear a few hours before the state of health deteriorates. Adequate response to these early signs can often arrest the process of further deterioration and avoid acute cardiac arrest, myocardial infarction, pulmonary embolism, stroke, and unplanned emergency admissions to the ICU for severe sepsis or organ failure. (23,29)

Table 1 Comparison of Input and Output Variables for several EWS (30)

EWS	Clinical Setting Where Score Was Tested	Input Criteria	Outcomes Measured
ViEWS[8]	ICU Medical ward Surgical ward	HR, RR, SBP, SpO_2, Supp. O_2, Temp, and AVPU	Mortality Length of stay
NEWS[9]	ICU Medical ward Surgical ward Prehospital communication	HR, RR, SBP, SpO_2, Supp. O_2, Temp, and AVPU	Mortality Unplanned ICU admit MET review Cardiopulmonary arrest and acute respiratory failure
NEWS2[10]	Emergency department Medical ward Surgical ward Prehospital communication	HR, RR, SBP, SpO_2, Supp. O_2, Temp, AVPU, and hypercapnic respiratory failure	Mortality Unplanned ICU admit MET review Cardiopulmonary arrest and acute respiratory failure
HEWS[11]	Upon admission to medical and surgical wards	HR, RR, SBP, SpO_2, Supp. O_2, Temp, and neurologic status (CAM and AVPU)	Mortality Unplanned ICU admit Cardiopulmonary arrest
PEWS[12]	Pediatric ward	Behavior (playing and lethargic), cardiovascular (color, capillary refill, and pulse), and respiratory (RR, WOB, and Supp. O_2)	Mortality Unplanned pediatric ICU admit Length of stay
TREWS[13]	Emergency department	Age, HR, RR, SBP, Supp. O_2, Temp, and AVPU	Mortality

Abbreviations: AVPU, alert, voice, pain, unresponsive; CAM, confusion assessment method; EWS, Early Warning Score; HEWS, Hamilton Early Warning Score; HR, heart rate; ICU, Intensive Care Unit; MET, Medical Emergency Team; NEWS, National Early Warning Score; PEWS, Pediatric Early Warning Score; RR, respiratory rate; SBP, systolic blood pressure; SpO_2, oxygen saturation; Supp. O_2, supplemental oxygen requirement; Temp, temperature; TREWS, Triage in Emergency Department Early Warning Score; ViEWS, VitalPAC Early Warning Score; WOB, work of breathing.

This table of Early Warning Scores shows the variety of income values a specific score is fed with. This review focuses especially on the outcome parameters a score is aimed and capable to predict.

There are many different established Early Warning Scores, like the ones shown above in table 1, the most common might be the ‘National Early Warning Score (NEWS)’, developed by research funded by the National Health Service (NHS) in Great Britain and published and implemented nationwide in all NHS hospitals and NHS service providers in the United Kingdom in 2012, updated to ‘NEWS 2’ in 2017 with the intend to include parameters and be more specific for early detection of sepsis (see table 1), revised in 2020 to add a component to include a Covid-19 infection into the prediction-parameters. (28)

The National Early Warning Score 2 is meant to be calculated during admission and on a regular basis throughout the hospital stay. It is designed to be used for patients from their 16th year of life onwards. Pregnant patients are not suitable and have a specific Early Warning Score assessment. Particular caution is advised when assessing the score in patients with chronic obstructive pulmonary disease (COPD).

With the National Early Warning Score 2, the respiratory rate, the oxygen saturation, the body temperature, the systolic blood pressure, the pulse, and consciousness are recorded. Consciousness is assessed according to the AVPU scheme (awake / alert, verbal response, response to pain, unconscious). A normal range is defined for each parameter. Depending on the extent of the deviation from the standard value, points are awarded and added up. This cumulative value is increased by two points when the patient receives supplementary oxygen.

The score leads to a corresponding catalog of measures, which is adapted to the circumstances of the respective institution.

In order to record as many patient risks as possible, but at the same time to conserve resources in the hospital, there is a subdivision into three risk groups: "low", "medium" and "high". These risk groups each trigger a specific cascade with specific measures. For example, a total value of 5 triggers a medium alarm. If only one parameter has a sum value of 3, the middle alarm will also be triggered. For example, immediate medical attention is required if the isolated heart rate falls below 40 beats per minute. A total value of 7 or more indicates a high risk.

For each risk group, it is described which professional group must assess the patient in which time window. In addition, the time intervals at which the score should be recorded again are specified. The higher the risk group, the shorter the time intervals. In addition, it is determined whether patients in the "high" risk group should be transferred to another department with more care, e.g., an intensive care unit. If the point value is 0, the NEWS is repeated every twelve hours. With a score of 1 to 4, the NEWS is collected again every four to a maximum of six hours.

In the case of a medium alarm, the nursing staff must quickly inform the medical treatment team. In addition, the patient is examined by a doctor with special knowledge of emergency medicine and the patient's vital signs are continuously monitored. The patient may need to be transferred to another department for this. If the total score is 7 or greater, the nurse must immediately inform the medical team, including at least one specialist. In addition, the patient should be assessed by a rapid response team with emergency medical expertise, especially in airway management. If necessary, the patient is transferred to an intensive care unit.
Different providers in different countries have developed their own early warning score, mostly based on the National Early Warning Score, to target specific needs, to adapt to different circumstances or just to ease workflow, acceptance, and compliance in order to improve measurable outcome.

Table 2 National Early Warning Score adapted from Royal College of Physicians (31)

Physiological parameter	Score						
	3	2	1	0	1	2	3
Respiration rate (per minute)	≤8		9–11	12–20		21–24	≥25
SpO_2 Scale 1 (%)	≤91	92–93	94–95	≥96			
SpO_2 Scale 2 (%)	≤83	84–85	86–87	88–92 ≥93 on air	93–94 on oxygen	95–96 on oxygen	≥97 on oxygen
Air or oxygen?		Oxygen		Air			
Systolic blood pressure (mmHg)	≤90	91–100	101–110	111–219			≥220
Pulse (per minute)	≤40		41–50	51–90	91–110	111–130	≥131
Consciousness				Alert			CVPU
Temperature (°C)	≤35.0		35.1–36.0	36.1–38.0	38.1–39.0	≥39.1	

NEW score	Clinical risk	Response
Aggregate score 0–4	Low	Ward-based response
Red score Score of 3 in any individual parameter	Low–medium	Urgent ward-based response*
Aggregate score 5–6	Medium	Key threshold for urgent response*
Aggregate score 7 or more	High	Urgent or emergency response**

* Response by a clinician or team with competence in the assessment and treatment of acutely ill patients and in recognising when the escalation of care to a critical care team is appropriate.
**The response team must also include staff with critical care skills, including airway management.

