# Digital early warning scores in cardiac care settings: Mixed-methods research


Baneen Alhmoud


PhD Thesis

Academic Supervisors

Prof. Amitava Banerjee

Dr. Timothy Bonnici

Prof. Riyaz Patel

Dr. Daniel Melley


Institute of Health Informatics

University College London


July 2022

## Declaration /statement of contribution

I, Baneen Alhmoud confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Signed

Date

24.07.2022

## Acknowledgement

Countless people supported my effort in this thesis. I would like to thank my primary supervisor Professor Amitava Banerjee for taking responsibility for my supervision and endeavouring to provide continuous and invaluable support and guidance. Dr Timothy Bonnici, Dr Daniel Melley and Professor Riyaz Patel for their expertise, support and encouragement in my research journey. My thank also goes to Professor Louise Hicks and the amazing team at Barts Hospital, who welcomed me and contributed to the conduct of my research.

My family, firstly Zeze, my little girl who was always there showing her love and kindness and patiently waiting for me to finish my endless study hours to have our playtime.

To my mum, who was always there by heart, even from afar, with her warm wishes and prayers. To my sister Zahra, who was there from the beginning of my undergraduate study providing any help I needed and amazing support responsibly from a young age, I don't think I would be here without what you did. To my beautiful sisters Mariam and Zainab for being there. To my brother Ibrahim for his light soul and sense of humour when things get tough.

To the beautiful people in my life who showed love and encouragement and made me laugh or feel proud when I needed it. To my friends who were there in the sound and hard times; I thank them all for showing the love and support along the way.

# UCL Research Paper Declaration Form.

## Referencing the doctoral candidate's own published work(s)

Declaration (1)

Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:

- have been uploaded to a preprint server;
- are in submission to a peer-reviewed publication;
- have been published in a peer-reviewed publication, e.g. journal, textbook.

*This form should be completed as many times as necessary. For instance, if you have seven thesis chapters, two of which containing material that has already been published, you would complete this form twice.*

<table>
<tr><td colspan="3">1. For a research manuscript that has already been published (if not yet published, please skip to section 2):</td></tr>
<tr><td>a) Where was the work published? (e.g. journal name)</td><td colspan="2">BMJ open</td></tr>
<tr><td>b) Who published the work? (e.g. Elsevier/Oxford University Press):</td><td colspan="2">BMJ Journals</td></tr>
<tr><td>c) When was the work published?</td><td colspan="2">01/04/2021</td></tr>
<tr><td>d) Was the work subject to academic peer review?</td><td colspan="2">Yes</td></tr>
<tr><td>e) Have you retained the copyright for the work?</td><td colspan="2">Yes</td></tr>
<tr><td colspan="3">[If no, please seek permission from the relevant publisher and check the box next to the below statement]:<br>☐ I acknowledge permission of the publisher named under 1b to include in this thesis portions of the publication named as included in 1a.</td></tr>
<tr><td colspan="3">2. For a research manuscript prepared for publication but that has not yet been published (if already published, please skip to section 3):</td></tr>
<tr><td>a) Has the manuscript been uploaded to a preprint server? (e.g. medRxiv):</td><td>No</td><td>If yes, which server? Click or tap here to enter text.</td></tr>
<tr><td>b) Where is the work intended to be published? (e.g. names of journals that you are planning to submit to)</td><td colspan="2">Click or tap here to enter text.</td></tr>
<tr><td>c) List the manuscript's authors in the intended authorship order:</td><td colspan="2">Click or tap here to enter text.</td></tr>
</table>

| **d) Stage of publication** | Please select. |
|---|---|

| |
|---|
| **3. For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4**):** |
| AB conceived the study. BA, AB and TB conducted the search, data extraction and data analysis. BA wrote the initial draft of the manuscript. All authors contributed to interpretation of findings, critical review and revisions of the manuscript. |
| **4. In which chapter(s) of your thesis can this material be found?** |
| Chapter three. |
| **5. e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work): |

| | | | |
|---|---|---|---|
| **Candidate:** | Baneen Alhmoud | **Date:** | **25/07/2022** |
| **Supervisor/ Senior Author** (where appropriate)**:** | Prof. Amitava Banerjee | **Date:** | 26/07/2022 |

# UCL Research Paper Declaration Form

## Referencing the doctoral candidate's own published work(s)

Declaration (2)

Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:

- have been uploaded to a preprint server;
- are in submission to a peer-reviewed publication;
- have been published in a peer-reviewed publication, e.g. journal, textbook.

*This form should be completed as many times as necessary. For instance, if you have seven thesis chapters, two of which containing material that has already been published, you would complete this form twice.*

| | | |
|---|---|---|
| **6. For a research manuscript that has already been published** (if not yet published, please skip to section 2)**:** | | |
| **f) Where was the work published?** (e.g. journal name) | Click or tap here to enter text. | |
| **g) Who published the work?** (e.g. Elsevier/Oxford University Press): | Click or tap here to enter text. | |
| **h) When was the work published?** | Click or tap to enter a date. | |
| **i) Was the work subject to academic peer review?** | Please select. | |
| **j) Have you retained the copyright for the work?** | Please select. | |
| [If no, please seek permission from the relevant publisher and check the box next to the below statement]:<br>☐ *I acknowledge permission of the publisher named under 1b to include in this thesis portions of the publication named as included in 1a.* | | |
| **7. For a research manuscript prepared for publication but that has not yet been published** (if already published, please skip to section 3)**:** | | |
| **e) Has the manuscript been uploaded to a preprint server?** (e.g. medRxiv): | Yes | **If yes, which server?** medRxiv |
| **f) Where is the work intended to be published?** (e.g. names of journals that you are planning to submit to) | BMJ Open | |
| **g) List the manuscript's authors in the intended authorship order:** | Baneen Alhmoud, Timothy Bonnici, Daniel Melley, Riyaz Patel and Amitava Banerjee. | |

| | |
|---|---|
| **h) Stage of publication** | Submitted |

**8. For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4**):**

AB, DM and TB conceived the study. BA carried the data collection with guidance of DM. BA conducted analysis and interpretation of findings. BA wrote the manuscript, and all authors contributed to the interpretation and revision of the manuscript.

**9. In which chapter(s) of your thesis can this material be found?**

Chapter four

**10. e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work):

| | | | |
|---|---|---|---|
| **Candidate:** | Baneen Alhmoud | **Date:** | **25/07/2022** |
| **Supervisor/ Senior Author** (where appropriate)**:** | Prof. Amitava Banerjee | **Date:** | 26/07/2022 |

# UCL Research Paper Declaration Form

## Referencing the doctoral candidate's own published work(s)

Declaration (3)

Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:

- have been uploaded to a preprint server;
- are in submission to a peer-reviewed publication;
- have been published in a peer-reviewed publication, e.g. journal, textbook.

*This form should be completed as many times as necessary. For instance, if you have seven thesis chapters, two of which containing material that has already been published, you would complete this form twice.*

| | | |
|---|---|---|
| **11. For a research manuscript that has already been published** (if not yet published, please skip to section 2)**:** | | |
| **k) Where was the work published?** (e.g. journal name) | Click or tap here to enter text. | |
| **l) Who published the work?** (e.g. Elsevier/Oxford University Press): | Click or tap here to enter text. | |
| **m) When was the work published?** | Click or tap to enter a date. | |
| **n) Was the work subject to academic peer review?** | Please select. | |
| **o) Have you retained the copyright for the work?** | Please select. | |
| [If no, please seek permission from the relevant publisher and check the box next to the below statement]:<br>☐ *I acknowledge permission of the publisher named under 1b to include in this thesis portions of the publication named as included in 1a.* | | |
| **12. For a research manuscript prepared for publication but that has not yet been published** (if already published, please skip to section 3)**:** | | |
| **i) Has the manuscript been uploaded to a preprint server?** (e.g. medRxiv): | No | **If yes, which server?** |
| **j) Where is the work intended to be published?** (e.g. names of journals that you are planning to submit to) | INQUIRY: The journal of healthcare organisation, provision and financing. | |
| **k) List the manuscript's authors in the intended authorship order:** | Baneen Alhmoud, Timothy Bonnici, Riyaz Patel, Daniel Melley and Amitava Banerjee. | |

| | |
|---|---|
| **l) Stage of publication** | Submitted |

| |
|---|
| **13. For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4**):** |
| BA and AB contributed to the development of the review questions. BA conducted the literature searches, reviewing the papers, data extraction, analysis of the results, and drafting the manuscript. AB reviewed the findings and contributed to the interpretation. all authors contributed to the study and revision to the manuscript. |
| **14. In which chapter(s) of your thesis can this material be found?** |
| Chapter five |
| **15. e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work): |

| | | | |
|---|---|---|---|
| **Candidate:** | Baneen Alhmoud | **Date:** | 25/07/2022 |
| **Supervisor/ Senior Author** (where appropriate)**:** | Prof. Amitava Banerjee | **Date:** | 26/07/2022 |

# UCL Research Paper Declaration Form
## Referencing the doctoral candidate's own published work(s)

Declaration (4)

Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:

- have been uploaded to a preprint server;
- are in submission to a peer-reviewed publication;
- have been published in a peer-reviewed publication, e.g. journal, textbook.

*This form should be completed as many times as necessary. For instance, if you have seven thesis chapters, two of which containing material that has already been published, you would complete this form twice.*

| | | |
|---|---|---|
| **16. For a research manuscript that has already been published** (if not yet published, please skip to section 2)**:** | | |
| **p) Where was the work published?** (e.g. journal name) | Click or tap here to enter text. | |
| **q) Who published the work?** (e.g. Elsevier/Oxford University Press): | Click or tap here to enter text. | |
| **r) When was the work published?** | Click or tap to enter a date. | |
| **s) Was the work subject to academic peer review?** | Please select. | |
| **t) Have you retained the copyright for the work?** | Please select. | |
| [If no, please seek permission from the relevant publisher and check the box next to the below statement]: ☐ *I acknowledge permission of the publisher named under 1b to include in this thesis portions of the publication named as included in 1a.* | | |
| **17. For a research manuscript prepared for publication but that has not yet been published** (if already published, please skip to section 3)**:** | | |
| **m) Has the manuscript been uploaded to a preprint server?** (e.g. medRxiv): | Yes | **If yes, which server?** medRxiv |
| **n) Where is the work intended to be published?** (e.g. names of journals that you are planning to submit to) | BMJ Open Quality | |
| **o) List the manuscript's authors in the intended authorship order:** | Baneen Alhmoud, Timothy Bonnici, Riyaz Patel, Daniel Melley, Louise Hicks and Amitava Banerjee | |

| | |
|---|---|
| **p) Stage of publication** | Undergoing revision after peer review |

| |
|---|
| **18. For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4**):** |
| Click or tap here to enter text.<br>BA, AB and TB conceived the study, BA carried the interviews and surveys with guidance from TB, DM, and LH. Data analysis was conducted by BA with guidance from AB. BA wrote the initial draft of the manuscript and all authors contributed to the interpretation of findings and revision to the manuscript. |
| **19. In which chapter(s) of your thesis can this material be found?** |
| Chapter six |
| **20. e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work): |

| | | | |
|---|---|---|---|
| **Candidate:** | Baneen Alhmoud | **Date:** | 25/07/2022 |
| **Supervisor/ Senior Author** (where appropriate)**:** | Prof. Amitava Banerjee | **Date:** | 26/07/2022 |

# UCL Research Paper Declaration Form

## Referencing the doctoral candidate's own published work(s)

Declaration (5)

Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:

- have been uploaded to a preprint server;
- are in submission to a peer-reviewed publication;
- have been published in a peer-reviewed publication, e.g. journal, textbook.

*This form should be completed as many times as necessary. For instance, if you have seven thesis chapters, two of which containing material that has already been published, you would complete this form twice.*

| | | |
|---|---|---|
| **21. For a research manuscript that has already been published** (if not yet published, please skip to section 2)**:** | | |
| **u) Where was the work published?** (e.g. journal name) | Click or tap here to enter text. | |
| **v) Who published the work?** (e.g. Elsevier/Oxford University Press): | Click or tap here to enter text. | |
| **w) When was the work published?** | Click or tap to enter a date. | |
| **x) Was the work subject to academic peer review?** | Please select. | |
| **y) Have you retained the copyright for the work?** | Please select. | |
| [If no, please seek permission from the relevant publisher and check the box next to the below statement]: ☐ *I acknowledge permission of the publisher named under 1b to include in this thesis portions of the publication named as included in 1a.* | | |
| **22. For a research manuscript prepared for publication but that has not yet been published** (if already published, please skip to section 3)**:** | | |
| **q) Has the manuscript been uploaded to a preprint server?** (e.g. medRxiv): | Yes | **If yes, which server?** medRxiv |
| **r) Where is the work intended to be published?** (e.g. names of journals that you are planning to submit to) | BMJ Quality Open | |
| **s) List the manuscript's authors in the intended authorship order:** | Baneen Alhmoud, Daniel Melley, Nadeem Khan, Timothy Bonnici, Riyaz Patel and Amitava Banerjee. | |

| | |
|---|---|
| **t) Stage of publication** | Submitted |

**23. For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4**):**

DM has developed the project plan, and NK executed the development with guidance from DM. BA evaluated the dashboard, including interviews and analysis, with the guidance of AB. BA wrote the manuscript, and all authors contributed to the finding's interpretation and revision of the manuscript.

**24. In which chapter(s) of your thesis can this material be found?**

Chapter seven

**25. e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work):

| | | | |
|---|---|---|---|
| **Candidate:** | Baneen Alhmoud | **Date:** | 25/07/2022 |
| **Supervisor/ Senior Author** (where appropriate)**:** | Prof. Amitava Banerjee | **Date:** | 26/07/2022 |

## Abstract

The broad adoption of the National Early Warning Score (NEWS2) was formally endorsed for prediction of early deterioration across all settings. With current digitalisation of the Early Warning Score (EWS) through electronic health records (EHR) and automated patient monitoring, there is an excellent opportunity for facilitating and evaluating NEWS2 implementation. However, no evidence yet shows the success of such standardisation or digitalisation of EWS in cardiac care settings. Individuals with cardiovascular disease (CVD) have a significant risk of developing critical events, and CVD-related morbidity is a critical burden for health and social care. However, there is a gap in research evaluating the performance and implementation of EWS in cardiac settings and the role of digital solutions in the implementation and performance of EWS and clinicians' practice.

This PhD aims to provide high-quality evidence on the effectiveness of NEWS2 in predicting worsening events in patients with CVD, the implementation of the digital NEWS2 in two healthcare settings, the experience of escalation of care during the COVID-19 pandemic, and the evaluation of EHR-integrated dashboard for auditing NEWS2 and clinicians' performance.

Chapter One: Introduction.

This chapter discusses the concept, history, and development of EWS until the standardised digitally assisted EWS in different settings. It shows the need for appropriate EWS for individuals with CVD and the importance of technological health solutions for prediction of deterioration, and escalation. In the context of the current COVID-19 pandemic, the complexity of patients and rapid responses impact the performance and implementation of EWS. From a background of cardiac critical-care and digital transformation background, the experience has motivated the research of EWS for deteriorating patients with CVD and digital solutions in the COVID-19 context.

Chapter Two: Methods.

The chapter discusses the methodologies, frameworks followed, and data sources used to conduct the methodology. Mixed methods were followed to give deep understanding of the quantifiable results and qualitative data as integrating in the process. The chapter explained the rationale for tools and methods applied. The first study was a systematic review of EWS in different settings. Then, a retrospective cohort validation was conducted using three health data sources. A scoping review of the escalation of care led to an implementation evaluation through nurses' interviews and surveys. Finally, a mixed methods approach was used to evaluate quality improvement.

Chapter Three: Systematic Review.

- The performance of Early warning scores in different subgroups and settings.

In a systematic review, I examined the predictive performance of different EWS in different clinical settings. Findings showed that validation studies of EWS have been heterogeneous in their methodology, performance measures, and studies in each subgroup. The validation of EWS performance and EHRs integrated with EWS were very limited in specialised settings, including cardiac patients. Therefore, there is a need to validate the performance of EWS in patients with CVD and examine the integration of EHRs into facilitating digital systems.

Chapter Four: Retrospective Evaluation.

- The performance of digital NEWS2 in patients with CVD.

The study investigated the performance of digital NEWS2 in predicting critical events in a specialised cardiovascular setting (St Bartholomew's Hospital). The performance in patients with CVD was insufficient for early prediction of deterioration. Supplementing NEWS2 with age and cardiac rhythm improved discrimination for cardiac patients, and age improved accuracy for COVID-19 cases. However, there is a need to explain the escalation of care and the implementation of digital EWS to understand the experience in practice.

Chapter five: Scoping Review.

- Escalation of care in the COVID-19 pandemic.

This study investigates the experience of escalation of care and factors leading to its success or failure during the COVID-19 pandemic. Emergency plans adjusted the escalation strategy while a lack of resources and learning opportunities challenged the adjustments. Organised workload and competent management facilitated the escalation of care; however, the role of EWS was not explored. The application of EWS in the context of the pandemic for escalation of care and EHR integration is to be explored in cardiac and non-cardiac settings.

Chapter Six: A qualitative study.

- The implementation of digital NEWS2 in cardiac and general hospital settings.

Following NEWS2 performance evaluation and reviewing the escalation of care, the implementation of NEWS2 as a digitalised systemic intervention for escalation requires evaluation. This study evaluated the implementation of EHR-integrated NEWS2 in a cardiac care setting and a general hospital setting in the COVID-19 pandemic. The value of NEWS2 was partly positive in escalation, yet concerns led to undervaluing NEWS2, particularly in cardiac care. Challenges, such as clinicians' behaviours, and lack of resources and training, limit implementation success. EHR integration and automation are solutions that are not fully employed. Evaluating the work of health professionals utilising advanced health technology may help manage the challenges in managing acutely ill patients.

Chapter Seven: Quality Improvement Study.

- Evaluating a dashboard for NEWS2 and deteriorating patients.

The qualitative study findings indicated the need to address the challenges facing clinicians utilising advanced health technologies. This study evaluated a real-time dashboard of NEWS2 and deteriorating patients’ assessment, referral, and therapy. The dashboard is perceived as a facilitator for auditing NEWS2 and escalation of care to improve practice. However, guiding clinicians and adjusting data sources and metrics could enhance functionality. NEWS2 recording, referral and assessment have improved after the dashboard rollout.

Chapter Eight: Discussion.

In this chapter, I assimilated the findings across studies. Findings on the predictive ability for CVD patients, the success of NEWS2 in cardiac care, implementation challenges and digital facilitation were reviewed. The performance of NEWS2 may correlate with how it is implemented in cardiac settings resulting in the prediction of deterioration effectiveness. EHR-integrated digital solutions can facilitate the success of NEWS2 in the escalation of care if improved and fully employed. Better development of EWS for cardiac disease and understanding the relationship between implementation, performance, and digitalisation may enhance patient outcomes.

## Impact statement

The thesis has discussed various areas in deteriorating patients' management using Early Warning Scores in cardiac care and applying digital health solutions. The impact of this research can be of great potential in the clinical settings, research, academia, clinical guidelines and through the dissemination of findings.

Clinical impact

Research findings may guide clinical experts to use their knowledge and experience when utilising EWS while continuing to assess the validity of NEWS2 for patients with CVD and examining suggested adjustments to improve its application. In addition, the report guides clinicians to incorporate the validity of EWS as a tool with the implementation elements, including the organisational support and the culture in the hospital setting when implementing or updating an EWS. Findings may be considered to review and adjust digital health solutions to serve as facilitators for EWS and to review the EWS in EHRs regularly to find areas needing alteration.

Clinical guidelines

The findings addressed the need to take clinical experts' opinions when planning the development and validation of standardised or specialised EWS. In addition, it is suggested to involve clinical experts in updating the guidelines on EWS use, including parameter thresholds and the appropriate response to alarms.

Academically

The research highlights the need for integrating Health informatics competencies into medical training curricula and implementing continuous digital health training during clinical practice while tailoring training to fit the needs of health professionals from different levels.

Research

The findings addressed a need for potential research, including prospective validation studies of EWS in patients with CVD, qualitative research exploring the ethnography of the work culture, examining the role of EWS in escalating deteriorating patients at the time of the pandemic and examining the clinical benefit of the digital tools facilitating EWS.

Dissemination of findings

Two chapters in the thesis have already been peer-reviewed, published in a medical journal, and presented at two international conferences: cardiovascular care and healthcare systems-related conferences. One chapter is accepted to be presented at an international conference for intensive care medicine, and other studies are already undergoing peer review for publication.

# Table of Contents

## Table of figures

## List of tables

## List of abbreviations

| | |
|---|---|
| EWS | Early Warning scores. |
| CVD | Cardiovascular diseases. |
| CHD | Coronary heart disease. |
| COVID-19 | Corona virus disease. |
| CAD | Coronary artery disease. |
| ASCVD | Atherosclerotic cardiovascular disease. |
| TIMI | Thrombolysis in myocardial infarction score. |
| CHA2DS2-VASc. | Congestive heart failure, hypertension, age>75 (doubled), Diabetes, stroke(doubled), vascular disease, age 65 to 74 And sex category (female). |
| GRACE | Global Registry of Acute Coronary Events score. |
| ICU | Intensive care unit. |
| CCRT | Critical care response team. |
| RRS | Rapid response system. |
| MET | Medical emergency team. |
| RRT | Rapid response team. |
| CCOT | Critical care outreach team. |
| CPR | Cardiopulmonary resuscitation. |
| AWTTS | Aggregate weighted 'track and trigger' systems. |
| MEWS | Modified Early Warning Score. |
| ViEWS | Vitalpac Early Warning Score. |
| NEWS | National Early Warning Score. |
| NEWS2 | Updated National Early Warning Score. |
| RCP | Royal College of Physicians. |
| REMS | Rapid Emergency Medicine Score. |

| | |
|---|---|
| qSOFA | Quick sequential organ failure assessment. |
| OEWS | Obstetric Early Warning Score. |
| ACS | Acute coronary syndrome. |
| AF | Atrial fibrillation. |
| IHCA | Intra hospital cardiac arrest. |
| AUC | The area under the curve. |
| PPV | Positive predictive value. |
| EHR | Electronic health records. |
| CAGR | Compound annual growth rate. |
| PRISMA-P | Preferred Reporting Items for Systemic Reviews |
| CHARMS | Checklist for Critical Appraisal and Data Extraction for Systematic Reviews |
| PROBAST | Tool to Assess Risk of Bias and Applicability of Prediction Model Studies |
| RCT | Randomised Controlled Trials |
| AUC | Area under the curve |
| ED | Emergency department |
| GI | Gastrointestinal diseases |
| HOTEL | Hypotension, Oxygen Saturation, Temperature, ECG abnormality, Loss of independence score. |
| Worthing | Worthing physiological scoring system; |
| TREWS | Triage in Emergency department Early Warning Score |
| SOS | Search out Severity score. |
| HEWS | Hamilton Early Warning Score. |
| RA | Respiratory arrest. |
| CA | Cardiopulmonary arrest. |
| OF | Organ failure |

| | |
|---|---|
| HI | Health Informatics |
| UCL | University College London |
| UCLH | University College London Hospital. |
| ICD-10 | International Statistical Classification of Diseases and Related Health Problems 10th Revision |

# Chapter 1

## Introduction

### Cardiovascular diseases

*Disease prevalence*

Cardiovascular diseases (CVDs) were the primary cause of death in 2019. The estimated number of deaths attributed to CVD was 17.9 million people in 2019, representing 32% of the total deaths worldwide and estimated to be higher by 2030. Of the 17 million deaths due to non-communicable diseases, 38% were caused by CVD in 2019. Of these deaths, 85% were due to stroke and heart attacks, and coronary heart disease (CHD) is estimated to be the leading cause of deaths in 14.9% of males and 13.1% of females d worldwide (1,2).

In the UK, CVD affects around 7,6 million people and is one of the most significant causes of disability and death. CVD causes one-quarter of premature deaths – one death every three minutes- which represents a significant gap in health expectancy. The most common type of CVD, CHD, is a leading cause of death in the UK. Coronary heart disease and stroke came right after COVID-19 and Alzheimer's disease in the top five  UK causes of death in 2020 (3) (Figure 1). Although death rates from cardiovascular disease have fallen by more than 75% from 1961 to 2020, which may be related to people living longer and improvements in medical diagnosis and care, it remains a significant burden that deserves national health attention (Figure 2).

The total healthcare cost of CVD cases in the UK is estimated at £9 billion annually, and the total cost, including disability and informal care, is estimated at around £19 billion yearly(4).

CVD is a term for a group of disorders of the heart, peripheral tissues, and the brain. It encompasses CHD, coronary artery disease (CAD), atherosclerotic cardiovascular disease (ASCVD), rheumatic heart disease, congenital disease, heart failure, all diseases of the circulatory system, peripheral arterial disease, deep vein thrombosis and pulmonary embolism (5,6). One of the NHS major plans identifies CVD as “the single biggest health condition” and a clinical priority to focus on for lives can be saved in the next ten years (7).

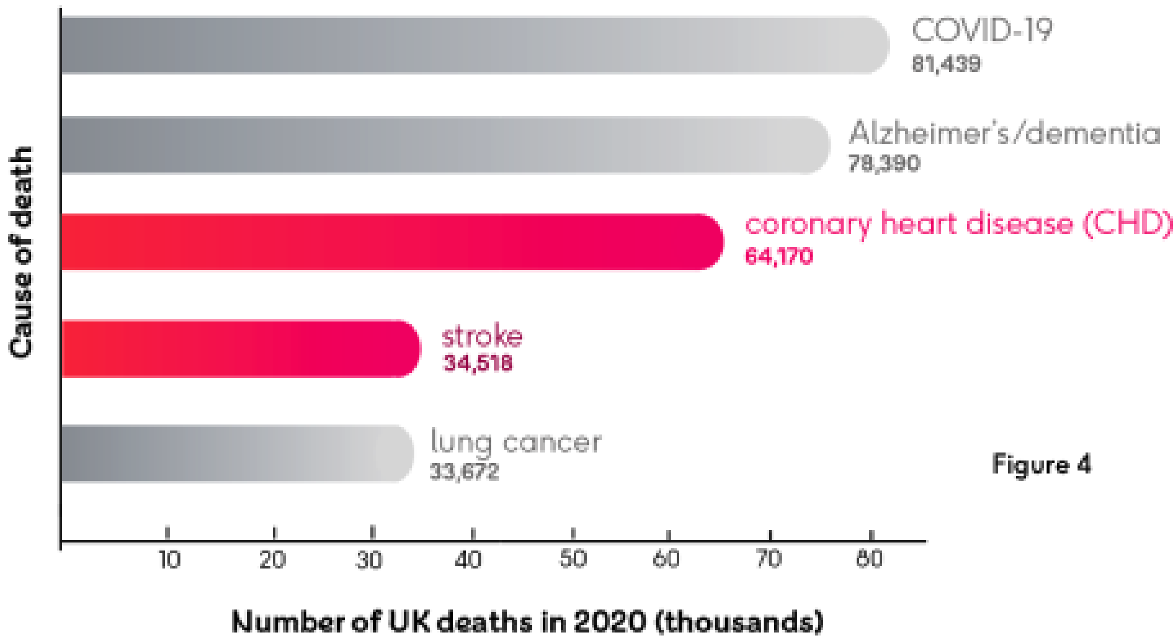



Figure 1. The top 5 causes of death in the UK in 2020 (3).

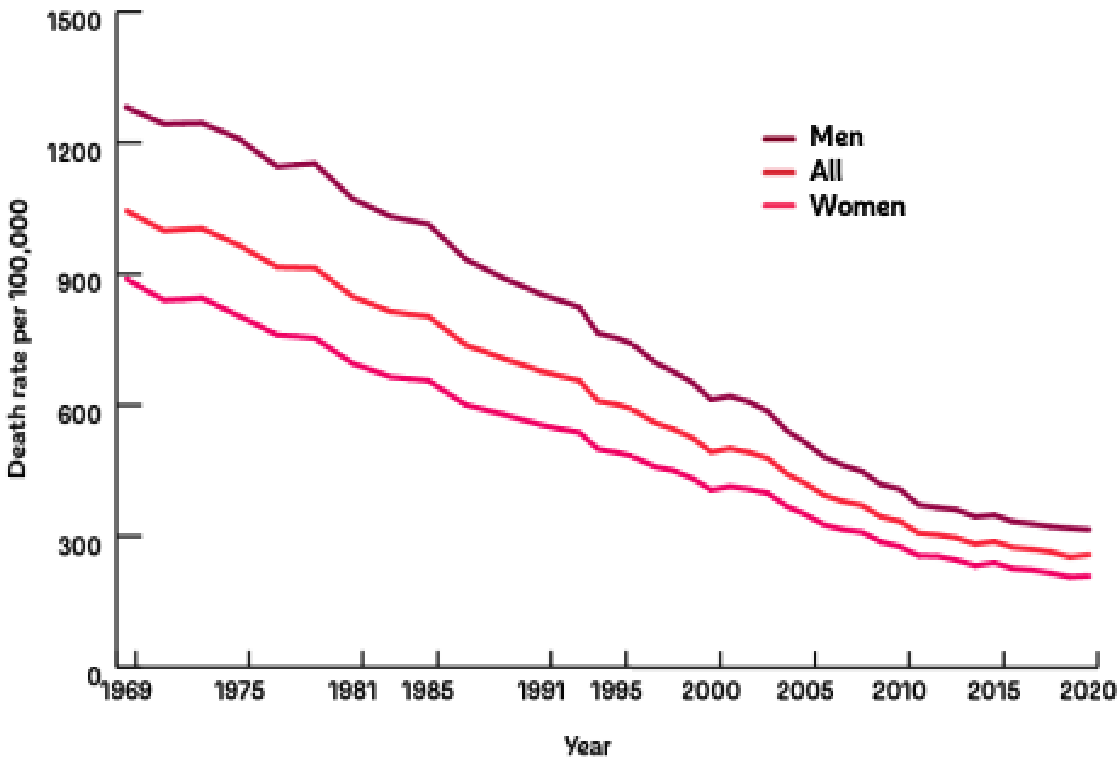



Figure 2. Death rates from heart and circulatory diseases (CVD),UK, from 1969 to 2020 (3).

### *Cardiovascular risk scores*

The majority of CVD are avoidable when risk factors are addressed as early so management can be effective and adverse events are prevented (2). Health professionals use cardiovascular risk factors to identify patients who will benefit from prevention therapy at a primary level and deliver it to those at a higher risk than others for developing CVD(8,9). A risk is a probability of having or developing an unwanted event or condition or the value of that probability by the event severity measured(10). Risk scores are derived from a quantifiable measure of risk factors in an evidence-based equation that produces a numerical score for the estimated risk of a disease, condition, or an event. Various cardiovascular risk scores have been produced over the years for the prediction of risk of disease and to inform management. Standardised and disease-specific risk scores have been applied to individuals with CVD to provide clinical information to support or guide decision-making in the clinical setting (11).

### *Prognostic cardiovascular risk scores*

The concept of risk scores models is to estimate the probability of developing a condition or an outcome, termed prognosis risk scores. For CVD, prognostic risk scores were developed for the estimated long-term cardiovascular clinical outcomes. These models are derived from clinical trials and are used globally in primary and secondary health settings. Among the thoroughly validated and broadly utilised risk scores are the Framingham risk score for the risk of coronary heart disease (1), Thrombosis In Myocardial Infarction (TIMI) for the likelihood of cardiovascular ischaemic events (12), CHA2DS2-VASc for predicting thrombosis in patients with atrial fibrillation (13), and The Global Registry of Acute Coronary Events (GRACE) for mortality prediction in acute coronary syndrome (14). These scores were developed to predict the clinical outcome in a period from months to years in a patient's life in order to plan a targeted preventive treatment. However, rapid worsening in acute illness in patients' conditions requires different stratification methods. Risk factors and period of recognition of rapid deterioration vary from long-term prognostic risk scores to early and rapid recognition tools. In the latter, symptoms in hours or days prior to a worsening event account for their effectiveness in predicting a severe critical illness.

## Management of critical illness

### *Acute illness*

Acute illness is a medical condition that occurs in a short period. The illness can be minor or serious. Minor acute illnesses are common conditions for general practitioners, while serious illnesses represent an aggravation of an existing chronic illness or a sudden onset of undiagnosed disease (15). Serious or major acute illnesses vary in their representation according to the origin and presenting symptoms. They appear severe and often sudden in onset and change or worsen rapidly over time (16). The symptoms in the rapid onset of severe illness can be tricky for doctors and nurses to identify and anticipate deterioration. The term acute illness is often used to reflect a major or severe illness. Some of the most common severe illnesses include diabetic coma, cardiac arrest, epilepsy, stroke, sepsis, pneumonia, and increasing respiratory failure resulting from severe COVID-19 (17,18). Severe acute illness is frequently encountered in clinical practice and often requires rapid and intensive care. In England, 291,679 to 235,262 critical care records were registered in intensive care units (ICU) from 2019, when the COVID-19 pandemic began, until 2021(19). The numbers of critical care reflected the impact of the severity of critical illness caused by the pandemic and other illnesses associated with severe events on ICU admissions. Patients with cardiovascular diseases account for a higher critical care period than other patient groups. Data from the King's Fund critical care in 2020 shows that hospitalised patients with cardiovascular or respiratory organs-related conditions require more periods of critical care support compared to support for patients with other organ diseases (20) (Figure 3).

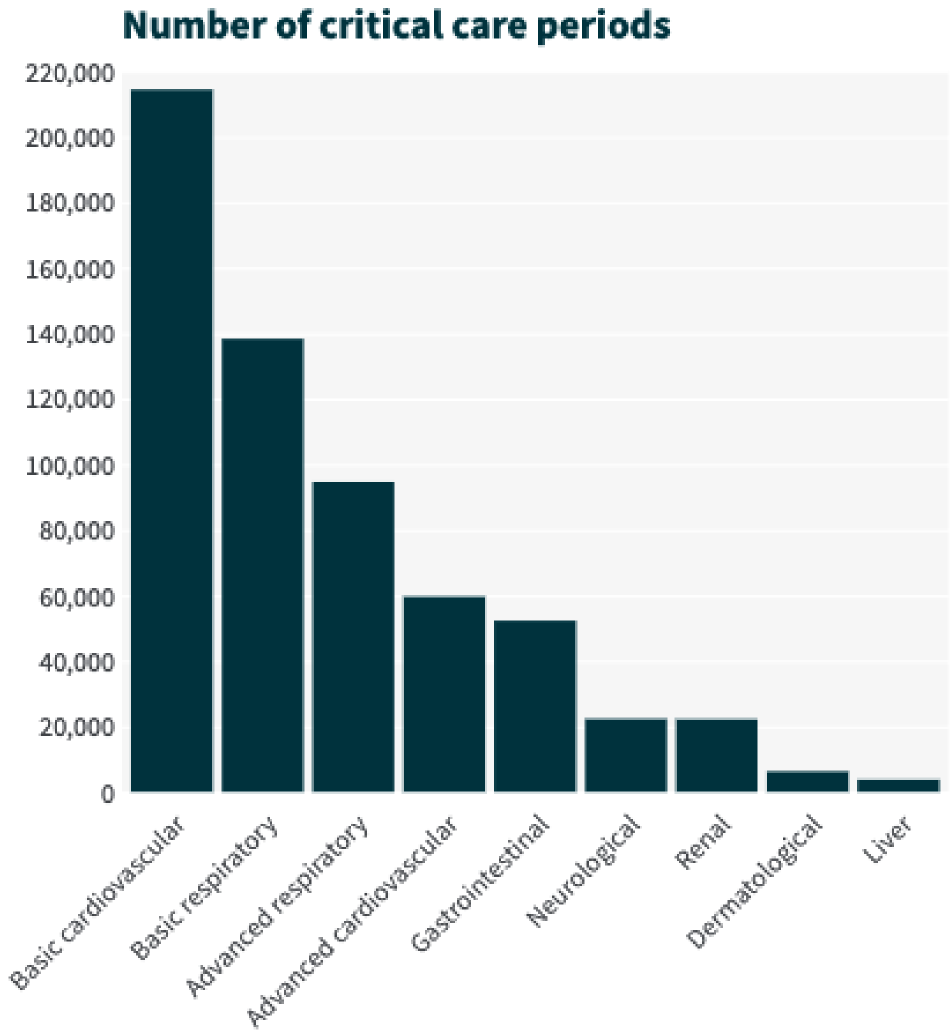



Figure 3 . Cardiovascular and respiratory support account for a large share of critical care activity (20).

### *Mechanism of critical illness*

A significant portion of patients experiences a serious acute illness that requires critical care during their hospitalisation. The major acute illness has specific characteristics around which recognition and management are shaped (15). The “alarm symptoms” phase, when symptoms are presented as flags indicating a patient may be acutely ill or potentially experience a critical condition related to a serious underlying problem, is significant in acute illness (15). This phase proceeds with the occurrence of a serious illness or the exacerbation of an existing condition. A set of subjective and objective criteria of physiological deterioration take place in this phase, including neurological abnormality, vital signs changes, or sudden pain (21). These changes are recorded by clinical staff up to 24 hours prior to serious events, as reported by Franklin (1994), Hillman (2002), Kause (2004), Shein (1990) and Smith (1998)(22–26). Other studies reported observing the disturbances eight hours before the events (27–29), while others indicated observing patients to be at high risk between 8 and 48 hours before the serious event occurring (27). It was noted that up to 84% of patients who experienced cardiac arrest had experienced slow deterioration in vital signs. Many cases admitted to the ICU from the ward needed critical response management prior to admission (21,26,30). Reaching a severe clinical event affects the patients' prognosis negatively and is found to increase the mortality rate (31). Recognising critical illness is a vital yet complex process. It requires a structured methodological preventive care plan.

### *Inadequate critical illness management*

Significant issues were identified in the quality of care prior to critical illness, such as cardiac arrest and unplanned intensive care transfers. In previous studies, the instability of physiological parameters was found to be unidentified or poorly managed in the alarming symptoms phase of critical illness (18,21,32,33). Inadequate or suboptimal care has been shown to contribute to most morbidity and mortality cases. Suboptimal care was found in 54% of the cases with failure to recognise Instability and escalate to a senior clinician or critical care response team (CCRT) (30). Studies found that up to 27% of deaths were potentially preventable (34–36). Nonetheless, it has been demonstrated that nurses and health care workers may fail to interpret these changes accurately and therefore fail to intervene. As a result, there are fewer chances to prevent critical events such as cardiac arrest or sepsis (25,30,37,38). A previous study in the UK found that 65% of deaths of patients after resuscitation failed were avoidable, and 36% of patients admitted as an emergency cases to the intensive care were unrecognised in the symptoms phase and inappropriately managed (39). Supporting findings in a national confidential enquiry for acute illness management led to the recommendation of systemic recognition and response to deterioration in healthcare settings (40).

### *Rapid response models*

Recognising the complexity of managing clinical deterioration has produced the need for a structured system. Forming a complete system that enables clinicians to manage critical illness is necessary. The rapid response system (RRS) is used to describe the whole scheme that provides a “safety net” for patients at risk of imminent critical illness and who have needs unmatched by resources (41). In the RRS, there is an afferent, or the “crisis detection” limb, which detects an event and triggers a response. An efferent or an “acting” limb is activated when a sign is detected. This is when the higher-capability team – referred to as the Medical Emergency Team (MET), Rapid Response Team (RRT), or Critical Care Outreach Team (CCOT) – is involved. This response should provide the necessary stabilisation of the patient and thus prevent serious deterioration. The consensus recommendation regarding medical emergency teams (41) was that the afferent limb must follow a systematic approach of utilising identified objective criteria, along with clinical subjective criteria to complement the assessment in discriminating which patients need an emergency response (Figure 4).

In 2005, the European Resuscitation Council enforced the importance of recognising critical illness and preventing serious deterioration such as cardiac arrest in their presented “chain of survival” (42). This included an early response to cardiac arrest with early CPR and advanced life support. Early recognition remained a complicated task and required attention. Smith (2010) claimed that the RRS might be unnecessarily complex, with “special” nervous system terminologies that add extra work to routine monitoring by nursing staff. He presented a plan called “chain of prevention”. The aim was to assist healthcare settings in building a system clinicians can refer to when patients experience a clinically acute phase in the hospital (43). It consists of five rings: education, monitoring, recognition, call for help, and response (Figure 5).

In both models, the RRS and the chain of prevention, there is agreement that detecting deterioration and rapid response are vital. However, the chain of prevention is expressed in more easily understood and memorable words. Although these actions seem inevitably achievable as routine parts of care delivery – such as continuous monitoring – nonetheless, recognition is a fundamental, yet still a difficult step in the process (43,44). Various methods have been followed to guide recognition (45) while searching for an optimal layout for acutely ill patient management.

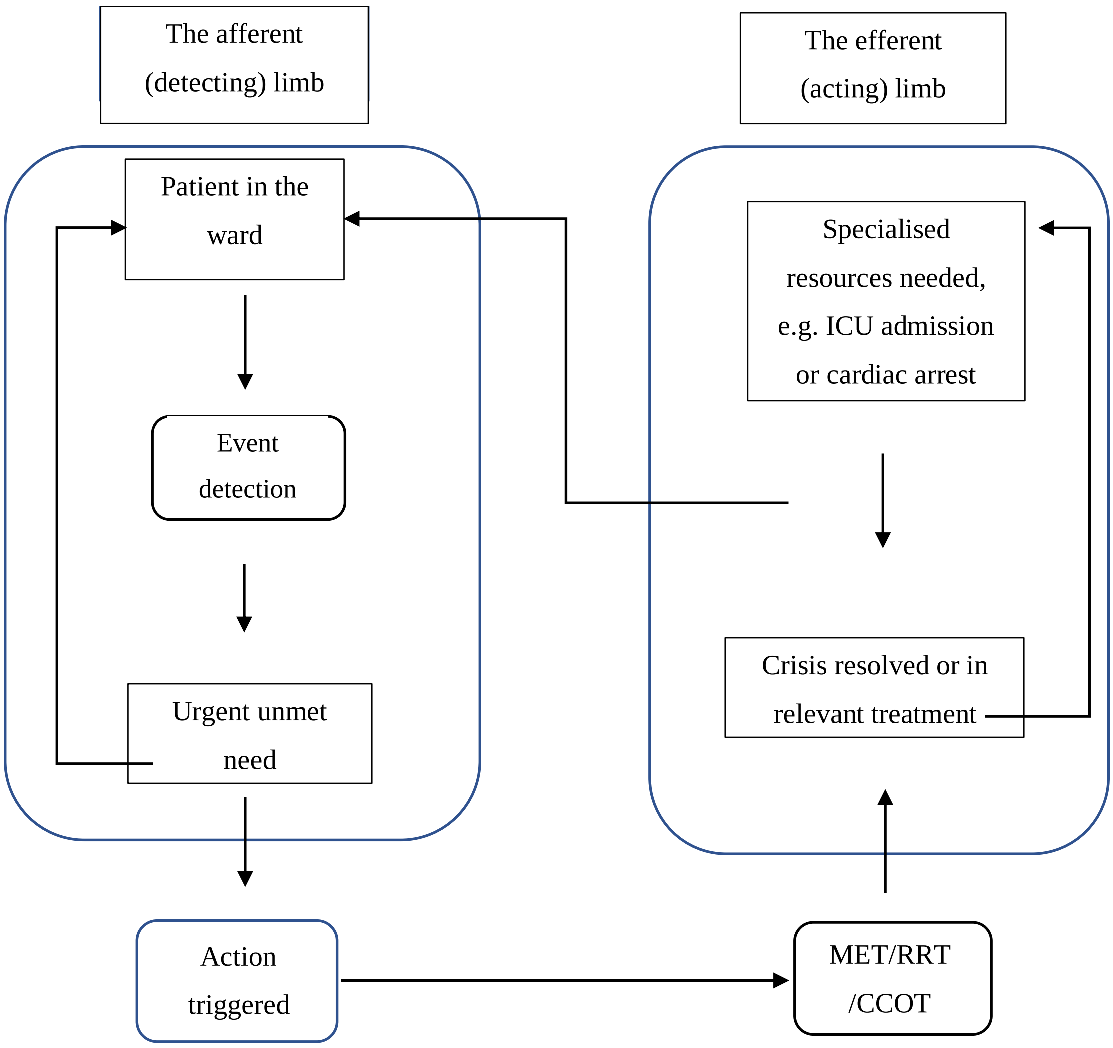



Figure 4. Afferent and efferent limbs in RRS (41).


Figure 5. The chain of prevention by © Gary Smith, 2010 (43).

## Early Warning Scores

### *Development of EWS*

Research findings supporting the possibility of preventing deaths and unanticipated critical events led to the introduction of early detection innovations, the Early Warning Score (EWS) systems (46). EWS are tools designed for the systemic monitoring of a patient's physiological parameters to match the afferent limb of the RRS. They are formed of a simple algorithm with an aggregate-weighted track-and-trigger system (AWTTS) that evaluates the physiological parameters, such as heart rate, systolic blood pressure, temperature, respiration rate, and neurological status, to produce either a single or an aggregate score depending on points given to each parameter deviating from normal.

The concept of EWS was initiated in 1997 by Morgan, William and Wright in a presented poster at a conference(47). The first track and trigger system was developed as part of Australia's wider rapid response system to facilitate critical care in hospital wards (48). The system routinely monitored a selected set of vital signs and other indicators. If a threshold hits the point of an abnormal value, it triggers a response. The response involves activating a critical care response team or a rapid response team.

The first published validation study was conducted in 2001 on the Modified Early Warning Score (MEWS)(49). EWS tools continued to emerge; in 2010, ViEWS was developed based on previously published EWS and formed by antecedents to critical events using experts' opinions (50). Following that, the National Early Warning Score (NEWS) was introduced in 2012 by the Royal College of Physicians (RCP) in the UK. It was recommended for early detection and response for deteriorating patients (51) (Appendix 1 and Table 1). The RCP produced an updated version in 2017, named NEWS2, with modifications to NEWS in terms of appropriate scoring for type 2 respiratory failure, recognising confusion as a sign of deterioration, and more emphasis on identifying serious sepsis (52,53) (Table2). NEWS2 has received large-scale implementation in the NHS hospitals in England, advocating a standardised detection and response system for critical events as key elements of patient safety and improved outcomes. In addition, the NICE recommendation advocates their widespread use (54). The various systems developed were associated with the scope of specialist critical care teams, including CCOT, RRT, and the medical emergency team (MET). Nowadays, EWS is widely used in developed countries (e.g., the USA, UK, Netherlands, and Australia) that seek simple, reliable, and successful solutions to prevent or minimise healthcare burdens.