This table shows in the upper part the calculation by different parameters. In a paper – based scoring system, the process of calculation is done by checking boxes in a very similar form for every single patient. The lower part of the table shows the intended response in a track and trigger system. This step seems to be missed more often in a paper – based system.

There is a variety of modifications and adaptions to account for alterations in health care systems, proficiency of staff and to adopt local code and guidelines. These scores are called Modified Early Warning Scores, based mostly on the National Early Warning Score and further research.

Other Early Warning Scores have been developed in response to the needs of specific patient types, like the Paediatric Early Warning Score.

The Pediatric Early Warning System (PEWS) is an assessment tool designed to help ward staff better assess the condition of children. It is specifically designed for children and divided into five age groups, since the normal values of vital parameters differ for each age group (see table 2 for specific values). When calculating the score, the child is examined, the vital parameters (e.g., respiratory rate, heart rate, oxygen saturation, etc.) are documented and converted into a number of points depending on the value. In addition, the concern of the parents is included in the score. Parents know their child best, so if they express concern that their child is different than usual, it is important to take it seriously.

Table 3 normal vital parameters of paediatric patients by age group (32)

Age Group	Heart Rate	Respirations	Systolic BP
Preterm	120 – 180	50 – 70	40 – 60
Newborn (0 to 1 Month)	100 – 160	35 – 55	50 – 70
Infant (1 to 12 Months)	80 – 140	30 – 40	70 – 100
Toddler (1 to 3 Years)	80 – 130	20 – 30	70 – 110
Preschool (3 to 6 Years)	80 – 110	20 – 30	80 – 110
School Age (6 to 12 Years)	70 – 100	18 – 24	80 – 120
Adolescents (12+ Years)	60 – 90	14 - 22	100 – 120

The table visualizes the normal vital parameters according to age group. It shows an additional step in the process of calculating the Pediatric Early Warning Score.

The scores are then added together, and a total score is calculated. This results in instructions for action, e.g., when the child is to be monitored next and the vital signs checked or whether the ward doctor or even the intensive care unit needs to be informed. Each patient is monitored at least once a day with the PEWS score, and more often if the score is higher. The PEWS thus provides the nursing staff with a clear structure for assessment and instructions for action (this actions are shown in the table 4 and will be discussed in a later part of this review). (33)

Table 4: Pediatric Early Warning Score Card adapted from Monaghan (34)

Table 1.1	0	1	2	3
Cardiovascular	Pink **or** capillary refill 1-2 seconds.	Pale **or** capillary refill 3 seconds.	Grey **or** capillary refill 4 seconds. Tachycardia of 20 above normal rate.	Grey and mottled **or** capillary refill ≥5 seconds. Tachycardia of 30 above normal rate **or** bradycardia.
Respiratory	Within established baseline. No retractions Room Air	≥10 above established baseline. Mild Contractions Up to 2L/min **or** 30%	≥20 above established baseline. Moderate Contractions Up to 4L/min **or** 40%	≥30 above established baseline. Severe Contractions Grunting Up to 5L/min **or** 50%
Behavior	Playing/Appropriate or Sleeping	Irritable, but Consolable	Irritable and Inconsolable Restless **or** Pain	Lethargic or Confused Reduced Response to Voice or Pain
Score an additional 2pts for nebulizer use, suctioning, or persistent vomiting after surgery.				
				Total

Table 1.2	Retraction Severity	
Mild	**Moderate**	**Severe**
Subcostal or Substernal	Intercostal or Supraclavicular	Suprasternal or Sternal

Figure 1 Nursing interventions associated with different PEWS scores. (34)

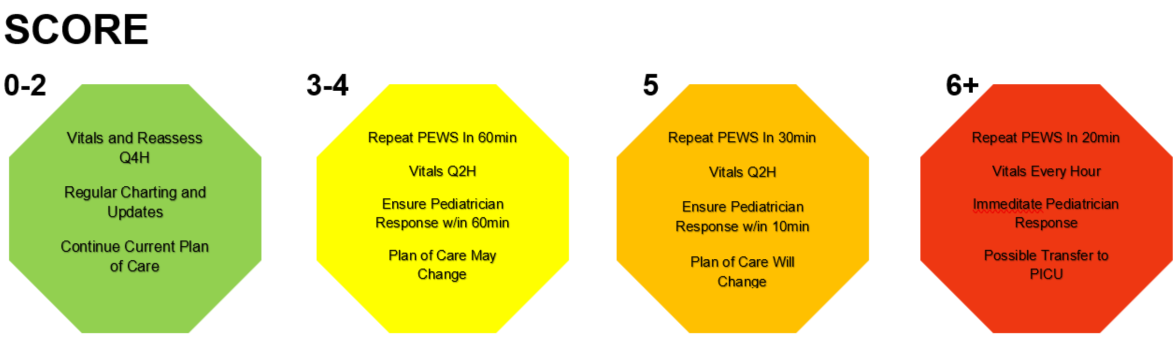

Table 4 and Figure 1 show the color – coded steps for evaluating the Pediatric Early Warning Score. It shows the added value for intercostal retractions in children. This score works as a track and trigger system, here the responses are color – coded for better association.
Q4H and Q2H stand for Quaque 2/4 Hora or Every 2/4 hours.

The Targeted, Real-Time Early Warning System (TREWS) for sepsis is another iteration and a progression in the development of early warning scores. (35)

It was developed more recently in 2015 and is designed to be used in Emergency departments to predict mortality from sepsis and allow for an early, aggressive intervention. (36,37)
This score combines early goal-directed therapy (EGDT) with usual care, which seems to have improved over time with early antibiotic treatment and aggressive fluid resuscitation. (38,39)
However, the main stepstone of sepsis treatment remains early sepsis detection. (40,41)
'General-purpose illness severity scoring systems such as the Acute Physiology and Chronic Health Evaluation (APACHE II), Simplified Acute Physiology Score (SAPS II), Sequential Organ Failure Assessment (SOFA) scores, Modified Early Warning Score (MEWS), and Simple Clinical Score (SCS) have been validated to assess illness severity and risk of death in sepsis, they typically cannot distinguish with high sensitivity and specificity which patients are at highest risk of developing a specific acute condition.' (36)
The TREWS Score is also the first system developed with the idea to facilitate the increased use of electronic health records to create predictive models. (19,42,43)
The researcher who developed and validated the score used a machine learning methodology, supervised learning and the MIMIC (Multiparameter Intelligent Monitoring in Intensive Care)–II Clinical Database. (44)
Other scores, like ViEWS, or HEWS (Hamilton Early Warning Score) are based on the National Early Warning Score or a Modified Early Warning Score and have been adapted for specific use in monitoring solutions by different healthcare companies.