Table 1. The National Early Warning Score (NEWS) (51).

| PHYSIOLOGICAL PARAMETERS | 3 | 2 | 1 | 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|
| Respiration Rate | ≤8 | | 9 - 11 | 12 - 20 | | 21 - 24 | ≥25 |
| Oxygen Saturations | ≤91 | 92 - 93 | 94 - 95 | ≥96 | | | |
| Any Supplemental Oxygen | | Yes | | No | | | |
| Temperature | ≤35.0 | | 35.1 - 36.0 | 36.1 - 38.0 | 38.1 - 39.0 | ≥39.1 | |
| Systolic BP | ≤90 | 91 - 100 | 101 - 110 | 111 - 219 | | | ≥220 |
| Heart Rate | ≤40 | | 41 - 50 | 51 - 90 | 91 - 110 | 111 - 130 | ≥131 |
| Level of Consciousness | | | | A | | | V, P, or U |

Table 2. The National Early Warning Score (NEWS2) (53).

| 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 | |

### *Standardisation of early recognition*

Following the spread of EWS, many specialised tools have emerged with designs focused on particular subgroups, such as the Rapid Emergency Medicine Score (REMS) (55) for the emergency departments, Quick Sequential Organ Failure Assessment (qSOFA) (56) for patients with infections, and Obstetrics Early Warning Score (OEWS) for obstetric patients (57). While recognising the differences clinically, EWS moved away from the intended qualities of simplicity and timeliness of assessment (47). For example, some of these tools rely on parameters not available in the first hours of assessment, such as blood and imaging tests (58–60).

From fragmented and unsuitable early assessment via specialised tools, EWS has shifted back to standardised prediction models such as NEWS and NEWS2. NEWS2 was recommended as the standard system to be followed in ambulances and hospitals in the UK across all patient groups and settings. Despite the widespread application and recommendation of a standardised early warning scores system, there is a lack of evidence on the significance of their validation in various disease groups and settings and their significance on patient outcomes. (61,62).

Fragmented systematic reviews have investigated the performance of EWS in various settings (55,63–66), two of which were conducted by the same team who investigated single and aggregate track-and-trigger scores (65,66). The reviews by Smith et al. (65) and Smith et al. (66) examined general patients' settings, while the rest examined EWS in medical settings (61), medical and surgical settings (64), emergency departments (55), and patients with sepsis (63). Smith et al. (64) presented results contrary to an older study by Gao et al. (24), which was conducted more than a decade earlier. Smith et al. showed an improved predictive ability which did not support the study by Gao et al., which indicated an unacceptably low performance. Nonetheless, the findings may be limited due to inclusion criteria, and none of the studies included in Gao et al. (61) met the methodological quality criteria. The systematic review by Wuytack et al. (55) in emergency department settings demonstrated that most of the studies (28 out of 36) were validated externally and with a potential bias due to quality studies. However, the predictive ability was positively reflected by certain EWS that were not used as frequently as MEWS, which had a less predictive ability.

On the other hand, the review of studies on EWS in patients with sepsis (63), with the majority of studies utilised MEWS, failed to demonstrate effectiveness in predicting mortality (63). However, the review had a narrow inclusion of the EWSs examined and exclusion of patients with specific diseases (e.g. meningitis and pneumonia). Moreover, systematic reviews of the many other patients' classifications and settings are absent.

There is no clear evidence of the effectiveness of EWS standardisation when used across different disease subgroups and settings. Patients in specialised care settings are given special consideration by physicians and nurses with regard to specific disease-related symptoms. Arguably, EWS has to be tailored to each specialised patient's group in order to be reliable (67). Despite the enthusiasm for unifying the management of deteriorating patients, standardised systems may not be the safest method in all subgroups. Given that the primary intention of implementing EWS is preventing and reducing critical events, enforcing standardisation has to be explored further in different patient categories.

### *Rapid deterioration and EWS in CVD*

Risk stratification models for patients with CVD were developed to predict long-term worsening conditions rather than early detection of acute events. Scores such as GRACE for mortality estimation in patients with ACS, and CHADSVASC for stroke risk in patients with AF, are commonly used in CVD cases. However, rapid deterioration of the condition of a patient with cardiovascular disease is common. Severe acute illness in patients with CVD develops in a short period in an unpredictable pattern by clinicians.

Both in hospital and out of the hospital, cardiac arrest is a critical medical emergency affecting patients with CVD. The UK survival rate is one out of ten cases. In-hospital cardiac arrests (IHCA) in England reach around 20,000 cases yearly, with an estimated resuscitation and post-arrest care cost of £50 million annually (31). Individuals with cardiac conditions, such as ischaemia and CAD, risk developing cardiac arrest (68,69). Conditions such as heart attacks, cardiomyopathies and myocarditis are the leading causes of cardiac arrest (70).

Over the years, the awareness of the need for prediction of early deterioration in patients with CVD has been increasing. The development and implementation of various standardised EWS were applied in patients with various disease aetiologies and clinical settings, including patients with CVD and cardiac care hospital settings. However, the development of disease- or setting-specific EWS for CVD patients was minimal, poorly examined, and restricted in application to a subset of CVD patients (71,72). CVD-specialised model lacks the fundamental feature of EWS, namely, simple and rapid detection while commonly used EWS scores, i.e., MEWS, lack validation in different specialities, including cardiac clinical settings.

*Validation challenges*

It is essential to understand that assessing deterioration is a difficult task due to the complexity of the deterioration process and the plan of care. It is therefore challenging to evaluate the role of EWS on patients' outcomes. Validation studies vary in diverse aspects, mainly regarding the methodologies and tools evaluated. In the review conducted in 2007, 33 tools were identified as AWTTSs (61), and further EWS have been developed to-date.

There was no evidence of the superiority of a single EWS over the others. It is important to bear in mind the potential bias in validation research due to caution in interpreting the clinical application and the development or validation process.

From a clinical application perspective, the clinical course of critically ill patients is highly interrupted by confounding variables in clinical settings (47). Symptoms' compatibility with predefined EWS criteria is questionable in different subgroups. From a validation point of view, there are issues concerning the reliability of validation studies due to the method used to measure scores and critical events, which may have shifted away from the foundations of EWS use in clinical practice. The key aim of EWS is to identify a worsening condition in days to hours when the symptoms represent an embedding critical illness (73). Then, clinicians are alerted to respond early to rescue the patients from reaching a critical state. However, contrary to this target, EWS is evaluated based on a score reached 14 days to a month prior to a serious event or when damage has already occurred, such as death or ICU transfer (74). In addition, scoring systems were developed based on an aggregate scoring system or an associated algorithm which may result in disregarding a single parameter deviation if the algorithm does not count for a trigger point. In some cases, elevation in heart rate alone or temperature rise may indicate the necessity for a higher response than what is indicated by EWS guidelines (75). Furthermore, the calculation of inappropriately related physiological parameters to produce a score and trigger action may lead to failure to identify deteriorating patients.

Another validation concern is the statistical measures used in studies. The commonly used measure is the area under the curve (AUC). Other statistical measures used in validation studies include c-statistics and odds ratio. AUC is a measure of the performance of the diagnostic, which reflects the test performance at the possible cut-off values (76). On the other hand, C-statistic is often used to assess the ability of new variables to improve the prediction of event risk. At the same time, odds ratios are values obtained by logistic regression analysis representing the associations of biomarkers with clinical events (77). Despite the popularity of AUC, the inclusion of unrealistic cut-off values and the association between contradictory positive predictive value (PPV) and AUC in low-incidence settings raises questions regarding the reliability of the method of evaluating AUC (78). However, to evaluate the probability of decimation ability of EWS, AUC may be a valid measure with cautious applicability of measured cut-off values. Evaluating EWS using odd-ratios and c-statistics may be reliable for the association between variables and events with attention to the value of AUC brings to validating EWS. Consequently, one of the issues that may arise is the heterogeneity of validation measures which makes it difficult to draw a conclusion between various studies on a single or multiple EWS discrimination abilities in single or various diseases or settings.

### *Deficiency in implementation*

The implementation of NEWS and NEWS2 is considered routine practice in hospitals in the UK. Their widespread use, however, did not demonstrate significant improvement in clinical practice or patients' morbidity and mortality. The implementation by the hospital organisation and clinicians has contributed to the significance of EWS in clinical settings. The practice of nurses recording EWS was reported to carry multiple recording and scoring errors (64-86%)  in several studies (79–82). Errors were common in correctly allocating a score to a parameter, summation of the score value, and documentation of parameters value or score. Complete documentation of EWS score was observed in 50-69.5% of routine monitoring and EWS recordings (79,80,83). Errors in using EWS have been noted to affect the response of clinicians and RRT in the case of need for higher medical attention (79,84). As a result, less escalation would be carried to the patient at great risk of deterioration and more escalation to patients who were more stable than others.

Issues were recorded in the frequency and pattern of monitoring EWS-related physiological parameters and recording in patients' records. Evidence from previous studies suggests missed parts of routine observations or prolonged periods of recording after monitoring, especially during night shifts (85). It is suggested that patients who became physiologically unstable with missed or incomplete observations were not escalated at the right time, or clinicians' alerts were missed as a result (86). The UK National Safety reported that 14 of 64 patients who died had no observation for an extended period, and 30 patients had no action taken after observations were recorded (87). In addition, it has been observed in multiple studies that respiratory rate recording was poorly done by nurses (88–91).

From the application side, despite complete and appropriate recordings of observations, the escalation guidelines may not be followed as recommended. In previous randomised trials, there were deficiencies in alert calls when patients' conditions required and miscommunication between nurses and doctors. It was also observed that despite well-established EWS, insufficient activation of rapid response occurs (92,93).

Contributing factors to deficiency in observation, recording and escalation were identified in previous studies. Organisational, human-centric and system-related factors contribute to nurses' and physicians' practice (83,91). Such factors may correlate with the validity and reliability of EWS in different hospital settings.

### *Prediction of deterioration in the COVID-19 context*

Until May 2022, over 500 million cases were identified worldwide with COVID-19 since the beginning of the pandemic. While nearly 80% of the positive cases had mild symptoms or were asymptomatic, a subset of patients required hospitalisation due to developing severe COVID-19 disease (94). It is essential to recognise the need for prediction of early deterioration for those who develop a severe critical illness such as respiratory failure or pneumonia and the need for mechanical ventilation and ICU admission (95).

Severe COVID-19 often does not occur in isolation from other critical diseases. Clinical studies have reported an association between CVD and COVID-19. Patients with COVID-19 were at a high risk of developing CVDs, such as dysrhythmias, ischaemic and non-ischaemic heart diseases, myocarditis, pericarditis, heart failure and thromboembolism. Whereas pre-existing CVD is associated with worsening outcomes and a high risk of death in patients with COVID-19 (96–98) (Figure 6).

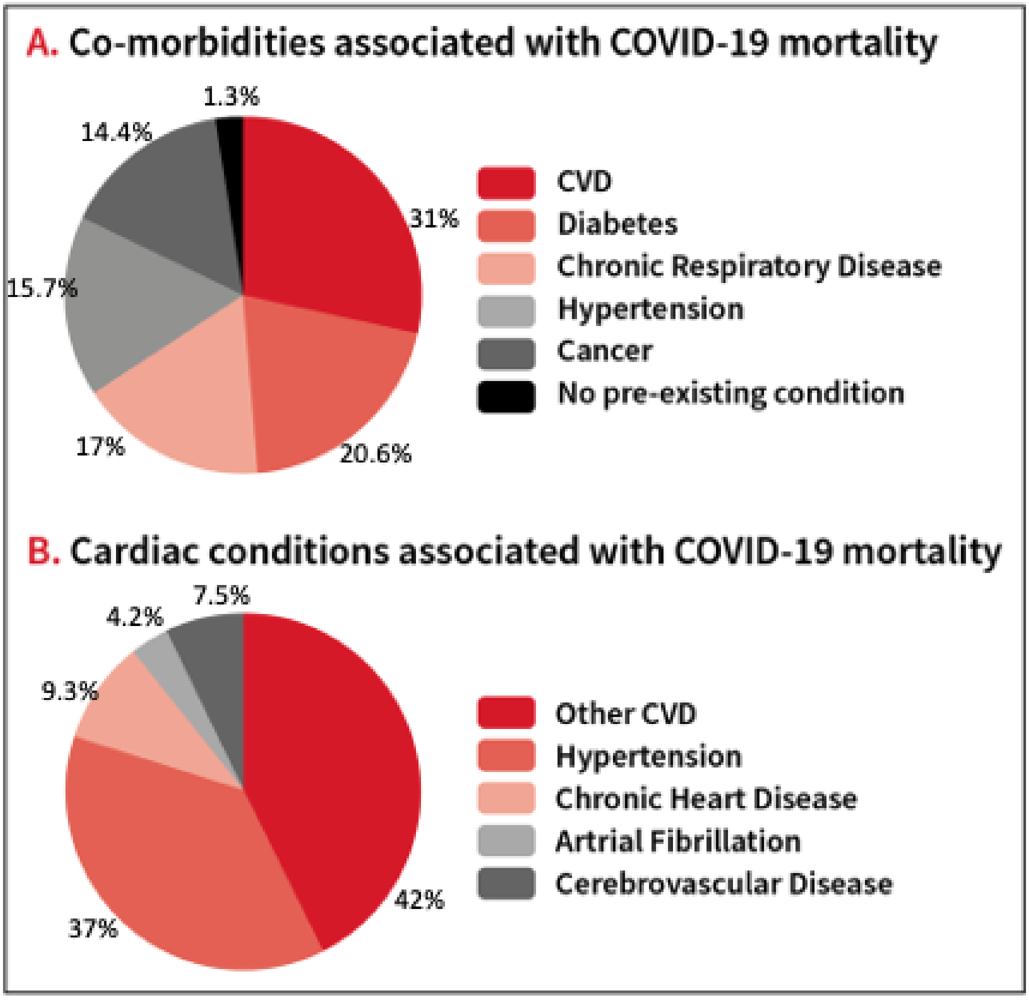



Figure 6. Distribution of CVD risk factors in COVID-19 mortality. (99)

With attention to this association and the complexity of this emerging disease, it is essential to consider the presence of COVID-19 when validating EWS tools in different disease groups and what is already known about their predictive ability in this emerging disease. There is little evidence of the predictive ability of the widely used standardised EWS, such as NEWS2, in hospitalised COVID-19 patients. Additionally, there were a number of COVID-19 specific risk and digital numeric scores were developed that were poorly validated in the actual hospitalisation context of COVID-19 while their generalisability is unknown (100–103). Given the observed association between CVD disease and COVID-19 severity and the current recommendation of utilising EWS for deterioration prediction, it is vital to explore their performance in patients with COVDI-19 in specialist settings.

From the healthcare perspective, the pressure of COVID-19 on healthcare systems was undeniably high and negatively affected resources and clinicians' daily tasks (104). With the increase in the number of admission to critical care, the complexity of patients care and escalating deterioration of hospitalised patients impact the daily routine of nurses and physicians(105,106). In addition, the rapid effect of the pandemic required significant changes in health care systems and policies, which have affected patients' pathways and clinicians' work plans. Routine observation and recording of physiological parameters and EWS and adherence to EWS and escalation guidelines may be affected due to enforced changes in nurses, doctors, and critical care teams. It is necessary to investigate the contributing factors to EWS implementation and the impact of COVID-19 on EWS utilisation and escalation of care practice.

## Digital implementation of EWS

### *Electronic health records integration*

For a long time since EWS was introduced, it has been applied in a paper format, filled in by staff nurses. As with any new health system application, healthcare staff may feel the load of additional work imposed on them. Cuthbertson and Smith (2007) reported that required routine documentation of EWS generates extra workload (48). With proper education on the application and documentation of EWS, recording an observation is expected to take only 30 seconds (73). However, the sum of those readings over a whole nursing shift may produce a feeling of burden for nurses. In addition, human error in documentation and scoring is expected behaviour in any work setting (see Appendix 1).

The work on embedding EWS into electronic data began in 2007 by Smith and colleagues to achieve greater accuracy when capturing data for EWS scoring (107). This work seemed underdeveloped since it was subject to the availability of EHRs in hospitals (73). The use of EHRs has grown rapidly over the past years, and further expansion is anticipated. The global growth is estimated to actuate a compound annual growth rate (CAGR) increase of 5.6% from 2019 to 2025 (108). The development of EHR utilisation for early prediction has made significant advances until the current time of derived predictive algorithms. Physiological and biomarkers parameters data from EHR have been successfully used in developing EWS and validating different derived tools  (70,109,110). With patients' data electronically available through routine documentation, the opportunities for utilising data in machine learning and artificial intelligence will contribute to more accurate deterioration prediction models.

Nonetheless, advocating EWS digitalisation has been supported only in recent years; studies that have investigated EHRs-embedded EWS are relatively recent (111,112). A recent implementation of electronic NEWS reported decreeing adverse events, including cardiac resuscitation (CPR) and unplanned transfer to ICU. However, despite the anticipated potential of this development, there is no evidence regarding the effect of this shift in achieving an improved performance of EWS and little is known about its impact on the escalation of care and clinicians' practice.

### *Automated recording of patient-level parameters*

Besides digitalising EWS in EHRs, scores and alarms have recently been produced automatically using automated monitoring devices. Automation of recordings transfers the parameters recorded and the resulting EWS score directly into patients' records (113) (Figure 7). This functionality is believed to facilitate nurses' and physicians' workflow and eliminate errors resulting from the entry of values in EHRs and delays when the workload is high. As mentioned previously, nurses' observation recording is subject to various errors leading to an increase in adverse events, which may manifest more due to the pressure of the pandemic (114). Therefore, automated monitoring is a potential valid solution to improve the workflow and clinical outcomes and facilitate the utilisation of EWS. Nonetheless, wide implementation of health technology will not guarantee the success of the application. As found in previous work, the ineffectiveness of EWS in escalating deterioration could be related to clinicians' response to guidelines, i.e. poor adherence to protocol (84,86).

Additionally, some issues detected in automation, such as false alarms, may hinder the desired goal of automated monitoring.

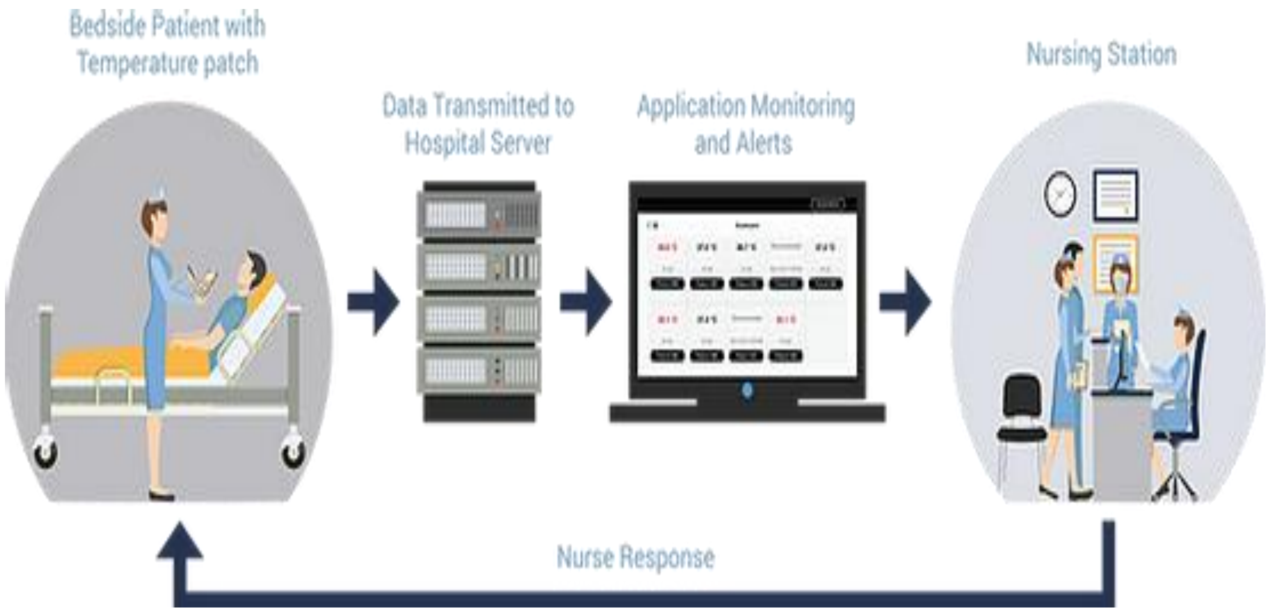



Figure 7. Automated patient monitoring system mechanism. (115)

## *Real time auditing of EWS*

The quality of clinicians' work may suffer due to the COVID-19 strain. Managing deteriorating patients has been affected in all the steps, including assessment, documentation, and referral to designated senior clinicians or RRT(104–106,116). To monitor these changes in practice, real-time auditing can be an effective method to examine areas in need of solutions in a health care setting. EHR-integrated dashboards are another generation of healthcare technology solutions that enable viewing clinicians' status regarding workflow and patients' prognostic status for on-time and historical surveillance by senior health professionals It works by capturing EHRs data and generating designed information on dashboards on the system and the professional performance or the patient's condition. Real-time dashboards have been utilised in recent years successfully by healthcare organisations, such as the NHS Pathway of Coronavirus Triage and Activity for monitoring COVID-19 management in NHS hospitals (117). Additionally, the Oxygen Therapy Dashboard for tracking the method and level of oxygen therapy delivered for COVID-19 patients was implemented in Barts Trust (118). The Oxygen Therapy Dashboard has effectively represented Barts Trust in the regular COVID-19 hub meetings with other northeast London trusts. In 2021, the Deteriorating Patient Dashboard was developed to tackle the issues found in clinical practice when managing sick patients in Barts Trust. The dashboard was created as an auditing tool for all the steps of deterioration management, from assessment to providing appropriate treatment. The aim was to improve individual clinicians' performance by providing complete and accurate documentation and clinical work when dealing with the acutely ill patients and by monitoring NEWS2, but evidence is needed to demonstrate its value. Few previously implemented dashboards to monitor individual clinicians' performance and the general wards practice have shown positive results as system users perceive them. An interactive dashboard for nurses' care displayed in a hospital in Canada and the medical dashboard developed to monitor units' general performance in a tertiary setting in the US were considered tools for driving quality improvement yet were less favoured by elderly users (119,120). Despite expectation of the dashboard's utilisation and improved performance, there is a lack of studies on their effectiveness in clinical settings and impact on clinical outcomes.

## Motivation for the thesis

### *1- Gaps in the research*

EWS have been advocated for use in all hospital settings and disease groups. Studies validate EWS in general settings and recommendations by health authorities to standardise early detection. However, the evidence to support their use in patients with CVDs and adult cardiac care settings is based on limited reviews and studies conducted in patient groups with different aetiology and other specialist settings. They are recommended by the Royal College of Physicians (RCP) and the NHS to be the standard tool for detecting severe critical events despite the systematic reviews identifying little evidence on their validity and reliability and how successful the implementation in specialist settings is. The impact of the COVID-19 pandemic on health settings was massive, and digital health solutions were employed more than ever to facilitate the healthcare delivery. However, it is not clear how the escalation of care was affected and what effect digital solutions had on EWS implementation and escalating deteriorating patients. The body of evidence of the criticality of CVD adverse events made the need for validating and adequately implementing on EHR, reliable EWS clear.

Research on standardised EWS in specialist settings are limited and has not, as yet, been systematically reviewed. The number of EWS and methods of scoring and alerting varies. Therefore, evidence to support their use in specialist settings has not been summarised, and no metanalysis has been performed to support their broad dissemination.

Studies on the performance of EWS in patients with CVD were limited to a single study of a subset of cardiac patients in a general hospital and another study of post-cardiac surgery EWS. The characteristics of the examined EWS, the clinical setting and the patient population make it hard to rely on or compare their validity with the standardised and recently digitalised EWS (NEWS2) in patients with CVD.

The impact of COVID-19 on the healthcare system has been massive to-date. Adhering to the escalation of care guidelines and EWS may be significantly affected and, as a result, influence the implementation of EWS and its validity. It is unclear how COVID-19 impacted the escalation of care in hospital settings and what factors contributed to facilitating or hindering the rapid management of the acutely ill.

Understanding the experience of clinicians and the implementation in practice is essential to the success of digital EWS. In hospital settings, the organisation, the system and the individual role in the implementation draw the map for the desired application and results by EWS. However, the qualitative studies on EWS were limitedly focused on general hospital settings. Studies have poorly examined the adoption of digital EWS in specialist settings. There is no evidence to-date of how digitally assisted EWS are perceived in cardiac care settings in the context of the pandemic.

We are aware of the pandemic pressure on clinical practice leading to errors increasing in routine observation and escalation of care. EHR-integrated dashboards were utilised to improve the quality of care through performance and patient monitoring. Studies evaluating health dashboards showed positive results in clinicians' practice yet were limited to nurses' routine monitoring and hospital wards performance. However, it is unclear how on-time visualising EWS and deteriorating patient management are perceived by clinicians and what impact it can have on documentation, referral and treatment of acutely ill patients.

## *2- Questions and problems*

The main research questions identified were:

1. What is the performance of universal, standardised EWS in different disease groups and clinical settings in predicting critical events, and what is the extent of EHRs integration of early warning scores in examined studies?

2. What is the performance of the digitally assisted National EWS (NEWS2) in predicting critical events for cardiac patients in a specialised cardiac setting?
3. How is the escalation of care practice and utilisation of EWS affected by the COVID-19 pandemic, and what factors facilitated or hindered any required changes?
4. How do nurses perceive the implementation of digital EWS (NEWS2) in a cardiac specialist setting and a general hospital setting during the pandemic?
5. What is the impact of implementing an EHR-integrated dashboard for improving deteriorating patients' management from clinicians' perspectives and change of practice over time?

### *3- The value of this research*

Worldwide, deaths related to CVD are 32%, and in the UK, it is one-quarter of the total deaths. There is good evidence of these high numbers resulting from deterioration in the disease course, and many are preventable. Death, morbidity, and associated CVD complication are life-changing for the patients and their families and significantly affect health care providers and the health system. Prevention through detection and early management is a necessity.

The use of EWS by clinicians to facilitate early detection and escalation of acutely ill patients was recommended in all settings despite limited evidence on its validity and the extent of its implementation success. A deep understanding of the validity and factors playing a role in the digital EWS implementation will allow managers and clinicians to make an informed decision when implementing EWS for cardiac patients. This research might help identify whether NEWS2 is optimal or what adjustments are needed to consider for reliable detection. It will inform the development of EWS models that match the needs of patients in a cardiac specialist setting. In addition, understanding clinicians' perception of digital EWS, whether the setting is specialist or general, will identify critical elements to improve for the individual staff, the organisation and the EWS system.

COVID-19 had an unprecedented burden on health care systems leading to possible changes in escalating care practice. Understanding the interactions, facilitators and barriers to coping with this burden can help realise the adoption of NEWS2 as an element of the escalation strategy and advise on the necessary adjustment in a crisis.

Finally, recognising the role of digital solutions in facilitating deteriorating patient management will inform clinicians and stakeholders of the potential benefits and areas needing adjustments to improve EWS utilisation and the escalation process. It may contribute to employing further digitalisation of EWS, automation and auditing of clinicians' performance on a broader scale, promoting quality of care for the acutely ill patients.

The detection and escalation of deterioration using EWS is a complex process shaped by various factors arising from the EWS tool, the perception of users, the condition in the health system, and the digitalisation of health systems. This PhD is a series of studies that can inform and support the development and implementation of EWS in cardiac care settings.

## *4- Motivation for this research*

The motivation to conduct this research arises from recognising the need to pay attention to real-life problems witnessed through my clinical work in a cardiac specialist setting. The motivation was led by my academic study of health informatics and interest in digital health.

When the updated NEWS2 was made official to implement in 2018 as recommended by the NHS leads, I was preparing to write my proposal for digital health in patients with CVD for a PhD study. An early discussion with my primary supervisor led to recognising the value of examining the digital EWS in the identified cardiac care setting as aligning with my interest and experience. As standardisation decisions were not based on sufficient quality evidence, and whilst there were limited studies on EWS and assisting digital tools effectiveness for clinical practice in cardiac settings, we sought to do this research. The validity and implementation of the digital form of EWS in a specialist cardiac setting while the pandemic is affecting all health systems was a unique and excellent opportunity to address some of the gaps identified by scientific evidence.

## 5- My research

### 1- Overall aim of this thesis

This research study aimed to assess the digital EWS, NEWS2 for patients with CVD from a performance and implementation sides with respect to the impact of the COVID-19 pandemic and employing digital health tools.

### 2- Component studies

Study 1: Systematic review.

The study examined the predictive performance of different EWS in different clinical settings. Findings show EWS validations have been heterogeneous in their methodology, performance measures, and studies in each subgroup; the validation of EWS performance and EHRs integrated with EWS is very limited in specialised settings, including cardiac patients.

Study 2: Retrospective evaluation.

The study investigates the performance of digital NEWS2 in predicting critical events in a specialised cardiac setting (St Bartholomew's Hospital). The performance in patients with CVD is insufficient to predict deterioration early. Supplementing NEWS2 with age and cardiac rhythm improved discrimination for cardiac patients, and age improved accuracy for COVID-19 cases.

Study 3: Scoping review.

The study investigates the experience of escalation of care and factors leading to its success or failure during the COVID-19 pandemic. Emergency plans adjusted the escalation strategy while a lack of resources and learning opportunities challenged the adjustments. Organised workload and competent management facilitated the escalation of care; however, the role of EWS was not explored in included studies.

Study 4: An implementation study.

The study evaluates the implementation of EHR-integrated NEWS2 in a cardiac care setting and a general hospital setting in the COVID-19 pandemic. The value of

NEWS2 was partly positive in escalation, yet concerns led to undervaluing NEWS2, particularly in cardiac care. Challenges, like clinicians' behaviours, and lack of resources and training, limit implementation success. EHR integration and automation are solutions that are not fully employed.

Study 5: Quality improvement study.

The study evaluates a real-time dashboard of NEWS2 and deteriorating patients' assessment, referral, and therapy. The dashboard is perceived as a facilitator for auditing NEWS2 and escalation of care to improve the practice. However, guiding clinicians and adjusting data sources and metrics could enhance the functionality. NEWS2 recording and deterioration management have improved after implementation. The dashboard is an effective, real-time, data-driven method for improving the quality of managing deteriorating patients.

.

# Chapter 2

## Methods

### Introduction

In this chapter, the study settings and research designs are described. The sampling technique, including the inclusion and exclusion criteria, determining the sample size and participants' recruitment and enrolment, are explained. Instruments used to guide the methodology, including quality appraisal and study frameworks that align with each research objective and scope, are discussed. The procedure for inclusion of participants and data protection, collection and management and data analysis are explained. Also, the methodological rigour of the study was discussed.

#### *Research design*

A mixed-methods approach was followed in this research series. Mixed-methods research focuses on the qualitative and quantitative sides of data in a single study or a series of studies (121,122).

In this approach, the quantitative and qualitative methods are used to address a gap in research by mixing the techniques during the data collection and analysis process to interpret evidence. Methods can be done in a particular order or simultaneously through data linkage or integration at an appropriate stage in the research process (123). Having both quantitative and qualitative questions answered through mixed methods can provide a better understanding of the connections and contradictions between data. In this research, studying EWS in a digitally facilitated form from the performance and the implementation sides provides a deep investigation of the numerical and human perspectives to explain this complex healthcare service (124,125)

In following this approach, NEWS2 users could have a strong voice and share their experience in the aspects examined. It has facilitated exploring different sides of the NEWS2 in the cardiac settings that significantly enriched the evidence and illuminated the issues found in this research (126)

In this chapter, the study settings and research designs are described. The sampling technique, including the inclusion and exclusion criteria, determining the sample size and participants' recruitment and enrolment, are explained. Instruments used to guide the methodology, including quality appraisal and study frameworks that align with each research objective and scope, are discussed. The procedure for participants and data protection, collection and management and data analysis are explained. Also, the methodological rigour of the study was discussed.

The first study was a systematic review that reviewed quantitative studies validating EWS in specialised care settings. Following that, a retrospective performance evaluation study was carried out to examine EWS in a cardiac specialist setting. Simultaneously, a qualitative study was conducted to examine the implementation in the cardiac specialist setting and another general hospital setting. A scoping review method was followed to examine qualitative studies on the experience of escalation of care during the COVID-19 pandemic. Finally, a quality improvement project to implement a deteriorating patient management dashboard was evaluated using a mixed-methods approach: evaluation of retrospective data and user perceptions.

## Settings

### *Site I*

Barts Health Trust is a group of hospitals providing a range of clinical services and specialities in East London and further. The patient population is over 2.5 million receiving care in the trust hospitals. It is the largest trust in England, accounting for 1.5% of all hospital activities in England. It runs five hospitals: Mile End Hospital, Newham University Hospital, Royal London Hospital, Whipps Cross University

Hospital and St Bartholomew's Hospital. St Bartholomew's Hospital (Barts Hospital) is a cardiac specialised and teaching in London and has heart and cancer centres, with other related specialities.

NEWS was first implemented in 2012, followed by the updated version of NEWS2 in 2018. NEWS shifted from paper version into EHRs embedded format calculated from each vital signs' measurements, via Cerner in Barts Trust, and a NEWS2 update was reflected in EHRs systems. In 2021, a quality improvement project was carried out to improve NEWS2 recording, and care of deteriorating patients by implementing an EHR-integrated dashboard in the trust.

The retrospective validation study and the implementation evaluation were conducted in Barts Hospital for its specialisation in cardiac care and the variety of cardiac care services provided. The Deteriorating Patient Dashboard evaluation was conducted in Barts Trust hospitals.

### *Site II*

University College London Hospital (UCLH) is a general teaching hospital in London. It is closely associated with University College London (UCL) in a partnership via the UCLH/UCL Biomedical Research Centre. It is renowned for its primary research activities, reaching 1500 studies at one time. It is a multi-speciality hospital providing various care services, including but not limited to accident and emergency, cancer care, critical care, neurology, general medicine and surgery. It has 665 in-patient beds and is the largest critical care unit in the NHS. The hospital treats over 500.000 outpatients and admits over 100.000 patients every year.

As NEWS was first implemented in 2012, it was endorsed in the hospital, followed by NEWS2 in 2018. NEWS2 is digitalised by embedding in EHRs via EPIC in UCLH.

The implementation study of NEWS2 was conducted in UCLH as the general hospital setting. As there is no ward designated for CVD patients, Cardiac care is delivered limitedly for patients with CVD in general medical wards and intensive care units.

### *Ethics*

To conduct the studies at both sites, approval for ethics was gained before commencing any research activity. The study was sponsored and insured by University College London by a covering policy from the UCLH/UCL Joint Research office. After sponsorship approval, an application for ethics approval was submitted to the Health Research Authority (HRA) and Health and Care Research Wales (HCRW). Confirmation of approval to conduct the study in both sites was gained by Stanmore Research Ethics Committee in London. Following that, the approval and proposal were communicated with the site's head of departments, where the data was collected, and participants were recruited. Finally, approval of capacity was received from both sites to confirm the capability and feasibility of carrying out the research activities in Barts Hospital and UCLH (Appendix 2).

## Study 1: systematic review

### *Study design*

My Systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses PRISMA-P guidelines. The guidelines were recommended for evaluating health intervention studies and were widely adopted, reaching 60.000 reports in 2020 since its development in 2019 and endorsed by over 200 journals and systematic review organisations (127,128). It is advised for its transparency and complete systemic method of reporting why and what is conducted and what outcomes are found.

### *Search strategy*

Published articles were identified in MEDLINE, CINHAL and EMBASE between 1997 (initial development of EWS) and 2019. The Cochrane database was searched for systematic reviews (CDSR) and trials (CENTRAL). For grey literature, Google Scholar was searched. During the screening procedure, studies were added from references in review articles and studies. Search strategies were developed by the candidate and the primary supervisor and reviewed by a secondary supervisor. Terms used for searching databases include terms for early warning or track and trigger scores and acronyms, identified subgroups and settings (e.g., MeSH) and free-text search terms (Appendix 3, 4 and 5).

### *Inclusion and exclusion criteria*

Patient subgroups were identified according to disease categories and clinical settings (Appendix 5). Studies were included if: (1) validation of a universal EWS with a standardised prediction model in adult patients; (2) EWS validation was in a specific setting or disease; (3) the performance of the EWS, or the impact on mortality, transfer to ITU and cardiac arrest, was examined; (4) they were prospective or retrospective cohort, cross-sectional, case-control design, or trials.

Studies were excluded if: (1) patients were less than 16 years of age; (2) EWS performance was only examined in derivation, not validation; (3) non-universal EWS was developed for a specific subgroup, e.g. Obstetric Early Warning Score (OEWS) for obstetric patients or qSOFA for patients with infections; or (4) EWS validation was performed in a general patient dataset or setting, e.g. validation in a general hospital without consideration of hospital subgroups.

### *Data extraction*

Articles were screened by title and abstract by the PhD candidate, and then full-text screening was conducted by the candidate and the primary supervisor. Data were extracted independently by two reviewers: the candidate and the primary supervisor, using a standardised and piloted data form. A third reviewer, the secondary supervisor, resolved any disagreements. Items for extraction for studies examining predictive accuracy were based on the critical appraisal and data extraction for systematic reviews of prediction modelling studies (CHARMS) (129) checklist, except for tool derivation, which was excluded. The CHARMS checklist provides a methodological appraisal of studies evaluating predictive models utilising scientific evidence in systematic reviews. It has been proven to show good transparency and clarity in this type of study (129,130). In addition, CHARMS indicates how to conduct a search according to the predictive model and the setting and population evaluated. It also provides key information to be extracted from the validation study of predictive models.

### *Quality assessment*

The risk of biases in validation studies was assessed using the Prediction Model Risk of Bias Assessment Tool (PROBAST) (131). PROBAST classifies studies as low, unclear, or high risk of bias in four aspects: participant selection, predictors, outcomes and analysis within the overall risk of bias and the study applicability domains. PROBAST tool provides a focused and transparent method to evaluate the risk of bias in studies that develop or validate prediction models for the prediction of outcomes and the applicability of methodology followed in studies conducted(102). The approach in PROBAST is believed to be relevant for prediction model validation studies for its ability to appraise these studies precisely and critically.

### *Evidence synthesis:*

The analysis was conducted using MS Excel and R programmes. The results were summarised using descriptive statistics and graphical plots. Meta-analysis was performed in different subgroups, using AUC (Area Under the Curve) for identified universal EWS and NEWS in studies. Fisher-Z transformation for correlation coefficients was conducted for AUC into normally distributed Z with 95% CI to evaluate the effect size and test for the heterogeneity. Where applicable, narrative synthesis was conducted.

## Study 2: Retrospective validation

### *Study design*

The study followed a retrospective cohort design. As a validation study with the aim to evaluate the performance of NEWS2, it was applicable to follow the Standards for Reporting Diagnostic Accuracy Studies framework (STARD) in reporting the study methods and findings (132). The discrimination accuracy of a model typically varies between settings, patient groups and the environment where the test is conducted. These variations are relevant to readers interested in applying findings to answer questions about adopting the discrimination tool in a different environment (133). Therefore, the STARD framework was followed to provide a transparent and complete reporting of the digital NEWS2 performance validation in our setting (Appendix 6).

### *Study cohort*

The study population was adult patients admitted to St Bartholomew's Hospital. Patients admitted from January to December 2020 under cardiac speciality care; for more than 24 hours were the study population. Due to the nature of the pandemic, we have also identified patients with Covid-19 based on positive PCR test results upon or during admission.

### *Data sources*

- Patients' EHR data

The primary source of data was patients' EHRs. Data were extracted from January to December 2020. The data included both predictors of deterioration and some of the outcomes in patients' records. This included Patients' demographics, physiological parameters, NEWS2 score, death, transfer to ICU, diagnoses, and comorbidities. Required data were ICD-10 coded.

- Resuscitation team data

The second source was data recorded by the Cardiac Resuscitation Team (CRT). Patients referred to the team due to a deterioration in condition observed by a nurse or a doctor or a high NEWS2 score were recorded in CRT databases. Outcome data, including Cardiac arrest and medical emergency, were extracted from the CRT database.

- COVID-19 pathology data

To identify patients diagnosed with COVID-19, data were extracted from the COVID-19 pathology database. The database incorporates continuously updated data submitted to NHS England for a patient with positive COVID-19. Patients' data were identified and extracted if a case was recorded positive based on a PCR test result upon admission or during the hospitalisation period.

### *Data processing*

Data were extracted for patients admitted from January to December 2020 from the three data sources selected. Patients' demographics, physiological parameters, NEWS2 score, death, transfer to ICU and diagnosis and comorbidities were extracted from EHR. Cardiac arrest and medical emergency were extracted from the CRT database, while positive COVID-19 cases were identified from the COVID-19 pathology data. Data for critical events and COVID-19 cases were linked to extracted EHR data using SQL by a clinical data analyst in Barts Hospital. Then, data was pseudonymised, transferred to the PhD candidate via the NHS network, and then to UCL data safe haven (DSH) for data analysis. The DSH is a secured database system with restricted access to the candidate and academic supervisors involved via safe gateway technology.

The data collection process was completed in a 13-month period from February 2021 to March 2022.

### *Measures*

- NEWS2 and physiological parameters

The variables chosen included physiological parameters and NEWS2 scores routinely obtained at hospital admission and 24 hours prior to deterioration. Included parameters that form the NEWS2 score were respiratory rate (breaths per minute), oxygen saturation (%), systolic blood pressure (mmHg), heart rate (beats/min), temperature (°C), and consciousness (measured by Glasgow Coma Scale (GCS)). Additionally, diastolic blood pressure, which is not part of NEWS2, was included.

Measurement time was chosen as the most completed set of parameters; measurements done 48 hours and seven days prior to events were not included due to missing and inconsistent data. Heart rhythm was included 24 hours prior to the event due to measurements recorded by CRT.

- Outcomes

The primary outcome was patients' critical status following an assessment on admission or 24 hours before a critical event. Outcomes were critical events categorised as in-hospital death, transfer to ICU, developing cardiac arrest, and medical emergency. A medical emergency was defined as deterioration, excluding cardiac arrest, requiring a patient to be seen by a critical care outreach team (CCOT) due to vasovagal attack, breathing difficulty, bleeding, loss of consciousness, seizure, cardiac tamponade, chest pain or pre-arrest rhythm.

### *Statistical analysis*

Analysis was done in the DSH using the R programme. Data cleaning and pre-processing were done in the first stage. Dependant and independent values, categorical and missing values, and splitting data into training and test data sets were addressed prior to analysis.

Statistical significance was defined as a p-value of <0.5 using two-tailed tests. Assessment of missing data in NEWS2 scores was done using a t-test to compare with another complete variable to identify the association with other variables or random missingness (134). Assessing the missingness of data was conducted to identify the appropriate method of dealing with missing values depending on the effect it can have based on the rest of the values and results when imputation or removal is done.

The categorical variables were presented as percentages (count), and the continuous variables were presented as the mean + standard deviation. The normality analysis of the data was assessed using box plots for the frequencies. Testing for normality is recommended to understand data distribution and to choose appropriate inferential tests to apply (135). The inter-group difference between categorical variables was evaluated using Pearson's chi-squared test. The difference between groups was compared using the Mann–Whitney U test for non-normally distributed data.

The correlations between NEWS2 and physiological parameters and outcomes were evaluated using the Pearson correlation coefficient. The test was used due to its statistical significance in examining the relationship between two quantifiable variables (136) . Correlation coefficient values range between -1.0 and 1.0, where -1.0 shows perfect negative correlation and 1.0 indicates perfect positive correlation. To supplement the model with parameters that could improve the prediction, data were split into training and testing datasets using the Train/Test method (70% for training and 30% for testing). Data splitting is essential in creating models based on data to ensure the process of using data in the model is accurate and to avoid overfitting issues (137). Univariate and multivariate logistic regression analysis were conducted to assess the association between score and outcomes. The prognostic value of NEWS2 and supplemented model for hospital death, transfer to ICU, cardiac arrest and medical emergency were evaluated using the receiver operating characteristic (ROC) analysis. The value of the area under the ROC curve (AUC) was measured. The cut-off points of the models were assessed using Youden's index: sensitivity, specificity, and positive and negative predictive values. AUC is a standardised classical discrimination measure widely used to assess a model's discrimination capacity (138). The measure has been reported to be statistically consistent and more discriminating than the accuracy recommended for evaluating discriminatory models (139). The AUC's values were interpreted using the reported criteria by Fischer et al.: AUC > 0.9, 0.7 to 0.9, and 0.5 to 0.7 indicate high, moderate and low predictive accuracy, respectively (140) (Figure 8).

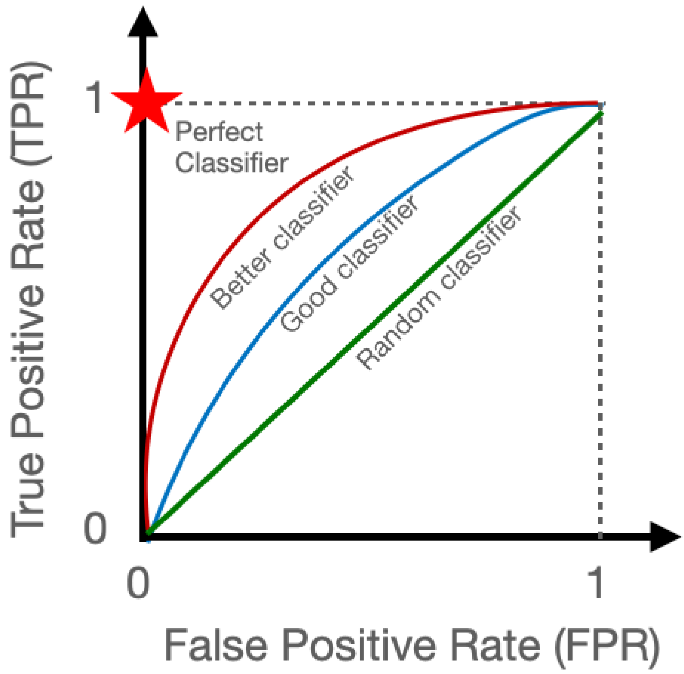



Figure 8. Discrimination ability explained using the area under the curve (AUC)(141)

## Study 3: Scoping review

### *Study design*

A scoping review was conducted to explore the process of escalation of care during the COVID-19 pandemic. The methodology facilitated mapping out key concepts in the research topic. The current pandemic has produced emerging evidence that is still unclear. Broadly examining the literature can raise more specific questions to recommend further precise research (142). The purpose of scoping reviews methodology is to identify gaps in knowledge and the scope of a body of literature (143). Provided that, the scoping review was deemed suitable for examining the background of escalating a deteriorating patient where EWS occurs during an evolving health care situation in the COVID-19 pandemic.

We followed the framework of Arksey and O'Malley (144), which included (1) Identifying the research question; (2) Searching for and identifying the relevant studies; (3) Selecting relevant studies; (4) Charting the data; and (5) Collate, summarise and report the results to guide this review (Appendix 7). Questions answered in the framework present comparisons between interventions, programs or approaches suitable to review the scope of escalation of care experience in the pandemic (145). We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) Checklist as a reporting guide (146). The design is recommended due to its method of reporting all aspects of the review in an accurate and transparent process (147). Screening, critical appraisal and data extraction were done in Covidence software (148).

### *Information sources and search strategy*

An initial search was conducted in August 2021 to reflect the core concept published in the literature and develop search terms. The last search was conducted in September 2021. Databases searched include Medline via Pubmed, CINAHL in Ebscohost and Emcare via Ovid for studies that fit the inclusion criteria, and the Cochrane library for reviews and protocols published relevant to the research. The search was restricted to studies from 2010 to 2021, full-text papers, and in the English language only. The study period aimed to identify previous and recent literature on the experiences of the escalation of care and early warning scores facilitating the process. We used Mesh terms, keywords, and Boolean operators to search the terms on the escalation of care and deteriorating patients, COVID-19 pandemic, and early warning scores. The search strategy is in Appendix (8).

### *Study selection:*

Search results from each database were uploaded and processed in Covidence. Title and abstract screening were done by the candidate to assess eligibility. The full-text screening was done by two reviewers, the candidate and primary supervisor, to determine relevancy and unclarity. The discrepancy was resolved by discussion within the supervisory team. Studies were included if they reported the experience, adjustments, or factors related to the escalation of care, rapid response teams, or

EWS's role in the escalation of care in the health care setting during the COVID-19 pandemic. The included studies were primary research using a qualitative or quantitative methods through surveys, interviews, focus groups, case studies or document analysis; due to the interest in the experience of clinicians and hospital management. Excluded studies examined hospitals' general rapid responses to COVID-19 spread and control. Inclusion criteria were entered into Covidence; then, studies were filtered out when duplicated or irrelevant.

### *Data synthesis:*

Data synthesis was done using a standardised form according to the Joanna Briggs Institute (JBI) reviewers' recommendation for methodologies in scoping reviews (149). JBI guidance enables research conduct, methods, and results to be reported appropriately, aligning with the PRISMA-ScR framework. It can highlight methodological issues, analyse data, and present results to facilitate research evaluation (150) Due to the focus of the reviews on qualitative methodological studies, further key information adopted from NICE guidelines for qualitative studies (151) was added as a subheading (Appendix 9). The added critical information added served as a supplement to guide the review into qualitative scope synthesis.

The critical appraisal was done using a CASP tool for qualitative studies (152) (Appendix 10). CASP is the most commonly used quality appraisal tool for qualitative evidence synthesis and is recommended by the Cochrane Qualitative and Implementation Methods Group (153) . Extraction and critical appraisal items were entered into Covidence, where the data synthesis took place.

## Study 4: Implementation study

### *Study design:*

A qualitative study design was conducted to evaluate the implementation following the Non-adoption, Abandonment, Scale-up, Spread, Sustainability (NASSS) tool (154). The NASSS design is a pragmatic, evidence-based design that can provide a thorough understanding of digitally supported tools in healthcare. It was chosen for its compatibility with evaluating the implementation of a digitalised health system, presented by the application of electronic recording and automation s in health care settings.

When examining the implementation of digital NEWS2 in hospital settings from the clinicians' perspective, a thorough investigation of the complex and dynamic service is needed. The service is not disaggregated into constituent components and is unpredictable in the COVID-pandemic and the unstudied specialist settings. Therefore, in evaluating the implementation, questions were focused on the following: how successful is the implementation in a cardiac and non-cardiac environment to ensure clinicians' and patients' needs are met and what are the challenges faced? And how to improve the process that integrates healthcare and technology to identify critically ill patients and escalate? Therefore, as per the complexity of the implementation and the questions to be addressed, the NASSS framework was followed. The framework investigated a multifactorial area of healthcare technology in a care setting; from the decision-making by the management to the clinicians impacted by the adoption; while addressing the environment in which the service is used: the technology facilitating and the setting where the care is delivered. It was adopted in previous qualitative studies examining the implantation success of technology in healthcare settings (155–157) and research examining complex health technology ((157). Therefore, it was deemed appropriate and research-enriching to follow the NASSS framework.

The adopted framework studies the challenges and facilitators in seven domains: the condition, the technology, the value proposition, and the adopter system (i.e., professional staff, the organisation, the broader context, and the interaction between domains over time). The recommendation of the framework was aided by incorporating sociotechnical informed theories of the individual, the organisation, and the system change (154). The factors in the framework were re-phrased to present the process of implementing NEWS2 and to guide structuring questions around the investigated areas (Figure 9). The domains investigated were explained in detail in chapter six.

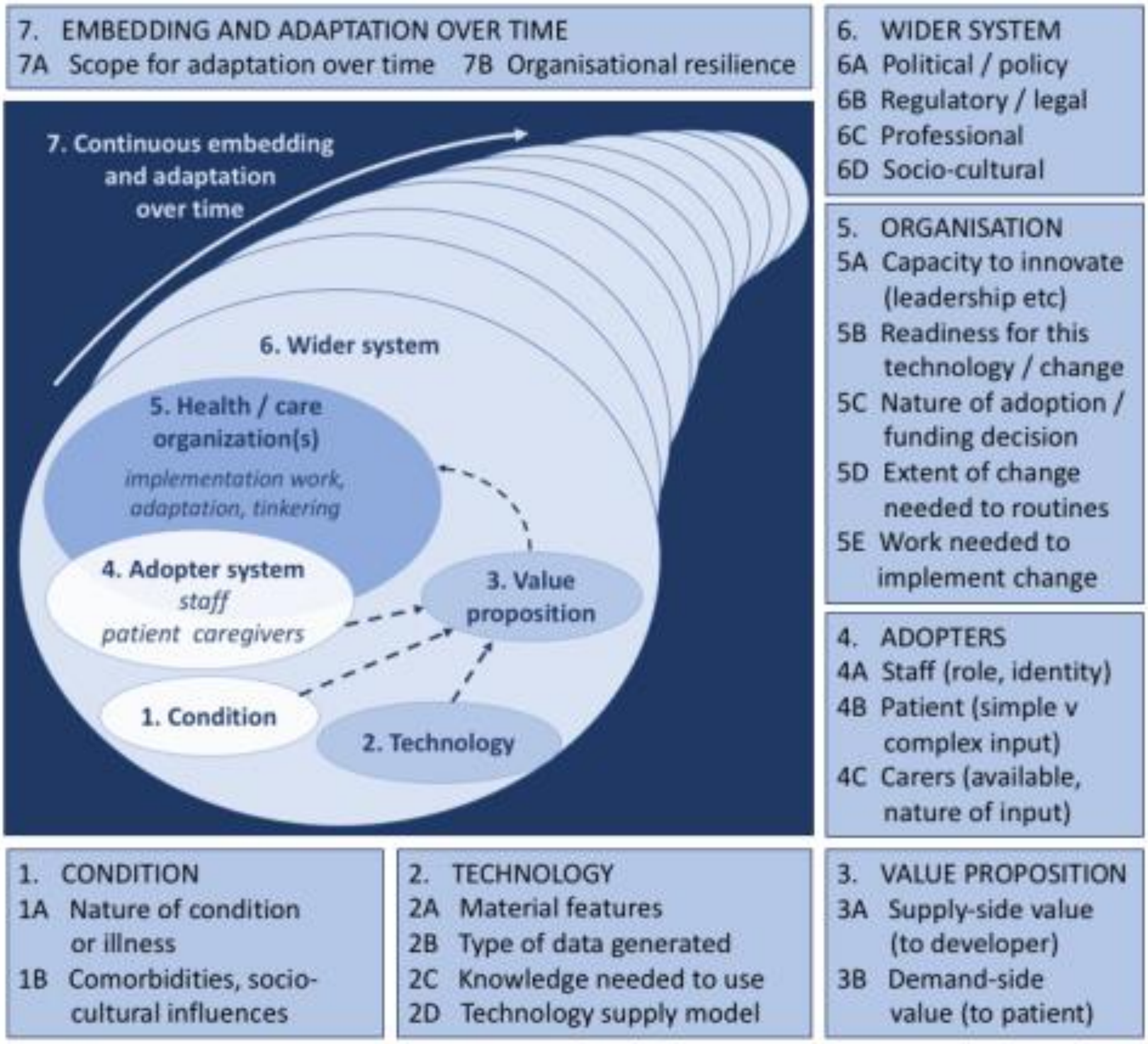



Figure 9. The NASSS framework domains (154).

*Study settings:*

The study was conducted at the two sites: St Bartholomew's Hospital (Barts Hospital) and University College London Hospital (UCLH).

- Pathway of NEWS2 in Barts Hospital

NEWS2 begins with assessment and vital signs measurement by nurses and nurse assistants via automated monitoring devices (Welch Alyn Connex Spot Monitors).

These monitors are connected to CernerTM, transmitting measurements directly to patients' charts. NEWS2 is calculated automatically in the electronic chart; a score is given, and an alarm is shown when a score indicates the need for intervention. Clinicians need to log in to view the score of the patient.

- Pathway of NEWS2 in UCLH

Nurses and nurse assistants perform routine vitals measurements. They input their recordings physically into the patient's chart in EPIC™. The score is calculated automatically, and an alarm shows when the status indicates attention. Nurses and physicians view the score when logged in to their patients' charts.

*Data collection:*

A purposive sampling method was followed with input from the supervisory team, CCOT and CRT in Barts, and Patient Emergency Response Team (PERT) in UCLH, to identify representative participants to contact based on roles and experience in utilising NEWS2. An online focus group was deemed convenient during the pandemic for time constrain and limiting personal contact in adherence to domestic guidance (158). Focus groups were initially planned to gather a collaborative perception of nurses from different hierarchical and role levels: ward nurses and managers. Invitation emails for focus groups were sent In March 2021 to ward managers and nurses in the cardiac specialist hospital, and a follow-up email was sent ten days later. Due to the workload pressure during the pandemic, assigning participants to the focus group at one time was impractical. Therefore, the issue was discussed with the primary supervisor, and it was decided to conduct an individual interview. In addition to time flexibility for each participant in conducting individual interviews, a maximised level of privacy allowed freedom of expression which might not be present when colleagues from different departments or seniority levels were attending (159,160). Invitation emails to online interviews were sent in April 2021 to ten nurses and managers in Barts and equally to UCLH staff in June, followed by a reminder after ten days. Information sheets and consents were sent before setting a date for interviews. Informed consent was obtained prior to conducting the interviews. Interview questions were semi-structured and covered the domains in the framework that can be explored in guided discussion with participants (Appendix 11.a)

An online questionnaire was created to cover domains that can be explained via direct questions providing simple and structured information. Questions in the questionnaire had multiple choices and scaled answers. Online questionnaires provide advantages for the research conducted, such as reaching a broader population, data reliability and anonymity of participants (161). A questionnaire was created in Smart Survey (162), including consent to answer the survey. A link was sent to nurses and managers in cardiac and non-cardiac wards: Cardiology, Cardiac Surgery, Haematology, oncology wards, and ICU in Barts and Medical, Oncology and Haematology wards, and ICU in UCLH. Wards in UCLH were chosen to provide a mutual environment of patients' speciality to Barts. Survey questions were matched, excluding the automated monitoring part of the UCLH survey (Appendix 11. b). A reminder was sent after 14 days to boost participation. The online questionnaire access was enabled for 30 days for each site; then the online link was closed for participation, and answers were exported. The data collection period was eight months in total.

### *Data analysis:*

Interviews were recorded in Teams and then saved with surveys in the NHS network. Recordings and surveys were pseudorandomised and then transferred to UCL Data safe haven (DSH), a secured database system with restricted access to the candidate and the primary supervisor, via safe gateway technology. Transcription of audio recordings and analysis of transcriptions and surveys were done in NVivo.

The interviews were analysed thematically to enable us to identify shared ideas and experiences and recognise patterns in datasets (163) by following four steps. First, familiarity with the interview was achieved by listening to the audio and reading the transcription and comparing them to achieve reliability. Second, initial codes were assigned to parts of the text relevant to research questions. Third, relevant themes and subthemes were identified to capture the idea of significance. Fourth, themes and sub-themes were checked by the candidate and primary supervisor to assess their quality. Fifth, themes were organised and named according to the relativity with the research aim and interest. Discussion with the supervisory team was carried out until an agreement was reached on the main themes produced. Results were reviewed and double-checked independently by the candidate and primary supervisor. Finally, the results report comprised four main themes exported from DSH.

## Study 5: Quality improvement evaluation

### *Study design*

The study evaluated a quality improvement intervention using a mixed-methods approach. Using both qualitative and quantitative approaches in combination provides a better understanding of the health intervention and aids in the evaluation process of the implementation (121,164,165). In the study, a digital dashboard was implemented for use and adoption by healthcare professionals. The intervention carries the complexity of a technological system introduced to audit and adopted by individual health professional users. Therefore, integrating mixed methods is a practical approach to explaining the quantifiable results and the human behaviour as an engagement in the process (166,167).

### *Study setting*

The study was conducted at Barts Hospital Trust. The study evaluated a performance tracking dashboard of data gathered from the five hospitals in Barts Trust.

### *Intervention context*

The dashboard was developed from what was initially created as a simple vitals data table into a broader generation of vitals data. Then, it was transformed into a thorough and more robust data visualisation of NEWS2, assessment and escalation of deteriorating patients via Qlik Sins. Data of around 1.2 million recordings of 110,000 admissions from August to October 2020 was extracted from the Datawarehouse of Barts trust hospitals, pulled from electronic health records (Cerner Millennium®). The dashboard metrics were indicators of the status of patients who needed escalation of care, like vital signs and sepsis scoring and time of entry and by whom. Afterwards, data were pulled continuously and maintained until the present time. The front view included live and accumulative data of patients with high NEWS2 and performance tracking of assessment stages of deteriorating patients by nurses and physicians on all trust levels. Clinicians' performance is measured by completing the assessment, escalation of care, and sepsis treatment.

The stages of assessment and escalation of deteriorating patients evaluated in the study are illustrated in the flowchart (Figure 10).

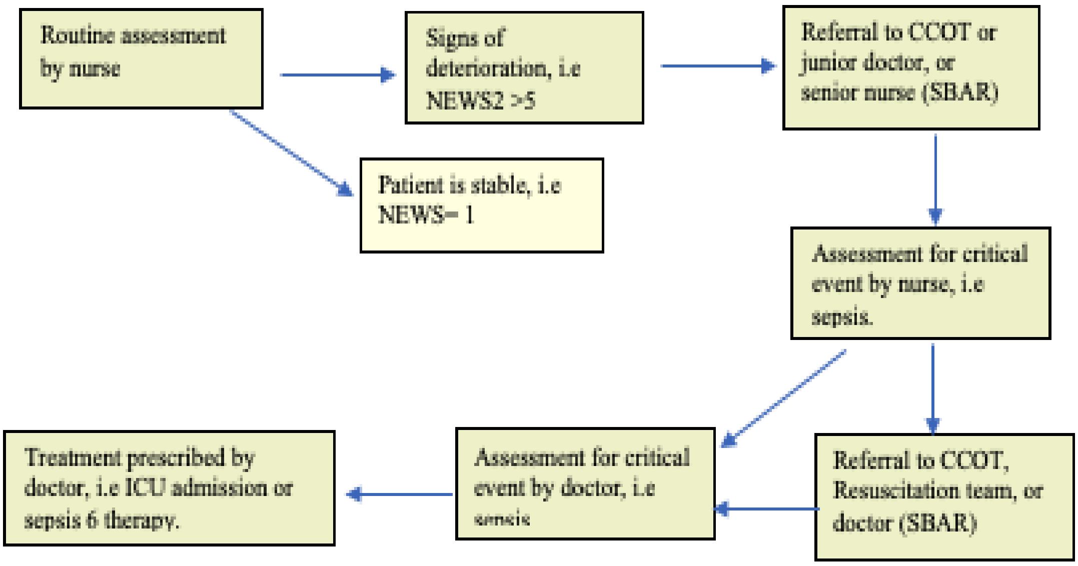



Figure 10. Escalation of care assessment flowchart.

Abbreviations: CCOT: critical care response team, SBAR: Situation-Background-Assessment-Recommendation tool for communication between health care team.

### *Intervention*

The PDSA (Plan-Do-Study-Act) (168) model was adopted to examine the objectives of creating the dashboard and evaluating clinicians' performance in the deteriorating patient management cycle. The PDSA model involves:

- Plan: plan the test, intervention, or observation, including a method for collecting data.
- Do: conduct the intervention on a small to a bigger scale.
- Study: analyse the data and study the results.
- Act: refine the change based on what was learnt from the best.

### *Measurements*

Individual interviews were conducted to evaluate the perception of the dashboard. Interview questions created to gather qualitative data were adapted from a previous evaluation of dashboards of ward-specific performance (169) and aligned with the Technology Acceptance Model framework (TAM)(170)(Figure 11). The TAM model is designed to assess the technology adoption in a work environment and has been implemented for years in evaluating digital tools in the health care settings. (171–173). The choice to adopt the model to assess the perception of the dashboard was influenced by its clarity in comprehending and ability to demonstrate a high level of predictiveness of a recent technology implemented(174,175). The key questions were on the perceived benefit, usability, the intention to use and the actual functionality, and desired adjustments needed to improve the dashboard (Appendix 12). A purposive sampling method was followed, guided by the help of the dashboard developer and manager. Key users of the dashboard were identified and invited to participate in the interview.

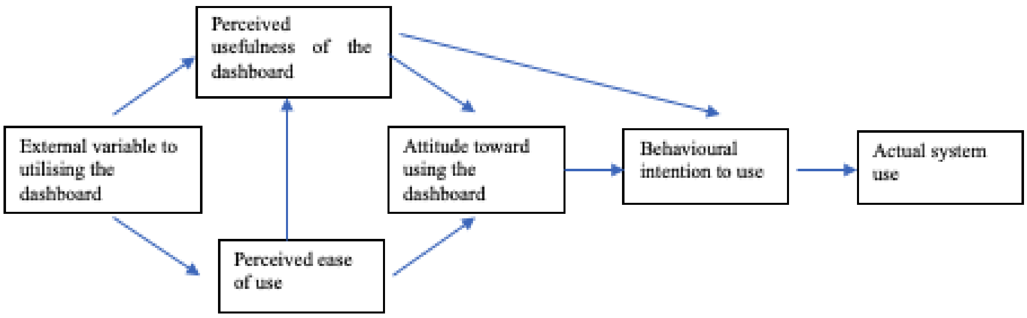



Figure 11. Illustration of the Technology Acceptance Model (TAM) to examine the perception of the deterioration dashboard.

A before and after data evaluation was run to assess the change in performance in the stages measured by the metrics. The period was divided into five phases to interpret the improvement in recordings and forms completion. Phases were as follows: pre-EHR integration (August-November 2019), post EHR integration (December 2019-September 2020), automation period (October 2020-April 2021), implementation period (May -September 2021), and post-feedback (October 2021-

April 2022). Due to the potential effect of skewing doctors' assessment and treatment data caused by shifting entry from EHRs to EPMA, the two metrics were compared between the implementation period (May to August 2021) and the post-EPMA rollout (September 2021 to April 2022).

### *Analysis*

Interviews were audio-taped and transcribed, and qualitative data were analysed using NVivo software following a content analysis approach. The content analysis describes the meaning characteristics of the narrative material (176). It is believed to be more well-suited than thematic analysis in the study context owing to its exploratory method of an area which not much is known about, to have a clear and direct reporting of the content and issues in the intervention (177,178). The method analyses interviews through systemic coding of transcriptions to indicate the presence of meaningful ideas related to the evaluated domains. Data analysis was iterative, where the content was coded, grouped to form subcategories, and then into themes that represented the topics creating the focus of the evaluation. The transcripts and analysis were checked independently by the primary supervisor as developed by the candidate and primary supervisor to ensure rigour.

Descriptive analysis was done on the data collected from the dashboard using the R programme. Pearson's chi-square test was used to compare periods identified for NEWS2 recording and forms completion. A p-value of $<0.05$ is considered statistically significant.

# Chapter 3

## Systematic review

Performance of Universal EWS in different subgroups and clinical settings.

(This chapter was published in BMJ Open Journal).

### Introduction

Across diseases, patient deterioration can range from critical care review and sepsis, to cardiorespiratory arrest and death, resulting in strain on healthcare resources (58,179). Delays or failures in timely detection of deterioration adversely affect prognosis, morbidity, mortality, and healthcare utilisation (62). For example, the 20000 in-hospital cardiac arrests per year in England are associated with costs of £50 million for resuscitation and post-arrest care (31). The rising global burden in healthcare can eventually lead to further deterioration of the severely ill receiving inadequate care due to lack of resources and inadequate critical care capacity. Preventive interventions are needed to overcome these challenges (180).

Specific characteristics have long been known to be associated with deteriorating patient health (179–181), including physiological parameters, such as heart rate and blood pressure (23,180,182). Early warning scores (EWS), widely used in high-income countries, were borne out of the need for early detection of patient deterioration. EWS are tools derived from prediction models that assess patient characteristics and physiological parameters to stratify the risk of developing a worsening event or need for medical attention (47). The algorithms underlying EWS can be "aggregate-weighted" to sum up a set of parameters to produce a score, or use more advanced statistical modelling (183). EWS inform clinical decision-making, enabling escalation of attention and care when required. Standardised tools, such as the modified early warning score (MEWS) (184) were developed for use across different hospital settings, but specialised, non-standard EWS are also designed for particular subgroups, e.g. Rapid Emergency Medicine Score (REMS) (185) and Quick Sequential Organ Failure Assessment (qSOFA) (56) for patients with infections. In recognising different settings, EWS may have compromised simplicity and timeliness of assessment (47). For example, a number of EWS rely on parameters that do not exist in the first hours of assessment, such as blood investigations and imaging (58–60).

From fragmented implementation and inadequate early assessment via specialised tools, EWS have shifted back to standardised prediction models, particularly, the national early warning score (NEWS) (51), followed by NEWS2 (53). NEWS was designed to produce a standardised assessment of acute illness severity across the NHS (186). While showing good discrimination compared with other EWS, especially in predicting mortality, there was a need to accommodate additional clinical parameters in the score. The updated NEWS2, emphasising appropriate scoring for type 2 respiratory failure, confusion and severe sepsis (53), was formally endorsed by NHS England (52) to be the EWS used in acute care. However, there have been concerns regarding excessive calls to clinicians, administrative workload, and variable symptoms across diseases and settings (187). The effectiveness of the universal EWS with standardised use across all settings is not clear in specific disease populations (67), and requires validation to estimate discrimination and calibration, like other clinical prediction models (188) While internal validation is useful, generalisability and reproducibility needs external validation (189).

Systematic reviews have evaluated EWS in pre-hospital, intensive care unit (ICU) and general settings (62,64,190), and sepsis (184), with narrow inclusion criteria and inadequate assessment of study quality. A recent systematic review evaluated development and validation of EWS in general patients, but did not include studies in specific disease subgroups or settings (191).

## Objective

In a systematic review, the performance of universal EWS in particular diseases and clinical settings was assessed in predicting severe acute events: mortality, transfer to ICU and cardiac arrest.

## Methods

Following the PRISMA-P guidelines (128), the search was carried in MEDLINE, CINHAL, EMBASE, Cochrane database and google scholar for grey literature from 1997 to 2019. For the search, terms for early warning or track and trigger scores and acronyms, identified subgroups and settings, and free text search terms were used. (Figure 12; Appendix 3 and 4).

Studies were included if: (1) validating a standardised EWS prediction model in adult patients; (2) the validation done in specific setting or disease; (3) evaluating the performance in predicting mortality, transfer to ITU and cardiac arrest, (4) they were prospective or retrospective cohort, cross-sectional, case-control design or trials.

For data extraction, data was independently extracted by the PhD candidate and primary supervisor using a standardised and piloted form based on CHRAMS checklist (129).

Quality was assessed using PROBAST tool to classify studies into low, unclear, or high risk of bias (131).

Evidence synthesis summarised the performance of different EWS and meta-analysis was performed in different subgroups and settings, using AUC. Fisher-Z transformation was done for AUC to convert into normally distributed Z with 95% CI.

Full description of tools utilised for search, extraction and appraisal, inclusion and exclusion criteria, and data analysis is explained the methods chapter.

Definition of standardised EWS, validation method and measurement tool are explained in table 3.

Table 3. Definition of terms.

| Term | Definition |
|---|---|
| **Universal EWS:** | EWS that are globally adopted and applicable in every setting and for any disease sub-group. |
| **Standardised EWS:** | EWS model with a set of parameters used in a unified approach to predict deterioration in any patient subgroup (52,181). |
| **External validation:** | Evaluation of the model's predictive accuracy with data different from the one used for model development (189). |
| **Internal validation:** | Evaluation of a model's predictive accuracy with the same data set used for the development or in a population in which the model is intended for use (189). |
| **Discrimination:** | The ability of a model to distinguish between the patients who will develop an outcome of interest and the ones who will not (188). |
| **Calibration:** | The accuracy of risk estimates in relation to the observed number of events (192). |

## Results

### *Study characteristics*

Of the 16,181 articles identified by the search, a total of 1,355 articles were screened by title and abstract, 770 articles were assessed in full for eligibility. The included articles were 103 studies, published between 2006 and 2019, in the final stage. These studies were predominantly observational (retrospective= 65, prospective= 36 and RCT=2). Emergency department (ED) (*n*=48) was the most common clinical setting, followed by medical (*n* = 12), ICU (*n* = 12), and surgical (*n*=9) settings. Sepsis (*n*=33) was the commonest disease subgroup. Other subgroups ranged from respiratory (n=8) to renal (n=1) (Figures 9 and 10). Mortality was the main studied outcome. Cardiac arrest was infrequently studied (*n*=8).

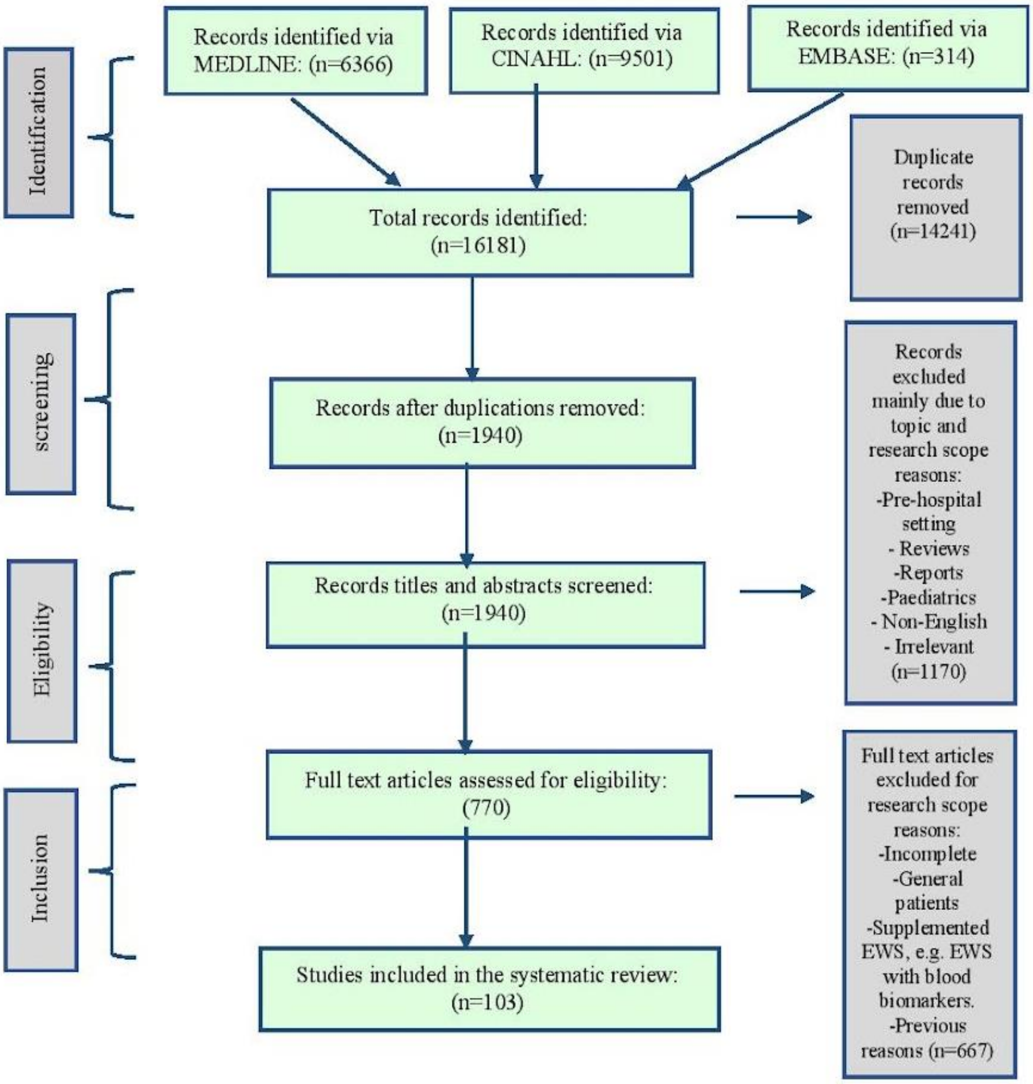



Figure 12. Search strategy and included studies regarding early warning scores in different disease subgroups and clinical settings.

### *Quality assessment*

There was a significant risk of bias found in the majority of studies (high risk=16; unclear risk=64), and low risk in only 28 studies. In terms of applicability, narrow inclusion of conditions in a certain disease group was commonly related to the risk of bias, while in general settings, biases were often due to low sample size or unspecified timing of EWS assessment. There was a wide variation in sample size (median: 551 and range: 43 - 920029). There was variation in defining study population by number of patients, hospital admissions or not specifying the particular study sample. Almost half of the studies (*n*=49; 48%) validated in <500 patients with either multiple observations or a single observation sets (Tables 4 and 5). External validation was more common (*n* = 83) than internal validation (*n* = 18) and two studies included internal and external validation (Appendix 13).

### *EWS validation in patient subgroups*

- Subgroups and EWS

In the studies validating EWS, there was heterogeneity in subgroup definitions, models, and methods of predictive accuracy. There was overlap between diseases and settings commonly between studies of patients with infections receiving care in ED (193,194) and patients with sepsis admitted to ICU (195,196) (Figure 13). EWS models that were integrated with electronic health records (EHR) were examined in recent studies (*n* = 9). Research on datasets utilising EWS-embedded EHRs had larger sample sizes, ranging from 504 (197) to 13,014 patients (198) (Tables 4 and 5), with moderate to high predictive ability (AUC: 0.65–0.85). Several studies included comparison between different EWS in the same cohort (n=21) (109,196,199) (Appendix 14).

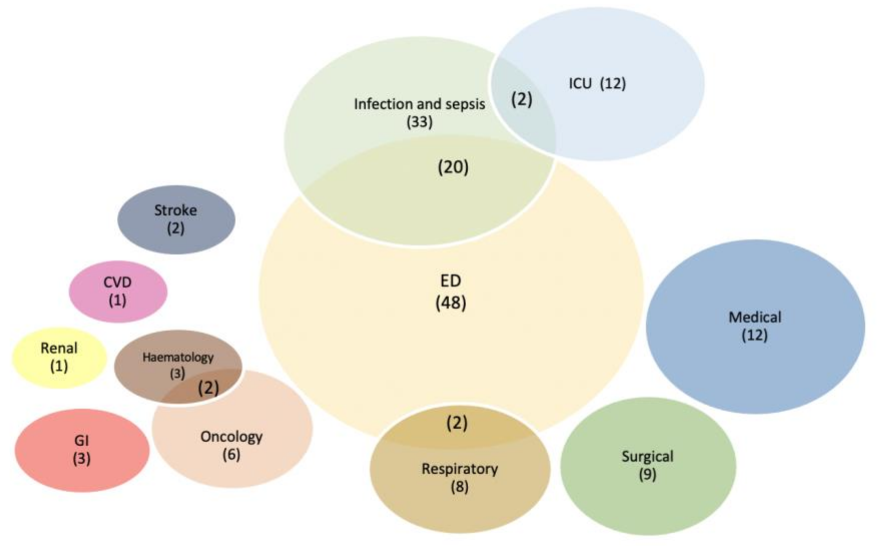



Figure 13. Number of studies regarding the performance of early warning scores in different disease subgroups and clinical settings.

Each bubble represents the disease subgroup and/or setting where different early warning scores were examined. The size of the bubble represents the number of studies (n); and overlapping bubbles show studies where disease subgroups and settings overlap.

Abbreviation: CVD: Cardiovascular diseases; ED: Emergency department; GI: Gastrointestinal diseases; ICU: Intensive Care Units.

## *Methodology*

There was significant heterogeneity in methods across studies. The majority of studies were observational. Evaluation of predictive accuracy of different EWS in the same study was common (186,200,201). To measure accuracy of EWS, AUC was most commonly used (*n*=94), especially when comparing different EWS in the same study (65,186). Presentation of results was variable; for example, confidence intervals were missing in many studies. Other measures, such as analysing sensitivity and specificity, prognostic index and odds ratios, were found in only eight studies (Tables 4-7). Consequently, it was only feasible to analyse predictive accuracy in studies where AUC was the selected measure.

Timing from EWS assessment to endpoints was variable. Many studies included (*n* = 43) AUC within 24 to 48 hours, while 11 studies had endpoints more than 48 hours after EWS. However, the majority (*n*=65; 63%) did not specify time horizon or in-hospital outcome.

Table 4. Characteristics of included studies of predictive performance for EWS in patient subgroups and settings.

| Author, year | Country | Subgroups | | | | | | | | Settings | | | | Study design | | | | Number of patients |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CVD | GI | Haematology | Renal | Stroke | Oncology | Respiratory | Infect/sepsis | ICU | ED | Surgical | Medical | Retrospective | Prospective | RCT | Case Control | |
| Kellett, 2012(202) | Canada | ● | ○ | ○ | ● | ● | ● | ○ | ○ | ● | ○ | ● | ● | ● | ○ | ○ | ○ | 10007 |
| Kim, 2017(203) | Korea | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 2172 |
| Bozkurt, 2015(204) | Turkey | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | 202 |
| Seak, 2017(205) | Taiwan | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 66 |
| Hu, 2016(206) | USA | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 565 |
| Liljehult, 2016(207) | Denmark | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 274 |
| Mulligan,2010(208) | UK | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | 71 |
| Cooksley, 2012(209) | UK | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 840 |
| Vaughn, 2018(197) | USA | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 504 |
| Young, 2014(210) | USA | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 61 |
| Von, 2007(211) | UK | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 43 |
| Pedersen, 2018(212) | Denmark | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 11266 |
| Forster, 2018(213) | UK | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 8812 |
| Pimentel, 2018(109) | UK | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 1394 |
| Sbiti-rohr, 2016(214) | Switzerland | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | ○ | ● | ○ | 925 |
| Brabrand, 2017(215) | Denmark | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | 570 |
| Jo, 2016(216) | Korea | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 553 |
| Barlow, 2007(217) | UK | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | 419 |
| Bilben, 2016(218) | Norway | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 246 |
| Delahanty, 2019(219) | USA | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 920026 |
| Redfern, 2018(220) | UK | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 241996 |
| Churpek, 2017[(1)](199) | USA | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | 53849 |
| Faisal, 2019(221) | UK | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 36161 |

| Author, year | Country | Subgroup | | | | | | | | Setting | | | | Study design | | | | Number of patients |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CVD | GI | Haematology | Renal | Stroke | Oncology | Respiratory | Infect/sepsis | ICU | ED | Surgical | Medical | Retrospective | Prospective | RCT | Case Control | |
| Churpek,2017[2](200) | USA | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | 18523 |
| Henry, 2015(198) | USA | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | 13014 |
| Brink,2019(193) | Netherlands | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 8204 |
| De Groot, 2017(222) | Netherlands | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 2280 |
| Corfield, 2014(223) | UK | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 2003 |
| Goulden, 2018(224) | UK | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 1818 |
| Khwannimit, 2019(196) | Thailand | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | 1589 |
| Ghanem- Zoubi, 2011(225) | Israel | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | 1072 |
| Saeed, 2019(226) | UK, France, Italy, Sweden & Spain | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 1058 |
| Innocenti, 2018(227) | Italy | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 742 |
| Camm, 2018(228) | UK | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 533 |
| Tirotta, 2017(229) | Italy | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | 526 |
| Pong, 2019(230) | Malaysia | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 364 |
| Prabhakar, 2019(231) | Malaysia | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 343 |
| Martino, 2018(232) | Italy | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 310 |
| Vorwerk, 2009(60) | UK | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 308 |
| Qin, 2017(233) | China | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 292 |
| Schmedding, 2019(234) | Gabon | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 277 |
| Albur, 2016(235) | UK | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | 245 |
| Cildir, 2013(194) | Turkey | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 230 |
| Chiew, 2019(72) | Malaysia | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 214 |
| Samsudin, 2018(236) | Malaysia | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 214 |
| Chang, 2018(237) | China | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 152 |
| Geier, 2013(238) | Germany | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 151 |
| Asiimwe, 2015(239) | Uganda | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | 150 |
| Hung, 2017(240) | Taiwan | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 114 |
| Garcea, 2006(241) | UK | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 110 |
| Yoo, 2015(242) | Korea | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | ○ | 100 |
| Siddiqui,2017(195) | Malaysia | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | 58 |

Table 5. Characteristics of included studies of predictive performance for EWS in patient subgroups and settings.

| Author, year | EHR | EWS | | | | | | | | | | Predictive measure | Outcomes studied | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VIEWS | MEWS | EWS | NEWS | NEWS2 | SOS | WORTHING | HOTEL | TREWS | HEWS | | Mortality | ICU | C A | R A | Sepsis |
| Kellett, 2012(243) | ✗ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Kim, 2017(203) | ✓ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✗ | ✓ | ✗ | ✗ | ✗ |
| Bozkurt, 2015(204) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Seak, 2017(205) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Hu, 2016(206) | ✓ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✓ | ✗ | ✗ |
| Liljehult, 2016(207) | ✗ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Mulligan,2010(208) | ✗ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Cooksley, 2012(209) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✓ | ✗ | ✗ |
| Vaughn, 2018(197) | ✓ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Young, 2014(210) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Sens & Spec | ✓ | ✗ | ✗ | ✗ | ✗ |
| Von, 2007(211) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Pedersen, 2018(212) | ✓ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Forster, 2018(213) | ✓ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | Sens & Spec | ✓ | ✗ | ✗ | ✗ | ✗ |
| Pimentel, 2018(109) | ✓ | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✓ | ✗ | ✗ |
| Sbiti-rohr, 2016(214) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Brabrand, 2017(215) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Jo, 2016(216) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Barlow, 2007(217) | ✗ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Bilben, 2016(218) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Delahanty, 2019(219) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✓ |
| Redfern, 2018(220) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Churpek, 2017[(1)](199) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Faisal, 2019(221) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✗ | ✗ | ✗ | ✗ | ✓ |

| Author, year | EHR | EWS | | | | | | | | | | Predictive measure | Outcomes studied | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VIEWS | MEWS | EWS | NEWS | NEWS2 | SOS | WORTHING | HOTEL | TREWS | HEWS | | Mortality | ICU | C A | R A | Sepsis |
| Churpek,2017[2] (200) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Henry, 2015(198) | ✓ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Brink,2019(193) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| De Groot, 2017(222) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Corfield, 2014(223) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Goulden, 2018(224) | ✓ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Khwannimit, 2019 (196) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Ghanem-Zoubi, 2011(225) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Saeed, 2019(226) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Innocenti, 2018(227) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Camm, 2018(228) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | Sens &Spec | ✓ | ✓ | ✗ | ✗ | ✗ |
| Tirotta, 2017(229) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Pong, 2019(230) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Prabhakar, 2019(231) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Martino, 2018(232) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Vorwerk, 2009(60) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Qin, 2017(233) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Schmedding, 2019(234) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Albur, 2016(235) | ✗ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Cildir, 2013(194) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Chiew, 2019(72) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Samsudin, 2018(236) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Chang, 2018(237) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Geier, 2013(238) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✓ |
| Asiimwe, 2015(239) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Prognostic index | ✓ | ✗ | ✗ | ✗ | ✗ |
| Hung, 2017(240) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Garcea, 2006(241) | ✗ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Yoo, 2015(242) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | OR | ✓ | ✓ | ✗ | ✗ | ✗ |
| Siddiqui,2017(195) | ✗ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |

Studies are ranked according to sample size from largest to smallest in each subgroup.

Abbreviations:

Subgroup: CVD: Cardiovascular disease; ED: Emergency department; GI: Gastrointestinal diseases; ICU: Intensive care unit.

EWS: Early Warning Score; ViEWS: Vital pack Early Warning Score; MEWS: Modified Early Warning Scores; EWS: Early Warning Scores; NEWS: National Early Warning Scores; HOTEL: Hypotension, Oxygen Saturation, Temperature, ECG abnormality, Loss of independence score; Worthing: Worthing physiological scoring system; TREWS: Triage in Emergency department Early Warning Score; SOS: Search out Severity score; HEWS: Hamilton Early Warning Score.

EHR: Electronic Health Records.

Predictive measures: AUC: Area under the curve; Sens and spec: Sensitivity and Specificity; OR: Odds Ratio.

Outcomes: ICU: Transfer to intensive Care Unit; CA: Cardiac arrest; RA: Respiratory arrest.

Note: Black dots in the subgroup column represent the disease or the settings where the sample was studied and brown dots in the study by Kellet (2012) represent different sample for each subgroup.

Table 6. Characteristics of included studies of predictive performance for EWS in clinical settings.

| Author, year | Country | Settings | | | | Study design | | | | Number of patients |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ICU | ED | Surgical | Medical | Retrospective | Prospective | RCT | Case Control | |
| Calvert 2016(244) | Israel | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | 29083 |
| Awad, 2017(245) | UK | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | 11722 |
| Reini, 2012(246) | Sweden | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | 518 |
| Chen, 2019(247) | Taiwan | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | 370 |
| Baker, 2015(248) | Tanzania | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | 269 |
| Gök, 2019(249) | Turkey | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | 250 |
| Moseson, 2014(250) | USA | ● | ○ | ○ | ○ | ○ | ● | ○ | ○ | 227 |
| Jo, 2013(251) | South Korea | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | 151 |
| Kwon, 2018(252) | Korea | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 1986334 |
| Usman, 2019(253) | USA | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 115734 |
| Jang, 2019(254) | Korea | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 56368 |
| Wei, 2019(255) | China | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 39977 |
| Lee, 2019(256) | Korea | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 27173 |
| Singer, 2017(257) | USA | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 22530 |
| Eick, 2015(258) | Germany | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 5730 |
| Bulut, 2014(259) | Turkey | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 2000 |
| Kivipuro, 2018(260) | Finland | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 1354 |
| Eckart, 2019(261) | USA | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 1303 |
| Ho, 2013(262) | Malaysia | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 1024 |
| Skitch, 2018(263) | Canada | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 845 |
| Liu, 2014(264) | Malaysia | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 702 |
| Dundar, 2016(265) | Turkey | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 671 |
| Yuan., 2018(266) | China | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 621 |
| Naidoo, 2014(267) | South Africa | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 590 |
| Liu, 2015(268) | China | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 551 |
| So, 2015(269) | China | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 544 |
| Dundar, 2019(270) | Turkey | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 455 |
| Lam, 2006(271) | China | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 425 |
| Xie, 2018(272) | China | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 383 |
| Cattermole, 2009(273) | China | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 330 |
| Heitz, 2010(274) | USA | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | 280 |

| Author, year | Country | Settings | | | | Study design | | | | Number of patients |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ICU | ED | Surgical | Medical | Retrospective | Prospective | RCT | Case Control | |
| Sirivilaithon, 2019(275) | Thailand | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | 250 |
| Cattermole, 2014(276) | China | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 230 |
| Najafi, 2018(277) | Iran | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | 185 |
| Bartkowiak, 2019(112) | USA | ○ | ○ | ● | ○ | ● | ○ | ○ | ○ | 32537 |
| Kovacs, 2016(278) | UK | ○ | ○ | ● | ● | ● | ○ | ○ | ○ | 20626 |
| Plate, 2018(279) | Netherlands | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | 1782 |
| Sarani, 2012(280) | Netherlands | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | 572 |
| Hollis, 2016(281) | USA | ○ | ○ | ● | ○ | ● | ○ | ○ | ○ | 522 |
| Gardner-Thorpe 2006(282) | UK | ○ | ○ | ● | ○ | ○ | ● | ○ | ○ | 334 |
| Garcea, 2010(283) | UK | ○ | ○ | ● | ○ | ● | ○ | ○ | ○ | 280 |
| Cuthbertson, 2007(48) | UK | ○ | ○ | ● | ○ | ● | ○ | ○ | ○ | 136 |
| Prytherch, 2010(50) | UK | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | 35585 |
| Smith, 2013(186) | UK | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | 35585 |
| Rasmussen, 2018(284) | Denmark | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | 17312 |
| Ghosh, 2018(285) | USA | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | 2097 |
| Duckitt, 2007(286) | UK | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | 1102 |
| Colombo, 2017(287) | Italy | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | 471 |
| Abbot, 2016(288) | UK | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | 322 |
| Wheeler, 2013(243) | Malawi | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | 302 |
| Graziadio, 2019(289) | UK | ○ | ○ | ○ | ● | ○ | ● | ○ | ○ | 292 |

Table 7. Characteristics of included studies of predictive performance for early warning scores in clinical settings.

| Author, year | EHR | EWS | | | | | | | | | | Predictive measure | Outcomes studied | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VIEWS | MEWS | EWS | NEWS | NEWS2 | SOS | WORTHING | HOTEL | TREWS | HEWS | | Mortality | ICU | CA | RA | Sepsis |
| Calvert 2016(244) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✗ | ✗ | ✗ | ✗ | ✓ |
| Awad, 2017(245) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Reini, 2012(246) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Chen, 2019(247) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✗ | ✗ | ✗ | ✓ | ✗ |
| Baker, 2015(248) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Gök, 2019(249) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✗ | ✗ | ✗ | ✗ | ✓ |
| Moseson, 2014(250) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Jo, 2013(251) | ✗ | ● | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Kwon, 2018(252) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Usman, 2019(253) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✓ |
| Jang, 2019(254) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✗ | ✗ | ✓ | ✗ | ✗ |
| Wei, 2019(255) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Lee, 2019(256) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ● | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Singer, 2017(257) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Eick, 2015(258) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Bulut, 2014(259) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Kivipuro, 2018(260) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Eckart, 2019(261) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Ho, 2013(262) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✗ | ✓ | ✗ | ✗ | ✗ |
| Skitch, 2018(263) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | AUC | ✗ | ✗ | ✗ | ✗ | ✓ |
| Liu, 2014(264) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✓ | ✗ | ✗ |
| Dundar, 2016(265) | ✗ | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Yuan., 2018 (266) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Naidoo, 2014(267) | ✗ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ○ | Sens & Spec | ✓ | ✗ | ✗ | ✗ | ✗ |
| Liu F.Y, 2015(268) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| So, 2015(269) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Sens & Spec | ✓ | ✗ | ✗ | ✗ | ✗ |
| Dundar, 2019(270) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Lam, 2006(271) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Xie, 2018(272) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Cattermole, 2009(273) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Heitz, 2010(274) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |

| Author, year | EHR | VIEWS | MEWS | EWS | NEWS | NEWS2 | SOS | WORTHING | HOTEL | TREWS | HEWS | Predictive measure | Mortality | ICU | C A | R A | Sepsis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sirivilaithon, 2019(275) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✗ | ✗ | ✗ | ✗ | ✗ |
| Cattermole, 2014(276) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ● | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Najafi, 2018(277) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Bartkowiak, 2019(112) | ✗ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✓ | ✗ | ✗ |
| Kovacs, 2016(278) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✓ | ✗ | ✗ |
| Plate, 2018(279) | ✗ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Sarani, 2012(280) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Sens & Spec | ✓ | ✓ | ✗ | ✗ | ✗ |
| Hollis, 2016(281) | ✗ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Gardner-Thorpe 2006(282) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Sens & Spec | ✓ | ✓ | ✗ | ✗ | ✗ |
| Garcea, 2010(283) | ✗ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Cuthbertson, 2007(48) | ✗ | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✗ | ✓ | ✗ | ✗ | ✗ |
| Prytherch, 2010(50) | ✗ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Smith, 2013(186) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✓ | ✗ | ✗ |
| Rasmussen, 2018(284) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Ghosh, 2018(285) | ✓ | ○ | ● | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Duckitt, 2007(286) | ✗ | ○ | ○ | ● | ○ | ○ | ○ | ● | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |
| Colombo, 2017(287) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Abbott, 2016(288) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Wheeler, 2013(243) | ✗ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ● | ○ | ○ | AUC | ✓ | ✗ | ✗ | ✗ | ✗ |
| Graziadio, 2019(289) | ✗ | ○ | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | ○ | AUC | ✓ | ✓ | ✗ | ✗ | ✗ |

Note: in the printed header, VIEWS through HEWS are grouped under "EWS", and Mortality through Sepsis are grouped under "Outcomes studied".