4.2 Implementation

Early Warning Scores are intended to use vital signs that are recorded during the daily patient`s ward routine. (20) This signs and values need to be obtained and either written down in a paper-based chart or partly put into an electronic system.
Respiratory rate and oxygen saturation: The correct counting of the respiratory rate over a minute is associated with a considerable additional effort for nurses but shows a high level of accuracy. When considering a more efficient method of measuring respiratory rate, the possibilities of electronic (automated) recording using a pulse oximeter or monitor should be taken into account, as well as the possibility of counting the respiratory rate over 15 seconds and extrapolating it to one minute. The latter method is routinely performed in most hospitals. For example, when using a pulse oximeter, heart rate and oxygen saturation could be measured simultaneously. Which of the measuring methods is used depends on the decision of the respective institution. It is of importance that the same method is used every time. The limit values for respiratory rate and oxygen saturation are not undisputed when used in patients with

chronic obstructive pulmonary disease since these patients have adapted to high initial values and have a high score from the outset. Therefore, the reaction to the scores achieved (efferent limb) should be defined individually for these patients. This may also apply to other chronic diseases in which the vital signs are greatly altered by the disease, but the patients are adapted to it.

Heart rate: Measuring the heart rate is one of the standard vital parameters. Adaptations can be caused by very low frequencies whose limit values have been left out in the Early Waning Score and must therefore be defined individually if necessary. This vital parameter is undisputed, but its limit values are not always differentiated enough for specific patient collectives, such as cardiological patients.

Blood pressure: In addition to heart rate, blood pressure must be recorded as a standard vital parameter for every measurement.

Vigilance: In order to assess vigilance, a differentiation must be made, particularly in patients with dementia or patients with delirium. Confusion should only be evaluated when it is new. Further specifications are to be defined according to the individual patient constellation on specialized bed wards. The lack of the possibility of having the patient situation assessed by the professional competence of the nursing staff is a criticism of the concept.

In principle, however, this parameter can be additionally recorded and the subjective perception of the patient's condition by the nursing staff, the importance of which should not be underestimated, can be used to assess the patient's state of health.

Temperature: Based on practical experience during the systematic application of early warning scores in surgical and medical departments, body temperature seems to be of different relevance for different medical disciplines. Nevertheless, this parameter should be measured in a standardized way when using an early warning system and should not be neglected.

Urine output: The measurement and evaluation of urinary excretion can only be practiced with insufficient accuracy in patients without a urinary catheter and the results are therefore not very meaningful. In patients with a urinary catheter, the amount of urine excreted can be recorded as a parameter, but here too the frequency of measurement/assessment must be tailored to the individual patient situation.

A critical and often overlooked component of the implementation of the early warning score system is the responses reaching a predefined threshold trigger. (45)

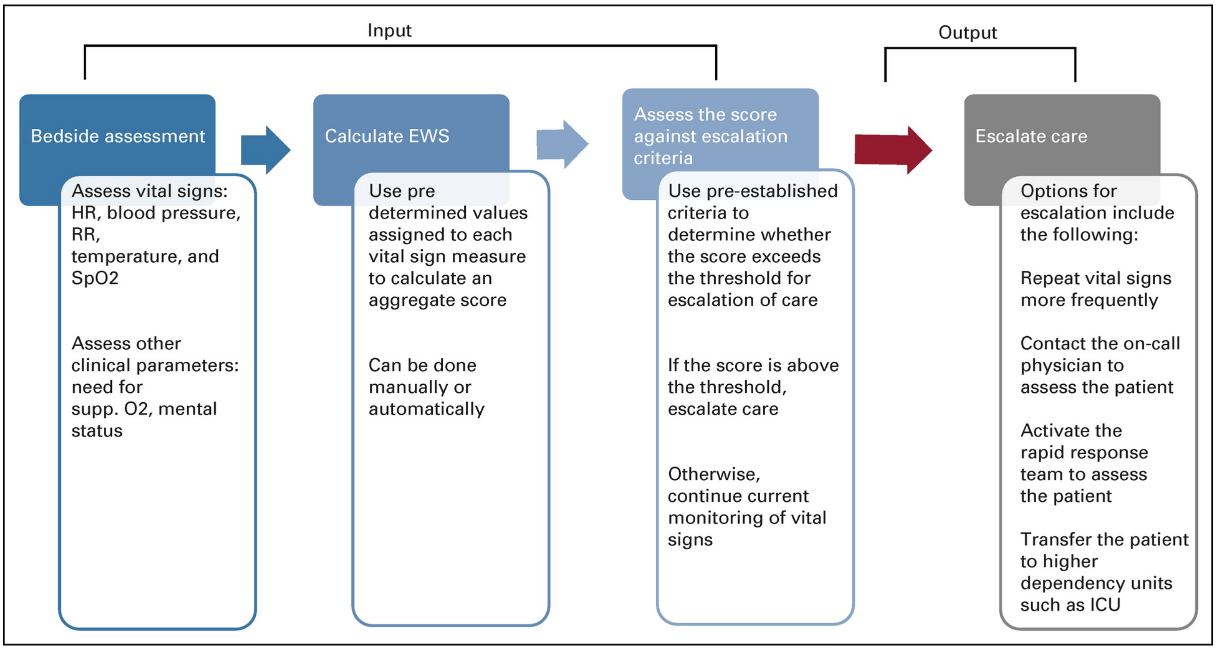

Figure 2: Process for identification of a deteriorating patient using the EWS system. (30)

The combined use of the afferent (systematic measurement of defined parameters) and the efferent limb (defined reaction to the measured parameters) enables nurses and doctors to get a quicker overview of the current state of health of the patient. (46) The greater the deviation of the measured values from the physiological norm, the higher the early warning score and the more critical the patient's current state of health is to be assessed. Based on the systematic monitoring by the early warning score, defined measures are required, graded according to the urgency and the type of reaction required. The clear definition of the reactions and their temporal urgency are a prerequisite for the action algorithm beyond hierarchical structures, which is essential for the effectiveness of the score. If physiological parameters are measured and the point values are converted into a score as a sum, the defined reaction to the determined score is revealed.

The first implemented National Early Warning Score in the United Kingdom was designed and used as a paper-based system, as well as a fair amount of Early Warning Scores today.