Studies are ranked according to sample size from largest to smallest in each subgroup.

Abbreviations:

Subgroup: ED: Emergency department; ICU: Intensive care unit.

EWS: Early Warning Score; ViEWS: Vital pack Early Warning Score; MEWS: Modified Early Warning Scores; EWS: Early Warning Scores; NEWS: National Early Warning Scores; HOTEL: Hypotension, Oxygen Saturation, Temperature, ECG abnormality, Loss of independence score; Worthing: Worthing physiological scoring system; TREWS: Triage in Emergency department Early Warning Score; SOS: Search out Severity score; HEWS: Hamilton Early Warning Score.

EHR: Electronic Health Records.

Predictive measures: AUC: Area under the curve; Sens and spec: Sensitivity and Specificity; OR: Odds Ratio.

Outcomes: ICU: Transfer to intensive Care Unit; CA: Cardiac arrest; RA: Respiratory arrest.

### *Predictive performance of EWS*

Outcomes were most commonly mortality, transfer to ICU, developing sepsis (in patients with infections), and cardiac arrest. Few studies examined other outcomes, e.g., respiratory arrest (*n* = 1) and organ failure (*n* = 4). Mortality, ICU admission and cardiac arrest were best predicted in medical (AUC mean: 0.74, 0.75 and 0.74) (47–49) and surgical settings (0.80, 0.79 and 0.75) (48,112), and respiratory diseases (0.75, 0.80 and 0.75) respectively. EWS prediction of sepsis had reasonable predictive performance in all subgroups (AUC: 0.71–0.79), and infectious diseases in particular (AUC: 0.79). Certain outcomes related to specific disease groups were not studied, e.g. cardiac arrest was not studied in cardiac patients (186); respiratory arrest was not tested in respiratory patients (202,214,233).

The best predictive performance was found in studies examining cardiac(202), stroke(202,207) and renal (202) diseases (AUC: 0.93, 0.88 and 0.87 respectively). In emergency settings, predictive accuracy was variable (AUC: 0.56–0.91) (72,259). In haematology and oncology diseases, EWS predictive accuracy was suboptimal in mortality (Appendix 15), cardiac arrest and ICU transfer (AUC: 0.52-0.69; Figures 14 and 15) (66,209). EWS prediction of ICU transfer was reasonable in ED (261,265), infectious diseases (225,235), and where both groups overlap (200,227), but not in gastroenterology and haematology (AUC: 0.64 and 0.60) (206,208) (Appendix 16). Cardiac arrest was the least examined outcome among the three endpoints (*n*=8) and unstudied in cardiac diseases. (Figures 14, 15 and Appendix 17)

For mortality prediction, meta-analysis of included EWS showed high degree of statistical heterogeneity across all subgroups ($I^2$ = 72% -99%)(Figure 16). In validation studies of NEWS in different disease subgroups, there was also significant heterogeneity ($I^2$= 99%; Figure 17).

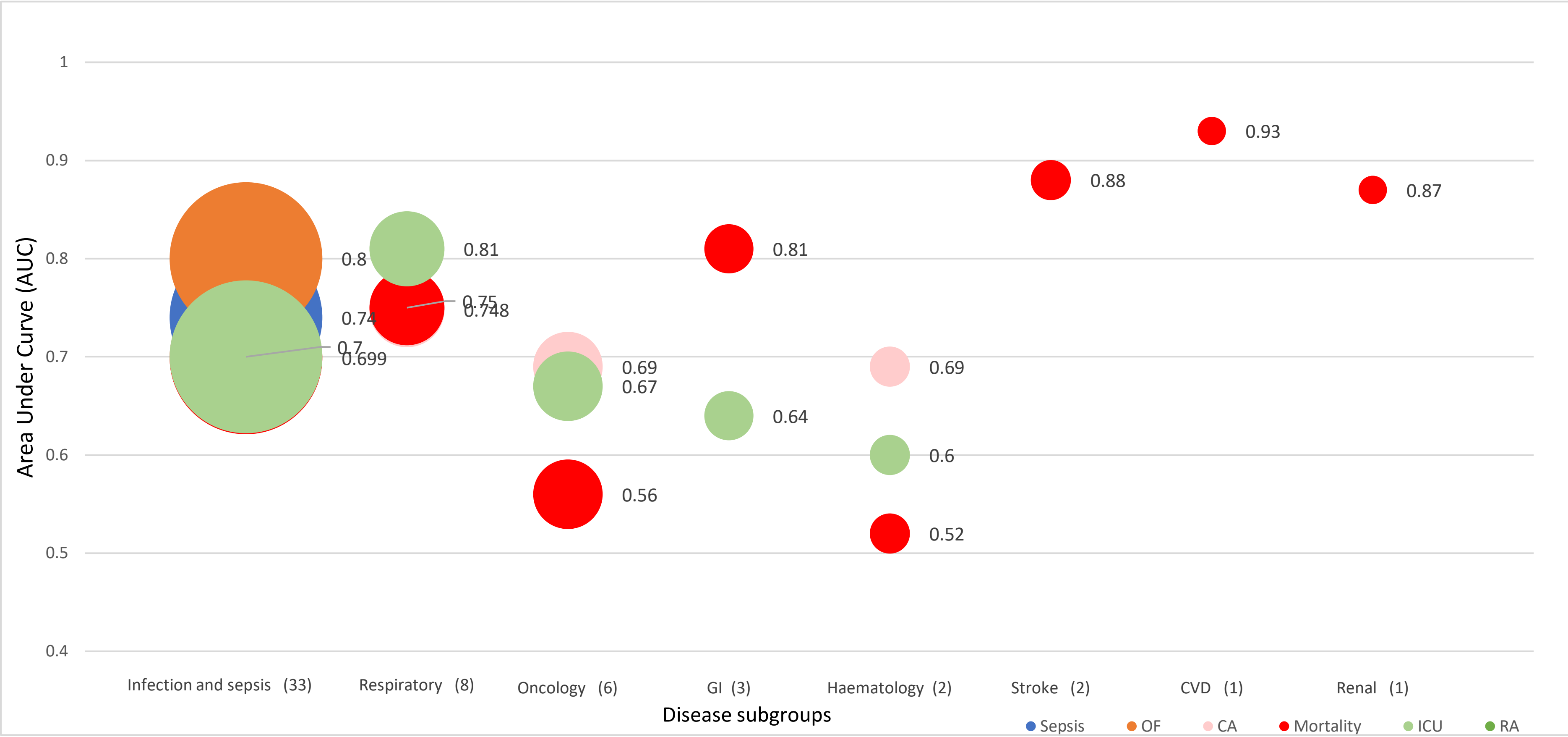



Figure 14.Early warning scores performance in different disease subgroups

Each bubble represents critical events predicted by early warning scores for each disease subgroup with average AUC of studies beside each event type. The size of the bubble represents the number of studies in each subgroup. Abbreviations: CA: cardiac arrest; CVD: cardiovascular diseases; GI: Gastrointestinal Diseases; ICU: Transfer to Intensive Care Unit; OF: Organ Failure; RA: Respiratory Arrest.

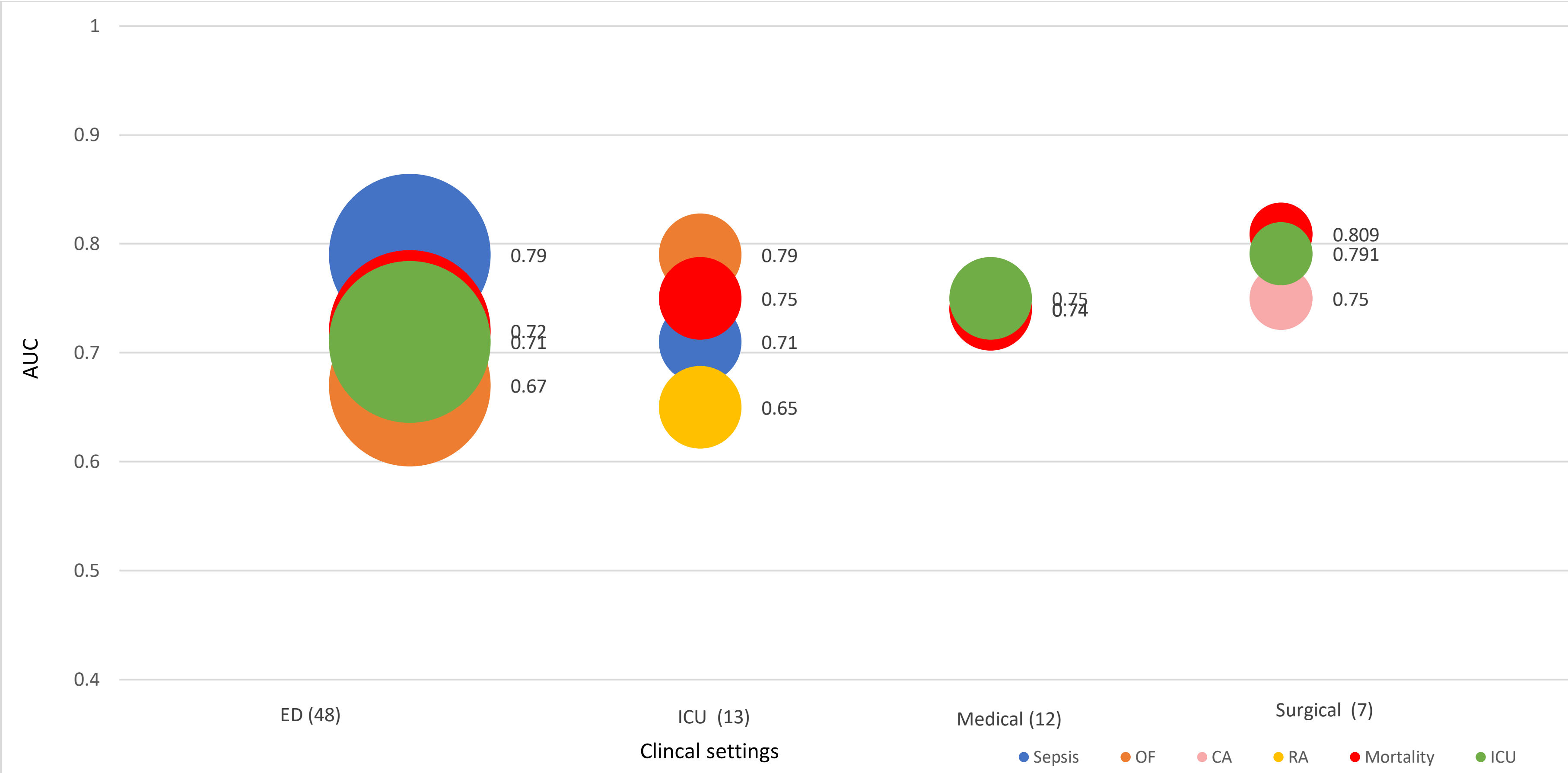
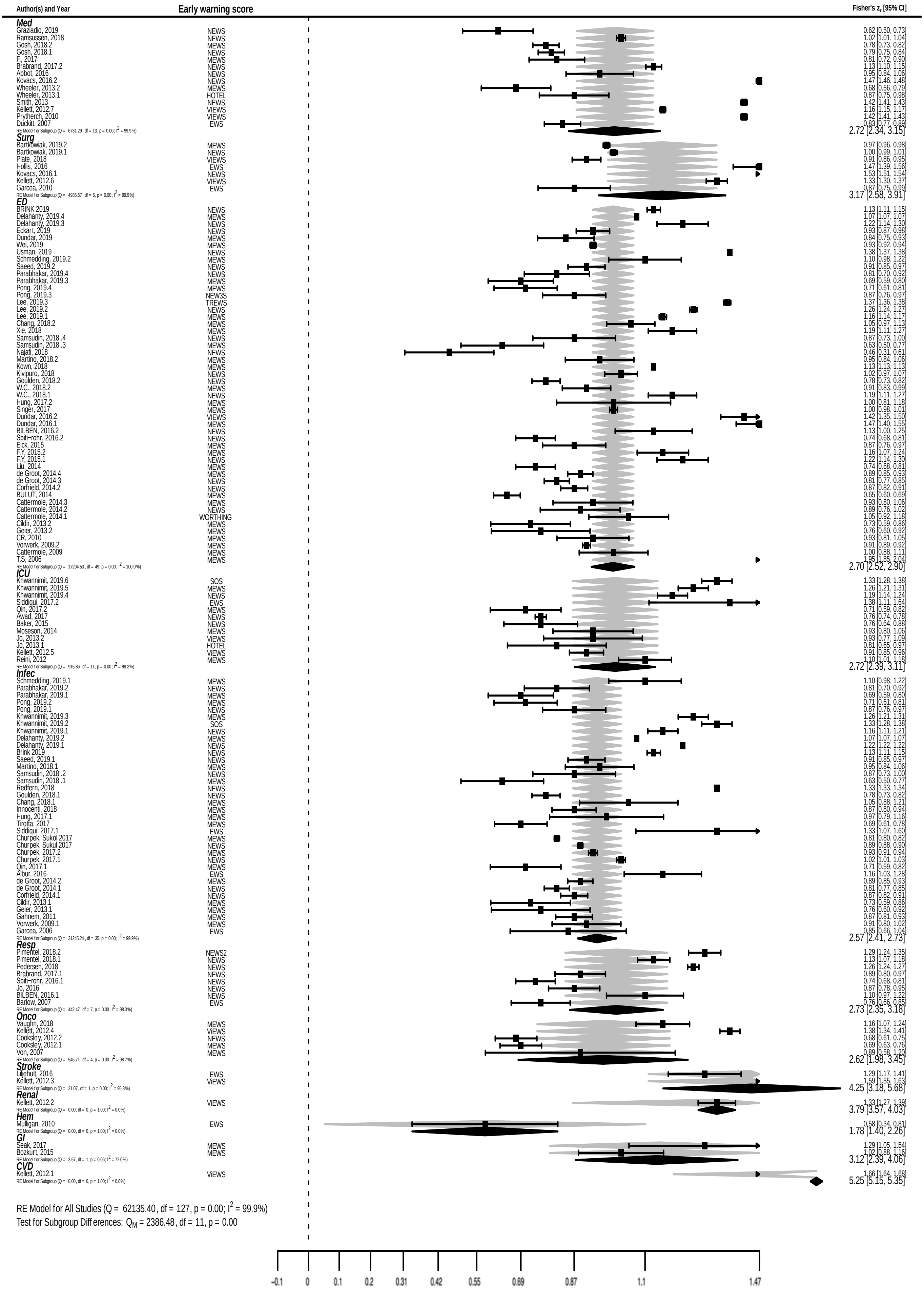



Figure 15. Early warning scores performance in different clinical settings.

Each bubble represents critical events predicted by early warning scores for each clinical setting with average AUC of studies beside each event type. The size of the bubble represents the number of studies in each subgroup. Abbreviations: ED: Emergency Department; ICU: Intensive Care Units; OF: organ failure; CA: Cardiac Arrest; ICU: Transfer to Intensive Care Units; RA: Respiratory Arrest.



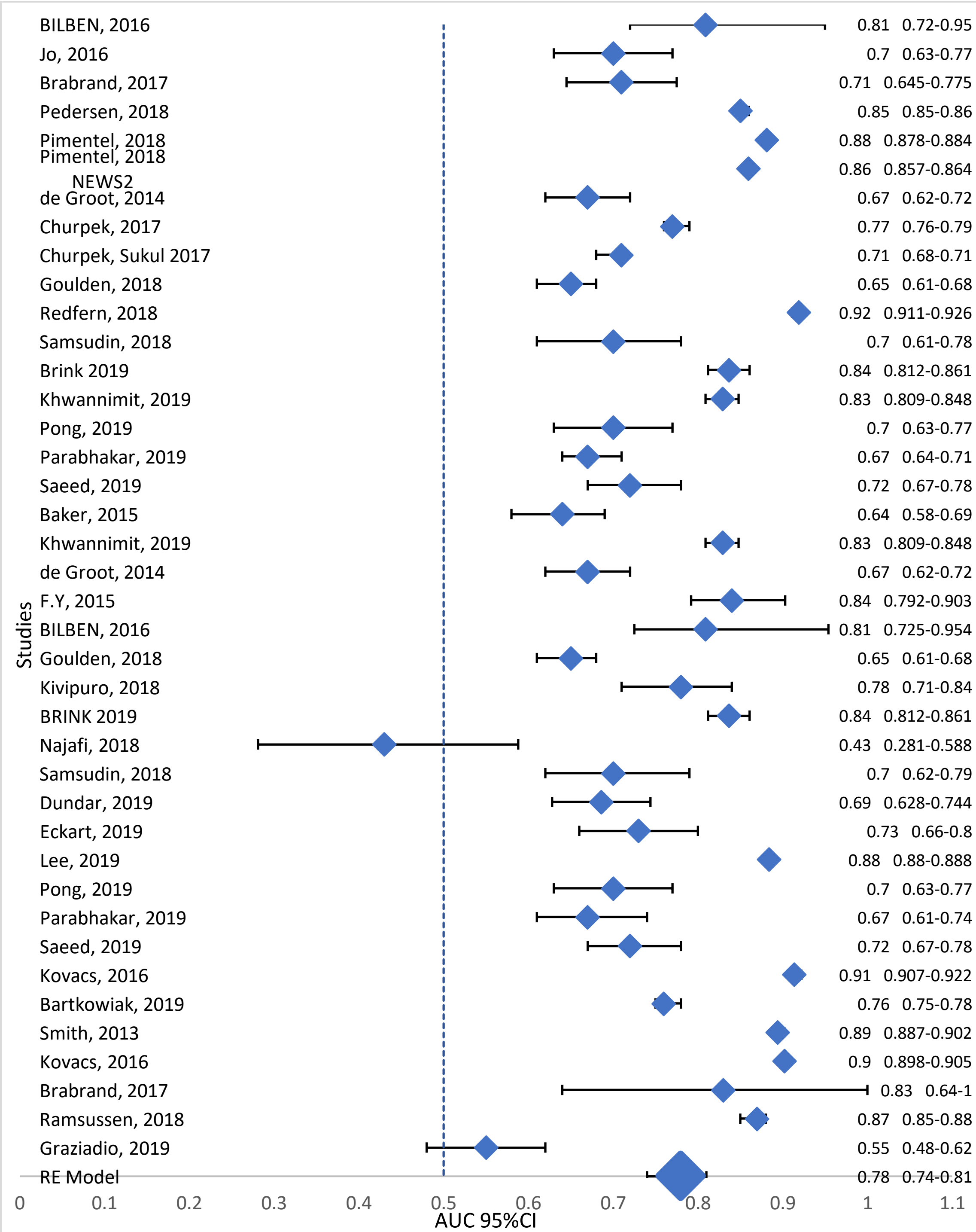
Author(s) and Year
Early warning score
Fisher's z, [95% CI]
Med
2.72 [2.34, 3.15]
Surg
3.17 [2.58, 3.91]
ED
2.70 [2.52, 2.90]
ICU
2.72 [2.39, 3.11]
Infec
2.57 [2.41, 2.73]
Resp
2.73 [2.35, 3.18]
Onco
2.62 [1.98, 3.45]
Stroke
4.25 [3.18, 5.68]
Renal
3.79 [3.57, 4.03]
Hem
1.78 [1.40, 2.26]
GI
3.12 [2.39, 4.06]
CVD
5.25 [5.15, 5.35]
RE Model for All Studies (Q = 62135.40, df = 127, p = 0.00; I2 = 99.9%)
Test for Subgroup Differences: QM = 2386.48, df = 11, p = 0.00
-0.1
0
0.1
0.2
0.31
0.42
0.55
0.69
0.87
1.1
1.47

Figure 16. Forest plot of predictive accuracy of early warning scores for mortality in different disease subgroups and clinical settings.

Abbreviations: Med: medical settings, Surg: surgical settings, ED: Emergency Department, ICU: Intensive Care Units, Infec: Infectious Diseases, Resp: Respiratory Diseases, Onco: Oncology diseases, Stroke: Patients with stroke, Renal: Renal diseases, Hem: Haematological diseases, GI: Gastrointestinal diseases, CVD: Cardiovascular Diseases.

Note: number following Author(s) and year indicate more than one EWS evaluated in the study.

Author(s), year AUC (95%CI, upper-lower)




RE model for all studies: Q (df = 39) = 37566.8345, p-val < .0001, $I^2 = 99.8$

Figure 17. Forest plot of predictive accuracy of NEWS for mortality.

## Discussion

In this comprehensive review of Universal EWS across all diseases and settings, there were three main findings identified. First, EWS studies in different diseases and clinical settings were heterogeneous in methodology, predictive performance measures, and number of studies in each subgroup. Second, validation of EWS is limited in specialised settings, including cardiac disease. Third, despite widespread EHR and EWS integration, few studies have explored EHR-based EWS.

Inconsistency in evaluation and the lack of high-quality validation makes the evidence of validity questionable, ultimately affects how EWS can and should be used in clinical practice as a risk score for deterioration prediction. Heterogeneity across studies in all subgroup's challenges implementation of EWS in all diseases and all settings. In methodology, observations selections method, time horizon between EWS score and event, and the metric used in assessment were inconsistent. Choosing multiple observations or a single observation  prior the outcome may not significantly affect the ranking of EWS (290). Yet, selecting a single observation is generally associated with high AUC compared to multiple observations (202,290), supporting the use of multiple observations for each episode. Moreover, AUC, the most commonly used measure of predictive performance, has limitations and other metrics, including positive predictive value, should also be assessed (291). Recording observations at an agreed threshold point before events in a standardised method is necessary to evaluate EWS effectively.

The Universal EWS with standardised models were primarily designed for general patient populations in wards and emergency departments and remain under-evaluated in specific diseases and settings. In medical and ED contexts, EWS perform well, suggesting the role of EWS in general settings, or at the early stage of clinical assessment. Our positive findings in respiratory disease may indicate the emphasis of several EWS, such as NEWS2, on respiratory changes when patients are deteriorating. Specific disease areas may show unique alarm signs when critical events are anticipated, which may not be captured by standardised EWS, such as

NEWS2, where prediction of deterioration is based on predefined thresholds in all patients (52). Critical events are commonly associated with CVD. With CVD being a leading cause of mortality globally, and the significant impact of morbidity on health and social care, early detection of deterioration is necessary (292). However, EWS are poorly validated in CVD, some of the parameters may not be applicable, and EWS may be unrepresentative (67). A recent study of  NEWS2 in patients with coronavirus infection found poor performance in severity prediction (95), despite pre-existing conditions being common and predictive in patients with severe outcomes. EWS may need to take account of disease-specific risk factors and comorbidities.

Widespread uptake of EHR and digitisation of patient observations are expected to contribute to efficient use of EWS, by reducing human errors in documentation and calculation, as well as delays in escalation of care. However, relatively few studies have considered EHR-based EWS, and those studies have not analysed whether predictive performance of EWS is related to EHR use, diseases or settings. Investigating implementation and adoption of EWS is necessary to understand the application and performance of EWS. Predictive algorithms derived by machine learning have been successfully used in developing and validating EWS (109,110), but will require robust evaluation. Studying the implementation process of EWS within EHR will provide opportunities for qualitative and quantitative insights into escalation of care, as well as facilitators and barriers to use of EWS in routine practice.

There are several limitations in this review and in included studies. The research aim was for a comprehensive investigation of all EWS developing since 1997, but this long study period may lead to bias in comparing studies with old and new validation approaches statistically and technically. There was exclusion of EWS specifically derived and validated for particular disease populations or settings, and an exclusion of studies considering a general patient population. Meta-analysis was only done for studies using AUC, excluding other methods for assessing performance of EWS. The distinction between general patient settings and specific disease or patient subgroups is dependent on hospital, healthcare system and country, and there was inevitably overlap between patients and settings at different stages in patient pathways. It was only feasible to include studies with a clear disease or setting identified to avoid confusion.

Validation of EWS in disease subgroups should consider similarities and differences across diseases, sample size, and include measures of model discrimination and calibration. Further research should adhere to established guidelines on clinical outcomes and predictive clinical scoring for decision-making, such as the PROGRESS framework (293).

## Conclusion

Universal EWS in specific disease subgroups and settings require further validation of their performance in detecting worsening outcomes. Despite good performance in respiratory patients and medical and surgical settings in studies to-date, the predictive accuracy of EWS in all disease subgroups and all clinical settings remains unknown. The current evidence base does not necessarily support use of standard EWS in all patients in all settings. Future research should include validation of EWS in particular patient subgroups and settings, with standardised methodology following established guidelines. Going toward the utilisation of EHR for EWS development, validation and implementation within EHR should be considered for improved EWS systems.

# Chapter 4

## Retrospective cohort study

Performance of digital Early Warning Score (NEWS2) in a cardiac specialist setting: retrospective cohort study.

### Introduction

In the previous chapter, the literature on the performance of EWS in disease subgroups and clinical settings has been systematically reviewed, and gaps were identified in EWS validity in poorly examined diseases, including CVD. In this chapter, the digital EWS (NEWS2) performance was validated in a specialised cardiac care setting.

Disease severity classification of patients with cardiovascular diseases (CVD) is challenging for nurses and physicians. Individuals with CVD can present with various sorts of critical events due to the disease's pathophysiology or the comorbidities associated (292). The aetiology of the disease and the specialised care provided may impose the standardised use of deterioration risk scores, such as the widely adopted National Early Warning Score 2 (NEWS2) (52). Heterogeneity in the process of patient deterioration complicates detection and escalation.

CVD are the leading cause of death in the UK and worldwide, with an estimated health care cost of £9 billion annually (4,292). Short-term critical events, such as cardiac arrest and transfer to the Intensive Care Unit (ICU), are common in patients with CVD (68,69). In addition, mortality and morbidity are major concerns in patients with CVD globally (292). Risk stratification tools for long term outcomes have long been favoured in this disease subgroup. Models like the Global Registry of Acute Coronary Events (GRACE) and the CHADS2-VASc are validated long term risk scores in cardiovascular diseases (13,294). For early stage risk prediction, risk stratification of critical deterioration was unified for all disease groups and settings using early warning scoring systems (EWS) (95,186).

The recently implemented and developed NEWS2 has been recommended by the consensus of clinical experts. A minimum set of physiological parameters and standardised application across the NHS to promote patient safety and unify clinicians' practice were the aims of NEWS2 (51,95,295). The predictability of NEWS and NEWS2 of critical events was found fair to acceptable to the emergency department (270,296) and medical and surgical settings. On the other hand, issues reported in specialised settings, like poor predictive performance in haematology settings (296) and the need to supplement NEWS in emergency settings (261,270) and for Covid patients (95), indicate its inefficiency in particular contexts. In cardiac settings, studies on EWS performance in critical events are poor and insufficient to defend the application for escalating the acutely ill. A Study in 2012 showed high predictive ability in cardiac patients using ViEWS, a model with different parameters than NEWS (202). Another examined RACE, a postoperative cardiac EWS tool for cardiac surgical ICU; a narrowly included subset of cardiac patients (67). Little is known about the predictive value of some NEWS2 components to be deemed reliable in this subgroup, i.e. inclusion of temperature or missing heart rhythm. Despite the need for reliable early deterioration detection, it is reported that specialised cardiac centres may overlook the value of developing and validating EWS. The complexity of models and difficulties in analysing electronic health records (EHR) data formed barriers to the validation of EWS (67). However, in the era of predictive modelling generated from EHRs, and EWS embedded in EHR, validating EWS in patients' population with a high rate of critical events is necessary.

## Objective:

To investigate the performance of digital NEWS2 in predicting critical events, at admission and prior to deterioration, for cardiac patients in the COVID-19 context in a cardiac specialist setting.

*The specific aims are:*

1- To explore the independent association of physiological parameters and NEWS2 at hospital admission and 24hr prior critical events; with disease severity (ICU admission, Cardiac arrest, medical emergency and death).

2- To examine the predictive ability of NEWS2 and the supplemented NEWS2 with potential determinants of disease severity on admission and 24 hrs prior to the condition worsening.

3- To compare the predictive value of NEWS2 with supplemented NEWS2 models.

## Methods

- Study cohort

Adult patients admitted to St Bartholomew's hospital, from January to December 2020, under cardiac speciality care; and patients with Covid-19 based on positive PCR test results

- NEWS2 and physiological parameters

We included physiological parameters and NEWS2 scores routinely obtained Including parameters that form NEWS2 score measured upon admission and 24 hrs prior critical event. Heart rhythm was included 24 hours prior to event

- Outcomes

Outcomes were critical events categorised as in-hospital death, transfer to ICU, developing cardiac arrest, and medical emergency.

- Data processing and analysis.

Data were extracted from EHRs, CRT database, and COVID-19 pathology data, and linked to produce one data set. Pseudonymised data were analysed by the candidate. Analysis was done R programme. Statistical significance was defined as a p-value of <0.5. The inter-group difference was evaluated by Pearson's chi-squared test while the difference between groups was assessed by the Mann–Whitney U test. The correlations testing between parameters and outcomes were evaluated using the Pearson correlation coefficient. The prognostic value of NEWS2 and produced models were evaluated using ROC analysis.

Full explanation of reporting method, data sources and processing, inclusion and exclusion and data analysis is covered in the methods chapter.

## Results

### *Baseline characteristics*

The initial cohort comprised of 16978 admitted patients, forming 40901 encounters and 68867 admissions to the wards from various specialities in oncology, cardiology, medicine and surgery. Patients with a primary cardiovascular disease diagnosis were 7313 (36%), 14798 encounters and 24792 ward admissions. Patients with missing NEWS2 or physiological parameters values were 21% of the total cohort and 16% of cardiac patients. Using *the t*-test, the means of NEWS2 and age were similar (60.3 and 59.8, respectively) with a statistical significance of *p-value* < 0.01. Therefore, considered Missing completely at random (MCAR) (18) and can be removed (19). Included cardiac patients were 6134 patients admitted under cardiology, cardiothoracic surgery, congenital heart diseases, or cardiac surgery specialities (Figure 18). Patients with COVID-19 were 248 (4%), 40% were cardiac patients.

The mean age of the cardiac population is 63.73+14.47, and 69% were males. The in-hospital mortality was 12% (743 patients), ICU admission was 15% (921 patients), and 117 cardiac arrests and 160 medical emergencies. The characteristics of the study population are tabulated in table 8. The difference between dead cases, patients admitted to ICU, who developed cardiac arrest, or medical emergencies, and those who did not develop critical outcomes according to the NEWS2 scoring category were statistically significant ($p < 0.001$). The comparison is tabulated in table 9.

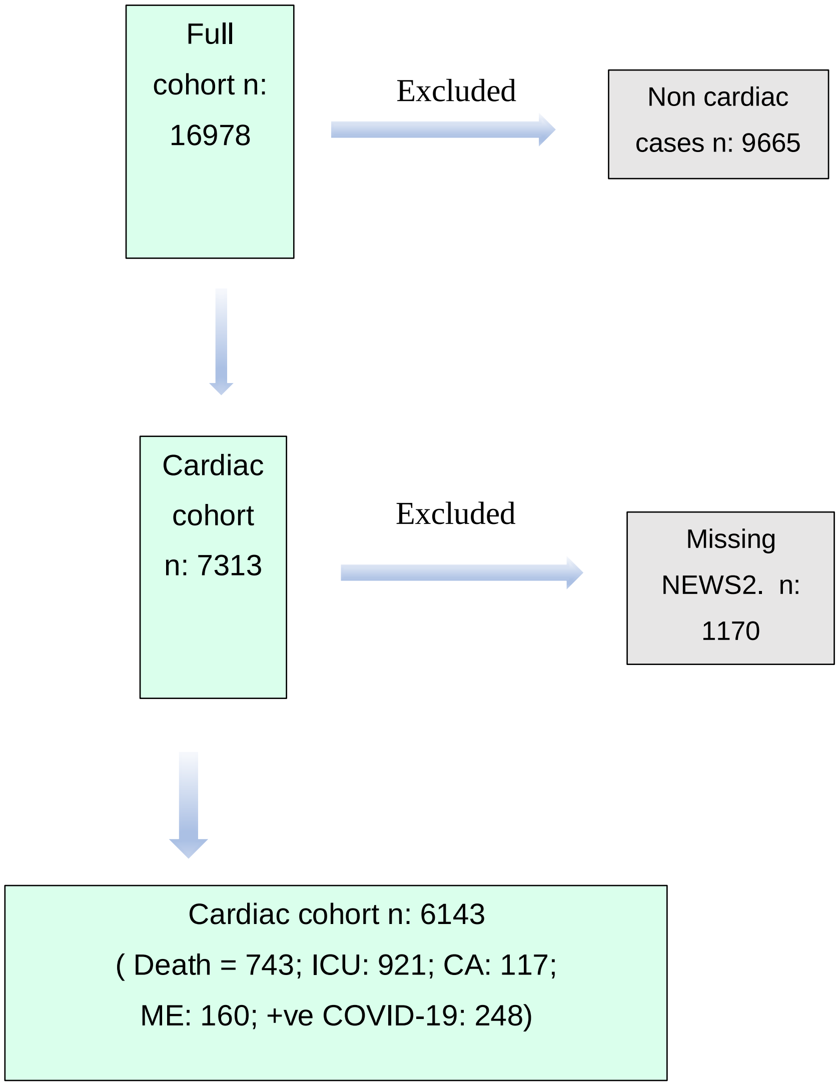



Figure 18. Flowchart of patients' cohort.

Abbreviations: n: number of patients; ICU: cases admitted to Intensive care unit; ME: medical emergency cases; CA: cardiac arrest cases; |+veCOVID-19: cases diagnosed with COVID-19.

Table 8. General characteristics of patients

| Variables | Descriptive (n=6143) |
|---|---|
| **Age, years** | 63.7 ± 14.47 |
| ***Gender*** | |
| **Male** | 4239(69%) |
| **Female** | 1904(31%) |
| | |
| ***Speciality*** | |
| **Cardiology** | 3817 (62%) |
| **Cardiothoracic surgery** | 2020 (33%) |
| **Congenital heart disease** | 184 (3%) |
| **Cardiac surgery** | 122 (2%) |
| | |
| ***Covid patients*** | 248 (4%) |
| **Cardiology and cardiothoracic surgery** | 100 (40%) |
| **Other (Oncology, Haematology, Respiratory and Thoracic surgery)** | 148 (60%) |
| | |
| ***NEWS2 numerical parameters*** | |
| **Systolic blood pressure, mm Hg** | 128.3±23.2 |
| **Mean arterial pressure, mm Hg** | 91.21±14.1 |
| **Pulse rate, beats/min** | 74.43±16.7 |
| **Temperature, °C** | 36.5±0.6 |
| **Oxygen saturation, %** | 96.7±2.23 |
| | |
| **Diastolic blood pressure, mm Hg** | 72.7±11.9 |
| **NEWS2** | 1.5+1.7 |
| | |
| ***Outcomes*** | |
| **In hospital mortality** | 743 (12%) |
| **ICU admission** | 921 (15%) |
| **Cardiac arrest** | 117 (2%) |
| **Medical emergency** | 160 (3%) |

Table 9. Comparison between categorical parameters of study population

| | NEWS 2 categories | | | P value |
|---|---|---|---|---|
| **characteristic** | Low (0-4) | Moderate (5-6) | High (7=<) | |
| ***Speciality*** | | | | |
| **Cardiology** | 3431 | 249 | 128 | >0.001 |
| **Cardiothoracic surgery** | 1931 | 86 | 10 | >0.001 |
| **Congenital heart disease** | 164 | 17 | 3 | >0.001 |
| **Cardiac surgery** | 113 | 6 | 3 | >0.001 |
| | | | | |
| ***Outcomes*** | | | | |
| **In hospital mortality** | 597 | 62 | 84 | >0.001 |
| **ICU admission** | 850 | 36 | 35 | 0.013 |
| **Cardiac arrest** | 85 | 14 | 18 | >0.001 |
| **Medical emergency** | 140 | 12 | 8 | >0.001 |

The mean of NEWS2 in death cases was higher by a small difference than alive patients (difference = 1.005, 95%CI, p<0.001). Between ICU admission and non-admitted cases, the mean was similar (difference = 0.01, 95% CI, p<0.09). Between cardiac arrests and non-arrest cases, and medical emergency and stable cases, there was a small variation (difference= 1.99, 95%CI, p<0.001 & difference= 0.99, 95% CI, P<0.001, respectively) (Figure 19,20, 21 &22).

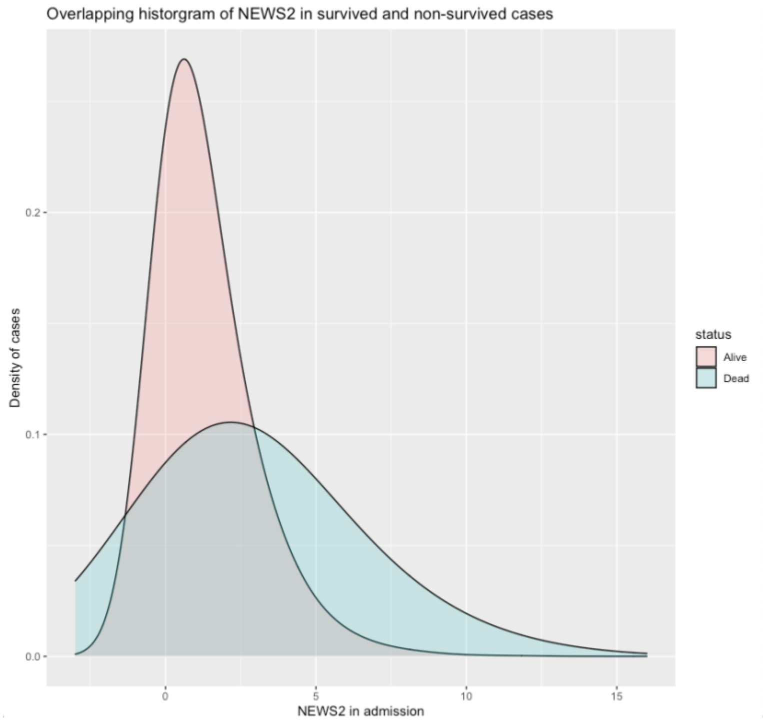



Figure 19. NEWS2 in survived and non-survived cases.

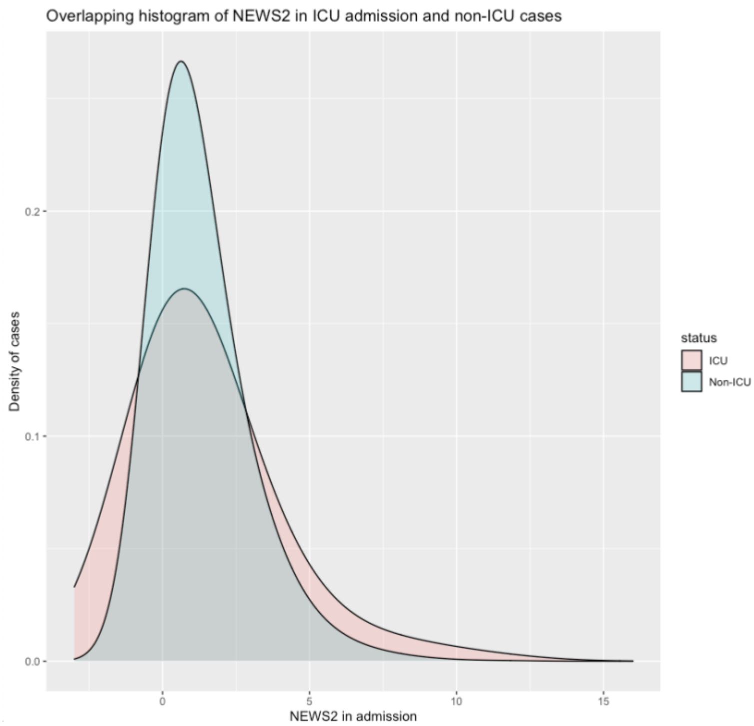



Figure 20. NEWS2 in ICU admission and non-ICU cases.

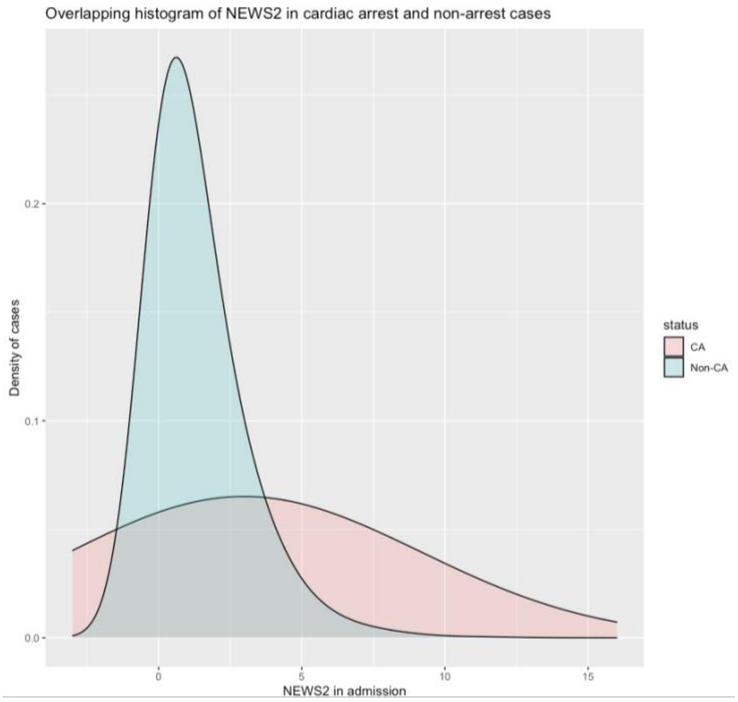



Figure 21. NEWS2 in cardiac arrest and non-arrest cases.

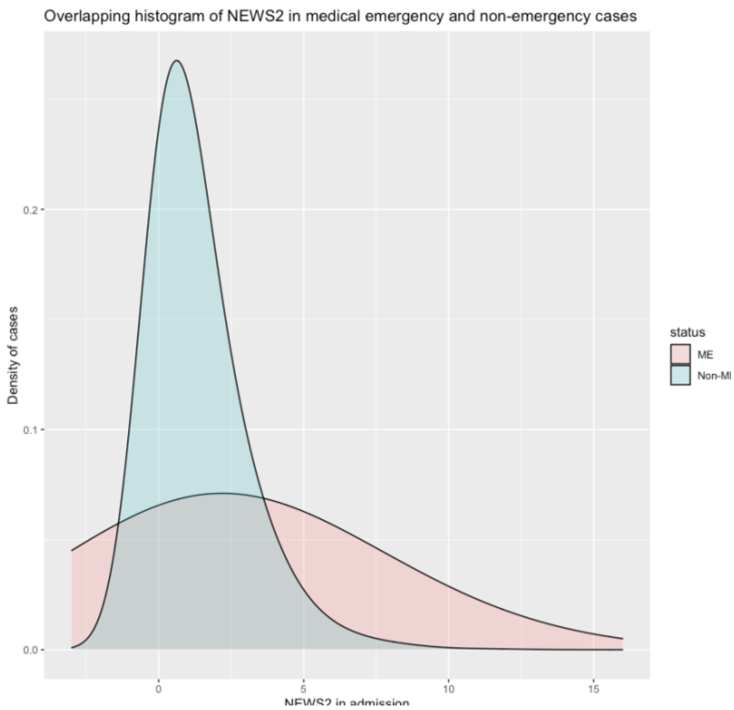



Figure 22. NEWS2 in medical emergency non-emergency cases.

Using the correlation matrix between parameters measured on admission and outcomes, we found a positive correlation between temperature with heart rate (0.32); respiration rate, heart rate and death with NEWS2 (0.41, 0.31, 0.30); and death with cardiac arrest (0.31). In the parameters 24 hours prior to critical events, there was a strong correlation of SpO2 with Systolic pressure, CVPU with NEWS2 (0.42, 0.41, 0.42), and Systolic pressure, SpO2 and death with age (0.30, 0.31, 0.34). Cardiac rhythm is strongly correlated with cardiac arrest and death (0.51, 0.90) (Figures 23 and 24).

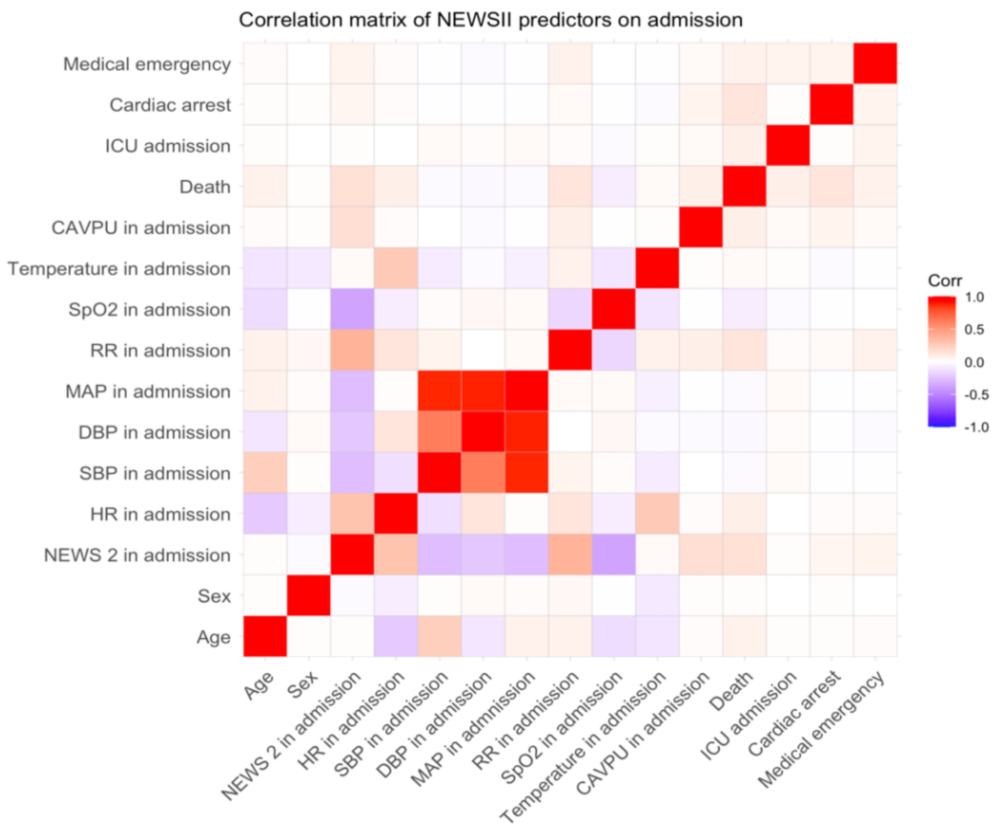



Figure 23. Correlation matrix using Pearson’s correlation coefficient between parameters and NEWS2 on admission and outcomes.

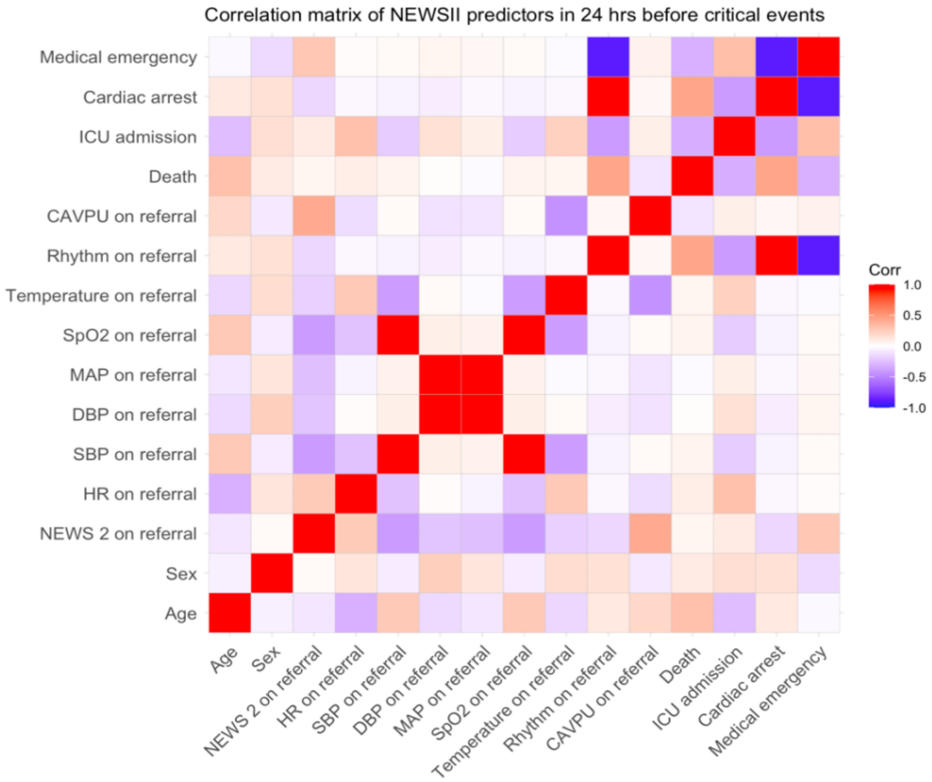
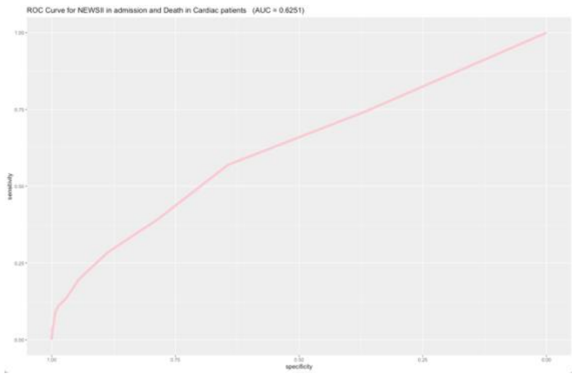



Figure 24. Correlation matrix using Pearson's correlation coefficient for parameters and NEWS2 24 hrs before outcomes.

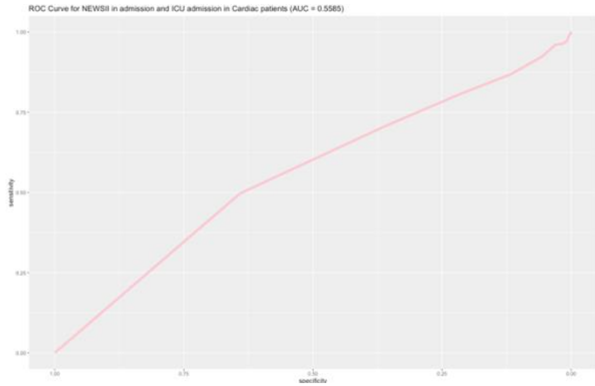
Regarding the discrimination, NEWS2 showed moderate to low predictive accuracy with death, ICU admission, cardiac arrest, and medical emergency (AUC: 0.63, 0.56, 0.7& 0.63; 95% CI) respectively, while NEWS2 24 before event showed low predictive value (AUC: 0.57, 0.61, 0.53 & 0.56; 95% CI) respectively. In patients with Covid-19, NEWS2 showed good to poor performance (AUC: 0.64, 0.5, 0.81& 0.81; 95%CI). When NEWS2 was supplemented with age, there was insignificant change in the predictive performance for all patients (AUC:0.63, 0.5, 0.73 & 0.64; 95% CI) However, there was significant improvement for Covid patients (AUC: 0.96, 0.7, 0.87& 0.88; 95% CI). This was also true for the model of NEWS2 supplemented with heart rhythm for the cardiac patients (AUC: 0.75, 0.84, 0.95 & 0.94; 95%CI). The calculated optimum cut off value for NEWS2 was ≥5 showed sensitivity for NEWS2 model of 20% and specificity of 94%, while for the model supplemented with heart rhythm sensitivity was 30% and specificity 85% (Table 10 & figure 25-30).

Table 10. NEWS2 as a predictor of critical events compared to supplemented NEWS2.

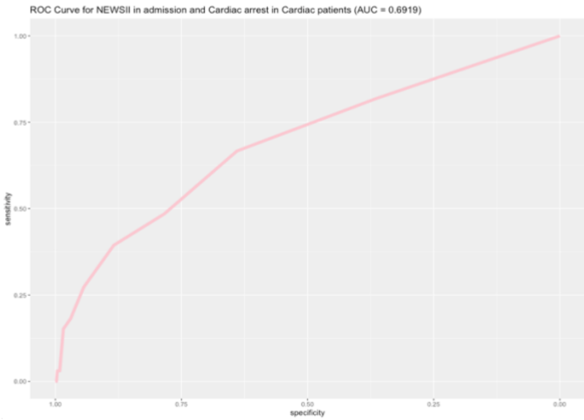
| Model | Death (AUC 95% CI) | ICU admission (AUC 95%CI) | Cardiac arrest. (AUC 95% CI) | Medical emergency (AUC 95% CI) |
|---|---|---|---|---|
| ***Cardiac patients*** | | | | |
| **NEWS2 (admission)** | 0.63 (0.58-0.67) | 0.55 (0.51-0.62) | 0.69 (0.65-0.74) | 0.62 (0.57-0.67) |
| **NEWS2 (24 hrs before outcome)** | 0.58 (0.53-0.65) | 0.63 (0.58-69) | 0.54 (0.51-0.67) | 0.56 (0.52-0.60) |
| **NEW2 +Age** | 0.63 (0.58-0.69) | 0.53 (0.50-0.59) | 0.73 (0.68-0.79) | 0.64 (0.59-0.68) |
| **NEWS2 +Rhythm** | 0.75 (0.67-0.80) | 0.84 (0.78-0.88) | 0.95 (0.89-0.98) | 0.94 (0.89-0.97) |
| ***Covid patients*** | | | | |
| **NEWS2** | 0.64 (0.59-0.69) | 0.51 (0.50-0.56) | 0.81 (0.75-0.86) | 0.80 (0.74-0.86) |
| **NEWS2 +Age** | 0.96 (0.89-0.98) | 0.69 (0.63-0.76) | 0.87 (0.81-0.94) | 0.88 (0.82-0.94) |



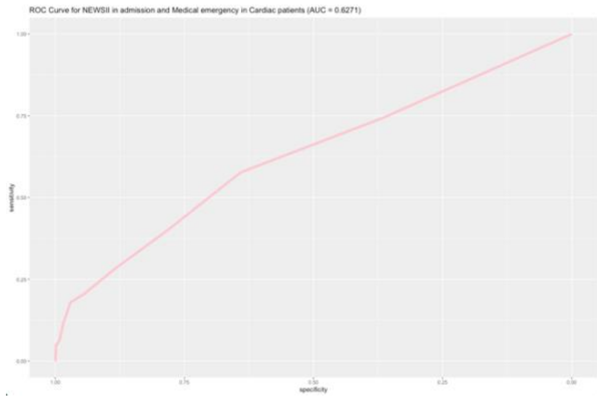

1. Death AUC:0.63




2. ICU. AUC:0.56

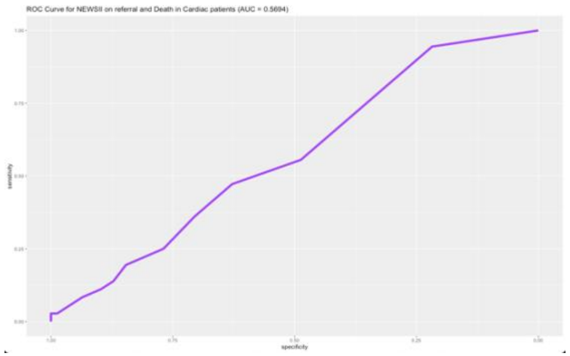



3. CA AUC:0.69

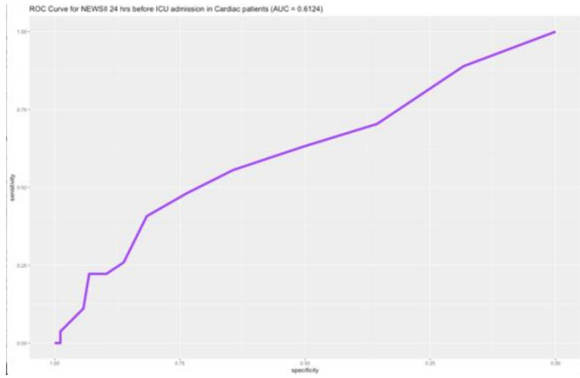



4. ME AUC: 0.63

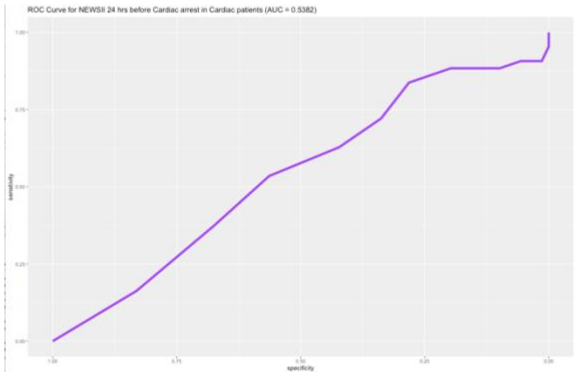
Figure 25. Predictive ability of NEWS2 on admission for death, ICU admission, cardiac arrest, and medical emergency.



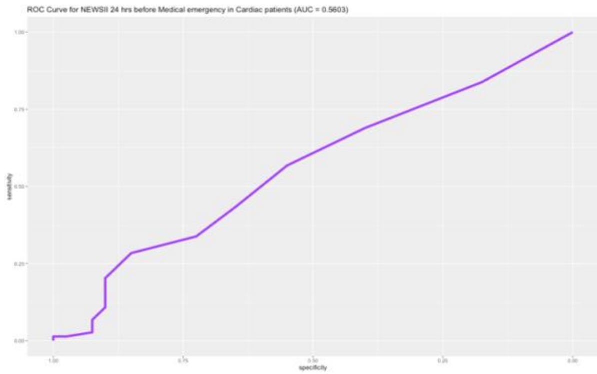

1. Death AUC:0.57




2. ICU. AUC:0.61

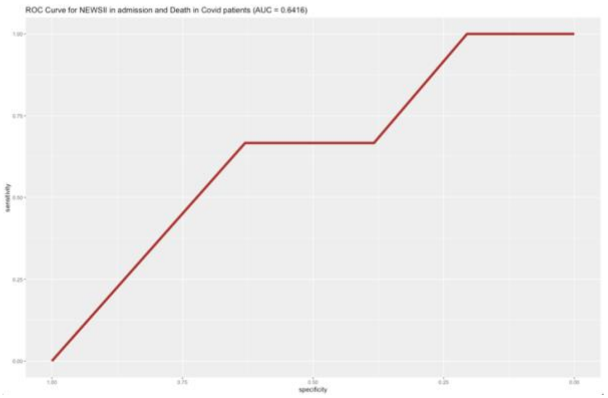


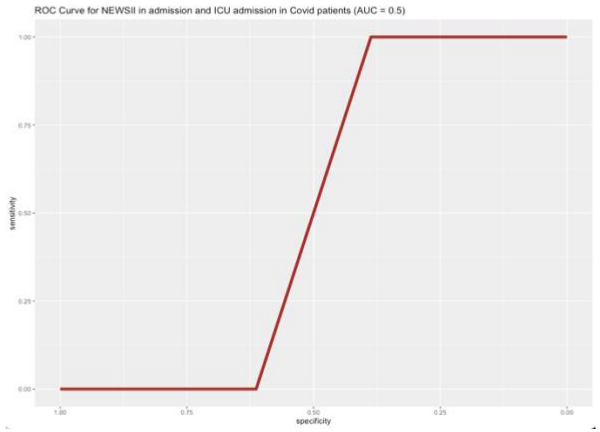

3. CA. AUC:0.53




4. ME. AUC:0.56

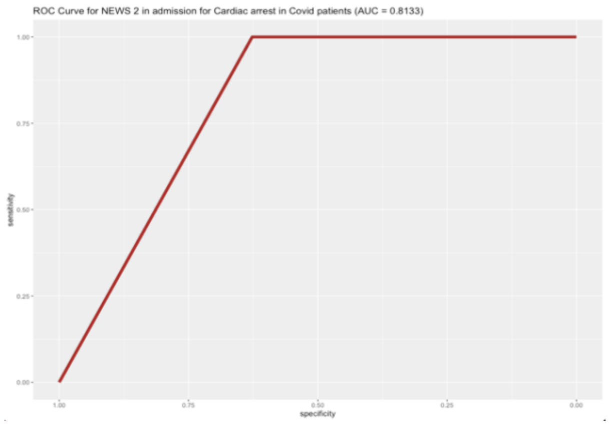
Figure 26. NEWS2 predictive ability 24 hours before critical events.

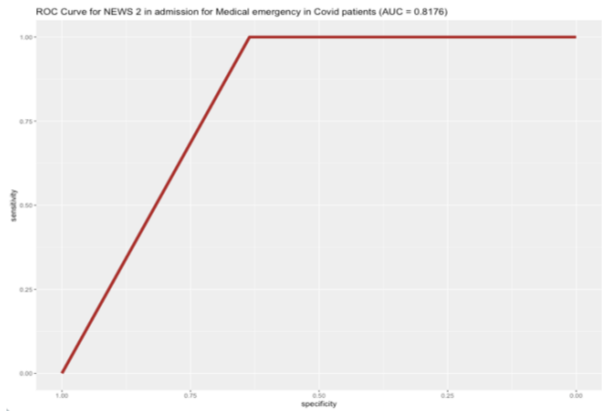



1.Death AUC :0.64

2. ICU AUC :0.5

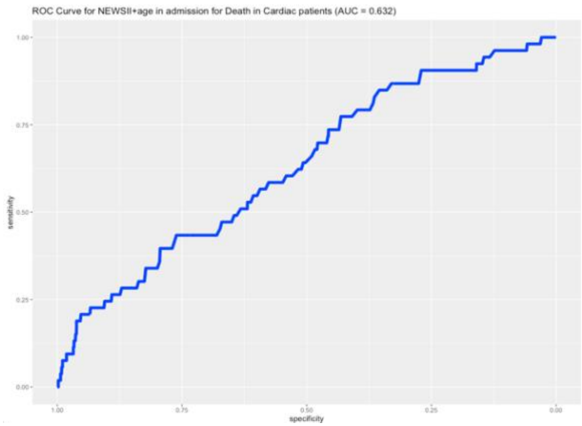


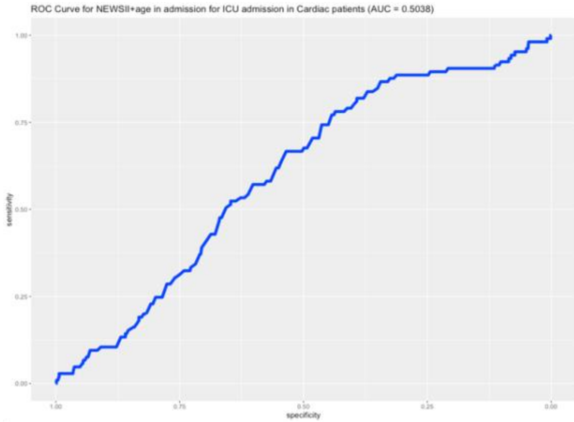

3.CA AUC :0.81

4. ME. AUC: 0.81

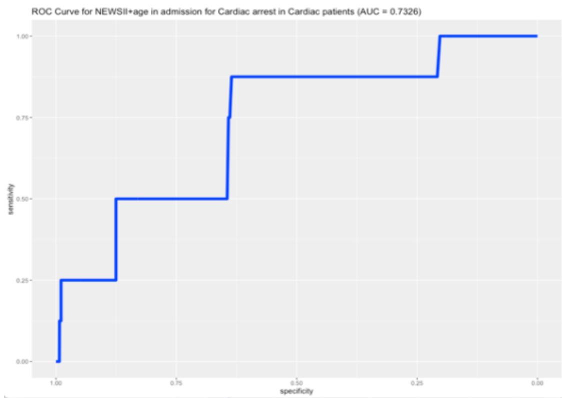
Figure 27. NEWS2 predictive ability on admission in patients with COVID-19.



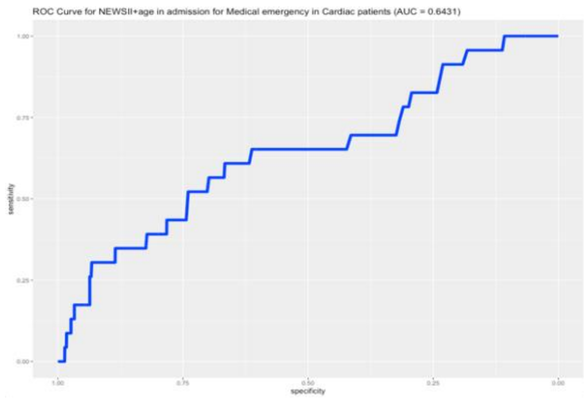

1. Death AUC: 0.63




2. ICU AUC:0.5

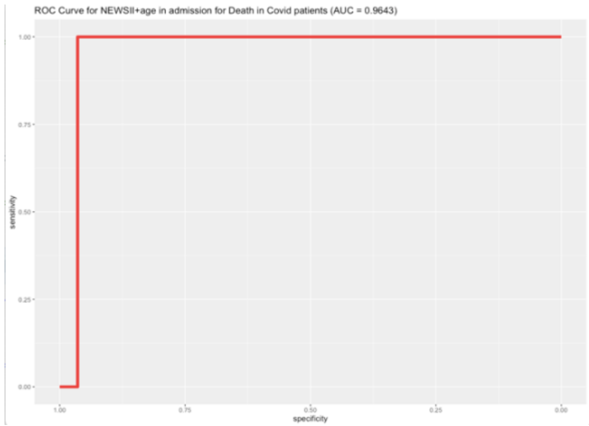



3.CA AUC:0.73

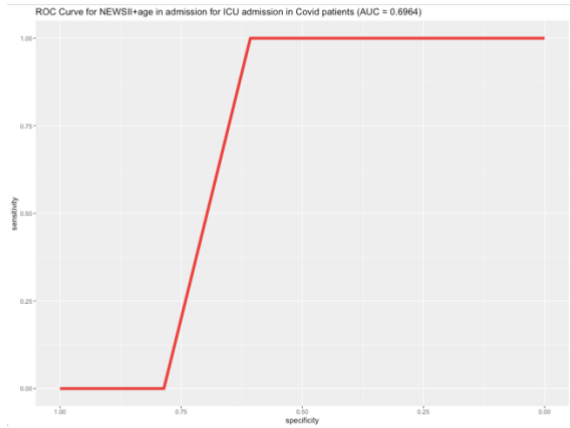



4.ME. AUC:0.64

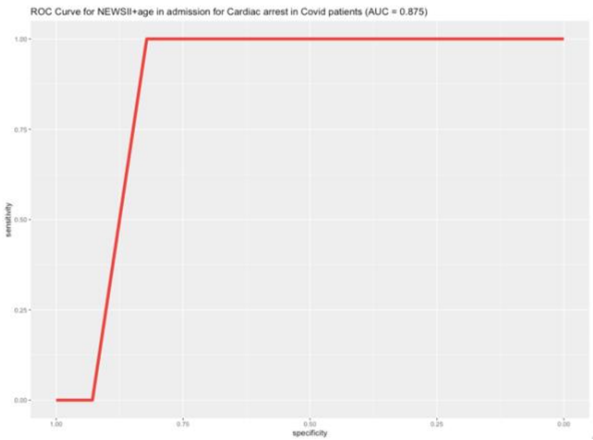
Figure 28. NEWS2+age predictive ability in cardiac patients.



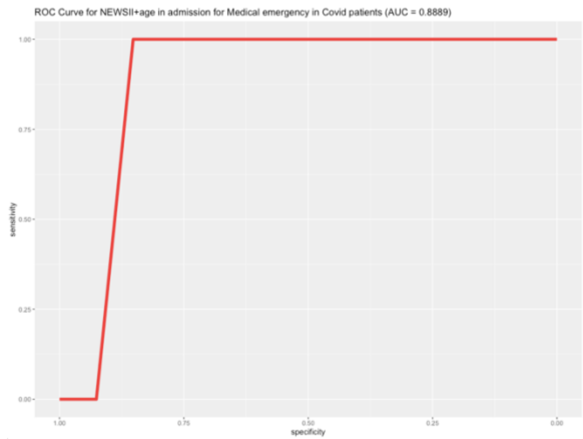

1.Death AUC :0.96




2. ICU AUC : 0.7

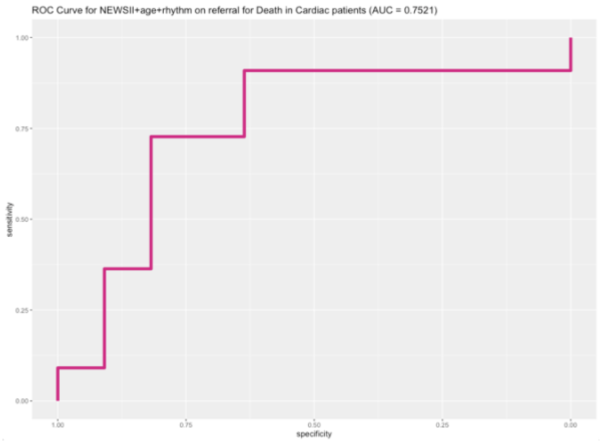



3.CA AUC :0.87

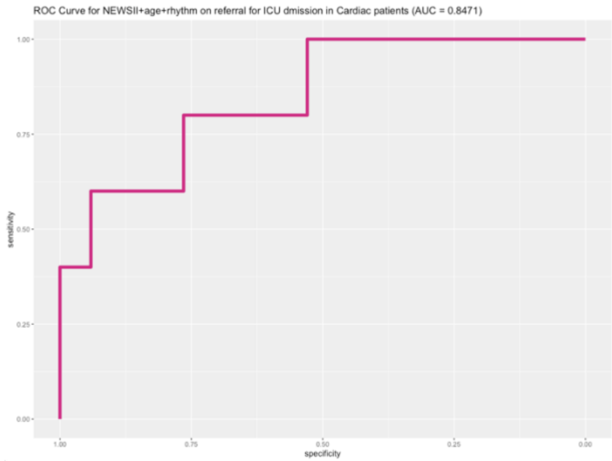



4.ME AUC:0.88

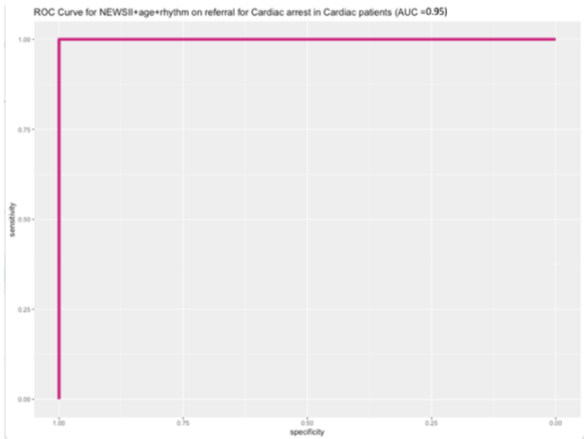
Figure 29. NEWS2+ age predictive ability in COVID-19 patients.



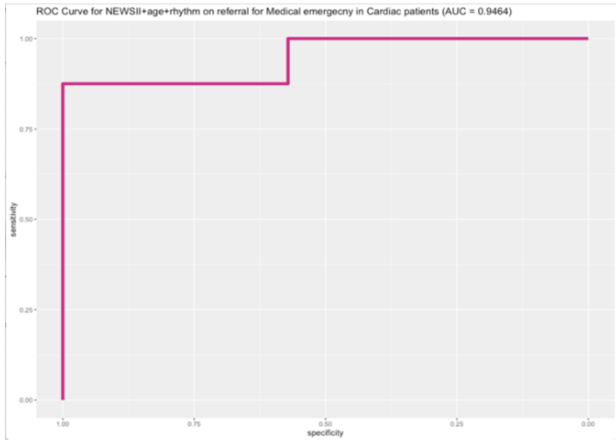

1- Death AUC: 0.75




2. ICU. AUC:0.84




3.CA AUC: 0.95




4.ME AUC:0.94

Figure 30. NEWS2 +age + cardiac rhythm predictive ability in cardiac patients.

Abbreviations: AUC: are under receiving curve, ICU: admission to intensive care unit, CA: cardiac arrest and ME: medical emergency.

## Discussion

The retrospective study is among the first to evaluate the prognostic ability of the digital early warning score, NEWS2, in patients with CVD in a specialist cardiac setting. An additional benefit was gained in in validating NEWS2 in identified patients with COVID-19 in the cardiac setting. The main findings of the study reveal that: (1) NEWS2 is inadequate on its own to predict deterioration in patients with CVD in the examined specialist cardiac setting; (2) adjustment of the tool by supplementing with positively correlated parameters can strengthen the prognostic performance and therefore reduce the burden of critical events associated with CVD.

The findings were consistent with a previous study in patients with chest pain (264) while contrary to findings by a study that examined a subset of CVD patients in a single hospital (202). MEWS showed low predictive accuracy in patients with chest pain in ED (264). However, good discrimination was found of ViEWS in a subset of patients in Canada a decade ago and using a distinct EWS than the current NEWS2 (202). Studies were limited in number, scope and population and varied in EWS models. Patients with "normal" vital signs may be sicker than they look through traditional routine monitoring (297). When EWS was explicitly developed for post-cardiac surgery patients, prognostic accuracy was excellent in predicting ICU mortality (71). It included a range of organ system-specific parameters that correlate with cardiac surgery outcomes, such as lactic acid, FiO2 and platelets. Relevant parameters were found using machine learning, including clinical signs and heart rate variability, to improve scoring systems for adverse cardiac events (264). The cardiac rhythm combined with NEWS2 in this study, and the heart rate variability, such as the average of the instantaneous heart rate (avHR) or Ratio of LF power to HF power (LF/HF) selected by Nan et al. (2014), may not be routinely measured or readily available for clinicians as SBP or temperature. Yet, their predictive value indicates the need for highly illness-correlated parameters to be present for clinicians through facilitating timely and thorough assessment.

The subset of patients admitted with Covid-19 showed improvement in NEWS2 when the model was adjusted with age. The finding is supported by a study that reported low to moderate discrimination of NEWS2 for the severity of COVID-19 disease (298). Adjusting the model with age alone did not improve prediction in the study by Ewan et al. (2021), as shown in our findings. However, supplementing with age, routinely collected blood and physiological parameters enhanced discrimination in a multisite (UK and non-UK hospitals) study (95), which seems to further support our results yet may detect the need for additional criteria adjustment. This study indicates that EWS are not a stand-alone rapid assessment tool as it accords with reported limitations in rapid risk scores for predicting cardiovascular complications (299,300). In clinical settings, and before implementing EWS, clinicians look for signs of abnormality related to body organs affected, disease pathophysiology, or procedure side effect to critically assess the situation. Systems that existed to stratify the risk of long term cardiac complications have been successfully validated and utilised for years, such as the thrombolysis in myocardial infarction score (TIMI) (12) and GRACE (14) . They included cardiac disease variables: heart rate variabilities and serum cardiac biomarkers, which may not be available routinely or at the first admission presentation for rapid assessment. It was also observed that combining nurses' objective assessment with traditional EWS in the Dutch-Early-Nurse-Worry-Indicator-Score (DENWIS) improved the prediction of ICU admission and mortality in surgical patients (301). Therefore, thorough tracking of short-term deterioration parameters to develop decisive intelligent scoring systems will potentially outperform EWS in various diseases and settings.

It is essential to consider possible issues in developing EWS for specialised subgroups. A potential complexity may be present when having a variety of multiple parameters measured at various times during admission to form a scoring system that is meant to be simplistic and standardised. In addition, the endpoints favoured by researchers in validation studies may not be the ideal points to measure triggered EWS against. In the clinical application of EWS, a high score triggers an action to prevent a critical event (302). In the event of clinically intervening at the right time, the examined adverse events may not occur. Prior to reaching or while preventing an adverse event, precise and proper deterioration endpoints may be more fitted than traditionally studied outcomes, such as death and ICU admission. At the current time of available EHRs integration and data science techniques, it is possible and may be more valid to identify and define appropriate critical illness endpoints to examine EWS against.

The assessment was conducted of the performance of digitally integrated EWS; the integration generates NEWS2 in patients' charts from remotely captured parameters by automated monitoring. EHR integration and automation can improve the accuracy and alerting promptness(54). There was a significance when a good sample of CVD patients was extracted, and patients diagnosed with Covid-19 were identified despite the missingness of some NEWS2 recordings. The issue in recording completion could be due to a lack of staff adherence to routine and timely monitoring, as each measurement would be automatically transmitted to patients' charts.

Therefore, careful and selective modelling of algorithms from parameters that can be available routinely and reflect significant clinical meaning is needed. The validity of NEWS2 in specialist settings like cardiology indicates the need for either score enhancement or systemic supplementing and finer endpoints definition for better detection. Studying the clinical environment from a practical side of EWS will explain the adoption and implementation role in the success or failure of EWS. From various specialities, clinicians' involvement in models' development and validation is invaluable to produce a higher accuracy and finely clinical expertise-born warning scores.

## Strengths and limitations

The study is the first to examine the performance of universal EWS (NEWS2) in patients with cardiovascular diseases in a cardiac specialist hospital. It was advantageous to extract data from EHRs systems where NEWS2 is integrated and automated, reflecting the accuracy of captured parameters and enabled us to integrate other data sources for critical outcomes and COVID-19 cases. The study followed a retrospective data collection from three data sources where there was less control of missingness of NEWS2 recordings, heart rhythm at several points in time, and other parameters that could be examined like Fio2 level. The validation was external of NEWS2 and internal of the supplemented model; external validation studies are needed for generalisability.

## Conclusion

The Early Warning Score (NEWS2) in patients with CVDs is suboptimal to predict early deterioration. Adjusting early warning scores with variables that strongly correlate with critical cardiovascular outcomes will improve the early scoring models. Thorough tracking of parameters in EHRs and data availability can support the generation of decisive, intelligent models for a readily feasible system in routine clinical work. There is a need for defining and revising critical endpoints and the involvement of clinicians in models' development that reflect a significant meaning for deterioration detection. Further validation and implementation studies in cardiac specialist settings and other specialist subgroups are required to investigate methods needed to enhance the effectiveness of EWS.

# Chapter 5

## Scoping review

Examining the situation of escalation of care in the covid pandemic:

### Introduction and background

In chapter three and four, the validation of EWS in specialised subgroups was examined and the performance of digital NEWS2 was validated in a cardiac specialised setting during the pandemic. In this chapter, the escalation of care situation where EWS is implemented is reviewed in the time of the pandemic.

Reversible complications resulting from failure to detect and escalate patients significantly impact mortality and morbidity. Patients dying from these complications are classified as "failure to rescue" (303) (304). Around 32% of harm incidents reported are caused by poor assessment and recognition (305). EWS can guide the escalation of care by providing a systemic approach (306). By timely recognition and analysis of abnormalities in physiological parameters through EWS, clinicians can identify deterioration, informing their decision regarding escalation. However, the validity of EWS in different clinical settings and the success of their implementation influence their reliability in escalating the care of critically ill patients.

Escalation of care is the course of detecting an abnormality, communicating the change to a senior medical or nursing professional, and providing the necessary healthcare management plan (91). Since the beginning of the COVID-19 pandemic, healthcare systems in escalating emergencies have been affected in different respects. There has been a soaring demand for ICU bed occupancy and increasing intensity of healthcare staff workload (307). The success or failure of escalating care can be drastically affected in intense times, and system or human-related errors are more likely. Although EWS have the potential to facilitate recognising acutely ill patients, their role in rapid response during the pandemic is unclear.

Escalation involves a combination of contextual elements that set the theme for rapid response teams. Studies to date have shown the need for improving team members' understanding of their roles, capabilities, and available tools when rapid response is needed (91). These factors arise from applied systems and cultures within health organisations. Socio-cultural elements such as situational awareness or decision-making play major roles. Such elements can either improve or cause unnecessary faults, i.e. the culture of disregarding accuracy or completion of recordings makes the referral a high-risk task. In addition, the organisational structure, such as policies and seniority level of clinicians, can also shape the scene of managing a deteriorating patient.

Examining the escalation of care during the pandemic is necessary to detect and learn from the challenges in the health systems and manage unforeseen emergent circumstances. Understanding the contemporary scenario will establish knowledge on implementing tools utilised for detection and communication, such as NEWS2. EWS are not meant to work in isolation from clinical judgement or clinical settings(62,308), and therefore it is essential to understand the environment where they are used. In a critical situation, readiness for possible risks can save resources and, more importantly, patients' lives. This study explored qualitative and quantitative research on the experience, adjustments, or factors facilitating or hindering the escalation of care in the COVID-19 pandemic. Examining studies utilising interviews, surveys or case studies can illuminate experiences and provides the interpretation of events (309)Hence related research have not been reviewed in relation to the pandemic, investigating published work to conduct a review may help prepare for future pandemics.

## Aim of this research:

To examine qualitative and quantitative studies describing the escalation of care in the COVID-19 pandemic and explore barriers and facilitators.

## Methods:

- Study design

A scoping review method was conducted. The methodology facilitated mapping out key concepts in our research topic that is not explored (142). The framework of Arksey and O'Malley was followed (144). As a reporting guide, the PRISMA-ScR Checklist was used (146).

- Information sources and search strategy:

The initial search was done in August 2021 to find published work and develop search terms. And a final search in September 2021. Medline via Pubmed, CINAHL in Ebscohost and Emcare via Ovid and the Cochrane library were searched for studies that fit the inclusion criteria from 2010 to 2021. Mesh terms and keywords on the escalation of care and deteriorating patients, COVID-19 pandemic, and early warning scores were used (Appendix 8).

- Study selection:

Title and abstract screening were done by the candidate then full-text screening was by two the candidate and primary supervisor followed by discussing with supervisory team. Studies were included if (1) conducted surveys, interviews, focus groups, case studies or documents analysis; (2) reported the experience, adjustments, or factors related to the escalation of care or rapid response teams or EWS role in the escalation of care in the health care setting during the COVID-19 pandemic.

- Data synthesis:

JBI reviewers manual was used for evidence synthesis (149) with additional information from NICE guidelines for qualitative studies (151) (Appendix 9). Critical appraisal was done using a CASP for qualitative studies (152) (Appendix 10).

Detailed explanation of the scoping review methods is mentioned in the methodology chapter.

## Results:

From 695 studies imported for screening, 48 full texts were assessed for eligibility, and three studies were included in this review that fit our aim and inclusion criteria. Figure (31) describes the included and excluded studies. The studies examined the adjustments that took place in the escalation of care, the challenges, and the adaptation factors that facilitated change. Two studies were conducted in the United States, one in a single hospital setting (310) and another in 40 hospitals (311); and one in Spain in a single setting (312). Methodology followed mixed methods through surveys and focus groups, quanitative through surveys, and in the third study documents analysis was conducted. The population in all studies has included various clinicians from different specialities. Factors affecting the escalation of care have been explored in each study, focusing on the decision-making process (310), Rapid Response teams and intrahospital cardiac arrests and escalation and de-escalation strategy. Study characteristics are charted in table (11) and summary of findings are in table (12).

In quality appraisal, studies had stated clear aims, conducted proper study design, expressed findings clearly, and showed the generalizability of results. However, we detected issues, like unclear requirement strategy in Mitchell et al. (2021) and Bard et al. (2021), and the method of data analysis was not explained in Bardi et al. (2021). CASP critical appraisal is found in Appendix (10)

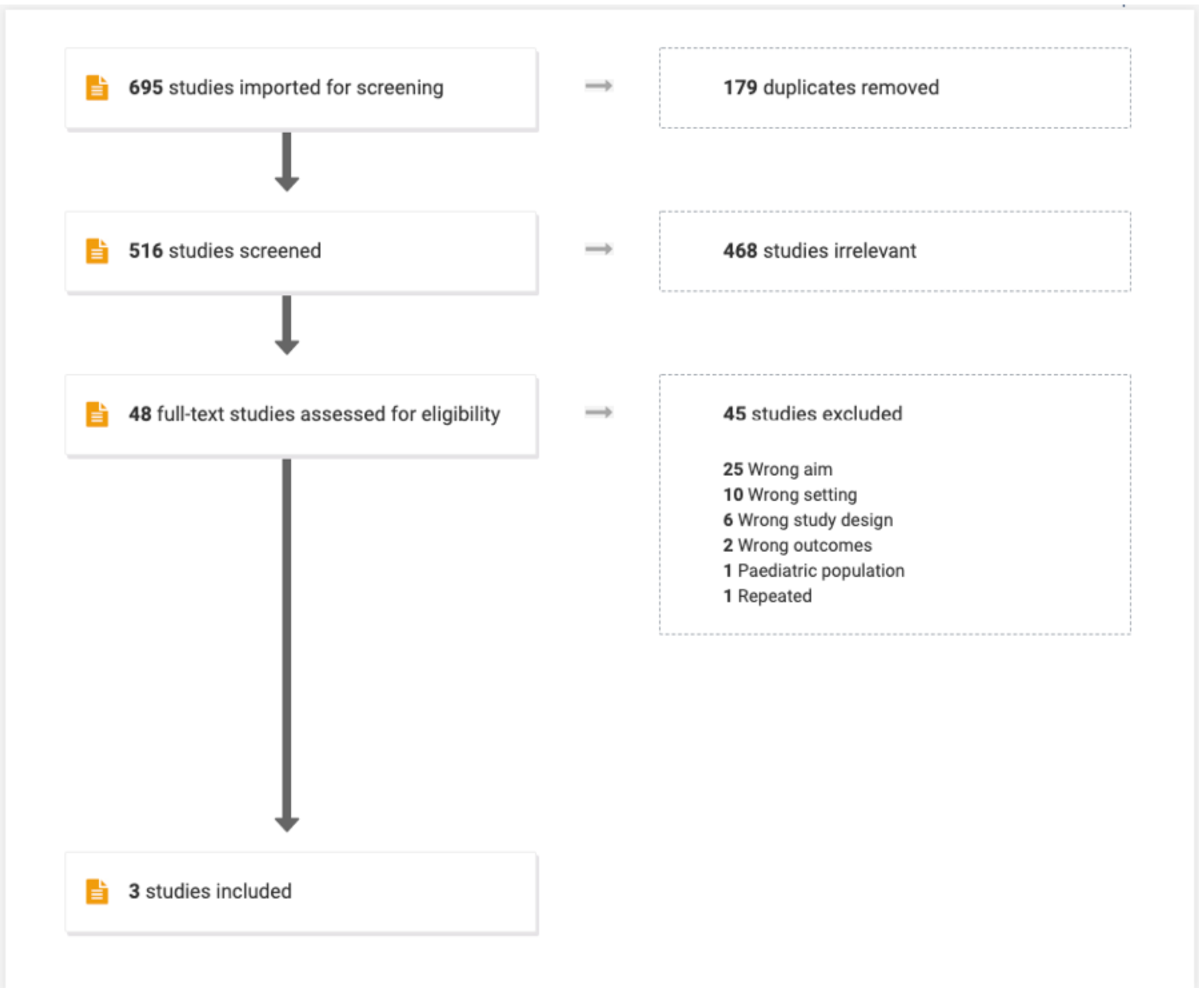



Figure 31. Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) checklist for the escalation of care in COVID-19 pandemic

Table 11. Summary of study characteristics

| Study ID | Author | Year of publication | Country | Methodology | Data collection method | Setting | Sample size | Study population | Outcome measured | Key findings | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Anton 2021 (310)** | Anton et.al | 2021 | United States | Mixed methods study – Interviews and survey | Semi-structured interviews and questionnaires | Single Hospital | 10 Nurses | Qualified Nurses from different clinical settings. | Factors affecting decision making for deteriorating patients. COVID-19 role in decision making. | 1- Identifying patient care needs, e.g., identifying potential risks. 2- Workload management, e.g., Bundling care tasks. 3-Missed opportunities inform learning, e.g., Critical reflection.<br><br>4- Factors related to COVID-19 and their outcome: Organisational, interpersonal, and intrapersonal factors, leading to Issues of recognition and quality of care. | The study informs the effect of COVID-19 on nurses' decision making and the identification of patients' care needs. when patients deteriorate. |
| **Mitchell 2021 (313)** | Mitchell et.a l | 2021 | United States | Quantitative study - Survey | Online cross-sectional survey | 46 hospitals in the US | 40 Clinicians | RRT leaders, physicians, and resuscitation researchers | Hospital characteristics, RRS structure before and during the COVID-19, adaptations made to IHCA management like mechanical CPR devices, use of simulation. | 1-RRS teams: an increase in emergency team resources during COVID-19 pandemic. 2-IHCA protocols: multiple adaptations to the protocol are made, like using viral filters for ventilation or PPE prior to | The study explains the adaptation in RRT that took place in US hospitals. |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | CPR in most cases.<br>3-Decrease in simulation activities.<br>4-Adaptations by emphasis on extra precautionary measures in clinical care. | |
| **Bardi 2021 (312)** | Bardi et.al | 2021 | Spain | Qualitative study - Document analysis | Data retrieval from patients EHRs and hospital contingency plans. | The Ramón y Cajal Hospital | >983 patients record and clinicians | Patients admitted to ICU and intensive medicine and anaesthesiology and intensive care specialists | The increase in ICU admission and challenges related to ICU increased capacity. | 1-New escalation and de-escalation strategy took place, led to an increase in ICU capacity by 340% from 38 to 129.<br>2- Challenges faced: hospital infrastructure, the number and experience of medical and nursing staff, lack of equipment.<br>3- Skilful and flexible management helped establish a contingency plan and overcome challenges. | The study explains a COVID19 strategy on escalation to ICU and challenging factors in the process. |

Abbreviations: RRT: Rapid response team; IHCA: Interhospital cardiac arrest; CPR: Cardiopulmonary resuscitation

### *Adjustments in escalation of care*

Various adaptations to hospital protocols for emergency events took place in response to the pandemic. The adjustments aimed to manage the escalation of care in a rapidly changing environment. Adaptation was executed by implementing a contingency plan that provides more resources to accommodate the increase of acutely ill patients and reform the hospital protocol to adjust to the new structure.

In the resources management, critical care capacity was re-evaluated. A substantial increase in space, staffing and equipment was reported in most hospitals in the US (45-58% of hospitals) (313) and in-hospital in Spain (312). ICUs were reorganised: non-medical critical care units were assigned to COVID-19 patients, and new ICU units were opened to safely care for patients requiring a high level of care. Physicians and nurses with different experience levels were assigned to work in critical care(312). More clinical staff joined emergency teams (313), such as rapid response teams (RRT), cardiac arrest and emergency intubation teams, or formed additional groups. ICUs and emergency teams were supplied with a higher number of materials and devices than before the pandemic. Ventilatory support was redistributed, and personal protective equipment was provided more in ICU and for RRT for intubation or during IHCA as a precautionary measure during COVID-19.