Studies and database analysis have shown that these paper-based systems are prone to errors and missed trigger responses and “false alarms”. (47)

In Great Britain, all patient safety incidents that lead to the unexpected death of a patient in hospital are recorded in a mandatory reporting system. Over a period of 17 months, these were over 2,000 patients. One of the most important causes of these incidents was due to mismanagement of clinical worsening on wards (35%). (1)

In addition, a high rate of patients being transferred back to the intensive care unit and deficits in the treatment of emergency patients on wards indicate that there is a need for action in the medical care of patients on wards. (48)

The need to act was shown by the National Patient Safety Agency (NPSA) in 2007 with the following study results: an analysis of 576 reported deaths in the mandatory National Reporting and Learning System (NRLS) showed that 11 percent of the deaths were due to the failure to detect a deterioration in the health of the patient at an early stage were attributable to patients. A lack of observation, not recognizing early signs of deterioration and a lack of communication or a lack of reaction to this deterioration in the patient's state of health were listed as causes. (2,3)

For this reason, the implementation of new standards to increase patient safety can be observed more frequently in practice and seems to have undoubtedly led to success in recent years. For example, as part of the "5 million lives campaign" patient safety campaign, the Institute for Healthcare Improvement (IHI) defined the goal of implementing so-called "rapid response teams" for the early detection of deteriorating patients on peripheral wards. (49)

With the introduction of a “track & trigger” early warning system and the “rapid response teams”, various healthcare facilities, mainly in the USA and Australia, have already achieved initial success. Various published studies also show that the delayed alerting of a rapid-response team is significantly associated with the risk of an unplanned transfer of the deteriorating patient to the ICU, and that the increasing frequency of rapid-response team calls to emergency services with a reduction in unexpected cardiopulmonary resuscitation and a reduction in mortality correlated. (50,51)

A recent retrospective cohort study from 2021 found that one-quarter of measurements of EWS assessments were wrong or incomplete. That number rose in the medium or high-risk EWS groups up to 70%. In the high-risk group, improvements in recordings and protocol adherence were primarily noted in five hours immediately preceding the event. The authors conclude that “this finding suggests missed opportunities to detect clinical deterioration.” (52)

The authors identify two possible factors that might limit the clinical effectiveness of paper-based Early Warning Scores: Poor adherence to the protocol (compliance) and inaccurate recordings of vital signs in the charts. (53,54)

This is supported by a study from the United Kingdom, where researchers investigated the daily pattern of vital signs measurement and charting. They compared the pattern of vital signs and VitalPAC Early Warning Score (ViEWS) data collected from admissions of a NHS district general hospital in the vicinity of London.

From a number of nearly 1 million data set recordings, the pattern of observation documentation was inhomogeneous and differed in a wide range. A peak in recordings in the morning and the afternoon were shown, but half of patients with an Early Warning risk score requiring vital sign checks every 2 or 4 hours received none at night, exceeding an interval of 6 hours without any recordings. The authors come to the conclusions, that "there was only partial adherence to the vital signs monitoring protocol. Sicker patients appear more likely to have vital signs measured overnight, but even their observations were often not followed by timely repeat assessments. (55)

4.3 Outcome

The World Health Organization defines an outcome measure as a "change in the health of an individual, group of people, or population that is attributable to an intervention or series of interventions." 'Outcome measures (mortality, readmission, patient experience, etc.) are the quality and cost targets healthcare organizations are trying to improve.' (56–59)

"The primary outcome of the analysis was death within 24 hours based on a set of observations. The ability to distinguish between survivors and non-survivors was assessed using the AUROC (area under the receiver-operating characteristics) curve.

Using 24-hour in-hospital mortality within 24 hours, the AUROC for the New Early Warning System indicated a value of 0.89 (95% confidence interval: 0.880-0.895). This was better than most existing early warning systems. " (28)

The logical next step in the evolution of this process is the automatization of those processes.

A 2019 retrospective before-and-after comparative analysis of the implementation of the automated and non-automated Modified Early Warning Score for patients admitted to the surgical high-dependency unit in a rural hospital looked for hospital length of stay, in-hospital and 28-day mortality, and ICU readmission rate.

2466 admissions served as baseline cohort, 2303 patients in the intervention cohort.

The unplanned ICU admissions decreased from 3.4% to 2.3% (P=0.03) as well as the rapid response teams calls from 4.3% to 3.1% (P=0.02).

The number of calls for the rapid response team that did result in ICU admission was not significantly different (2.1% to 1.6%, P=0.16). (60)

So the number of rapid response team calls where the patient needed to be transferred to an ICU did not declined in a statistically significant manner, but the "wrongful" rapid response team calls, where there was no need for the patient to be transferred to another unit, declined. As well did the number of overall unplanned ICU admissions.

The analysis had no focus or data towards other outcome criteria like short- or long-term survival. (61)

4.4 Outlook into the future or 'ward monitoring 3.0'

As the main burden of implementation seems be the necessity to record and document the vital signs and adapt their frequency in certain circumstances, which might collide with other tasks or exceed the possibilities of the staff otherwise, a continuous wireless vital sign monitoring can be a possible solution to the problem of lacking compliance. (62,63)

Before discussing such possibilities, the differences between the concepts should be explained. Experts and researchers categorize the evolution of ward monitoring in 3 stages:

Ward monitoring 1.0 or intermittent spot-checks describes the known practice where ward patients shall get their vital signs recorded every 4 – 6 hours by medical staff, traditionally in a paper – based fashion. Multiple studies showed missed events of abnormalities and failure to escalate monitoring or treatment procedures. (64,65)

Ward monitoring 2.0 or continuous bedside monitoring describes the monitoring of vital signs by stationary electronic equipment like oxygen saturation by pulse oximetry or heart rate by ECG leads. This method seems to perform better than the ward monitoring 1.0 by eliminating the human error from the equation, but bears a burden on the patient in form of discomfort and lack of mobility and therefore shifts the lack of compliance from the side of the staff to the patient. (66,67) Other forms of contactless monitoring equipment was tested, like a sensor recording heard rate and rate of breathing in the patient mattress, but deemed to unreliable. Therefore, this concept did never reach beyond intensive care or intermediate care units in a larger scale.

Ward monitoring 3.0 is a rather new concept that implements continuous non – invasive vital sign measurement in real-time into the patient's electronic health record and can further combine it with other health record data and laboratory results.

This new approach can be realized in form of a wireless monitoring device which is worn by patients on their wrists. It offers the advantages of enabling full patient mobilization and automated electronic medical record (EMR) linkage. First pilot-studies on this topic point towards an improvement compared to intermittent vital sign monitoring. (68–70)

So far, the first systematic review on this topic which was found in the conducted search was published in June 2020 in the Royal Journal of Medicine.

The study compared continuous and non-invasive vital sign monitoring with wearable monitor devices with wireless datalink in adult general ward patients compared with intermittent monitoring with EWS calculations. (71) The study also referred to a sub-group of sepsis and septic-shock patients.

The results show that patients on multi-parameter continuous non-invasive monitoring had a 39% decrease in risk of mortality (risk ratio 0.61; 95% confidence interval 0.39, 0.95) when compared to patients with regular intermittent monitoring and calculation of some sort of Early Warning Score. The calls for the rapid response team were significantly reduced (risk ratio 0.61; 95% confidence interval 0.26–1.43), as well as the unplanned admission to an intensive care unit (risk ratio 0.86; 95% confidence interval 0.67, 1.11).