Reorganising the infrastructure required new protocols in hospitals to inform hospital workers of the directions in the new pathway. The escalation plan was redesigned following the opening and equipping of critical care services (312). Hospital strategy adjusted admission decisions to critical care to accommodate and prioritise the unwell, then promptly deescalate when they were stable. However, there was no report on EWS role in the prioritisation plan implemented. New protocols for safe practice were implemented, like using viral filters for ventilation in cardiac resuscitation or intubation (313) and admission of suspected COVID-19 cases to "unclean" ICU until a diagnosis is confirmed or ruled out (312).

*Challenges in delivering care*

One of the anticipated challenges reported is the inadequacy of resources in hospitals. ICU suffered from a lack of medical and nursing staff, resulting in the redeployment of ward staff to critical areas (312) and employing the newly graduated to take clinical care tasks. Wards and interventional areas were disadvantaged as a result. It also created intensified workload by a higher doctor- and nurse-to-patient ratios and bundling of additional tasks, such as senior staff preceptorship for the newly qualified (310,312).

The supply of ventilatory support and personal protective equipment was becoming exhausted gradually. The hospital's oxygen supply and the availability of ventilators or gas outlets in non-ICU units was significant challenge.

Training and professional development were pushed back because of the workload and the pandemic constraints. There were many missed opportunities for learning reported by staff (310,313). Learning through critical reflection, medical research, case reviews, and debriefing were inaccessible since patient's care was the priority. Simulation clinical training was reduced; from being conducted in most hospitals 35/40 (88%) in the US before the pandemic to only half of the hospitals (21/40; 53%). Learning activities were focused on emergency events like IHCA and intubation and missed other deterioration management like decompensating patients (313).

Table 12. Summary and examples of findings.

| Key concept | Main findings | How are they presented? | Example |
|---|---|---|---|
| Adjustments in escalating care (311,312) | Re-designing escalation of care strategy and structure | Increase in emergency team resources and critical care capacity | Converting wards to ICU's and more staff in rapid response team. |
| | | Adaptation to new protocol of precautionary measures | Using viral filters for ventilation |
| Challenges in delivering care (310–312) | Training and experience shortage | Missed opportunities inform learning | Critical reflection. |
| | | Decrease in simulation activities | No hands-on training |
| | Inadequate resources | Health care staff | Lack of experienced nurses |
| | | Health care facilities | Lack of ventilators |
| Factors that improved coping with critical care surge(310,312) | Workload management | Bundling care tasks | Gathering information to prioritize patient care task |
| | Careful assessment to Identifying patient care needs | Identifying potential risks. | Holistic assessment by experienced staff to rapidly identify patients need. |
| | Skilful and flexible management | Establish a contingency plan in crisis | escalation and de-escalation strategy |

*Factors improved coping with critical care surge*

There have been facilitating factors that were found to assist the adaptation to the constant pressure during the pandemic. The studies in the US and Spain reported inter-and intra-personal management and skilful organisational management had a positive impact on the escalation of care and staff decision-making (310,312). The delivery of critical care was supported by these fundamental skills: workload management, identification of patient care needs, and competent and flexible organisational management.

Experienced nurses and physicians utilise their clinical judgement to manage the workload. Managing care tasks and information by critical thinking, as described by *"Bundling care tasks"* (310), allows them to prioritise their assignments, ultimately by having time for effective patient care and processing information that help in decision-making. It allowed them to carefully observe changes in patients' status that can signal the need for escalation or de-escalation of care. With experience, nurses and physicians could conduct a thorough assessment of patients holistically. Regardless of utilising risk scores or early detection tools, a holistic approach was found to guide in narrowing down the possible clinical problems of the patients and the potential risks (310). Through this approach, patient needs could be met effectively and safely, especially in critical circumstances.

Another major factor was skilful and flexible hospital management. Redesigning a healthcare strategy was vital to recovering from the pandemic (310,312). The design had to adapt to new decisions and protocols to go hand in hand with the rapidly changing situation. In addition, appropriately reorganising and sufficiently supplying resources by competent management was reported to improve the staff's ability to deliver care safely and confidently. The managing professionals must have the skills and experience necessary to validate and implement the hospital protocols in critical times.

## Discussion

Despite the surge in ICU admissions and global death rates, it was surprising to find limited evidence of the escalation of care experience in healthcare settings during the pandemic. The scoping review has explored three main themes: the adjustments in the escalation of care, the challenges faced when delivering care, and adaptation factors that facilitated change. The review results show two conclusions: (i) the necessary adjustments in hospitals systems can be successfully implemented with early and rapid support in the infrastructure and individual staff level; (ii) recommended EWS are to be recognised and conceived better along with guidelines, i.e. NICE (38) and AHA (314) guidelines for deteriorating patients, to understand EWS significance in rapid response and support the strategy of escalation.

In facing the pandemic in healthcare, more challenges are posed to the escalation of care than before the pandemic. The change of hospital strategy or adoption of new guidelines must put the hospital on a flexible route to absorb rapid changes. Changes affecting hospital care pathways and resources are unsteady and rapidly evolving in the COVID-19 pandemic or any unanticipated outbreak. Skilled healthcare management has led to the start-up of several rapid response projects in handling the pandemic. For example,  the response teams' strategies during the spread of the coronavirus (SARS-CoV-2) and COVID-19; in secondary and tertiary care settings; have shown significance in improving clinical outcomes in countries with high survival rates(315–318). Methods applied in hospitals' rapid response to the pandemic, such as process mapping, effect analysis, and failure modes (315) may be constructive to adopt when implementing changes in the escalation of care designs; however, they require further investigation. Developing a flexible, adaptable contingency plan for the outreach and rapid response teams can mitigate the COVID-19 impact on escalation, especially the significant resources constraint.

Experienced clinicians are a great asset in the critical care and deterioration management plan. While the junior and the newly qualified nurses and physicians have responded to the surge in critical care demand(312,319), experienced staff were assigned to supervise them. Furthermore, experienced clinicians were required to carry clinical responsibilities with a higher intensity in level and ratio than before the pandemic. Although professional and managerial support to clinicians may not be optimum during the pandemic, it is essential to maintain prior and post-pandemic recovery. The absence of critical reflection and simulation activities during the pandemic (311) may negatively affect professional development. The direct impact of lack of training is yet unclear. However, in previous studies, junior clinicians have shown a lack of confidence and concerns in managing critically ill patients and decision making during the pandemic (320,321). In situ simulation, whereby the drill is conducted in the clinical environment by clinicians on a typical working day, is an efficient method to facilitate interprofessional training (322,323). It has been delivered previously in alignment with clinical practice during the pandemic to evaluate the performance of rapid response teams and identify hazards and deficiencies (315). It is deemed an excellent high-fidelity training to identify areas of weakness and needs for improvement when the burden on healthcare and risk of transmission prohibits traditional training.

As the escalation of care is a multifactorial area, examining the experience in the pandemic requires investigating all the elements contributing to the recognition of the critically ill and communicating the process from all dimensions. EWS is developed to predict deterioration and facilitate or prevent the escalation of the critically ill. Therefore, they may reduce the burden in times of crisis. Despite validation studies on their performance in variable settings (64,191,296), There is a significant limitation of EWS validation in specialised disease groups including patients with COVID-19 (296,324). Not to mention, EWS implementation is limitedly examined. These deficiencies in evidence may explain the inadequate recognition of EWS and the lack of defining their role in the process of escalation of care in the pandemic. A refined and clear validated role of EWS needs to be proclaimed in the rapid response process. In addition, the recommended adoption of COVID-19 responses updates and guidelines were conducted, yet their impact on patients' outcomes is to be studied. AHA guidance for management of in-hospital cardiac arrest (IHCA) (325) and CDC for redesigning the infrastructure of health facilities during COVID-19 (318,326), were applied in different settings; nonetheless, no evidence has been reported yet on their effectiveness in staff safety and patients outcomes. The health working system elements interact and influence the health care process (327,328), and therefore, investigating and improving these elements will improve the health care system in the escalation of care.

The evidence found on the changes in the escalation of care due to COVID-19 was very limited, considering the global impact on mortality and ICU capacity. Despite the transitions in clinical experience during COVID-19 and the availability of EHRs data, qualitative and quantitative studies are poor. The pandemic is a worldwide health challenge that redefined hospital systems globally in different aspects, and undoubtedly the rapid response practice and resources. The few studies in the US and Spain may not represent the significant impact on the escalation of care in other parts of the world affected by the pandemic, such as the UK. In addition, the socio-economic implications, clinician's role and patients' outcomes were disregarded in the studies. More studies are needed to evaluate the escalation of care during the pandemic and the consequences; affecting patients, clinicians and resources; resulting from changes in the rapid response structure.

## Conclusion

The continuing effect of COVID-19 on the escalation of care has posed challenges to recognising and managing the acutely ill. However, there was limited evidence of the changes in the escalation of care due to COVID-19. Adjustments in hospitals' critical care strategies and adapting the protocols and guidelines helped establish the rapid changes. Support to nurses and physicians through training and reflective thinking is poorly delivered. Alternatives to traditional learning methods, such as in-situ simulation and debriefing, are efficient methods that need to be examined further. EWS facilitate clinicians in detection and escalation, yet its role is not firmly recognised in the escalation of care during the pandemic. Implemented EWS are to be validated appropriately in their performance and implementation in the escalation process to advocate their endorsement. In addition, applied guidelines' impact on patients' outcomes needs to be examined. Studying the experience of rapid response to deteriorating patients during the pandemic on a large scale, and considering essential tools in escalation, will shed light on more coping strategies and successful examples to learn.

## Strengths and limitations

The study examined the evidence to date on changes in a significant process in managing deteriorating patients during the majorly challenging pandemic. The scoping review was conducted to map out the key concept in the escalation of care and bring a more specific questions for further research. The scoping review is limited to three qualitative studies due to the limited research, COVID-19 period, and current evolving situation. The study did not examine the direct impact of changes in the escalation of care on patients' outcomes and the clinician's role. The studies included are missing some factors that contribute to the escalation of care, such as the economic impact of the pandemic on resources, early warning score's role, and different hospitals' specialities and patients admitted.

# Chapter 6

## Qualitative study

Evaluating the implementation of EHR integrated NEWS2 in a cardiac specialised and a general hospital setting in the COVID pandemic.

### Introduction:

Following the evaluation of the performance of digital NEWS2 and examining the escalation of care experience in previous chapters, the implementation of digital NEWS2 in two hospital settings was examined qualitatively in this chapter.

Prediction tools in acute care settings can improve patient safety through enhanced efficiency of care and reduced pressure on health systems. Early Warning Scores (EWS) are a potential solution to decrease critical events, unnecessary deaths and debilitating resources. EWS have become part of the escalation guidelines directing clinicians to the level of care needed. In conjunction, clinicians utilise their education and clinical experience, as when EWS did not exist, to make clinical judgments. Implementing EWS advise clinical assessment when puzzles are missing from knowledge and experience.

However, there is a gap in evidence on the performance of EWS in different settings and specialities. (296,329–331). For instance, in cardiac care and complex comorbidities, i.e. COVID-19 patients, the performance of EWS are poorly and in the early stages. Equally, there is a lack of evidence on implementing integrated EWS in Electronic health records (EHR) in specialised clinical settings. With the electronic assessment recording, EWS scores and alarms are produced automatically, facilitating its utilisation by clinicians. The functionality gives more confidence in EWS generated when part of the burden becomes the role of the machine. It has improved clinical outcomes and staff workflow (113)

For EWS to be successful, they have to be properly implemented. Errors in assessment, recording and escalation of care contributed to 20-80% of the severe adverse events (114). As shown in previous EWS and digital solutions, wide dissemination does not necessarily lead to successful adoption (332). It is well established that failure of EWS are related to patients' physiology or professionals' practice, i.e. poor adherence to the prescribed protocol for deterioration  (332,333). In addition, the downsides of automated monitoring, i.e. measurements errors, artefacts and false alarms (334) can challenge the progress needed. The significance of NEWS2 and automated application is only valuable if resulting in a tangible improvement.

Therefore, the implementation of NEWS2 requires investigation by understanding clinicians' perceptions of EWS. A qualitative study of EHR-integrated NEWS2 was conducted in a specialised cardiac; and a general hospital; from the perception of nurses utilising it. The non-adoption, abandonment, scale-up, spread, sustainability (NASSS) tool (154) is a pragmatic, evidence-based design that can provide a thorough understanding of digitally supported tools in healthcare. Due to the application of electronic recording and automation, the NASSS framework was followed in the study.

### Previous implementation studies

EWS models that proceeded NEWS2 were examined from nurses' and doctors' experiences in acute and non-acute settings. In a study in Norway, MEWS supported early recognition and knowledge sharing between nurses (335). Another study found that nurses value NEWS as it incorporates their knowledge and judgment, yet may not necessarily lead to desired clinical outcomes (336). In non-acute settings, it is believed to facilitate communication and decision making. However, EWS used in emergency departments (HEWS) was unvalued by physicians and nurses (337). HEWS may not be as advanced as NEWS and NEWS2 in development. Nonetheless, results from specialised departments like ED demonstrates the need to examine settings with unique functionality. The negative experience of NEWS caused tension when it was implemented (338). Compliance, workload pressure and discrepancies between clinical judgment and the scores generate workplace anxiety(332,338). As pressure increases in busy hours, defective collaboration and miscommunication arise between clinicians leading to failed implementation (332). The experience of EHR-integrated EWS in specialised settings is missing from the literature.

## Objectives:

To evaluate the success and role of implementing EHR-integrated NEWS2 from nurses' perception in a cardiac specialist and general hospital settings in the COVID-19 pandemic.

## Methods

- Study settings:

St Bartholomew’s Hospital; the cardiac specialist hospital and University College London Hospital; the general teaching hospital.

- Study framework:

A qualitative study design to evaluate the implementation, following the NASSS framework (154) (Figure 32). The factors were presenting the implementation of NEWS2

- Data collection:

A purposive sampling method was followed to conduct individual interviews for the qualitative data collection. Invitation emails to 10 nurses and managers in Barts, and equal number to UCLH staff to conduct individual semi-structured online interviews. An online questionnaire of the quantitative data was sent to nurses and managers in cardiac and non-cardiac wards in Barts and UCLH. (Appendix 11.a and 11.b)

- Data analysis:

The interviews were analysed thematically to identify experiences and recognise patterns in inter views (163). Detailed explanation of study sites, framework, data collection and analysis is in the methods chapter.

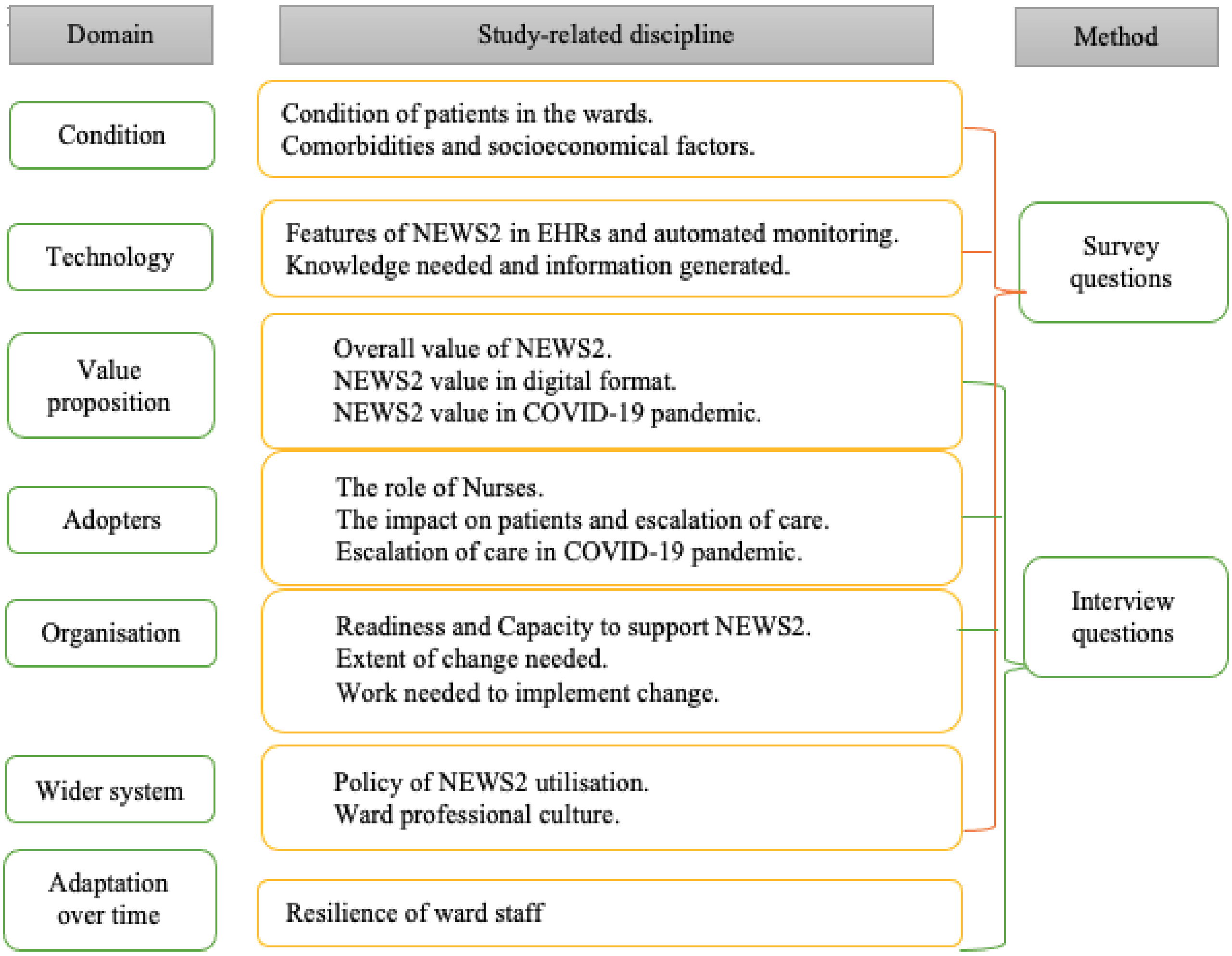



Figure 32. NASSS framework domains and methods in the study.

## Results

11 nurses and managers participated in interviews that lasted 35 minutes each. Survey respondents were 67 nurses and managers.

- Interviews

In the cardiac setting, 6 staff responded, and 4 agreed and were interviewed. In the general hospital, 7 nurses participated: 3 interviewed from the first invite. After follow-up emails, 5 responded, and 4 were interviewed. (Table 13)

- Questionnaires

28 staff answered the surveys in the cardiac setting, from cardiology, critical care, medical and oncology. From the general hospital, 39 answered the questions from critical care, medical and oncology wards (Table 14).

Table 13. Characteristics of interviews and survey respondents.

| | | **Cardiac specialist hospital** | | **General hospital** | |
|---|---|---|---|---|---|
| | | Interviews | Surveys | Interviews | Surveys |
| **Role** | Manager | 2 | 5 | 4 | 10 |
| | Nurse | 2 | 20 | 3 | 23 |
| | Nurse assistant | | 3 | | 6 |
| **Speciality** | Cardiology | 4 | 12 | | |
| | Critical care | | 3 | 2 | 26 |
| | Medical | | 4 | 3 | 5 |
| | ER | | | 1 | |
| | Oncology/Haematology | | 11 | 1 | 8 |

### *Themes*

Three themes emerged from applying the NASSS framework on studying the success of implementing NEWS2 in the two hospitals. The themes from domains were as follows: (i) Organisation, wider system, and adaptation over time: Implementing NEWS2 between challenges and supports, (ii)value proposition and adopters: the perceived value of NEWS2 as an alarming tool; in escalation and during the pandemic; (iii) the condition and technology features: EHRs integration and automation of monitoring. Some domains from the framework intersect in themes due to the relativity in subthemes to more than one domain (Figure 33). Results from the survey served as a supplement that supported the themes (Table 15). Table 14 explains the characteristics of the interviewees hospital setting and digital system.

Table 14. Culture and system characteristics of interview participants.

| Participant | Hospital specialization | EHR integration | Automated monitoring | Role | Speciality |
|---|---|---|---|---|---|
| **S.M** | Cardiac Specialist | √ | √ | Manager | Cardiology |
| **S.M** | Cardiac Specialist | √ | √ | Manager | Cardiology |
| **G.S** | General | √ | X | Staff nurse | Cardiology |
| **G.M** | General | √ | X | Manager | Medical |
| **G.S** | General | √ | X | Manager | ICU |
| **G.S** | General | √ | X | Staff nurse | Oncology |
| **G.M** | General | √ | X | Manager | ICU |
| **S.S** | Cardiac Specialist | √ | √ | Staff nurse | Cardiology |
| **G.M** | General | √ | X | Manager | Medical |
| **G.M** | General | √ | X | Manager | Medical |
| **G.S** | General | √ | X | Staff nurse | Emerge**ncy** |

Note: Participants code: first letter: S is Specialist hospital and G is General Hospital; second letter: M is a manage and S is staff nurse.

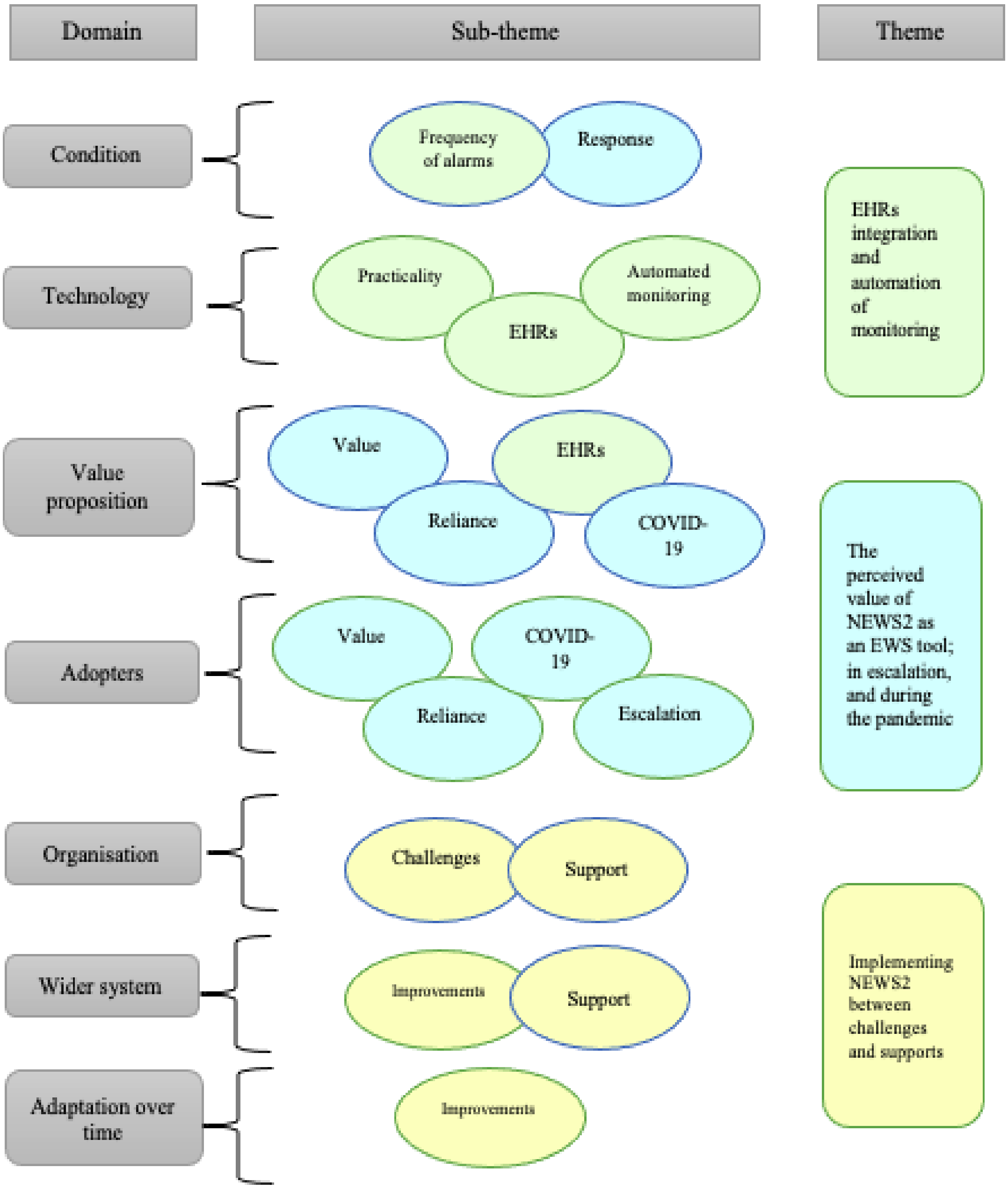



Figure 33. Themes and subthemes emerging from the NASSS framework domains.

Note: The grey boxes represent the domains explored in the interview. The bubbles in the middle represent the subthemes formed from the codes generated in the analysis. The boxes on the right represent the main themes formed from the subthemes in common. The colours indicate the subthemes and the themes they relate to.

- Implementing NEWS2 between challenges and supports.

The difficulties found by nurses and managers were human-related, tool-related, and resource-related factors.
From the human-centric side, Junior nurses worry if their judgement for escalation based on NEWS2, and their knowledge is inaccurate or undervalued. On the other hand, clinicians and rapid response teams may not always be cooperative when escalation is reported, resulting in timidness by junior staff and avoiding being involved in escalation.

- *I think NEWS2 can be unhelpful when I see how the medical team behave in the situation."* S.M
- *"It's about increasing the psychological safe space to speak up no matter who you are. We're not quite there yet."* G.M

The IT literacy and interest difference between staff cause a gap in adopting NEWS2 in EHRs in both hospitals. Resistance or delays in learning lead to errors in documentation and obstruct escalation.

- "*Documentation isn't Great."* S.M
- "*Because it's an electronic system, some staff aren't particularly comfortable using IT equipment. So, they do the Observation, write on a piece of paper, then enter it later."* G.M

NEWS2 parameters were considered problematic. Their format may not be appropriate for the patient group, specifically cardiac patients, as reported from both sites. There's a frequent need for parameters adjustment to suit a patient's medical history to avoid repetitive alarms. Adjustment is challenging as this role is assigned to doctors only.

- "*The problem with it is that the medical team needs to input the target parameters, and only when they do that it does trigger NEWS2."* G.S
- "*Particularly I think cardiology patients need parameter changing."* S.M

Poor resourcing of equipment and staff affects the adoption negatively. When workstations are occupied, recording may be incorrect, and escalation is delayed, yet the issue may not be present in the specialist hospital, where automated monitoring occurs. In addition, nursing assistants who do routine monitoring are not as trained as registered nurses. Reporting deterioration can be missed or delayed.

- "*The healthcare assistants do the observation, then by the time they report, or maybe they forget to tell you the patient is scoring five or six."* S.S
- "*We sometimes don't have access to an EHR machine because they're busy or broken, or we haven't got enough, or we don't have access to the handheld devices."* G.M

From the support side, nurses and managers had a consensus on the benefits training provided in both sites. However, training has declined due to the pandemic pressure in the workplace. They reported significant support by the hospital management to utilise NEWS2 and adopt the EHR-integrated version, including induction programs training. Ongoing guidance by informatics experts, superusers and ward managers was reported in surveys and interviews. Nonetheless, lack of training and auditing is an issue in both sites. An emphasis was reported on structuring a clear step-by-step process for implementation. Quality projects that focus on improving documentation and escalation, such as deteriorating patient's dashboard project in the specialist hospital, were valued by staff in both sites.

- "*I think they are supporting it. But I do think it's a shame that, throughout the pandemic, it's not audited anymore."* S.M
- *"Other hospitals created dashboards of patients scoring high for users and outreach team to focus on."* G.M

Some nurses in general hospitals perceive it as a mandatory tool rather than a choice yet agree to follow. Resilience was subject to personal and experience differences, such as age and recurrent guidelines updates. Younger staff were reported to be more receptive to change than older staff.

- "*They are quite resilient because there has been much structural process, which has changed constantly, the team have taken them forward quite well."* G.S
- "*They easily pick up on the new electronic things; it's quite a young team."* G.S
- "*Some don't change because they find the computer stuff and everything a little bit difficult."* S.S

Table 15. Survey domains, questions, and responses

Domains: (i) Condition, (ii)Technology, (iii)Wider system

| | General hospital respondents | | | | | Cardiac specialist hospital respondents | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Strongly agree | Agree | Neither agree nor disagree | Disagree | Strongly disagree | Strongly agree | Agree | Neither agree nor disagree | Disagree | Strongly disagree |
| A. The information generated by NEWS2; including score and alarms; are easy to understand | 6 | 24 | 6 | 3 | 0 | 3 | 19 | 3 | 0 | 3 |
| B. The implementation of digital recording of NEWS2 in EHRs helped in recording patients' parameters and NEWS2 | 9 | 21 | 5 | 2 | 4 | 2 | 22 | 2 | 5 | 0 |
| C. The implementation of digital recording of NEWS2 in EHRs helped in improving the escalation of care when needed | 7 | 20 | 29 | 4 | 2 | 2 | 15 | 5 | 4 | 0 |
| D. The presented model of NEWS2 in the EHRs is simple and practical. (EHR Electronic health records) | 2 | 27 | 10 | 2 | 4 | 4 | 5 | 7 | 0 | 5 |
| E. There is a clear policy on the application of NEWS2 in patients care in your hospital | 2 | 33 | 5 | 2 | 0 | 0 | 14 | 5 | 2 | 0 |
| | often | Occasionally | Sometimes | Almost never | I don't know | often | Occasionally | Sometimes | Almost never | I don't know |
| F. How often patients have complex conditions. i.e., comorbidities, metabolically unstable, or poorly understood condition (Excluding COVID-19) | 25 | 4 | 10 | 0 | 2 | 22 | 0 | 2 | 0 | 0 |
| G. How often patients cared for were diagnosed with COVID-19 | 6 | 11 | 15 | 9 | 0 | 10 | 0 | 4 | 4 | 4 |
| H. How often patients have socioeconomic factors i.e., family, income, house condition, education, affecting their prognosis | 14 | 12 | 8 | 4 | 5 | 9 | 4 | 8 | 0 | 0 |
| I. The need for help in understanding NEWS2 and who to refer to. | Senior staff/superusers in my department. | Informatics/ tech professionals | Materials or online resources | Didn't kw where to go | Didn't need help | Senior staff/superusers in my department. | Informatics/ tech professionals | Materials or online resources | Didn't kw where to go | Didn't need help |
| | 12 | 2 | 6 | 2 | 19 | 9 | 4 | 9 | 2 | 5 |
| J. Attending networking session with regard to NEWS2 and routine monitoring i.e., updates, or team meetings. | Internally in the department | Organised hospital sessions | Informal discussions with colleagues | Yes, I checked the materials we have or online resources | I haven't participated or attended any updates or networking sessions | Internally in the department. | Organised hospital sessions | Informal discussions with colleagues | Yes, I checked the materials we have or online resources | I haven't participated or attended any updates or networking sessions |
| | 10 | 5 | 6 | 0 | 28 | 5 | 2 | 4 | 5 | 12 |
| K. Training offered to understand and utilise NEWS2. | Informatics staff/ tech experts/superusers | L Manuals and resources online. | J. Orientation by ward staff or manager | K. Self-practice | | Informatics staff/ tech experts/superusers | L Manuals and resources online. | J. Orientation by ward staff or manager | K. Self-practice | |
| | 29 | 20 | 18 | 6 | | 12 | 9 | 4 | 5 | |

Note: The numbers represent the frequency, and the coloured boxes reflect most responses. Green highlights positive feedback, blue is neutral, and orange represents a negative or challenging aspect.

- Value of NEWS2 to alarm, escalate, and in the pandemic.

Overall, nurses and managers believed NEWS2 helps prioritise patients' needs according to acuity, therefore improving patient safety. They valued the unified language between clinicians to overcome disagreements arising. Tangible advantages of NEWS2 were seen in recognising a response to treatment, a need for transfer to Ward or ICU, or just an impression of the patient's status. Nonetheless, it is deemed "overvalued" by some nurses, and others anticipated the need for iteration due to its failure in some settings like cardiology and general surgery. From the survey responses, it was reported that cases treated are often complex due to comorbidities or COVID-19. Senior staff perceive its usefulness for junior doctors and nurses yet believe it poses the risk of over-reliance in utilising a tool that may not be reliable for each condition. It can restrict their critical thinking due to their lack of experience. They perceive it as an optional mean in the escalation process yet not dependable.

- "*It allows us to catch things before we have to send a patient elsewhere."* S.M
- "*Historically, sometimes nurses will argue if the patient is sicker or not; NEWS2 frames this with a nationally recognised number."* G.M
- "*I used to see patients that were unwell, that didn't trigger NEWS. Junior nurses worry about what the audit says, they can be completely fixated on a NEWS2 and not the patient holistically. Over-reliance becomes a danger."* G.M

In escalation of care, it provided clarity. When, where and whom to escalate to is coherent to everyone, potentially saving time and promoting safety. Yet, nurses from both sites reported that the impact of NEWS2 in the escalation is insignificant to make a noticeable difference.

- "*This is very clear cut in terms of NEWS2."* G.M
- "*I don't think it's made that much of a difference."* G.S

In the time of the pandemic, there was an agreement by most staff that no advantage observed is credited to implementing NEWS2 in clinical work or patients' outcomes. Nurses and doctors are more vigilant to deterioration due to international and organisational recommendations to manage and prevent COVID-19. Teams, i.e. medical, infection control and CCOT, were present, facilitating the escalation of care. An advantage reported was specific attention to temperature scores in NEWS2 to alert any suspected COVID-19 case.

- "*I don't think it had much of a value in the pandemic. We had a medical team on our Ward all the time, which we weren't used to, and of course, we had a good response."* S.M

- Digitalisation: EHRs integration and automation.

NEWS2 in EHRs is perceived to have several advantages, with some unpleasing downsides. Accuracy of calculation and timely scoring were reported once entered in patients' charts. This facilitates decisions for treatment or escalation; and the ability to audit documentation. On the other hand, it has been perceived to inhibit junior nurses' and doctors' thought processes when they rely on the system to produce a score without examining its parameters. Some nurses expressed a preference for the paper chart version of NEWS2 over the electronic one due to the absence of colour coding, inability to adjust thresholds, omission of score trend, and constant alarms pop-ups. From the surveys there was neutral perception on the simplicity and practicality of the NEWS2 model in EHRs. More dissatisfaction with the model in EHRs was expressed by general hospital staff than Specialist hospital, who agreed more to it. Personal differences like age and IT literacy causes a restrain to some nurses to adopt digital documentation.

- "*We can deep dive in the documentation to make sure that everyone is doing what they need to do."* S.M
- "There are *benefits of an electronic system, but it doesn't allow nurses and doctors at a junior level to think about their thought processes."* G.M
- "*I did use to like the graphs that we used to get in the paper version, to be able to see what the acuity trend is like for patients and across the floor."* G.S

With automated monitoring in the specialist hospital, the accuracy of recording and timely data transfer is reliable. Nurses are more aware of the need to accomplish this task when it's automated; not appearing on the screen means undone, while previously it could indicate late entry. Nonetheless, timely observations may not lead to timely escalation. Nurses do not carry computers or handheld devices all the time. Therefore, escalating a case is subjected to completing the documentation on the workstation, which may be by the end of assessing a number of patients.

- "*it's accurate and timely; the moment you open the screen, it will flash to remind you to act."* G.M
- *"They'll do a whole lot of patients, six to ten and then come back and escalate it at the end."* S.M

Understanding the information behind NEWS2 and generated by it was straightforward to most participants. Nurses who considered it unideal expressed the need to learn the rationale behind each parameter scoring and confusion related to triggering at the patients' baseline. Nonetheless, the NEWS2 score, and parameters value is perceived to be unrealistic. Constant unnecessary alarms are disadvantages reported by nurses working in cardiology and oncology wards in both sites, while not alarming when assessment indicates the need to escalate. Nurses who are the primary assessors for NEWS2 are not authorised to adjust the scale, causing annoyance and avoidable alarms when done by doctors.

- *"I suppose cardiology patients need parameter changing. It would help. I think here's a lot of unnecessary pop-up boxes."* S.M.
- *"Sometimes, the patient might not be newsing. But you just know and feel something changed. And often, we're quite right with that."* G.M.

## Discussion

The study in the general and specialist settings examined the facilitators, challenges, and value of implementing EHR-integrated EWS guided by the NASSS framework. Exploring the nurses' views was in a unique time of the pandemic. The framework's domains have intersected in the themes leading to three findings identified. The implementation support by hospital decision-makers was sufficient, yet, determined challenges, like clinicians' behaviours, IT literacy, lack of resources and training and the perception of NEWS2 value, can forbid the success of this implementation. Secondly, the impact of the pandemic on clinical practice and training has resulted in uncontrollable changes and enforcing guidelines that lead to undervaluing NEWS2. Lastly, EHR integration and automated monitoring are strong mediums for improvement that are not fully or precisely employed yet. There was an agreement from both sites on the facilitators and barriers, with preference from the specialist setting of the EHR integration and employing dashboards to improve escalation. The challenges found were cultural and setting related, or digital system related, as manifested by participants' views from both hospitals.

The challenge of seniority-related behaviour can be daunting to junior nurses and doctors that suppress their development in the work setting. Junior clinicians are the most receptive to change in the health system, and their ability to learn is high, a wasted advantage if discouraged. In previous EWS implementation, the seniority level of qualified nurses can affect the response of medical staff to review a patient or not (339).

Increasing the safe space to express clinical concerns by junior staff is a major need to be addressed to improve the work culture in hospital settings.

The perception of NEWS2 as a unified EWS for patients with complex conditions is appreciated for patients' safety and eliminating clinical judgment disagreement, yet insufficiently valued. They doubt their decision to escalate or have a dismissive culture to high NEWS2 score, majorly in the cardiology settings, owing to their clinical knowledge of patients' baseline and history. Applying an EWS system for critically ill patients can either be a confidence booster if perceived as reliable (335), or a source of tension between their own trusted knowledge and experience and nationally enforced guidelines (340). To date, there is insufficient evidence on the validity of NEWS2 in specialised subgroups, including cardiology and oncology settings (296); therefore, the call for unified NEWS2 remains weak. However, clinicians' belief toward applying NEWS2 to avoid further risk to patients' safety is valid.

Inadequate resources and training are challenges to implementing EWS that were heightened during the pandemic. Various medical devices are in shortage globally (312,341) and missed training opportunities created a gap in professional development, negatively impacting clinicians' confidence.(320,321). The surge in hospitalisation and escalation to ICU due to the COVID-19 pandemic necessitate the enforcement of national and international frameworks as a well emergency response to overcome the crisis (341–343). That came ahead of implementing a national EWS developed for ward patients when hospitals were more stable functionally. Greater attention was paid to all patients during the pandemic with the presence of various medical teams, facilitating critical care regardless of NEWS2 score.

Non-adherence to documentation presented a cultural issue in both hospitals, with more non-compliance and the need for auditing expressed in the specialist setting. Embedding NEWS2 in EHRs and automated monitoring can be robust solutions representing the role of digitalisation in improving documentation, clinical tasks, and patient outcomes. There is inadequate evidence on the benefit of EHRs integration in previous studies. This study indicates the advantage of accuracy and timeliness of scoring and alarming NEWS2, prompting decision making and early intervention, and potentially decreasing workload. Automated monitoring has motivated staff to complete documentation since what is seen is done (334). However, digital systems challenges, including insufficient workstations, IT assessment and training(344,345) and overlooking the positive aspects of paper workflow cause transformation to be hindered. Therefore, it is essential to address the obstacles to implementing EWS in EHRs that mimic the challenges of implementing EMRs or digital systems in health settings.

## Strengths and limitations

The study examined the implementation in two different sites in structure, policies, speciality, and care pathways. The NASSS framework was used as a guide, a solid theoretical foundation that analyses the complexity of implementing health technology solutions. The interviews and surveys were conducted at the time of the pandemic in England, which provided enhanced rapport and a rich narrative.
The sample is limited by purposive sampling and the pandemic pressure, which might have restricted further participation in the study. The interviews were guided by the domains and may have missed some richness of human-centric topics that could be explored deeply. i.e., seniority behaviours and EHRs users' preferences.

## Conclusion:

The significance of NEWS2 can be underestimated when challenges are overlooked, and evidence of its validation is not apparent. NEWS2 was appreciated partially by some nurses and managers; however, it was not sufficiently strong in specialised care like cardiology to empower the adoption. Implementation is affected by clinicians' behaviour in escalation from a cultural perspective, IT literacy and resources from digitalisation perspective. COVID-19-related Regulations and guidelines influence clinicians' practice more than implementing EWS and digital solutions. Implementing new EWS and digital solutions may be less complicated prior to the pandemic. However, more evidence is needed. Studying the validity of NEWS2 in specialised settings and complex conditions is required to guide the implementation. EHRs integration and automation are dynamic tools to facilitate NEWS2 utilisation if the principles of NEWS2 are reviewed and rectified, and resources and training are accessible. There is a need to explore the implementation further from human-centric, cultural, and digital transformation domains.

# Chapter 7

## Evaluating quality of care improvement

Evaluating a novel integrative dashboard for health professionals' performance in managing deteriorating patients.

### Introduction

The previous chapter identified the challenges of implementing NEWS2 and the need for improved management of deteriorating patients were identified. In this chapter, a novel EHR integrated dashboard for auditing NEWS2 and escalation of care was implemented and evaluated.

The Covid 19 pandemic has taken its toll on health care services globally. The escalating pressure has significantly raised the surge in deteriorating patients and the need to escalate their care (307). There was an increase in daily tasks for nurses, physicians and rapid response teams to cope with the COVID-19 strain (307). Clinicians' practice can be adversely affected by the increased patient to staff ratios (105), the complexity of patients' clinical care (106), and the ongoing pandemic impact on the healthcare service and individual staff (346). The quality of clinicians' assessment, documentation, and timely referral for escalation can suffer.

Early warning scores (EWS) are widely implemented predictive tools to detect deterioration in an early stage of critical illness. Their performance has been variable (296), and their effectiveness is subject to multielement in the clinical settings (332,347). EWS performance in detecting critical events is not only related to the score's sensitivity. Nurses' adherence to recommended monitoring and escalation guidelines and physicians' compliance with critical events and sepsis assessment may correlate with the outcomes studied in EWS validation (348). Common problems found in clinicians' behaviour toward EWS protocol include non-compliance with recommended monitoring frequency, notification of doctors when indicated by EWS, or timely response of doctors and CCRT (348,349). Therefore, serious adverse events (SAE) occur due to misclassification of patients and poor allocation to critical care despite the implementation of EWS and escalation guidelines. Along with established implementation and validated performance of EWS, human factors are vital for the success of EWS application.

Real-time auditing can be an effective method to detect the roots of clinicians' adherence defects. With the availability of Electronic health records (EHR) systems, a representative, generalisable dataset can be captured and analysed at scale via integrated EHR dashboards in a constructed, organised form (350). Healthcare dashboard is an electronic analytics tool to monitor healthcare key performance indicators (KPI) by displaying outcomes, auditing progress, identifying deficiencies, and manage professional and clinical activities in healthcare organisations (119,169,351). Digital dashboards systems capture EHR data to generate information on the healthcare system, individual professionals' performance, and the patient's prognostic status. Prompt, concise and context-specific display of the performance provides analysis of hospital and patients status, facilitating clinical decision making and quality improvement (120,352). For example, the NHS Pathways of Coronavirus Triages and Activity dashboards in NHS hospitals are examples of live data visualisation for the public information at an organisational level (117). Although dashboards have proven efficiency in providing real-time information for hospital management and stakeholders (120,353,354), functionality is limited when addressing performance issues from patient chart data. Logging into each patient's chart several times during the day for specific information is time-consuming and problematic, i.e. completion of EWS recording in a day shift. Healthcare dashboards are concise, time-saving, and intuitive tools for up-to-date assessment and escalation auditing of deteriorating patients.

## Problem

Despite the widespread implementation and expenditure of EHRs in healthcare settings, secondary use of data for improving quality and safety is limited. The full potential benefits from EHRs data are far from realisation currently despite massive efforts of investment in health technology (355). Challenges such as the conflicts between public interest, individual patient safety, and optimising application of health information systems, have restricted the potentials of data use (356,357). With the growing integration of EWS into EHR, a significant amount of data for critically ill patients are available (54), but not yet utilised.

Furthermore, COVID-19 has affected the quality of clinicians' routine practice and hindered tasks that could be regularly and efficiently carried out prior to the pandemic (104). As a result, appropriate, timely management of acutely ill patients declined(312,358). Escalating care of an acutely ill patient must follow timely and careful assessment, then communicating the evaluation to the designated critical care professional for further intervention. Errors in detecting worsening of the condition and failure to communicate or intervene can hamper escalation of care and negatively impact clinical outcomes and NEWS2 performance. Noncompliance with escalation protocols or recommended documentation guidelines may result in serious healthcare errors (359). The Record Management Code Practice 2021 provides a framework to guide organisational and individual responsibilities when managing patient records (359). Auditing is an integral part of healthcare records policy and guidelines to assess the standard achieved in records and find areas needing improvement for health data and staff (360).

In Barts Health NHS Trust, the National Early Warning Score (NEWS2) has been nationally endorsed and implemented (361). A digital transformation took place in Barts hospitals by shifting NEWS2 recording into digital format and automating routine monitoring, hoping to increase accuracy of information if the escalation protocol is optimally followed. However, implementing digital NEWS2 requires complete and updated her, which has been more difficult in the COVID context at

Barts and other hospitals. Local audits in the trust showed non-adherence to routine monitoring and recording, e.g. in 2019-2020 NEWS2 status was incomplete and not in line with guidelines in approximately a quarter of the patients' population (Complete vitals: 61-79%, 75-83%, 84-87%, 83-91% & 79-86% from September 2019 - January 2020 in Newham, Royal London, St Bartholomew's, and Whipps Cross hospitals, respectively) (Appendix 18).

A dashboard integrated in EHR would allow performance of health professionals, data quality patient care to be monitored and improved by facilitating timely health resources management and support informed clinical decision making. Therefore, a quality improvement study was conducted to evaluate deteriorating patient dashboard and provide evidence for an exemplary quality of care for other healthcare settings.

## Aims:

To evaluate an EHR data-driven dashboard of real-time assessment of deteriorating patients and escalation of care. The evaluation of the dashboard was done through PDSA cycles, including:

1- Examine the views on the dashboard and areas that need improvement from key users' perception; and implement necessary actions for development.
2- Evaluate the performance of nurses and physicians in the stages of managing deteriorating patients on all trust levels through historical tracking of data.

## Methods

- Context

The dashboard was implemented in the largest NHS trust in the UK (Barts Health NHS Trust) in five academic hospitals: Mile End Hospital, Newham University

Hospital, Royal London Hospital, Whipps Cross University Hospital and St Bartholomew's Hospital.