For the first time in this research paper, a significant reduction in hospital length of stay was found and attributed the implemented measures. The weighted mean difference was –3,32 days (95% confidence interval 8,82—2,19 days)

In the current age, multi-parameter continuous non-invasive monitoring of vital signs is standard practice in intensive care and high-dependency units. But with the advent of lightweight, wireless, and low-cost wearable sensors, there is a possibility of bringing a continuous non-invasive monitoring of vital signs to more, if not all hospital in-patients.

The advent of Smartwatches by the development effort of tech-giants like Apple, Alphabet and Samsung have introduced advancements in sensor technologies such as miniaturization, improved battery life and reduction in production cost that would otherwise not be possible. (72) Only this advancements in technology have made bringing multi-parameter continuous non-invasive monitoring of vital signs in general wards feasible and subsequently the 2020 implementation of an electronic tracking system in the National Institute for Health and Care Excellence (NICE) Guidelines for Early Warning Score systems that alert to deteriorating adult patients in hospital. (73,74) The reasoning for this implementation in the NICE Guidelines is not a suspected direct improvement in protocol adherence and compliance, but indirectly to release resources for care-givers as the implementation of wearable sensors will reduce the need for manual observations by nurses. (75)

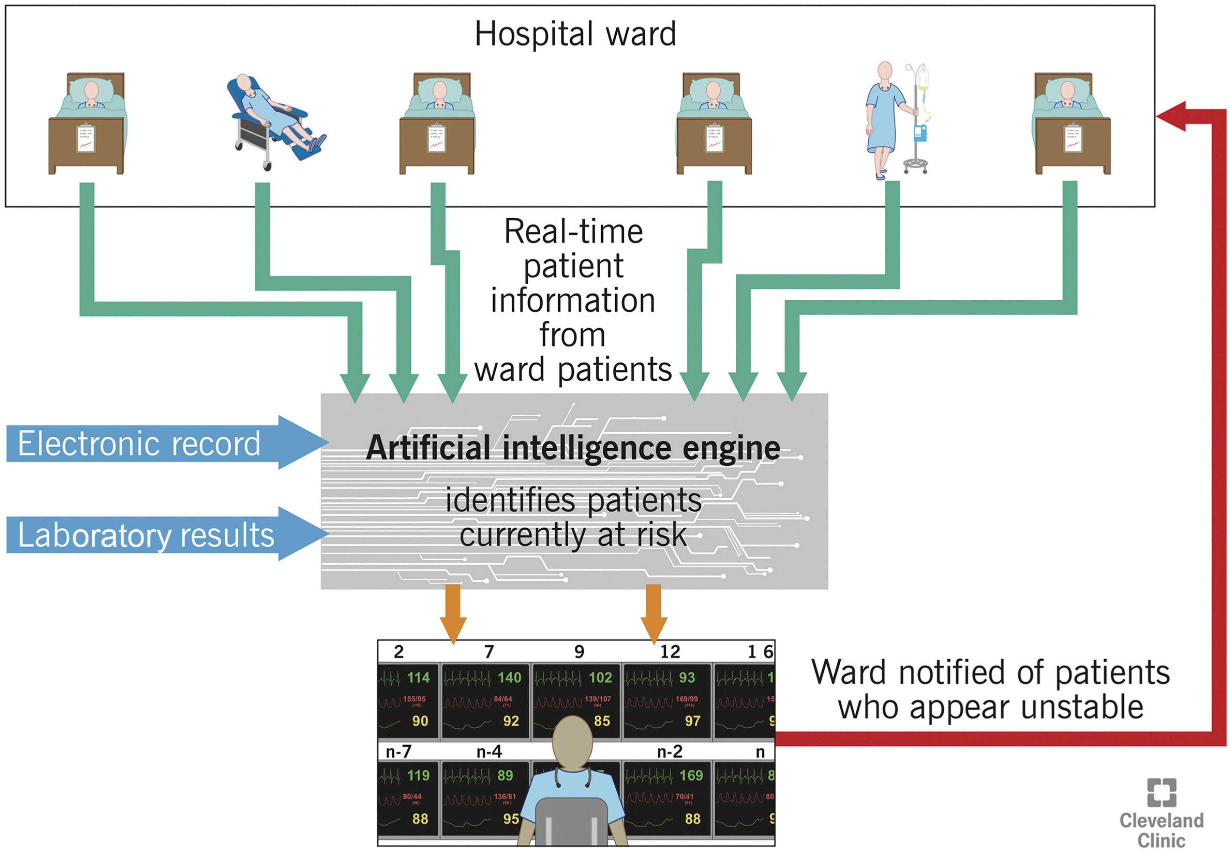

Figure 3 'Ward monitoring: schematic illustration of data recording and processing. Modern wirdeless wearable systems can now continuously evaluate a combination of physiologic variables such as BP, HR and rhythm, oxygen saturation, ventilatory frequency, temperature, activity, body position, and location in ward patients. This real-time patient information from ward monitoring along with other patient-specific clinical information (electronic record, laboratory results) goes to an artificial intelligence engine that will identify patients (perhaps 10%) who are currently at risk and project information about these selected patients to a command centre clinician for review. After review, the clinician alerts the ward team to patients who need attention. Our expectation is that timely identification of high-risk patients will allow clinicians to anticipate serious complications and intervene to prevent them, rather than trying to rescue patients thereafter. The overall goal is to go beyond rescuing patients who suffer major complications, and instead to anticipate and prevent such complications.' (61)

V. CONCLUSION

"Patients who are admitted to hospital believe that they are entering a place of safety. They feel confident that, should their condition deteriorate, they are in the best place for prompt and effective treatment. Yet there is evidence to the contrary." NICE statement from 2018. (62)

As a result of economic pressure in health care, hospitals are having to save more and more, which is often reflected in scarce human resources and shorter lengths of stay. International studies have found that the care of inpatients on peripheral wards in emergency situations and prior to transfer to the intensive care unit is often suboptimal. A study from the USA shows that more than half of the patients examined have insufficient oxygen therapy received and at least 39 percent of emergency patients were only transferred to the intensive care unit at a late stage. (5)

Other studies conclude that early treatment of unstable patients by a medical emergency team reduces both the occurrence and mortality of sudden cardiac arrest, or the use of an early warning system led to significantly earlier transfers to the intensive care unit. (76)

Early warning systems are useful tools for making good clinical decisions and signalling an acute deterioration in a patient's health. However, the sensitivity depends on the number of parameters measured, which reflect the physiological trend of the patient's state of health. In addition, early warning systems facilitate communication between the professional groups of nurses and doctors. They can support their decisions with objective facts and complement them with their individual perception of the patient's situation.

The systematic use of an early warning system primarily means additional work for the nursing staff. You must carry out the regular measurements of the parameters, document them and inform a doctor accordingly. The fact that the routine monitoring of the defined parameters of the score is associated with an additional effort for nursing staff means that the existing work processes have to be optimised. If necessary, medical devices should be used to relieve the nursing staff when measuring parameters. In addition, the use of modern clinical information systems can reduce the effort for the nursing staff and thus make the benefits of the early warning system noticeable. However, the effort is justified by the increased safety for the patient, which is equivalent to a measurable increase in the quality of care.

The subjective perception of the patient's situation, which cannot be made visible using objective criteria, should be a parameter in every early warning system, since it represents an important competence of the nursing staff and must not be ignored. It should at least be possible for nurses' concerns about the patient's state of health to be taken into account in an early warning system, even without objective data. The assessment of the overall situation by the nursing staff and the perception of the smallest changes in the patient before vital parameters change is often a first indicator of an impending deterioration. Nursing professionals with a lot of professional experience in particular can recognize and assess these sensitive changes without objectively changed measured values already being available. In addition, the regular assessment of the patient's situation promotes the competence of the nursing staff, who may not yet have many years of practical experience. The systematic use of an early warning system, furthermore in addition with a multi-parameter continuous non-invasive monitoring of vital signs, and the subjective assessment of the patient's situation are not in competition with each other and do not make each other superfluous. At best, they complement each other.

The current data situation suggests that the concept of ward monitoring 3.0 with continuous, non – invasive recording of vital signs in connection with electronic medical records and the adapted calculation of Early Warning Scores with the aid of an artificial intelligence engines, in combination with soft – skill and communication training as well as education of medical staff in their new part – time role as data analysts.

Nevertheless, more research is needed on this topic in the future, especially on the human factor and staff's new role in becoming the backbone of a standardized decision – making und communication process.

Ward patient can benefit from the use of early warning scores, if implemented correctly and medical staff adheres to the protocol and initiate the proper track and trigger response. Novel innovations could remedy the problem of compliance and protocol adherence without affecting patient comfort. The use of technological support would also reduce the workload of healthcare workers significantly and provide more resources for other neglected tasks.

The sticking point might be the role shift of the healthcare provider from performing routine tasks to becoming the backbone of a standardized decision – making und communication process. The implementation and acceptance of Early Warning Scores has a significant impact on every measurable outcome parameter. A key role in the near future plays the multi – parameter continuous, non – invasive monitoring with wearable devices that report in real – time to the electronic medical record which calculates a risk score and supports medical staff in their decision – making process.

VI. REFERENCES

1. Donaldson LJ, Panesar SS, Darzi A. Patient-safety-related hospital deaths in England: thematic analysis of incidents reported to a national database, 2010-2012. PLoS Med. 2014 Jun;11(6):e1001667.
2. Britain) NPSA (Great. Recognising and Responding Appropriately to Early Signs of Deterioration in Hospitalised Patients: November 2007. National Patient Safety Agency; 2007. 38 p.
3. Safer Care for the Acutely Ill Patient: Learning from Serious Incidents. [cited 2022 Apr 19]; Available from: https://psnet.ahrq.gov/issue/safer-care-acutely-ill-patient-learning-serious-incidents
4. Seward E, Greig E, Preston S, Harris RA, Borrill Z, Wardle TD, et al. A confidential study of deaths after emergency medical admission: issues relating to quality of care. Clin Med Lond Engl. 2003 Oct;3(5):425–34.
5. McQuillan P, Pilkington S, Allan A, Taylor B, Short A, Morgan G, et al. Confidential inquiry into quality of care before admission to intensive care. BMJ. 1998 Jun 20;316(7148):1853–8.
6. Andersen LW, Holmberg MJ, Berg KM, Donnino MW, Granfeldt A. In-Hospital Cardiac Arrest: A Review. JAMA. 2019 Mar 26;321(12):1200–10.
7. Roberts D, Djärv T. Preceding national early warnings scores among in-hospital cardiac arrests and their impact on survival. Am J Emerg Med. 2017 Nov 1;35(11):1601–6.
8. Rutherford, P. Transforming Care at the Bedside [Internet]. [cited 2022 Apr 18]. Available from: http://www.ihi.org:80/resources/Pages/IHIWhitePapers/TransformingCareattheBedsideWhitePaper.aspx
9. Albutt A, O'Hara J, Conner M, Lawton R. Involving patients in recognising clinical deterioration in hospital using the Patient Wellness Questionnaire: A mixed-methods study. J Res Nurs JRN. 2020 Feb;25(1):68–86.
10. Murphy A, Cronin J, Whelan R, Drummond FJ, Savage E, Hegarty J. Economics of Early Warning Scores for identifying clinical deterioration-a systematic review. Ir J Med Sci. 2018 Feb;187(1):193–205.
11. HealthGrades Quality Study: Third Annual Patient Safety in American Hospitals Study. [cited 2022 Apr 18]; Available from: https://psnet.ahrq.gov/issue/healthgrades-quality-study-third-annual-patient-safety-american-hospitals-study
12. Tiru B, DiNino EK, Orenstein A, Mailloux PT, Pesaturo A, Gupta A, et al. The Economic and Humanistic Burden of Severe Sepsis. PharmacoEconomics. 2015 Sep;33(9):925–37.
13. Moerer O, Burchardi H. [The cost of sepsis]. Anaesthesist. 2006 Jun;55 Suppl 1:36–42.
14. Young MP, Gooder VJ, McBride K, James B, Fisher ES. Inpatient transfers to the intensive care unit: delays are associated with increased mortality and morbidity. J Gen Intern Med. 2003 Feb;18(2):77–83.
15. Ng YH, Pilcher DV, Bailey M, Bain CA, MacManus C, Bucknall TK. Predicting medical emergency team calls, cardiac arrest calls and re-admission after intensive care discharge: creation of a tool to identify at-risk patients. Anaesth Intensive Care. 2018 Jan;46(1):88–96.
16. Gao H, McDonnell A, Harrison DA, Moore T, Adam S, Daly K, et al. Systematic review and evaluation of physiological track and trigger warning systems for identifying at-risk patients on the ward. Intensive Care Med. 2007 Apr 1;33(4):667–79.
17. Morgan R, Lloyd-Williams F, Wright M, Morgan-Warren R. An early warning scoring system for detecting developing critical illness. undefined [Internet]. 1997 [cited 2022