The dashboard was developed by creating Vitals data table, then transformed into a thorough and more robust data visualisation of NEWS2, assessment and escalation of deteriorating patients via Qlik Sins. Development was led by clinical informatics and quality improvement teams.  Data of around 1.2 million recordings of 110,000 admissions from August to October 2020 were extracted from EHR (Cerner Millennium®) (Figure 34). Detailed steps of development are in appendix (19).
The user interface includes live and accumulative data of patients with high NEWS2, and performance tracking of stages in deteriorating patients' management by nurses and physicians on all trust levels. Health professionals' performance is measured by the completion of the assessment, escalation of care, and sepsis treatment (Figure 35)

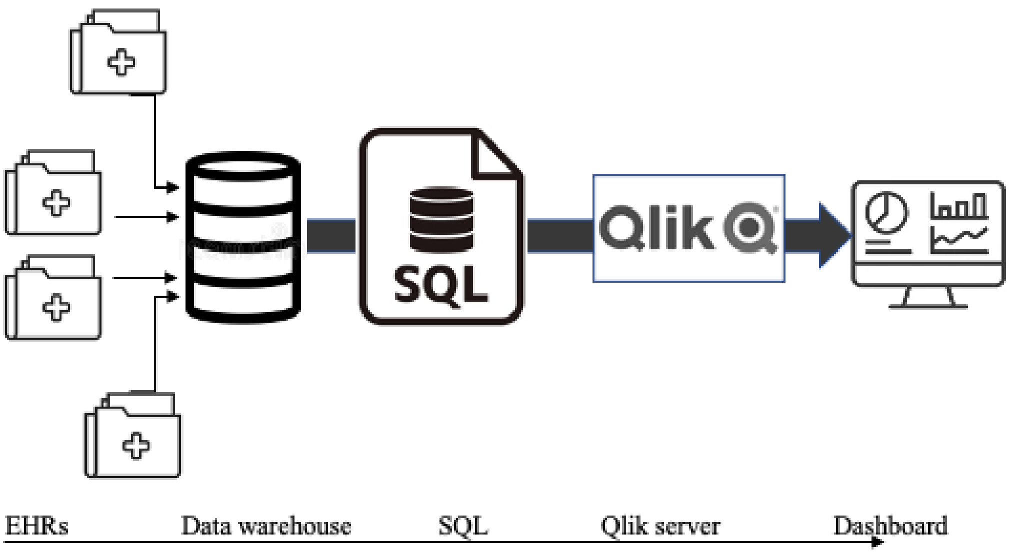



Figure 34.  Illustration of deteriorating patient's dashboard development from patients EHRs data.

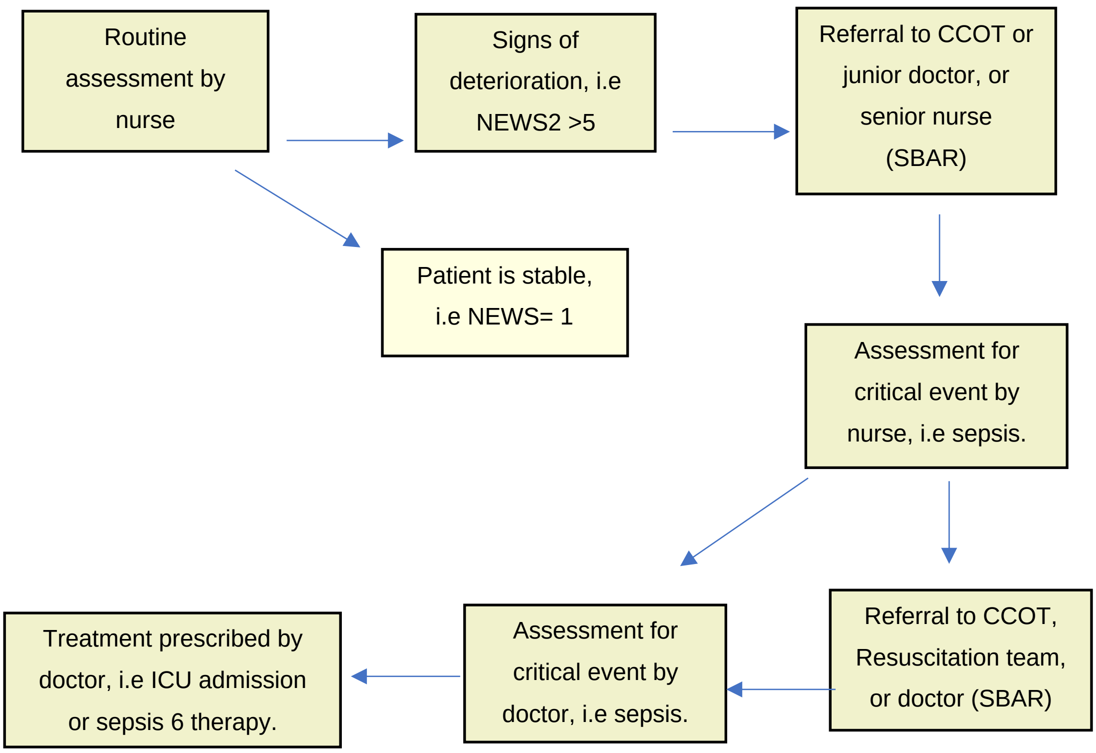



Figure 35. Escalation of care assessment flowchart.

Abbreviations: CCOT: critical care response team, SBAR: Situation-Background-Assessment-Recommendation tool for communication between health care team.

- Intervention

PDSA model was adopted to examine the objectives of intervention (168).

- PDSA cycle 1:

In the first cycle, the PDSA stages were as follows:

- *Plan:* the rollout of the dashboard was planned, and the performance evaluation was designed to obtain the perspective of key people in management who utilised the dashboard for auditing.

- *Do:* The dashboard was initially launched in May 2021, and several functionality improvements, i.e. metrics and filters, were added until the examined version in September 2021. The dashboard was introduced to ward managers, quality improvement, and patient safety teams. The teams were informed of the improvement plan, the dashboard objectives and functions. No guidelines for the utilisation of the dashboard have been developed yet.
- *Study:* In the evaluation phase (October 2021), Interviews were conducted with three staff who took part in the initial rollout: a senior nurse for quality and safety, a nursing informatics specialist, and a patient safety practitioner.
- *Act:* The information collected allowed the creation of the next PDSA cycle to improve the effectiveness of the dashboard for a broader cohort of users.

.

- PDSA cycle 2:

In this phase, a second PDSA cycle was followed:

- Plan: A how-to guide was designed, and data collection metrics were created to assess the dashboard's performance. At the same time, the implementation of Electronic Prescribing for Medicine Administration (EPMA) was planned at this stage.
- Do: The how-to guide became available online, and orientation was conducted to educate users on effectively making the most of the dashboard.
- Study: Data from the dashboard front end were assessed to evaluate changes through time in deteriorating patients' management.
- Act: The dashboard metrics were refined. Managers were encouraged to view and report information from the dashboard, and nurses and doctors were informed of areas in practice that needed adjustments. There was a plan to integrate EPMA data into the dashboard in the coming stage and provide further valuable data, i.e. time of treatment prescribing.

- Measurements

individual interviews to evaluate the perception on the dashboard using the TAM framework (170) (Figure 36) (Appendix 12). Interviews were conducted on a purposive sample of key users.
For data evaluation, a before and after assessment was done to assess the change in performance in five phases pre-EHR integration, post EHR integration, automation period, implementation, and post-feedback. Definitions of terms are in table 16.

- Analysis

Qualitative data were analysed using NVivo in a content analysis approach. Quantifiable data collected from the dashboard was analysed using the R programme. Pearson's chi-square test was conducted with. *A p-value* of <0.05 for significance.

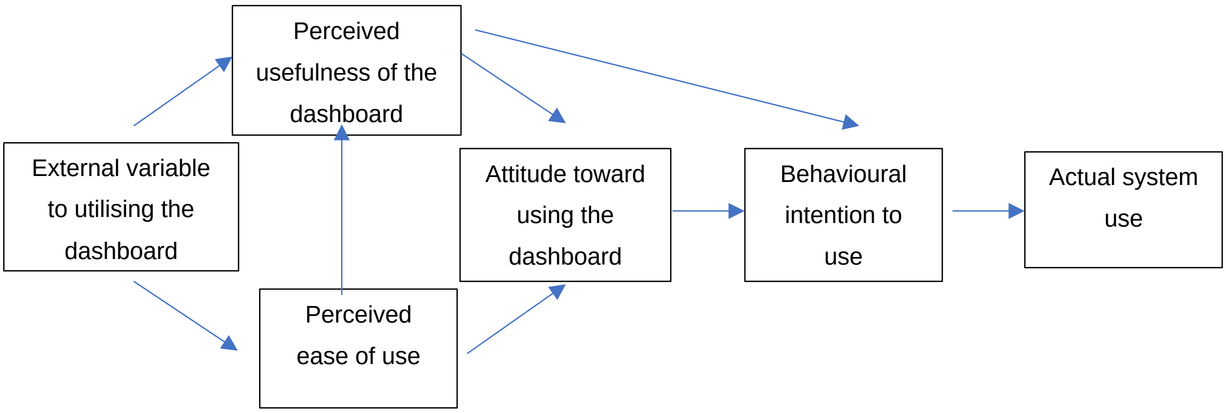



Figure 36. Illustration of the Technology Acceptance Model (TAM) to examine the perception of the deterioration dashboard.

Table 16. Definitions of terminologies.

| **Definitions** | |
|---|---|
| **Dashboard** | Electronic analytics tool to monitor key performance indicators (KPI) by displaying outcomes, progress, deficiencies in an organisation(117,351) |
| **Automated monitoring** | Integration of patients routine monitoring and EHRs by transmitting measurements directly from monitoring machine to patients' charts and continuously calculating and updating NEWS2 (334,362). |
| **Electronic Prescribing for Medicine Administration (EPMA)** | Electronic system to facilitate the communication of a prescription, aiding the choice, administration, and supply of a medicine through decision support (363). |
| **Situation, Background, Assessment and Recommendation tool (SBAR)** | A communication tool including, Situation, Background, Assessment, Recommendation; for structuring conversations between doctors and nurses about situations requiring attention (364). |
| **Sepsis 6** | A structured care bundle for patients with sepsis including blood cultures, check full blood count and lactate, IV fluid challenge, IV antibiotics, monitor urine output and give oxygen (365). |

## Results

From the qualitative data, three participants were interviewed. Participants expressed their perceived advantages and usability of the dashboard for escalation of care, auditing NEWS2 recording and forms completion, and areas in need of improvement. The interviews data content formed two elements: (i)dashboard function, and (ii) obstacles and improvement.
From the descriptive data, there was a gradual improvement in NEWS2 and forms compliance by nurses and physicians.

### *Dashboard function*

The dashboard was perceived as a serving tool for quality improvement tool. There was an agreed perception of its analytics function on individual nurses' and doctors' performance in the escalation of the care process. Primary auditors are ward managers, senior nurses, and quality improvement officers. They could view periods and specific ward improvements and where the trend is dropping off; in patients' status and clinician's practice; to analyse the reasons for changes to planning for enhancement.
The dashboard helps nurses and doctors chase the escalation of deteriorating patients from the auditing function by monitoring NEWS, SBAR referral, and assessment completion to push for a better result.
Another benefit found was the attention to one's performance due to being tracked lively. It was reported that staff are becoming more interested in completing the forms and monitoring within the time frame and how properly the documentation in return to the observed numbers of deteriorating patients scoring high NEWS2.

### *Obstacles and improvements*

Participants reported issues in lack of engagement by managers in relation to difficulty in usability, such as locating and navigating it properly. It was suggested to improve in the dashboard function and utility. They recommended comprehensive showcasing of the dashboard for clinicians to understand the benefits and purpose. Participants expressed the need for a clear guide for utilisation to encourage clinicians make the most of the dashboard confidently. In addition, it was suggested for databases to be stored in a unified standard system to facilitate data extraction and query writing and explore the possibility of creating more functions from the health systems. Several additions were recommended by participants to enhance the role of the deterioration dashboard, including additional assessment metrics, sepsis diagnosis and treatment time, and monitoring wrist bands scanning for ID confirmation.

*Compliance measure*

The audit showed poor compliance with vital signs and NEWS2 recording in the baseline period (64%), then improved gradually after the EHR integration of NEWS2 (81.5%), followed by an increase after automating vitals monitoring and dashboard rollout (85 & 83%, respectively). Patients with high NEWS2 reached a peak between April and May 2020 and in January 2021 (~25%) when the first and second waves of COVID-19 occurred. Complete referral and nurse assessment forms were boosted after dashboard rollout (n: 170 to 6800 & 23 to 540, respectively). The screening and prescribing by doctors improved in the first dashboard phase (n: 22 to 36 &15 to 26, respectively), then had a sudden drop (n: 8 &6, respectively) after EPMA became the data entry point (Table 17 and Figure 37).

Table 17. Dashboard metrics trend measured in different phases.

| Measure | Routine monitoring phase. (Aug-Nov 2019) (min-max, median) | EHRs-EWS phase. (Dec 2019-Sep 2020). (min-max, median) | Automation phase (Oct 2020-Apr 2021). (min-max, median) | Implementation phase (May-Sept 2021). (min-max, median) | Evaluation phase (Oct 2021-Apr 2022). (min-max, median) |
|---|---|---|---|---|---|
| **Vitals (%)** | 59-72, 64 | 74-84, 81.5 | 84-86, 85 | 81-84, 83 | 81-83, 82 |
| **NEWS>5 (%)** | 5-6.5, 6 | 5-17.5, 6 | 4-20, 11.5 | 5.5-7, 6 | 5-7, 6.5 |
| **SBAR (n)** | - | - | 100-230, 170 | 220-3100, 650 | 3800-8300, 6800 |
| **Nurse screening (n)** | - | - | 13-94, 23 | 36-250, 75 | 250-750, 540 |
| | | | **Automation phase. (Oct 2020-Apr 2021). (min-max, median)** | **Implementation phase (May-Aug 2021) (min-max, median)** | **EPMA phase (Sept 2021-Mar 2022) (min-max, median)** |
| **Doctor screening (n)** | - | - | 10-82, 22 | 25-60, 36 | 3-14, 8 |
| **Sepsis 6 (n)** | - | - | 8-64, 15 | 19-47, 26 | 1-12, 5.5 |

Note: Each number is presented as minimum to maximum and median.

Abbreviations: Vitals: vital signs recordings; NEWS2: Updated National Early Warning Score; SBAR: situation, background, assessment, recommendation; Sepsis 6: clinical care bundle for sepsis management in the first hour of diagnosis.

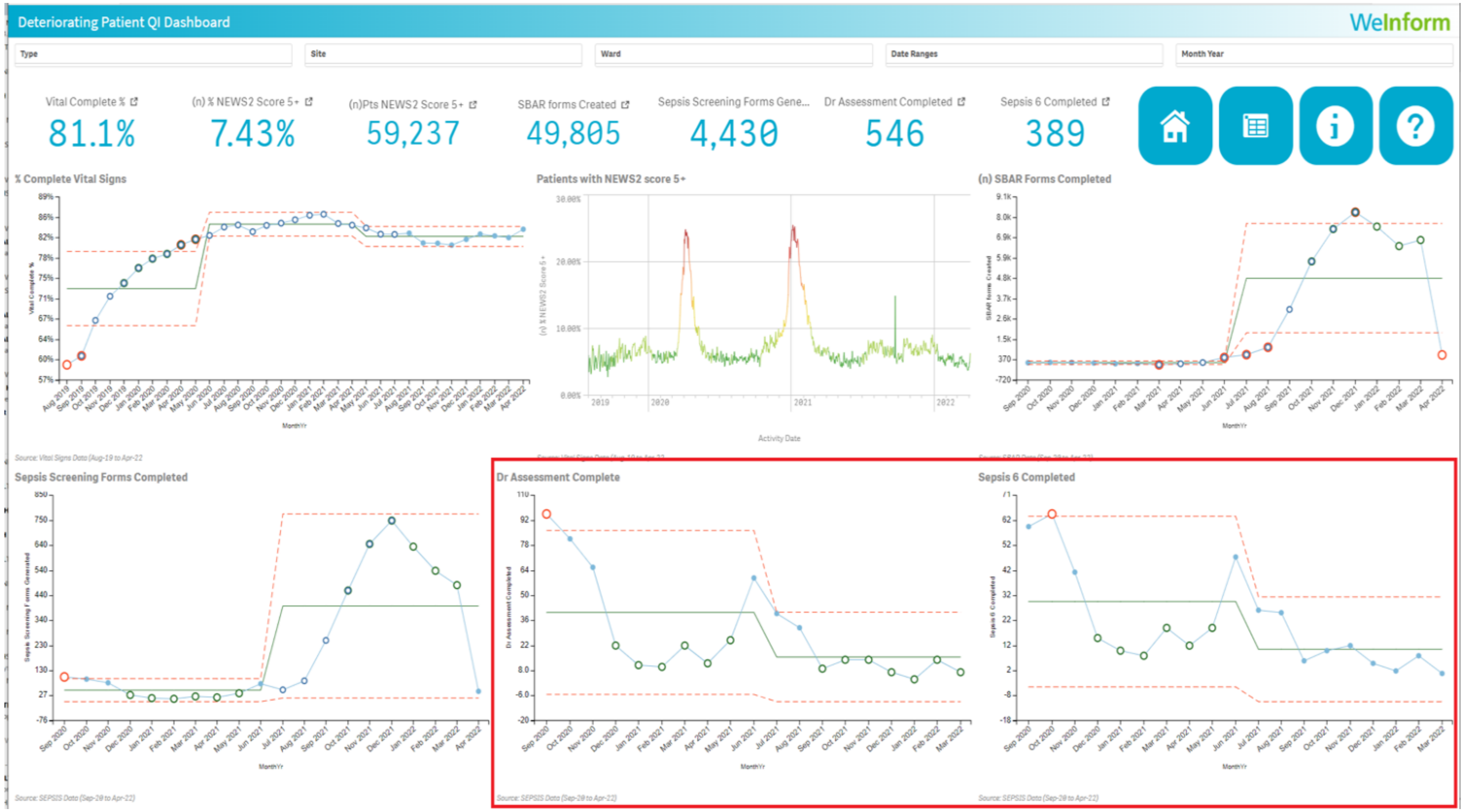



Figure 37. Snapshot of front page of deteriorating patients' dashboard from August 2019 to March 2022.

Abbreviations: SBAR: esclation of care handover tool (situation, background, assessment, and recommendation); Sepsis screening forms: assessment of sepsis forms by nurses; Dr Assessment complete: sepsis screening by doctors; Sepsis 6: prescribing sepsis 6 bundle therapy.

Colour codes: orange: upper and lower control limits and outliners; light blue: complete; dark blue: trends; green: central lines; graphs with red frame represent metrics that will be adjusted in the next stage.

## Discussion

The study reported the experience of development and implementation of an EHR-integrated dashboard for NEWS2 and escalation of care auditing in cardiac specialist teaching hospitals. This novel and unique initiative focused on monitoring and improving early recognition and expediting shared care by nurses and physicians. The data visualisation is a practical and effective way for performance tracking; and, therefore, promoting timely NEWS2 recording and forms completion for improved escalation of care. We had three main findings. First, participants perceived the dashboard as an excellent auditing tool that improves deteriorating patients' care. Second, some improvements are needed to enhance its functionality and user experience. Third, historical data have shown an increase in clinicians' compliance with documentation and escalation protocol that may have responded to monitoring individual and unit performance and, therefore, driving quality improvement.

The results were consistent with previous findings confirming the effectiveness of dashboard analytics in evaluating clinical performance (366,367). It has been shown that dashboards are visual tools to examine the programme or protocol's effectiveness in meeting the objectives (16). The perceived individual staff monitoring and improving own actions came supporting to previously highlighted impact of dashboards on nurses' awareness. Nurses' attention to the ward's accomplishments affected patients' outcomes and gave them a sense of control and satisfaction with their achievements (351,353,367). Investigating the deteriorating patient management provides on-time tracking of escalation of care steps and NEWS2 recording to have a transparent understanding of its predictive performance in the care settings. Display and use of performance data are keys to identifying areas of strengths and weakness for quality improvement.

For a dashboard system to be widely used, it must be an easy, user-friendly, and intuitive system. Our results indicate the need for clinicians to learn about digital tools' usability, as the previous implementation of digital health systems showed the demand for embedding technology training and education (368,369). In addition, expanding the structure and functionality through integrating different data sources and refining the design is a substantial gain. Previous health dashboards where EHRs are combined with other systems, such as PACS, have given professionals a broader view and knowledge of patients' health status (120). By integrating multiple digital systems, there is a potential for great use of information to understand, research, and explain unclear data of one system by the other. The reduction in doctors' assessment and Sepsis 6 was due to the data entry shift from EHRs to EPMA. In the trust, EPMA is believed to add the benefit of providing more true, timely treatment information for auditing. EPMA integration can provide data on prescribing antibiotics as per the recommended protocol, therefore, will be conducted in the next phase. Other data resources could also enhance and maximise the functionality, such as COVID-19 patients' data, resources tracking such as ICU beds and Critical Care Outreach (CCOT) staff, and timeliness of escalation of care steps data. Data sources addition could help doctors, nurses and managers organise the treatment plan promptly for clinicians' and patients' benefit.

From time series analysis, we interpreted a positive change in NEWS2 recording and formed completion post dashboards intervention and potential for a further improvement as quality is monitored. In the current integration of EWS into EHRS, displaying the real-time score and generating alerts of EWS, like Modified Early Warning Score (MEWS), Paediatric EWS (PEWS), and NEWS, has shown several advantages in different care settings (370–372). It allowed for a real-time prediction of critical events associated with reduced hospitalisation costs and, more importantly, is believed to be a keystone for safe practice.  In addition, dashboards have been increase implemented in healthcare and supported healthcare services, such as communicating patient-reported and clinical data in cystic fibrosis (373). Ward patient status and clinician performance auditing represent a modern method of quality improvement in the digital clinical environments to be promoted and examined widely.

Several additional characteristics could enhance the function of dashboard auditing deterioration management. Producing a live NEWS2 score for patients would add an advantage to estimating validation if analysed on wards and specialities level. In addition, alerting the first-line responders to escalation, including the CCOT team and bedside nurses, would benefit managers in tracking the escalation and whether it occurred due to the score, clinicians' observation or the two combined. Expanding the functionality guided by the escalation of care and early warning scores protocols would be needed to enhance the performance impact. However, further studies need to evaluate the effect of advancing the dashboard in the coming stages from a user perspective and the extent to which it can positively impact clinical care outcomes and work performance.

## Limitations

The dashboard was developed and tested at the time of the COVID-19 pandemic. This factor could have affected the engagement of key users and, therefore, the response to utilising the dashboard for auditing. Another disadvantage is the small team of clinical informatics that developed the dashboard during the pandemic pressure, which might have resulted in delays for further adjustments and applying a third PDSA cycle. There were interviews with three health professionals during the examined phases; feedback from ward managers, nurses, and doctors will show a better view of its validity for monitoring escalation of care. Furthermore, there was no examination of the generalizability of the dashboard system in other trusted hospitals. Studies need to examine its feasibility and usefulness in different hospitals with differing structures and patients' population.

## Conclusion

On-time data visualisation of deteriorating patient care is an effective and efficient method for establishing quality improvement. The deteriorating patient dashboard facilitated timely investigation and improvement of the practice of assessment and treatment from key users' perspectives and performance analysis over time. Evaluating adherence to NEWS2 recording and escalation of care protocol can help clarify EWS validation where it is implemented. Advancing health dashboards by facilitating multiple health systems integration and clinicians learning digital health solutions will enhance dashboard functionality and improve user experience. In addition, functionality could be upgraded by analysing further NEWS2 and escalation of care protocol metrics and times, promoting live and historical data value. There is a need for further validation and quality improvement studies to verify the generalizability of the dashboard system in different settings.

# Chapter 8

## Discussion

### Introduction

Certain significant elements of the effectiveness of digital early warning scores for the detection of deteriorating patients were examined in the context of cardiac care settings during the time of the COVID-19 pandemic using a mixed methods approach in this thesis. These aspects were investigated based on the gap in evidence to utilise them for patients with CVD and the significant need for better management of acute illness in CVD, while employing the available cutting-edge health solution to improve the level of care. Studies have presented real-world problems in identifying acutely ill CVD patients and challenges faced by clinicians. In addition, studies explored areas where research was considerably weak in EWS and escalation of care and investigated solutions that can be employed to enhance care for acutely ill patients in clinical settings.

### Research objectives

The main research questions identified are:

1- What is the performance of the universal standardised early warning scores in different disease groups and clinical settings in predicting critical events, and to what extent was there EHR integration of EWS?

2- What is the performance of the digitally assisted National Early Warning Score (NEWS2) in predicting critical events for cardiac patients in a specialised cardiac setting?

3- How is the escalation of care practice and utilisation of EWS affected by the COVID-19 pandemic, and what factors facilitated or hindered any changes?

4- How do nurses perceive the implementation of digital Early Warning Score (NEWS2) in a cardiac specialist setting and a general hospital setting during the pandemic?

5- What is the impact of implementing an EHR-integrated dashboard for improving deteriorating patients' management from clinicians' perspectives and change in performance over time?

## Summary of the main findings

A systematic review of the literature was conducted of validation studies of standardised EWS in disease groups and clinical settings in chapter three. One hundred and three studies were included validating standardised EWS in concept, yet with different parameters values and triggering methods. Validation studies were heterogeneous in the number conducted in each subgroup, the methodology used, the predictive performance measure, and the technology integration of early detection of deterioration. In specialised care settings and disease groups where the incidents of critical events are high, research is limited. There was a significantly limited number of studies exploring the EHR-integrated EWS despite the global widespread of EHRs and the growing EWS digitalisation.

An observational retrospective cohort study of the predictive performance of the digital EWS, NEWS2, in a specialist cardiac setting was presented in chapter four. The predictive ability of NEWS2 to predict death, cardiac arrest and admission to ICU was assessed in 6143 patients admitted under cardiac care and 248 COVID-19 patients. With the availability and integration of three different data sources, EHRs data, CRT data and COVID-19 pathology data, retrospective data analysis was conducted on a representative sample of patients with CVD. NEWS2 showed suboptimal discrimination (AUC: 0.56-0.7; 95%CI) while improving when supplementing the model with cardiac rhythm for CVD patients (AUC: 0.75-0.95; 95%CI) and with age for patients with COVID-19 (AUC: 0.7-0.96; 95%CI). NEWS2 was inadequate on its own to predict deteriorating CVD patients. It was shown that adjusting EWS tools by examining disease-related parameters that correlate positively with critical events can enhance the prognostic ability and ultimately lessen the burden of CVD morbidity and mortality.

In chapter five, a scoping review of the qualitative work examining the escalation of care during the COVID-19 pandemic was reported. The examined experience of escalating the acutely ill patients was reported in three studies exploring changes, facilitators, and barriers to rapid response in clinical settings. While COVID-19 had a significant impact on healthcare, particularly in critical care, the evidence on the escalation of care in the pandemic was found to be poor. The findings reported the need for adjustments in escalation strategies through new emergency plans and protocols. There were obstacles manifested in a lack of resources and learning opportunities, yet competent management and skilled clinical work facilitated the adjustment. Despite the recommendation to adopt EWS as a guide in the escalation of care practice, their role was not explored in studies examining the escalation of care experience.

An exploratory implementation study into the perception of nurses of digital NEWS2 in two hospital settings was reported in chapter six. In this qualitative work, the NASSS framework was adopted to examine the success of NEWS2 as a digitally enhanced tool in hospitals. Nurses from cardiac specialist and general hospital settings were interviewed. Three themes emerged around the implementation challenges and support, the value of NEWS2, and the role of digitalisation. The perception of NEWS2 was mixed between appreciation for patients' safety and clinical judgement and doubted value, especially for patients with CVD. The implementation process was supported by decision-makers; however, challenges like IT literacy, lack of training and resources and the perception of NEWS2 value can hinder the process. The impact of the pandemic resulted in enforced changes and guidelines, which led to an undervalued role of NEWS2. The role of EHR integration and automated monitoring was perceived as a positive factor for improvement despite limitations in the digital transformation.

A mixed-methods evaluation study of implementing an EHR-integrated dashboard; named Deteriorating Patients Dashboard; for NEWS2 and escalation of care auditing was reported in chapter seven. The dashboard was evaluated by adopting the PDSA model and SQUIRE framework by interviewing key users and analysing retrospective dashboard performance data from 2019 to 2022. There were positive views on the effectiveness of the dashboard in improving the quality of deteriorating patient management; however, there was a reported need for clinicians' guidance and enhancing the dashboard data sources and metrics. These findings were supported by the improvement reflected in analysing audited data, including improved NEWS2 recording and an increase in referral and assessment completion after the dashboard was implemented.

### *Original contribution of this thesis*

The findings from the five studies have contributed to the evidence base on EWS in cardiac care settings:

1- A systematic review examined the performance of ten various standardised EWS in different disease groups and clinical settings.

2- A retrospective cohort study of the predictive ability, assessed by the AUROC; of digital NEWS2 in a cardiac specialist setting, identified a low level of predictive ability in patients with CVD.

3- A comparative analysis of the validity of NEWS2 and supplemented models with disease-related parameters in patients with CVD identified improved predictive ability.

4- A scoping review of the experience during the pandemic for rapid response teams highlighted the need for skilled managers and health professionals for protocols redesigning and adjusting escalation plans to cope with the COVID-19 impact.

5- An implementation study was assessing nurses' perceptions of adopting digital NEWS2 in two distinct settings, cardiac specialists, and general hospitals, and identified barriers that can be cultural and system-related.

6- The qualitative and scoping review study's findings indicate that lack of training and resources due to the pandemic pressure were obstacles to implementing a standard escalation of care and EWS guidelines.

7- An evaluation of a novel EHR-integrated dashboard for auditing deteriorating patient management had a positive impact on clinicians' performance in recording NEWS2 and escalation practice.

8- Evaluating the dashboard and the implementation of digital NEWS2 highlighted the significance of employing EHRs for routine and automated monitoring and on-time auditing in supporting NEWS2 and clinicians' practice

## Supporting and conflicting findings across the five studies

The findings from each of the five studies have explored different aspects of EWS application in a cardiac care setting. However, each study's findings may help explain and cultivate the understanding of another study. In addition, some findings may conflict with others which may be feasible for explanation or need further research to explore. The main findings will also be addressed in relation to previous studies in the literature. The following section will discuss findings that will be linked between the studies and with the literature.

### *Validating EWS predictive ability for patients with CVD*

The systematic review findings addressed the poor evidence from validating standardised early warning scores in patients with different aetiologies and various specialities. In patients with CVD, validation studies were not representative of the currently used EWS nor generalisable for CVD patients in cardiac care settings. Therefore, the recommendation for standardised Early Warning Scores uses across all settings, including caring for cardiac patients, was questioned. In chapter four, the results from validating NEWS2 would support these findings. In the retrospective analysis, the evaluated predictive performance using AUC for predicting death, ICU admission and cardiac arrest were below the optimal level (Figure 25 and 26). The timing of NEWS2 measurements examined was at the point of admission and 24 hours prior to a critical event. Consistent with the metric utilised in the retrospective study, most validation studies in the third chapter used the AUC metric to examine the performance (296) . However, the timeline of EWS recordings was mixed and inconsistent in validation studies included in the systematic review, ranging between single or multiple observations from 24 hours to 30 days prior to a critical event. In addition, selecting a single observation may yield different results compared to multiple observations (202,290). These results may be a source of uncertainty when interpreted as time recording may be significant in relation to the critical outcome predicted by the early warning score.

In chapter four, the examined endpoints were chosen as the most commonly known critical events and as what was recorded in EHRs and CRT databases. The severe adverse events, including death, ICU admission and cardiac arrest, were considered critical endpoint events. Despite these outcomes being in accord with outcomes examined in previous EWS validation studies (201,290,374–376), it is arguable that these outcomes may not be the accurate endpoints to test for reliable and representative EWS predictive ability (74). When NEWS2 was endorsed by the Royal College of Physicians, it did not aim to detect the outcomes commonly studied, i.e. death and cardiac arrest. The aim was to detect clinical deterioration in patients' health (51). Therefore, it produces a discrepancy between the purpose of EWS validation to predict the clinical state of deterioration and the common practice of EWS being validated for death and ICU admission. Pedersen (2017) suggested that the concept of using critical events as endpoints is unrealistic and contradicts the aim of EWS. The assumption that patients on the path toward critical illness, yet treatable through timely intervention, are experiencing similar physiological deviation as patients who reached irreversible adverse events may be improper. In a previous Delphi study addressing this issue, the endpoints favoured by experts were aligned with traditional ones; however, they suggested the development of more relevant endpoints (74). In the retrospective analysis study, a medical emergency as defined by a patient experiencing physiological deviation while on the path of deterioration, i.e. cardiac arrhythmia, was tested in addition to traditional endpoints. These data were extracted from the CRT database, which was not part of patients' EHRs. The increasing spread of EHRs encompasses clinical data that can provide the opportunity to identify reliable endpoints from critically ill patients' routine assessments. As EHRs in the chosen clinical setting were short of significant CRT information, developing EHRs to be integrative and inclusive of all necessary data has essential implication for examining the validity of EWS.

### *Success of NEWS2 in cardiac care*

Findings from the retrospective analysis indicate that NEWS2 performed moderately to poorly in relation to the targeted discrimination. The examined NEWS2 and physiological parameters were recorded automatically through automated monitoring. This application has taken away part of the role of nurses in inputting data in EHRs and calculating NEWS2. Despite that, there was missingness in NEWS2 recordings at different times, indicating a lack of adherence to the recommended routine monitoring. On the other hand, findings from the qualitative study in chapter six presented an undervalued view of NEWS2 by nurses in the examined settings, especially regarding care for deteriorating CVD patients. The combination of findings supports the conceptual premise that the performance of an EWS tool may be related to the perception and behaviour of clinicians utilising it, and this perception could be influenced greatly by the observed performance in practice.

*A previous* retrospective analysis of paediatric early warning score (PEWS) indicated an improved accuracy of PEWS recordings (99 %) using automated monitoring compared to manual recording accuracy (86%) (362). It can therefore be assumed that clinicians' practice can impact the accuracy of EWS scoring examined to assess the performance. Moreover, the qualitative study findings showed that nurses perceive NEWS2 as an optional means of escalation yet not a reliable tool for all patients, thus impacting their behaviour toward utilising NEWS2.

*"I used to see patients that were unwell, that did not trigger NEWS."*

*"Documentation is not great."*

These results support previous research showing that staff nonadherence to monitoring frequency was heavily related to their "gut feeling" that frequent monitoring is unnecessary (348). In addition, notifying doctors or senior nurses when EWS indicates this, i.e. score 3-6, was considered unrealistic and disruptive to their workflow because of the high number of patients with high scores (348). Correspondingly, Bunkenborg (2016) mixed methods research evaluated EWS scoring intervals, and nurses' perceptions of meaningfulness and the clinical relevance are crucial motivations for implementing EWS in the clinical practice (377). The findings from the retrospective study, qualitative data, and previous literature raise intriguing questions regarding the nature of the relationship between the predictive ability of EWS and clinicians' views and the extent of the impact these elements have on one another and ultimately on the success of EWS for desired patients' outcomes.

### *Implementation challenges*

The findings from the qualitative study highlighted challenges that were from a culturally base or a system base. From a cultural perspective, healthcare professionals' behaviour and their organisational background had a significant impact on the implementation process. The organisational culture was manifested by the role of the hospital management in supporting NEWS2 implementation to escalate the acutely ill in general and the specialist hospitals. These results reflected those of the scoping review, in which hospital management had a substantial role in supporting the escalation of care strategy. Establishing planned escalation protocols by hospital managements was reported to aid the success of escalation and improve clinical outcomes, i.e. ICU admission in previous studies (378,379).

On an individual level, the qualitative study showed that the seniority level had created a daunting effect on the development of junior nurses and doctors due to the lack of safe space with senior staff. However, from the scoping review findings, skilled senior staff attitudes had promoted a positive culture for the juniors and the adjustment of escalation of care during the pandemic. In implementing healthcare systems, the results of the previous studies were in line with these findings. Senior nurses and doctors were leading facilitators of a successful health system initiative (379,380).

Examining the views of nurses on EWS as a system has presented a mix of positive views as well as the undervalued perception of EWS. There was an appreciation by nurses for their guidance in decision making while others, in cardiac care, in particular, showed concerns when managing a deteriorating patient. The variation of views has been reported in previous studies in different hospital settings. Outside the acute hospital setting, NEWS was reported to support decision-making around the escalation of care (381). On the other hand, studies in other hospital settings found it to impede clinical judgement and did not account for the complexity of the setting in which it was applied (331,382). In a previous scoping review, it was described as a "bone of contention" due to the high number of patients with elevated scores (383). In addition, the overreliance on the EWS system reported in the findings of the interviews was in agreement with other qualitative studies in which inexperienced nurses were privileging EWS over their own assessment (383–385). Furthermore, the perception of the digital health solutions as additional burdens, including EHR integration and automated monitoring, were barriers to implementation in the qualitative study. Fredrix et al. (2019) explain how digital health care solutions in cardiology can be a barrier to health professionals due to their view of it as requiring time investment, being added "on top of" the existing care, and not blended into the care delivery (386).  From the conducted qualitative study findings and previous research, the perception with regard to the EWS system was highly correlated with the hospital setting evaluated and the level of knowledge and experience of nurses utilising the score and the digital system (383,385).

Another indisputable challenge when conducting the research was the enforced changes due to the COVID-19 pandemic. In the scoping review and the qualitative studies findings, COVID-19 impacted hospital resources and caused an acceleration of acute illness. It was reported to change the escalation of care strategy and influenced health professionals' adoption of the digital NEWS2 recommendations. Nonadherence and underappreciation of NEWS2 may be explained by the fact that it was introduced in all settings prior to the pandemic. In contrast, the complexity of patients' diseases and workload during the pandemic made the adoption of NEWS2 daunting. On the other hand, technological health systems aiming to directly optimise clinical management during the pandemic were rapidly growing, as found in the qualitative study, evaluating the dashboard, and published studies (387,388).

### *Digital facilitation for EWS*

In chapter four, the score recorded, and the parameters encompassed were assessed from remotely captured data and EHR-integrated NEWS2. The electronic recording of NEWS2 promoted the completion and accuracy of recordings as manifested by results reported from the qualitative study and the dashboard data results. These findings seem to be consistent with other research that found electronic observations recording of EWS increased the accuracy of EWS (389) and improved adherence to EWS recording (390). Nonetheless, the missingness of recordings in the retrospective study persisted despite the automated monitoring and electronic recording. This is likely caused by organisational cultural influences, as explored in the qualitative study. In addition, previous work by Geeenhalgh (2010) emphasised the interrelation between the system and the culture for the effectiveness of a digital health system (391). One of the domains in the adopted NASSS framework is the knowledge of the technical properties and utilisation. There was an absolute need for learning health systems as indicated in the qualitative study and evaluating the dashboard study. A previous study by Walpole et al. (2016) reported that health informatics education is low and rarely assessed in the undergraduate medical curriculum (392). Furthermore, Lydia et al. (2019) found that the necessary health informatics competencies were underrepresented in the medical curricula.

The study evaluating the dashboard showed exemplary evidence of the rapid growth of digital health systems. Despite the pandemic's escalating pressure on adherence to NEWS2 guidelines and recordings, it formed a cursor of motivation towards developing and implementing digital systems that directly facilitate clinical management. Data visualisation via a Deteriorating Patients Dashboard was effective in monitoring individual doctors' and nurses' performance as presented by interviews and data analysis and previous studies (351,366,367). Technology-based systems were widely developed and relied upon in response to COVID-19 to assist labour-intensive tasks, such as interoperable EHRs, EPMAs, and patient-facing technology (388,393,394). The overall level of adoption, however, is not yet reaching its full potential. This was indicated by the resistance to accepting EWS integration in EHRs in the qualitative study and the lack of engagement found when the dashboard was evaluated. The contextual factors discussed by Greenhalgh between the system, the individual and the setting may explain the situation in the pandemic if explored further (154).

## Strengths of the thesis

The thesis examined different aspects of early warning scores used in cardiac care. The research questions in the research were derived from problems experienced in the effectiveness and implementation of EWS for escalation of care in the clinical area. The findings from the answers to the questions were highly relatable in the cardiac care settings since the problems were based on real experiences and challenges.

The thesis has the strength of showing an inter-relationship between the findings of the five conducted studies. The intersection between findings enriches the understanding of the use of early warning scores for patients in a specialist cardiac setting in an environment affected by the COVID-19 pandemic while facilitated by digital solutions. The mixed-methods approach helped analyse the uncertainty in the results by combining the qualitative and quantitative data.

The research explored aspects of an up-to-date EWS, NEWS2, with evolving technological applications. Parts of the research were conducted during a well-established NEWS2 with evolving technological development due to the modern age and rapid response needed in the pandemic. The study findings may highlight that early warning systems can respond differently to modern systems. With the majority of hospital settings in developed countries implementing EWS and rapidly adopting digital health, research findings may be of great relevance to other clinical settings.

## Limitations of the thesis

The main source of limitation when the thesis studies were performed was the COVID-19 pandemic. Adherence to routine monitoring was affected by the increase in tasks, contributing to missingness in the data collected for the retrospective cohort evaluation. In the scoping review, the period was limited to three years due to the timeline when the pandemic took effect. In addition, during the qualitative study, the sampling and participation were restricted as a result of time restraint and health professionals' tasks. While evaluating the Deteriorating Patient Dashboard, there was a lack of engagement from key users, and the study was short on interviews of further key users to explore their views.

The outcomes studied in the systematic review and the retrospective evaluation predicted critical events. The studies did not examine the impact on long-term outcomes. Furthermore, the scoping review and the dashboard evaluation examined the current practice and lacked the long-term impact on patient outcomes and health professionals' roles.

Another limitation is the frameworks applied in the qualitative study and the dashboard evaluation study. In the qualitative study, the NASSS framework lacks an in-depth human-centric investigation that can deeply explain behaviours. In addition, when evaluating the dashboard, the TAM model focuses on basic elements in adopting a technology that seemed feasible to explore, given the early stage of the implementation. The model excludes institutional and technological system-related factors.

The EWS was evaluated in the retrospective cohort, and the qualitative study was the digitalised NEWS2. The performance and the implementation findings may not be applicable when utilising other EWS with different delivery methods. Moreover, the EWS implementation was examined in a cardiac specialist setting and a general teaching hospital, where the escalation of care policies and the hospital structures varies from each other and other hospital settings. As such, the studies' findings may not be generalisable to other settings.

## Dissemination of findings

- The systematic review in chapter three has been peer reviewed and accepted for publication in BMJ Open Journal and has been presented as an oral presentation at the Saudi Heart Association 22 conference.
- The evaluation of the dashboard study has been peer reviewed and presented as an oral presentation at the Healthcare Information and Management Systems Society (HIMSS) conference.
- The qualitative implementation study was accepted to be presented in October 2022 at the 35th annual conference of the European Society of Intensive Care Medicine, Paris.
- -The performance evaluation, the qualitative study, the scoping review, and the dashboard evaluation study were published as pre-prints in the medRXiv preprint server and are undergoing peer review for publication.

## Implementation in clinical practice

Parts of the thesis findings were reported and have been incorporated into clinical practice.

Chapter three reported the heterogeneity of Early Warning Scores performance and the lack of examining EHRs integration. The findings were shared with the senior clinicians and managers of the deteriorating patient committee at UCLH. In addition, they were shared with the senior consultant and chief nursing information officer at Barts Health Trust. The meetings resulted in planning the objectives and the structure of the retrospective cohort study and the implementation study. In Barts Hospital, the retrospective study took place as planned with the collaboration of the clinical informatics team, the critical care response and the cardiac resuscitation teams. However, at UCLH, two issues hindered conducting a performance evaluation of NEWS2 in patients with CVD in the setting. There was difficulty in identifying patients with cardiovascular diseases due to not having a designated cardiac care setting, and critical events recordings were not documented electronically in EHRs. Therefore, the arrangement of the feasibility of the study caused a delay in gaining ethical approval and conducting the study within the planned timeline. In Barts Hospital, after conducting the study, the findings were shared with critical care consultants and the quality improvement team. The implemented NEWS2 was considered to have the advantage of preventing the further proportion deterioration of acutely ill patients. Therefore, maintaining the recommended NEWS2 was suggested until further guidelines to review the score were published.

From the implementation studies, a number of meetings were conducted to discuss the findings and bring recommendations for developing the current practice of NEWS2 utilisation and escalation of care. In chapter six, the findings from the implementation study were reported. The interview results and defined elements that shaped the implementation of digital EWS were discussed with the chief information officer and critical care consultant. The cultural and the system-related factors were considered to implement change by managers and the quality improvement team. In chapter seven, the performance analysis and user interview findings were shared with the clinical informatics and quality improvement teams. Areas of improvement were highlighted, and suggestions for modification and additions for implementing the dashboard were shared to take into consideration in the current phase of dashboard development.

## Implication for clinical practice

The thesis has discussed various aspects of managing deteriorating patients in cardiac care. Managing a deteriorating patient is a complex process that has multifactorial elements for success. EWS was presented as a standardised method for predicting and managing acutely ill patients; however, it has not been delivering the anticipated benefits in improving detection and clinical outcomes. The findings reported in the thesis have significant clinical implications to be addressed.

- Recognising acutely ill patients

Chapter four has identified the deficiency of NEWS2 to predict critical events for patients with CVD. While NEWS2 may be used as a guide to direct nurses' and doctors' attention to a possible worsening in patients' condition; this function is variable when utilised for CVD patients. It may not perform as expected, decreasing staff confidence in its reliability. Using clinical knowledge and experience along the way is highly recommended. In addition, continuous assessment of NEWS2 validity for patients with CVD in different settings and examining suggested adjustments can improve its application in the clinical environment. It is essential to include clinical experts when planning the development and validation of standardised or specialised EWS. Accordingly, improving the system can bring reassurance to nurses and doctors that it is not harming patients but delivering the optimum desired care.

- implementing digital EWS in hospitals

The report highlights the need to incorporate the validation results and the implementation factors into clinical practice. From the retrospective validation, examining the predictive accuracy brings an insight into the tool's ability to be implemented. On the other hand, from the implementation study, the role of the organisational support, the effectiveness of EWS as a tool, and the culture in the hospital setting shape the scene for adopting and utilising EWS. The report emphasises the need to consider these elements when implementing or updating an EWS in hospitals. It is essential to include health professionals' opinions in a regular evaluation of the implementation, considering the factors in the NASSS framework with an in-depth examination of the human-centric factors.