Apr 18]; Available from: https://www.semanticscholar.org/paper/An-early-warning-scoring-system-for-detecting-Morgan-Lloyd-Williams/5d7dd63a226927e2f5558787f851c9ec67d3558c
18. Acute care toolkits [Internet]. RCP London. 2015 [cited 2022 Apr 18]. Available from: https://www.rcplondon.ac.uk/projects/acute-care-toolkits
19. Overview | Acutely ill adults in hospital: recognising and responding to deterioration | Guidance | NICE [Internet]. NICE; [cited 2022 Mar 20]. Available from: https://www.nice.org.uk/guidance/cg50
20. Goldhill DR, McNarry AF. Physiological abnormalities in early warning scores are related to mortality in adult inpatients†. BJA Br J Anaesth. 2004 Jun 1;92(6):882–4.
21. Ashworth S. A prelude to outreach: Prevalence & mortality of ward patients with abnormal vital signs. In 2002. p. S21–S21.
22. Sun L, Joshi M, Khan SN, Ashrafian H, Darzi A. Clinical impact of multi-parameter continuous non-invasive monitoring in hospital wards: a systematic review and meta-analysis. J R Soc Med. 2020 Jun;113(6):217–24.
23. Hillman KM, Bristow PJ, Chey T, Daffurn K, Jacques T, Norman SL, et al. Antecedents to hospital deaths. Intern Med J. 2001 Aug;31(6):343–8.
24. Harrison GA, Jacques T, McLaws ML, Kilborn G. Combinations of early signs of critical illness predict in-hospital death—The SOCCER Study (signs of critical conditions and emergency responses). Resuscitation. 2006 Dec 1;71(3):327–34.
25. Schein RMH, Hazday N, Pena M, Ruben BH, Sprung CL. Clinical Antecedents to In-Hospital Cardiopulmonary Arrest. Chest. 1990 Dec 1;98(6):1388–92.
26. Buist MD, Burton PR, Bernard SA, Waxman BP, Anderson J. Recognising clinical instability in hospital patients before cardiac arrest or unplanned admission to intensive care: A pilot study in a tertiary-care hospital. Med J Aust. 1999;171(1):22–5.
27. 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 Apr;85(4):549–52.
28. NHS England » National Early Warning Score (NEWS) [Internet]. [cited 2022 Apr 18]. Available from: https://www.england.nhs.uk/ourwork/clinical-policy/sepsis/nationalearlywarningscore/
29. Smith GB, Prytherch DR, Schmidt P, Featherstone PI, Knight D, Clements G, et al. Hospital-wide physiological surveillance-a new approach to the early identification and management of the sick patient. Resuscitation. 2006 Oct;71(1):19–28.
30. Nagarajah S, Krzyzanowska MK, Murphy T. Early Warning Scores and Their Application in the Inpatient Oncology Settings. JCO Oncol Pract. 2022 Jan 7;OP.21.00532.
31. Fig. 1 The NEWS2 scoring system. Reproduced from: Royal College of... [Internet]. ResearchGate. [cited 2022 May 17]. Available from: https://www.researchgate.net/figure/The-NEWS2-scoring-system-Reproduced-from-Royal-College-of-Physicians-National-Early_fig1_342903745
32. Kmartsbest. English: Pediatric Vital Range [Internet]. 2017 [cited 2022 May 17]. Available from: https://commons.wikimedia.org/wiki/File:Vitals.png
33. Early Warning Systems: Scorecards That Save Lives | IHI - Institute for Healthcare Improvement [Internet]. [cited 2022 Apr 18]. Available from: http://www.ihi.org:80/resources/Pages/ImprovementStories/EarlyWarningSystemsScorecardsThatSaveLives.aspx
34. Kmartsbest. English: PEWS System w/ Color [Internet]. 2017 [cited 2022 May 17]. Available from: https://commons.wikimedia.org/wiki/File:Color_PEWS.png
35. Aygun H, Eraybar S. The role of emergency department triage early warning score (TREWS) and modified early warning score (MEWS) to predict in-hospital mortality in COVID-19 patients. Ir J Med Sci. 2021 Jun 28;

36. Henry K, Hager D, Pronovost P, Saria S. A targeted real-time early warning score (TREWScore) for septic shock. Sci Transl Med. 2015 Aug 5;7:299ra122.
37. Lee SB, Kim DH, Kim T, Kang C, Lee SH, Jeong JH, et al. Emergency Department Triage Early Warning Score (TREWS) predicts in-hospital mortality in the emergency department. Am J Emerg Med. 2020 Feb;38(2):203–10.
38. ARISE Investigators, ANZICS Clinical Trials Group, Peake SL, Delaney A, Bailey M, Bellomo R, et al. Goal-directed resuscitation for patients with early septic shock. N Engl J Med. 2014 Oct 16;371(16):1496–506.
39. A Randomized Trial of Protocol-Based Care for Early Septic Shock. N Engl J Med. 2014 May 1;370(18):1683–93.
40. Levy MM. Early goal-directed therapy: what do we do now? Crit Care Lond Engl. 2014 Dec 29;18(6):705.
41. Mouncey PR, Osborn TM, Power GS, Harrison DA, Sadique MZ, Grieve RD, et al. Trial of Early, Goal-Directed Resuscitation for Septic Shock. N Engl J Med. 2015 Apr 2;372(14):1301–11.
42. Herasevich V, Pieper MS, Pulido J, Gajic O. Enrollment into a time sensitive clinical study in the critical care setting: results from computerized septic shock sniffer implementation. J Am Med Inform Assoc JAMIA. 2011 Oct;18(5):639–44.
43. Nguyen SQ, Mwakalindile E, Booth JS, Hogan V, Morgan J, Prickett CT, et al. Automated electronic medical record sepsis detection in the emergency department. PeerJ. 2014;2:e343.
44. Goldberger AL, Amaral LA, Glass L, Hausdorff JM, Ivanov PC, Mark RG, et al. PhysioBank, PhysioToolkit, and PhysioNet: components of a new research resource for complex physiologic signals. Circulation. 2000 Jun 13;101(23):E215-220.
45. Egholm CL, Helmark C, Doherty P, Nilsen P, Zwisler AD, Bunkenborg G. 'Struggling with practices' - A qualitative study of factors influencing the implementation of clinical quality registries for cardiac rehabilitation in England and Denmark. B M C Health Serv Res. 2019 Feb 6;19(102).
46. Wuytack F, Meskell P, Conway A, McDaid F, Santesso N, Hickey FG, et al. The effectiveness of physiologically based early warning or track and trigger systems after triage in adult patients presenting to emergency departments: a systematic review. BMC Emerg Med. 2017 Dec 6;17(1):38.
47. Clifton DA, Clifton L, Sandu DM, 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 Jul 1;5(7):e007376.
48. Rosenberg AL, Watts C. Patients readmitted to ICUs* : a systematic review of risk factors and outcomes. Chest. 2000 Aug;118(2):492–502.
49. Wachter RM, Pronovost PJ. The 100,000 Lives Campaign: A scientific and policy review. Jt Comm J Qual Patient Saf. 2006 Nov;32(11):621–7.
50. Calzavacca P, Licari E, Tee A, Egi M, Downey A, Quach J, et al. The impact of Rapid Response System on delayed emergency team activation patient characteristics and outcomes--a follow-up study. Resuscitation. 2010 Jan;81(1):31–5.
51. Chen J, Bellomo R, Flabouris A, Hillman K, Finfer S, MERIT Study Investigators for the Simpson Centre, et al. The relationship between early emergency team calls and serious adverse events. Crit Care Med. 2009 Jan;37(1):148–53.
52. Eddahchouri Y, Koeneman M, Plokker M, Brouwer E, van de Belt TH, van Goor H, et al. Low compliance to a vital sign safety protocol on general hospital wards: A retrospective cohort study. Int J Nurs Stud. 2021 Mar 1;115:103849.
53. 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. Crit Care Resusc. 13(2):83–8.

54. Smith AF, Oakey RJ. Incidence and significance of errors in a patient 'track and trigger' system during an epidemic of Legionnaires' disease: retrospective casenote analysis. Anaesthesia. 2006;61(3):222–8.
55. 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 Qual Saf. 2013 Sep 1;22(9):719–26.
56. DeVita MA, Hillman K, Bellomo R. Medical Emergency Teams: Implementation and Outcome Measurement. Springer Science & Business Media; 2007. 312 p.
57. Smith PG, Morrow RH, Ross DA. Outcome measures and case definition [Internet]. Field Trials of Health Interventions. Oxford University Press; [cited 2022 May 11]. Available from: https://oxfordmedicine.com/view/10.1093/med/9780198732860.001.0001/med-9780198732860-chapter-12
58. Tripepi G, Jager KJ, Dekker FW, Wanner C, Zoccali C. Measures of effect: relative risks, odds ratios, risk difference, and 'number needed to treat'. Kidney Int. 2007 Oct;72(7):789–91.
59. Types of Health Care Quality Measures [Internet]. [cited 2022 May 11]. Available from: https://www.ahrq.gov/talkingquality/measures/types.html
60. Mestrom E, De Bie A, van de Steeg M, Driessen M, Atallah L, Bezemer R, et al. Implementation of an automated early warning scoring system in a surgical ward: Practical use and effects on patient outcomes. PLoS ONE. 2019 May 8;14(5):e0213402.
61. Sessler DI, Saugel B. Beyond 'failure to rescue': the time has come for continuous ward monitoring. Br J Anaesth. 2019 Mar 1;122(3):304–6.
62. Michard F, Sessler DI. Ward monitoring 3.0. Br J Anaesth. 2018 Nov 1;121(5):999–1001.
63. Michard F, Kalkman CJ. Rethinking Patient Surveillance on Hospital Wards. Anesthesiology. 2021 Sep 1;135(3):531–40.
64. Sun Z, Sessler DI, Dalton JE, Devereaux PJ, Shahinyan A, Naylor AJ, et al. Postoperative Hypoxemia Is Common and Persistent: A Prospective Blinded Observational Study. Anesth Analg. 2015 Sep;121(3):709–15.
65. Sessler DI, Meyhoff CS, Zimmerman NM, Mao G, Leslie K, Vásquez SM, et al. Period-dependent Associations between Hypotension during and for Four Days after Noncardiac Surgery and a Composite of Myocardial Infarction and Death: A Substudy of the POISE-2 Trial. Anesthesiology. 2018 Feb;128(2):317–27.
66. Taenzer A.H. Pyke J.B. McGrath S.P. et al. Impact of pulse oximetry surveillance on rescue events and intensive care unit transfers: a before-and-after concurrence study. - Google Suche [Internet]. [cited 2022 May 13]. Available from: https://www.google.com/search?q=Taenzer+A.H.+Pyke+J.B.+McGrath+S.P.+et+al.+Impact+of+pulse+oximetry+surveillance+on+rescue+events+and+intensive+care+unit+transfers%3A+a+before-and-after+concurrence+study.&oq=Taenzer+A.H.+Pyke+J.B.+McGrath+S.P.+et+al.+Impact+of+pulse+oximetry+surveillance+on+rescue+events+and+intensive+care+unit+transfers%3A+a+before-and-after+concurrence+study.&aqs=chrome..69i57.611j0j7&sourceid=chrome&ie=UTF-8
67. Brown H, Terrence J, Vasquez P, Bates DW, Zimlichman E. Continuous monitoring in an inpatient medical-surgical unit: a controlled clinical trial. Am J Med. 2014 Mar;127(3):226–32.
68. Weenk M, Bredie SJ, Koeneman M, Hesselink G, Goor H van, Belt TH van de. Continuous Monitoring of Vital Signs in the General Ward Using Wearable Devices: Randomized Controlled Trial. J Med Internet Res. 2020 Jun 10;22(6):e15471.
69. Downey CL, Chapman S, Randell R, Brown JM, Jayne DG. The impact of continuous versus intermittent vital signs monitoring in hospitals: A systematic review and narrative

synthesis. Int J Nurs Stud. 2018 Aug 1;84:19–27.
70. Weenk M, Goor H van, Frietman B, Engelen LJ, Laarhoven CJ van, Smit J, et al. Continuous Monitoring of Vital Signs Using Wearable Devices on the General Ward: Pilot Study. JMIR MHealth UHealth. 2017 Jul 5;5(7):e7208.
71. Eddahchouri Y, Peelen RV, Koeneman M, Touw HRW, van Goor H, Bredie SJH. Effect of continuous wireless vital sign monitoring on unplanned ICU admissions and rapid response team calls: a before-and-after study. Br J Anaesth. 2022 May 1;128(5):857–63.
72. Joshi M, Ashrafian H, Aufegger L, Khan S, Arora S, Cooke G, et al. Wearable sensors to improve detection of patient deterioration. Expert Rev Med Devices. 2019 Feb;16(2):145–54.
73. The technology | National Early Warning Score systems that alert to deteriorating adult patients in hospital | Advice | NICE [Internet]. NICE; [cited 2022 May 12]. Available from: https://www.nice.org.uk/advice/mib205/chapter/The-technology
74. Wong D, Bonnici T, Knight J, Gerry S, Turton J, Watkinson P. A ward-based time study of paper and electronic documentation for recording vital sign observations. J Am Med Inform Assoc JAMIA. 2017 Jul 1;24(4):717–21.
75. Prgomet M, Cardona-Morrell M, Nicholson M, Lake R, Long J, Westbrook J, et al. Vital signs monitoring on general wards: clinical staff perceptions of current practices and the planned introduction of continuous monitoring technology. Int J Qual Health Care J Int Soc Qual Health Care. 2016 Sep;28(4):515–21.
76. Buist MD, Moore GE, Bernard SA, Waxman BP, Anderson JN, Nguyen TV. Effects of a medical emergency team on reduction of incidence of and mortality from unexpected cardiac arrests in hospital: preliminary study. BMJ. 2002 Feb 16;324(7334):387–90.