- Support and training

The report highlights the importance of supporting and training health professionals when introducing digital EWS and auditing dashboards. The thesis draws attention to the challenges experienced by nurses and managers in various health settings. The findings indicate that some participants gained knowledge and skills from a well-structured educational session while others were self-taught. It was reported that learning digital health systems is an urgent need for health care professionals. It was believed that the understanding and experience of digital EWS and the dashboard could be improved by integrating HI competencies into medical training curricula and conducting continuous training sessions during clinical practice (395). As health professionals' years of experience, IT literacy and speciality vary, training should be structured to fit the needs of health professionals from different levels.

Furthermore, as reported in the scoping review and the implementation study, a skilled senior professional is an asset in improving the implementation of EWS. However, a safe space between seniors and junior staff is still missing. Therefore, cross-boundary training can promote a better understanding of the system and its challenges and improve work relationships between different teams and professionals from different seniority levels.

- Technology incorporation

Incorporating EWS into digital healthcare systems is essential in the current era of vast adoption in the majority of health settings. In facilitating the recognition and response to deterioration, technology was proposed as a mean to bridge the gaps in the process. In the implementation study, the integration of EWS into EHRs and automated monitoring were found to carry some challenges that forbid maximising their benefits. It is necessary to review and adjust digital health solutions to be blended into clinical work in order to serve the function of a facilitator. There is a need to review the EWS in EHRs regularly to examine areas needing alteration, such as parameters thresholds and individuals assigned for this role, enforcing measures for routine and timely recordings, and guidelines for justifiable response or disregard to alarms. In addition, in evaluating the dashboard, findings highlighted a lack of engagement by key users and a need for adjustment of the user interface and data integration. Induction training would improve the utilisation of the dashboard. Incorporating patient EWS alarms that require a response from automated monitoring would prompt staff to be alerted on time without the need to open patients' charts, which might only occur at the end of a ward round. Auditing the response of individual patients may provide a clear view to evaluate the performance of the nurses and doctors in charge. Finally, integrating health systems databases, such as CCRT and COVID-19 pathology data, into the dashboard system is advisable for a robust and in-depth evaluation of resources and performance at a different levels in a care setting.

## Implications for research

The thesis reported the limitations of the outcomes found in the five studies conducted. For this reason, there is a need to develop further research objectives and outcomes in the aspects investigated and other areas that lack evidence. Supporting collaborative multicentre research can increase the outputs and back the generalisability of the findings. This is important for improving the deteriorating patient management in cardiac care and preventing exacerbation of mortality and morbidity rates. There is an urgent need to address the lack of research on early detection in patients with CVD and the limited evidence on digital health evaluation and its role in the escalation of care.

The following areas should be addressed in future research:

1- Prospective cohort study evaluating the performance of EWS in predicting defined deterioration endpoints for patients with CVD in specialist settings and general settings.

2- Qualitative research exploring the ethnography of the work culture in assessing and managing deteriorating patients in specialist settings in relation to recognition, escalation, and utilisation of EWS guidelines and digital tools.

3- Studies to examine the role of EWS in escalating deteriorating patients at the time of the pandemic by exploring the escalation of care structure and the experience of nurses and doctors.

4- Examining the clinical benefit of the digital tools facilitating recording, calculation, alerting and auditing EWS and deteriorating patients.

5- Examining the subsequent phases of implementing auditing dashboards as a quality improvement tool and further studies in other hospital settings.

6- Studying the appropriate methods for validating EWS by defining accurate, critical endpoints, assessment timeline, and validation metrics using consensus methods, i.e., Delphi or nominal method, of clinical experts' opinion.

7- Mixed methods research examining the relationship between the performance and the implementation of EWS.

## Conclusion

This thesis aimed to provide evidence-based research that would support clinical applicability for deteriorating patients with cardiovascular diseases. The findings indicate that the detection and management of a deteriorating patient is a complex process. There seems to be a relationship between the performance of Early Warning Scores and the implementation process in the clinical settings while facilitated by EHR-integrated digital solutions. The outcomes of patients with CVD will likely be improved by integrating and examining these elements. Better development and validation of EWS, examining technological solutions, and understanding the escalation of care can bring clinical advantages for the health professionals and the patients' outcomes.

# References:


1. Gaziano JM, Wilson PWF. Cardiovascular Risk Assessment in the 21st Century. JAMA. 2012 Aug 22;308(8):816–7.

2. WHO. Cardiovascular diseases (CVDs). 2021.

3. Health Intelligence Team B. BHF UK CVD Factsheet. 2022;(January).

4. BHF. UK Factsheet. British Heart Foundation. 2019;(April):1–21.

5. Go AS, Mozaffarian D, Roger VL, Benjamin EJ, Berry JD, Blaha MJ, et al. Heart disease and stroke statistics—2014 update: a report from the American Heart Association. Circulation. 2014;129(3):e28–292.

6. Goff DC, Lloyd-Jones DM, Bennett G, Coady S, D'agostino RB, Gibbons R, et al. 2013 ACC/AHA guideline on the assessment of cardiovascular risk: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. J Am Coll Cardiol. 2014;63(25 Part B):2935–59.

7. NHS. Cardiovascular disease (CVD). 2019;

8. Anderson TJ, Grégoire J, Hegele RA, Couture P, Mancini GBJ, McPherson R, et al. 2012 update of the Canadian Cardiovascular Society guidelines for the diagnosis and treatment of dyslipidemia for the prevention of cardiovascular disease in the adult. Canadian Journal of Cardiology. 2013;29(2):151–67.

9. Brindle P, Beswick A, Fahey T, Ebrahim S. Accuracy and impact of risk assessment in the primary prevention of cardiovascular disease: a systematic review. Heart. 2006;92(12):1752–9.

10. Payne RA. Cardiovascular risk. Br J Clin Pharmacol. 2012;74(3):396–410.

11. Liew SM, Blacklock C, Hislop J, Glasziou P, Mant D. Cardiovascular risk scores: qualitative study of how primary care practitioners understand and use them. British Journal of General Practice. 2013 Jun 1;63(611):e401 LP-e407.

12. Antman EM, Cohen M, Bernink PJLM, McCabe CH, Horacek T, Papuchis G, et al. The TIMI Risk Score for Unstable Angina/Non–ST Elevation MIA Method for Prognostication and Therapeutic Decision Making. JAMA. 2000 Aug 16;284(7):835–42.

13. Shariff N, Aleem A, Singh M, Z Li Y, J Smith S. AF and Venous Thromboembolism - Pathophysiology, Risk Assessment and CHADS-VASc score. J Atr Fibrillation. 2012 Oct 6;5(3):649.

14. Eagle KA, Lim MJ, Dabbous OH, Pieper KS, Goldberg RJ, Van de Werf F, et al. A Validated Prediction Model for All Forms of Acute Coronary SyndromeEstimating the Risk of 6-Month Postdischarge Death in an International Registry. JAMA. 2004 Jun 9;291(22):2727–33.

15. Jones R, White P, Armstrong D. Managing acute illness An Inquiry into the Quality of General Practice in England. The King's Fund. 2010;24.

16. National Library of Medicine (US). Acute vs. chronic conditions. 2020.

17. Chang R, Elhusseiny KM, Yeh YC, Sun WZ. COVID-19 ICU and mechanical ventilation patient characteristics and outcomes—A systematic review and meta-analysis. PLoS One. 2021;16(2):e0246318.

18. Goldhill, Worthington, Mulcahy, Tarling, Sumner. The patient-at-risk team: identifying and managing seriously ill ward patients. Anaesthesia. 1999 Sep 30;54(9):853–60.

19. NHS DIgital. Hospital Admitted Patient Care Activity 2020-21. 2021.

20. Anandaciva S. Critical care services in the English NHS. The King's fund. 2020;

21. Goldhill DR, White SA, Sumner A. Physiological values and procedures in the 24 h before ICU admission from the ward. Anaesthesia. 1999 Jun;54(6):529–34.

22. Franklin C, Mathew J. Developing strategies to prevent inhospital cardiac arrest: analyzing responses of  physicians and nurses in the hours before the event. Crit Care Med. 1994 Feb;22(2):244–7.

23. Hillman KM, Bristow PJ, Chey T, Daffurn K, Jacques T, Norman SL, et al. Duration of life-threatening antecedents prior to intensive care admission. Intensive Care Med. 2002;

24. Kause J, Smith G, Prytherch D, Parr M, Flabouris A, Hillman K. A comparison of Antecedents to Cardiac Arrests, Deaths and EMergency Intensive care Admissions in Australia and New Zealand, and the United Kingdom - The ACADEMIA study. Resuscitation. 2004;

25. Smith AF, Wood J. Can some in-hospital cardio-respiratory arrests be prevented? A prospective survey. Resuscitation. 1998 Jun;37(3):133–7.

26. Schein RM, Hazday N, Pena M, Ruben BH, Sprung CL. Clinical antecedents to in-hospital cardiopulmonary arrest. Chest. 1990 Dec;98(6):1388–92.

27. Hillman KM, Bristow PJ, Chey T, Daffurn K, Jacques T, Norman SL, et al. Antecedents to hospital deaths. Intern Med J. 2001;31(6):343–8.

28. Bedell SE, Deitz DC, Leeman D, Delbanco TL. Incidence and characteristics of preventable iatrogenic cardiac arrests. JAMA. 1991 Jun;265(21):2815–20.

29. George ALJ, Folk BP 3rd, Crecelius PL, Campbell WB. Pre-arrest morbidity and other correlates of survival after in-hospital cardiopulmonary arrest. Am J Med. 1989 Jul;87(1):28–34.

30. 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;316(7148):1853–8.

31. Hogan H, Hutchings A, Wulff J, Carver C, Holdsworth E, Welch J, et al. Interventions to reduce mortality from in-hospital cardiac arrest: a mixed-methods study. Health Services and Delivery Research. 2019;7(2):1–110.

32. Lighthall GK, Markar S, Hsiung R. Abnormal vital signs are associated with an increased risk for critical events in US veteran inpatients. Resuscitation. 2009;80(11):1264–9.

33. Kause J, Smith G, Prytherch D, Parr M, Flabouris A, Hillman K. A comparison of Antecedents to Cardiac Arrests, Deaths and EMergency Intensive care Admissions in Australia and New Zealand, and the United Kingdom—the ACADEMIA study. Resuscitation. 2004 Sep 1;62(3):275–82.

34. Wilson RM, Runciman WB, Gibberd RW, Harrison BT, Newby L, Hamilton JD. The Quality in Australian Health Care Study. Med J Aust. 1995 Nov;163(9):458–71.

35. Brennan TA, Leape LL, Laird NM, Hebert L, Localio AR, Lawthers AG, et al. Incidence of adverse events and negligence in hospitalized patients. Results of the Harvard Medical Practice Study I. N Engl J Med. 1991 Feb;324(6):370–6.

36. Dubois RW, Brook RH. Preventable deaths: who, how often, and why? Ann Intern Med. 1988 Oct;109(7):582–9.

37. (UK C for CP at N. Acutely ill patients in hospital: recognition of and response to acute illness in adults in hospital [Internet]. 2007;

38. Acutely ill adults in hospital : recognising and responding to deterioration. NICE guideline. 2021;(July 2007).

39. McGloin H, Adam SK, Singer M. Unexpected deaths and referrals to intensive care of patients on general wards. Are some cases potentially avoidable? J R Coll Physicians Lond. 1999;33(3):255–9.

40. Patel S, Warusavitarne J. 'National confidential enquiry into patient outcome and death (NCEPOD) timescales of intervention': Are we adhering to national guidelines? International Journal of Surgery. 2013;8(11):707.

41. DeVita MA, Bellomo R, Hillman K, Kellum J, Rotondi A, Teres D, et al. Findings of the First Consensus Conference on Medical Emergency Teams*. Crit Care Med. 2006;34(9).

42. Nolan J. European Resuscitation Council Guidelines for Resuscitation 2005: Section 1. Introduction. Resuscitation. 2005 Dec 1;67:S3–6.

43. Smith GB. In-hospital cardiac arrest: Is it time for an in-hospital 'chain of prevention'? Resuscitation. 2010 Sep 1;81(9):1209–11.

44. National Patient Safety Agency. Recognising and Responding Appropriately to Early Signs of Deterioration in Hospitalised Patients: November 2007. National Patient Safety Agency; 2007.

45. Chatterjee MT, Moon JC, Murphy R, McCrea D. The "OBS" chart: an evidence based approach to re-design of the patient observation chart in a district general hospital setting. Postgrad Med J. 2005;81(960):663–6.

46. Smith GB, Osgood VM, Crane S. ALERT™—a multiprofessional training course in the care of the acutely ill adult patient. Resuscitation. 2002;52(3):281–6.

47. Morgan RJM, Williams F, Wright MM. An early warning scoring system for detecting developing critical illness. Clin Intensive Care. 1997;8(2):100.

48. Cuthbertson BH, Boroujerdi M, McKie L, Aucott L, Prescott G. Can physiological variables and early warning scoring systems allow early recognition of the deteriorating surgical patient? Crit Care Med. 2007 Feb;35(2):402–9.

49. Subbe CP, Kruger M, Rutherford P, Gemmel L. Validation of a modified Early Warning Score in medical admissions. Qjm. 2001;94(10):521–6.

50. Prytherch DR, Smith GB, Schmidt PE, Featherstone PI. ViEWS--Towards a national early warning score for detecting adult inpatient deterioration. Resuscitation. 2010 Aug;81(8):932–7.

51. Royal College of Physicians of London. National Early Warning Score (NEWS): standardising the assessment of acute-illness severity in the NHS. Royal College of Physician. 2012;

52. Inada-Kim M, Nsutebu E. NEWS 2: an opportunity to standardise the management of deterioration and sepsis. BMJ. 2018 Mar 20;360:k1260.

53. Royal College of Physicians of London. NHS England approves use of National Early Warning Score (NEWS) 2 to improve detection of acutely ill patients. Royal College of Physician. 2017;

54. National Institute For Health And Care Excellence (NICE). National Early Warning Score systems that alert to deteriorating adult patients in hospital. Medtech innovation briefing. 2020;978-1–4731:1–18.

55. 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;

56. Plevin R, Callcut R. Update in sepsis guidelines: what is really new? Trauma Surg Acute Care Open. 2017 Sep 7;2(1):e000088.

57. Carle C, Alexander P, Columb M, Johal J. Design and internal validation of an obstetric early warning score: secondary analysis of the Intensive Care National Audit and Research Centre Case Mix Programme database. Anaesthesia. 2013 Apr;68(4):354–67.

58. Cetınkaya HB, Koksal O, Sigirli D, Leylek EH, Karasu O. The predictive value of the modified early warning score with rapid lactate level (ViEWS-L) for mortality in

patients of age 65 or older visiting the emergency department. Intern Emerg Med. 2017 Dec;12(8):1253–7.

59. Mohammed MA, Rudge G, Watson D, Wood G, Smith GB, Prytherch DR, et al. Index blood tests and national early warning scores within 24 hours of emergency admission can predict the risk of in-hospital mortality: a model development and validation study. PLoS One. 2013 May 29;8(5):e64340–e64340.

60. Vorwerk C, Loryman B, Coats TJ, Stephenson JA, Gray LD, Reddy G, et al. Prediction of mortality in adult emergency department patients with sepsis. Emerg Med J. 2009 Apr;26(4):254–8.

61. 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 Medicine. 2007.

62. Alam N, Hobbelink EL, van Tienhoven AJ, van de Ven PM, Jansma EP, Nanayakkara PWB. The impact of the use of the Early Warning Score (EWS) on patient outcomes: A systematic review. Resuscitation. 2014.

63. Hamilton F, Arnold D, Baird A, Albur M, Whiting P. Early Warning Scores do not accurately predict mortality in sepsis: A meta-analysis and systematic review of the literature. Journal of Infection. 2018;

64. Smith MEB, Chiovaro JC, O'Neil M, Kansagara D, Quiñones AR, Freeman M, et al. Early warning system scores for clinical deterioration in hospitalized patients: A systematic review. Annals of the American Thoracic Society. 2014.

65. Smith GB, Prytherch DR, Schmidt PE, Featherstone PI, Higgins B. A review, and performance evaluation, of single-parameter "track and trigger" systems. Resuscitation. 2008;

66. Smith GB, Prytherch DR, Schmidt PE, Featherstone PI. Review and performance evaluation of aggregate weighted "track and trigger" systems. Resuscitation. 2008.

67. Badreldin AMA, Doerr F, Bender EM, Bayer O, Brehm BR, Wahlers T, et al. Rapid clinical evaluation: An early warning cardiac surgical scoring system for hand-held digital devices*. European Journal of Cardio-thoracic Surgery. 2013;

68. Herlitz J, Bång A, Ekström L, Aune S, Lundström G, Holmberg S, et al. A comparison between patients suffering in-hospital and out-of-hospital cardiac arrest in terms of treatment and outcome. J Intern Med. 2000 Jul 1;248(1):53–60.

69. Sandroni C, Nolan J, Cavallaro F, Antonelli M. In-hospital cardiac arrest: incidence, prognosis and possible measures to improve survival. Intensive Care Med. 2007;33(2):237–45.

70. Li B, Ding S, Song G, Li J, Zhang Q. Computer-Aided Diagnosis and Clinical Trials of Cardiovascular Diseases Based on Artificial Intelligence Technologies for Risk-Early Warning Model. J Med Syst. 2019;43(7):228.

71. Badreldin AMA, Doerr F, Bender EM, Bayer O, Brehm BR, Wahlers T, et al. Rapid clinical evaluation: An early warning cardiac surgical scoring system for hand-held digital devices*. European Journal of Cardio-thoracic Surgery. 2013;

72. Chiew CJ, Liu N, Tagami T, Wong TH, Koh ZX, Ong MEH. Heart rate variability based machine learning models for risk prediction of suspected sepsis patients in the emergency department. Medicine. 2019 Feb;98(6):e14197–e14197.

73. Morgan RJM, Wright MM. In defence of early warning scores. BJA: British Journal of Anaesthesia. 2007;99(5):747–8.

74. Pedersen NE. Early warning scores for the detection of critical illness in hospitalised patients. 2017;(September).

75. Cuthbertson BH, Smith GB. A warning on early-warning scores! BJA: British Journal of Anaesthesia. 2007 Jun 1;98(6):704–6.

76. Hong W, Wu J, Chen X. Receiver operating characteristic curve and odds ratio should be used with caution. Hepat Mon. 2011 Sep;11(9):757.

77. Grund B, Sabin C. Analysis of biomarker data: logs, odds ratios, and receiver operating characteristic curves. Curr Opin HIV AIDS. 2010 Nov;5(6):473–9.

78. Cook NR. Use and misuse of the receiver operating characteristic curve in risk prediction. Circulation. 2007 Feb;115(7):928–35.

79. 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.

80. Gordon CF, Beckett DJ. Significant deficiencies in the overnight use of a Standardised Early Warning Scoring system in a teaching hospital. Scott Med J. 2011;56(1):15–8.

81. Beckett DJ, Inglis M, Oswald S. Reducing cardiac arrests in the acute.

82. Austen C, Patterson C, Poots A, Green S, Weldring T, Bell D. Using a local early warning scoring system as a model for the introduction of a national system. Acute Med. 2012;11(2):66–73.

83. Odell M. Detection and management of the deteriorating ward patient: an evaluation of nursing practice. J Clin Nurs. 2015;24(1–2):173–82.

84. Jones S, Mullally M, Ingleby S, Buist M, Bailey M, Eddleston JM. Bedside electronic capture of clinical observations and automated clinical alerts to improve compliance with an Early Warning Score protocol. Critical Care and Resuscitation. 2011;13(2):83–8.

85. Buist M, Stevens S. Patient bedside observations: what could be simpler? Vol. 22, BMJ quality & safety. BMJ Publishing Group Ltd; 2013. p. 699–701.

86. 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;5(7):e007376.

87. Nadel S, Britto J, Booy R, Maconochie I, Habibi P, Levin M. Avoidable deficiencies in the delivery of health care to children with meningococcal disease. Emergency Medicine Journal. 1998;15(5):298–303.

88. Butler-Williams C, Cantrill N, Maton S. Increasing staff awareness of respiratory rate significance. Resuscitation. 2005;62(2):137–41.

89. Bonafide CP, Roberts KE, Weirich CM, Paciotti B, Tibbetts KM, Keren R, et al. Beyond statistical prediction: qualitative evaluation of the mechanisms by which pediatric early warning scores impact patient safety. J Hosp Med. 2013;8(5):248–53.

90. Rohde LE, Clausell N, Ribeiro JP, Goldraich L, Netto R, Dec GW, et al. Health outcomes in decompensated congestive heart failure: a comparison of tertiary hospitals in Brazil and United States. Int J Cardiol. 2005;102(1):71–7.

91. Donohue LA, Endacott R. Track, trigger and teamwork: communication of deterioration in acute medical and surgical wards. Intensive Crit Care Nurs. 2010;26(1):10–7.

92. Niegsch M, Fabritius ML, Anhøj J. Imperfect implementation of an early warning scoring system in a Danish teaching hospital: a cross-sectional study. PLoS One. 2013;8(7):e70068.

93. Guinane J, Bucknall T, Currey J, Jones D. Incidence of missed medical emergency team (MET) activation. Australian Critical Care. 2011;24(1):63–4.

94. Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. The lancet. 2020;395(10229):1054–62.

95. Carr E, Bendayan R, Bean D, O'Gallagher K, Pickles A, Stahl D, et al. Supplementing the National Early Warning Score (NEWS2) for anticipating early deterioration among patients with COVID-19 infection. medRxiv. 2020 Jan 1;2020.04.24.20078006.

96. Xie Y, Xu E, Bowe B, Al-Aly Z. Long-term cardiovascular outcomes of COVID-19. Nat Med. 2022;28(3):583–90.

97. Abbasi J. The COVID Heart—One Year After SARS-CoV-2 Infection, Patients Have an Array of Increased Cardiovascular Risks. JAMA. 2022 Mar 22;327(12):1113–4.

98. Nishiga M, Wang DW, Han Y, Lewis DB, Wu JC. COVID-19 and cardiovascular disease: from basic mechanisms to clinical perspectives. Nat Rev Cardiol. 2020;17(9):543–58.

99. Thienemann F, Chakafana G, Piñeiro D, Pinto FJ, Perel P, Singh K, et al. WHF position statement on COVID vaccination. Glob Heart. 2021;16(1).

100. Ji D, Zhang D, Xu J, Chen Z, Yang T, Zhao P, et al. Prediction for progression risk in patients with COVID-19 pneumonia: the CALL score. Clinical Infectious Diseases. 2020;71(6):1393–9.

101. Shi Y, Yu X, Zhao H, Wang H, Zhao R, Sheng J. Host susceptibility to severe COVID-19 and establishment of a host risk score: findings of 487 cases outside Wuhan. Crit Care. 2020;24(1):1–4.

102. Wynants L, Van Calster B, Collins GS, Riley RD, Heinze G, Schuit E, et al. Prediction models for diagnosis and prognosis of covid-19: Systematic review and critical appraisal. The BMJ. 2020 Apr 7;369:26.

103. Sun S, Folarin A, Ranjan Y, Rashid Z, Conde P, Stewart C, et al. COVID-19 Analyses COVID-19 Analyses.

104. H.A.L. R, A.C.D.C. A, F.C.D.B. N, F.L.P. I, L.A. L, S.G.M.O. R. Dealing with the impact of the COVID-19 pandemic on a rapid response team operation in Brazil: Quality in practice. International Journal for Quality in Health Care. 2021;33(1):mzaa114.

105. Redfern OC, Griffiths P, Maruotti A, Saucedo AR, Smith GB. The association between nurse staffing levels and the timeliness of vital signs monitoring: a retrospective observational study in the UK. BMJ Open. 2019;9(9):e032157.

106. Salvatore FP, Fanelli S. Patient-related complexity of care in healthcare organizations: a management and evaluation model. Int J Environ Res Public Health. 2020;17(10):3463.

107. 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 1;71(1):19–28.

108. Andrews Alan. Global Electronic Health Records (EHRs) Market to Witness a CAGR of 5.6% during 2019-2025 [Internet]. 2019 [cited 2020 Feb 28]. Available from: https://www.globenewswire.com/news-release/2019/04/24/1808641/0/en/Global-Electronic-Health-Records-EHRs-Market-to-Witness-a-CAGR-of-5-6-during-2019-2025.html

109. Pimentel MAF, Redfern OC, Gerry S, Collins GS, Malycha J, Prytherch D, et al. A comparison of the ability of the National Early Warning Score and the National Early Warning Score 2 to identify patients at risk of in-hospital mortality: A multi-centre database study. Resuscitation. 2018 Oct;131:N.PAG-N.PAG.

110. Churpek MM, Yuen TC, Park SY, Gibbons R, Edelson DP. Using electronic health record data to develop and validate a prediction model for adverse outcomes in the wards*. Crit Care Med. 2014 Apr;42(4):841–8.

111. Hirai T, Tate S, Dryer K, Jones D, Rosenberg J, Nathan S, et al. Electronic cardiac arrest triage score best predicts mortality after intervention in patients with massive and submassive pulmonary embolism. Catheter Cardiovasc Interv. 2018 Aug 1;92(2):366–71.

112. Bartkowiak B, Snyder AM, Benjamin A, Schneider A, Twu NM, Churpek MM, et al. Validating the Electronic Cardiac Arrest Risk Triage (eCART) Score for Risk Stratification of Surgical Inpatients in the Postoperative Setting: Retrospective Cohort Study. Ann Surg. 2019 Jun;269(6):1059–63.

113. Subbe CP, Duller B, Bellomo R. Effect of an automated notification system for deteriorating ward patients on clinical outcomes. Crit Care. 2017;21(1):52.

114. Difonzo M. Performance of the Afferent Limb of Rapid Response Systems in Managing Deteriorating Patients: A Systematic Review. Artigas A, editor. Crit Care Res Pract. 2019;2019:6902420.

115. VIVALINK. COVID-19 Automated Patient Monitoring System [Internet]. 2021. Available from: https://www.vivalink.com/covid-19-patient-monitoring

116. I. K, G.B. S, D. P, P. M, C. P, A. C, et al. The performance of the National Early Warning Score and National Early Warning Score 2 in hospitalised patients infected by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Resuscitation. 2021;159:150–7.

117. Data dashboards - NHS Digital [Internet]. [cited 2022 Apr 14]. Available from: https://digital.nhs.uk/dashboards

118. Barts Health NHS Trust. Accountability Report and Annual Accounts. 2020;(March).

119. Donaldson N, Brown DS, Aydin CE, Bolton MLB, Rutledge DN. Leveraging nurse-related dashboard benchmarks to expedite performance improvement and document excellence. JONA: The Journal of Nursing Administration. 2005;35(4):163–72.

120. Lee K, Jung SY, Hwang H, Yoo S, Baek HY, Baek RM, et al. A novel concept for integrating and delivering health information using a comprehensive digital dashboard: An analysis of healthcare professionals' intention to adopt a new system and the trend of its real usage. Int J Med Inform. 2017;97:98–108.

121. Creswell JW, Clark VLP. Designing and conducting mixed methods research. Sage publications; 2017.

122. Tariq S, Woodman J. Using mixed methods in health research. JRSM Short Rep. 2013 May 7;4(6):2042533313479197–2042533313479197.

123. Ivankova N v, Creswell JW, Stick SL. Using mixed-methods sequential explanatory design: From theory to practice. Field methods. 2006;18(1):3–20.

124. Creswell J, Wisdom J. Mixed methods: Integrating quantitative and qualitative data collection and analysis while studying patient-centered medical home models. Lincoln: University of Nebraska. 2013;

125. Tashakkori A, Teddlie C. Mixed methods handbook in social and behavioral research. Sage Publications: Thousand Oaks, CA; 2003.

126. Shorten A, Smith J. Mixed methods research: expanding the evidence base. Evidence Based Nursing [Internet]. 2017 Jul 1;20(3):74 LP – 75. Available from: http://ebn.bmj.com/content/20/3/74.abstract

127. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021 Mar 29;372:n71.

128. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. J Clin Epidemiol. 2009;

129. Moons KGM, de Groot JAH, Bouwmeester W, Vergouwe Y, Mallett S, Altman DG, et al. Critical Appraisal and Data Extraction for Systematic Reviews of Prediction Modelling Studies: The CHARMS Checklist. PLoS Med. 2014;

130. Palazón-Bru A, Martín-Pérez F, Mares-García E, Beneyto-Ripoll C, Gil-Guillén VF, Pérez-Sempere Á, et al. A general presentation on how to carry out a CHARMS analysis for prognostic multivariate models. Stat Med. 2020 Oct 15;39(23):3207–25.

131. Wolff RF, Moons KGM, Riley RD, Whiting PF, Westwood M, Collins GS, et al. PROBAST: A Tool to Assess the Risk of Bias and Applicability of Prediction Model Studies. Ann Intern Med. 2019 Jan 1;170(1):51.

132. Cohen JF, Korevaar DA, Altman DG, Bruns DE, Gatsonis CA, Hooft L, et al. STARD 2015 guidelines for reporting diagnostic accuracy studies: explanation and elaboration. BMJ Open. 2016 Nov 1;6(11):e012799.

133. Bossuyt PM, Reitsma JB, Bruns DE, Gatsonis CA, Glasziou PP, Irwig LM, et al. Towards complete and accurate reporting of studies of diagnostic accuracy: the STARD initiative. Ann Intern Med. 2003;138(1):40–4.

134. Kang H. The prevention and handling of the missing data. Korean J Anesthesiol. 2013/05/24. 2013 May;64(5):402–6.

135. Park HM. Univariate analysis and normality test using SAS, Stata, and SPSS. 2015;

136. Sedgwick P. Pearson's correlation coefficient. BMJ : British Medical Journal. 2012 Jul 4;345:e4483.

137. Faraway JJ. Does data splitting improve prediction? Stat Comput. 2016;26(1):49–60.

138. Jiménez-Valverde A. Insights into the area under the receiver operating characteristic curve (AUC) as a discrimination measure in species distribution modelling. Global Ecology and Biogeography. 2012 Apr 1;21(4):498–507.

139. Ling CX, Huang J, Zhang H. AUC: a statistically consistent and more discriminating measure than accuracy. In: Ijcai. 2003. p. 519–24.

140. Fischer JE, Bachmann LM, Jaeschke R. A readers' guide to the interpretation of diagnostic test properties: clinical example of sepsis. Intensive Care Med. 2003;29(7):1043–51.

141. Sipio R Di. A Quick Guide to AUC-ROC in Machine Learning Models. Towards Data Science. 2021;

142. Armstrong R, Hall BJ, Doyle J, Waters E. 'Scoping the scope'of a cochrane review. J Public Health (Bangkok). 2011;33(1):147–50.

143. Munn Z, Peters MDJ, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. BMC Med Res Methodol. 2018;18(1):143.

144. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol. 2005;8(1):19–32.

145. Daudt HML, van Mossel C, Scott SJ. Enhancing the scoping study methodology: a large, inter-professional team's experience with Arksey and O'Malley's framework. BMC Med Res Methodol. 2013;13(1):48.

146. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. Ann Intern Med. 2018;169(7):467–73.

147. Sarkis-Onofre R, Catalá-López F, Aromataris E, Lockwood C. How to properly use the PRISMA Statement. Syst Rev. 2021;10(1):117.

148. Veritas Health Innovation, Melbourne A. Covidence systematic review software [Internet]. 2015 [cited 2021 Sep 10]. Available from: www.covidence.org

149. Joanna Briggs Institute. Joanna Briggs Institute Reviewers' Manual: 2015 Edition. Methodology for Scoping Reviews. 2015;

150. Peters MDJ, Marnie C, Tricco AC, Pollock D, Munn Z, Alexander L, et al. Updated methodological guidance for the conduct of scoping reviews. JBI Evid Implement. 2021;19(1).

151. British Pscyhological Society. National Collaborating Centre for Mental Health (UK). Dementia: A NICE-SCIE Guidline on Supporting People With Dementia and Their Carers in Health and Social Care. 2007.

152. CASP UK. CASP Qualitative Studies Checklist [Internet]. [cited 2021 Sep 20]. Available from: https://casp-uk.net/casp-tools-checklists/

153. Long HA, French DP, Brooks JM. Optimising the value of the critical appraisal skills programme (CASP) tool for quality appraisal in qualitative evidence synthesis. Research Methods in Medicine & Health Sciences. 2020;1(1):31–42.

154. Greenhalgh T, Wherton J, Papoutsi C, Lynch J, Hughes G, A'Court C, et al. Beyond Adoption: A New Framework for Theorizing and Evaluating Nonadoption, Abandonment, and Challenges to the Scale-Up, Spread, and Sustainability of Health and Care Technologies. J Med Internet Res [Internet]. 2017;19(11):e367. Available from: http://www.jmir.org/2017/11/e367/

155. Blankush JM, Freeman R, McIlvaine J, Tran T, Nassani S, Leitman IM. Implementation of a novel postoperative monitoring system using automated Modified Early Warning Scores (MEWS) incorporating end-tidal capnography. J Clin Monit Comput. 2017 Oct;31(5):1081–92.

156. Kadesjö Banck J, Bernhardsson S. Experiences from implementation of internet-delivered cognitive behaviour therapy for insomnia in psychiatric health care: a

qualitative study applying the NASSS framework. BMC Health Serv Res. 2020;20(1):1–14.

157. Papoutsi C, Wherton J, Shaw S, Greenhalgh T. Explaining the mixed findings of a randomised controlled trial of telehealth with centralised remote support for heart failure: multi-site qualitative study using the NASSS framework. Trials. 2020;21(1):1–15.

158. Almujlli G, Alrabah R, Al-Ghosen A, Munshi F. Conducting Virtual Focus Groups During the COVID-19 Epidemic Utilizing Videoconferencing Technology: A Feasibility Study. Cureus. 2022;14(3).

159. Self B. Conducting interviews during the covid-19 pandemic and beyond. In: Forum Qual Soc Res. 2021.

160. You S. Challenges and gains in conducting online interviews during the pandemic. 2021.

161. Rice S, Winter SR, Doherty S, Milner M. Advantages and disadvantages of using internet-based survey methods in aviation-related research. Journal of Aviation Technology and Engineering. 2017;7(1):5.

162. SmartSurvey [Internet]. [cited 2022 Feb 21]. Available from: https://www.smartsurvey.com/

163. Braun V, Clarke V. Thematic analysis. 2012;

164. Morse JM. Mixed method design: Principles and procedures. Routledge; 2016.

165. Patton MQ. Qualitative research & evaluation methods: Integrating theory and practice. Sage publications; 2014.

166. Stange KC, Crabtree BF, Miller WL. Publishing multimethod research. Vol. 4, The Annals of Family Medicine. Annals Family Med; 2006. p. 292–4.

167. Pluye P, Hong QN. Combining the power of stories and the power of numbers: mixed methods research and mixed studies reviews. Annu Rev Public Health. 2014;35:29–45.

168. Christoff P. Running PDSA cycles. Curr Probl Pediatr Adolesc Health Care. 2018;48(8):198–201.

169. Albanese MP, Evans DA, Schantz CA, Bowen M, Disbot M, Moffa JS, et al. Engaging clinical nurses in quality and performance improvement activities. Nurs Adm Q. 2010;34(3):226–45.

170. Davis FD, Bagozzi RP, Warshaw PR. User acceptance of computer technology: A comparison of two theoretical models. Manage Sci. 1989;35(8):982–1003.

171. Bagozzi RP. The legacy of the technology acceptance model and a proposal for a paradigm shift. J Assoc Inf Syst. 2007;8(4):3.

172. Pagani M. Determinants of adoption of third generation mobile multimedia services. Journal of interactive marketing. 2004;18(3):46–59.

173. Nysveen H, Pedersen PE, Thorbjørnsen H. Explaining intention to use mobile chat services: moderating effects of gender. Journal of consumer Marketing. 2005;

174. Venkatesh V, Davis FD. A theoretical extension of the technology acceptance model: Four longitudinal field studies. Manage Sci. 2000;46(2):186–204.

175. Venkatesh V, Bala H. Technology acceptance model 3 and a research agenda on interventions. Decision sciences. 2008;39(2):273–315.

176. Powers BA, Knapp TR. Dictionary of nursing theory and research. Springer publishing company; 2010.

177. Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol. 2006;3(2):77–101.

178. Vaismoradi M, Turunen H, Bondas T. Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. Nurs Health Sci. 2013 Sep 1;15(3):398–405.

179. Cei M, Bartolomei C, Mumoli N. In-hospital mortality and morbidity of elderly medical patients can be predicted at admission by the Modified Early Warning Score: A prospective study. Int J Clin Pract. 2009;

180. Adhikari NKJ, Fowler RA, Bhagwanjee S, Rubenfeld GD. Critical care and the global burden of critical illness in adults. The Lancet. 2010;376(9749):1339–46.

181. Paterson R, MacLeod DC, Thetford D, Beattie A, Graham C, Lam S, et al. Prediction of in-hospital mortality and length of stay using an early warning scoring system:

Clinical audit. Clinical Medicine, Journal of the Royal College of Physicians of London. 2006;

182. Moon A, Cosgrove JF, Lea D, Fairs A, Cressey DM. An eight year audit before and after the introduction of modified early warning score (MEWS) charts, of patients admitted to a tertiary referral intensive care unit after CPR. Resuscitation. 2011;

183. Linnen DT, Escobar GJ, Hu X, Scruth E, Liu V, Stephens C. Statistical modeling and aggregate-weighted scoring systems in prediction of mortality and ICU transfer: A systematic review. J Hosp Med. 2019;14(3):161–9.

184. Hamilton F, Arnold D, Baird A, Albur M, Whiting P. Early Warning Scores do not accurately predict mortality in sepsis: A meta-analysis and systematic review of the literature. Journal of Infection. 2018;

185. 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;

186. Smith GB, Prytherch DR, Meredith P, Schmidt PE, Featherstone PI. The ability of the National Early Warning Score (NEWS) to discriminate patients at risk of early cardiac arrest, unanticipated intensive care unit admission, and death. Resuscitation. 2013 Apr;84(4):465–70.

187. Direkze S, Jain S. Time to intervene? lessons from the NCEPOD cardiopulmonary resuscitation report 2012. Br J Hosp Med. 2012 Oct 16;73(10):585–7.

188. Altman DG, Royston P. What do we mean by validating a prognostic model? Stat Med. 2000 Feb 29;19(4):453–73.

189. Debray TPA, Vergouwe Y, Koffijberg H, Nieboer D, Steyerberg EW, Moons KGM. A new framework to enhance the interpretation of external validation studies of clinical prediction models. J Clin Epidemiol. 2015;68(3):279–89.

190. Williams TA, Tohira H, Finn J, Perkins GD, Ho KM. The ability of early warning scores (EWS) to detect critical illness in the prehospital setting: A systematic review. Resuscitation. 2016.

191. Gerry S, Bonnici T, Birks J, Kirtley S, Virdee PS, Watkinson PJ, et al. Early warning scores for detecting deterioration in adult hospital patients: systematic review and critical appraisal of methodology. bmj. 2020;369.

192. Van Calster B, McLernon DJ, van Smeden M, Wynants L, Steyerberg EW, Bossuyt P, et al. Calibration: the Achilles heel of predictive analytics. BMC Med. 2019;17(1):230.

193. Brink A, Alsma J, Verdonschot RJCG, Rood PPM, Zietse R, Lingsma HF, et al. Predicting mortality in patients with suspected sepsis at the Emergency Department; A retrospective cohort study comparing qSOFA, SIRS and National Early Warning Score. PLoS One. 2019 Jan 25;14(1):e0211133–e0211133.

194. Cildir E, Bulut M, Akalin H, Kocabas E, Ocakoglu G, Aydin SA, et al. Evaluation of the modified MEDS, MEWS score and Charlson comorbidity index in patients with community acquired sepsis in the emergency department. Intern Emerg Med. 2013 Apr;8(3):255–60.

195. Siddiqui S, Chua M, Kumaresh V, Choo R. A comparison of pre ICU admission SIRS, EWS and q SOFA scores for predicting mortality and length of stay in ICU. J Crit Care. 2017 Oct;41:191–3.

196. Khwannimit B, Bhurayanontachai R, Vattanavanit V. Comparison of the accuracy of three early warning scores with SOFA score for predicting mortality in adult sepsis and septic shock patients admitted to intensive care unit. Heart Lung. 2019 May;48(3):240–4.

197. Vaughn JL, Kline D, Denlinger NM, Andritsos LA, Exline MC, Walker AR. Predictive performance of early warning scores in acute leukemia patients receiving induction chemotherapy. Leuk Lymphoma. 2018 Jun;59(6):1498–500.

198. Henry KE, Hager DN, Pronovost PJ, Saria S. A targeted real-time early warning score (TREWScore) for septic shock. Sci Transl Med. 2015 Aug 5;7(299):299ra122-299ra122.

199. Churpek MM, Snyder A, Sokol S, Pettit NN, Edelson DP. Investigating the Impact of Different Suspicion of Infection Criteria on the Accuracy of Quick Sepsis-Related Organ Failure Assessment, Systemic Inflammatory Response Syndrome, and Early Warning Scores. Crit Care Med. 2017 Nov;45(11):1805–12.

200. Churpek MM, Snyder A, Han X, Sokol S, Pettit N, Howell MD, et al. Quick Sepsis-related Organ Failure Assessment, Systemic Inflammatory Response Syndrome, and Early Warning Scores for Detecting Clinical Deterioration in Infected Patients outside the Intensive Care Unit. Am J Respir Crit Care Med. 2017 Apr 1;195(7):906–11.

201. Smith GB, Prytherch DR, Schmidt PE, Featherstone PI. Review and performance evaluation of aggregate weighted "track and trigger" systems. Resuscitation. 2008.

202. Kellett J, Kim A. Validation of an abbreviated Vitalpac™ Early Warning Score (ViEWS) in 75,419 consecutive admissions to a Canadian regional hospital. Resuscitation. 2012 Mar;83(3):297–302.

203. Kim WY, Lee J, Lee JR, Jung YK, Kim HJ, Huh JW, et al. A risk scoring model based on vital signs and laboratory data predicting transfer to the intensive care unit of patients admitted to gastroenterology wards. J Crit Care. 2017 Aug;40:213–7.

204. Bozkurt S, Köse A, Arslan ED, Erdoğan S, Üçbilek E, Çevik İ, et al. Validity of modified early warning, Glasgow Blatchford, and pre-endoscopic Rockall scores in predicting prognosis of patients presenting to emergency department with upper gastrointestinal bleeding. Scand J Trauma Resusc Emerg Med. 2015 Dec 30;23:109.

205. Seak CJ, Yen DHT, Ng CJ, Wong YC, Hsu KH, Seak JCY, et al. Rapid Emergency Medicine Score: A novel prognostic tool for predicting the outcomes of adult patients with hepatic portal venous gas in the emergency department. PLoS One. 2017 Sep 15;12(9):e0184813–e0184813.

206. Hu SB, Wong DJL, Correa A, Li N, Deng JC. Prediction of Clinical Deterioration in Hospitalized Adult Patients with Hematologic Malignancies Using a Neural Network Model. PLoS One. 2016 Aug 17;11(8):e0161401–e0161401.

207. Liljehult J, Christensen T. Early warning score predicts acute mortality in stroke patients. Acta Neurol Scand. 2016 Apr;133(4):261–7.

208. Mulligan A. Validation of a physiological track and trigger score to identify developing critical illness in haematology patients. Intensive Crit Care Nurs. 2010 Aug;26(4):196–206.

209. Cooksley T, Kitlowski E, Haji-Michael P. Effectiveness of Modified Early Warning Score in predicting outcomes in oncology patients. QJM. 2012 Nov;105(11):1083–8.

210. Young RS, Gobel BH, Schumacher M, Lee J, Weaver C, Weitzman S. Use of the modified early warning score and serum lactate to prevent cardiopulmonary arrest in hematology-oncology patients: a quality improvement study. American Journal of Medical Quality. 2014 Nov;29(6):530–7.

211. von Lilienfeld-Toal M, Midgley K, Lieberbach S, Barnard L, Glasmacher A, Gilleece M, et al. Observation-based early warning scores to detect impending critical illness predict in-hospital and overall survival in patients undergoing allogeneic stem cell transplantation. Biol Blood Marrow Transplant. 2007 May;13(5):568–76.

212. Pedersen NE, Rasmussen LS, Petersen JA, Gerds TA, Østergaard D, Lippert A. Modifications of the National Early Warning Score for patients with chronic respiratory disease. Acta Anaesthesiol Scand. 2018 Feb;62(2):242–52.

213. Forster S, Housley G, McKeever TM, Shaw DE. Investigating the discriminative value of Early Warning Scores in patients with respiratory disease using a retrospective cohort analysis of admissions to Nottingham University Hospitals Trust over a 2-year period. BMJ Open. 2018 Jul 30;8(7):e020269–e020269.

214. Sbiti-Rohr D, Kutz A, Christ-Crain M, Thomann R, Zimmerli W, Hoess C, et al. The National Early Warning Score (NEWS) for outcome prediction in emergency department patients with community-acquired pneumonia: results from a 6-year prospective cohort study. BMJ Open. 2016 Sep 28;6(9):e011021–e011021.

215. Brabrand M, Hallas P, Hansen SN, Jensen KM, Madsen JLB, Posth S. Using scores to identify patients at risk of short term mortality at arrival to the acute medical unit: A validation study of six existing scores. Eur J Intern Med. 2017 Nov;45:32–6.

216. Jo S, Jeong T, Lee JB, Jin Y, Yoon J, Park B, et al. Validation of modified early warning score using serum lactate level in community-acquired pneumonia patients. The National Early Warning Score-Lactate score. American Journal of Emergency Medicine. 2016 Mar;34(3):536–41.

217. Barlow G, Nathwani D, Davey P. The CURB65 pneumonia severity score outperforms generic sepsis and early warning scores in predicting mortality in community-acquired pneumonia. Thorax. 2007 Mar;62(3):253–9.

218. Bilben B, Grandal L, Søvik S. National Early Warning Score (NEWS) as an emergency department predictor of disease severity and 90-day survival in the acutely

dyspneic patient - a prospective observational study. Scand J Trauma Resusc Emerg Med. 2016 Jun 2;24:80.

219. Delahanty RJ, Alvarez J, Flynn LM, Sherwin RL, Jones SS. Development and Evaluation of a Machine Learning Model for the Early Identification of Patients at Risk for Sepsis. Ann Emerg Med. 2019 Apr;73(4):334–44.

220. Redfern OC, Smith GB, Prytherch DR, Meredith P, Inada-Kim M, Schmidt PE. A Comparison of the Quick Sequential (Sepsis-Related) Organ Failure Assessment Score and the National Early Warning Score in Non-ICU Patients With/Without Infection. Crit Care Med. 2018 Dec;46(12):1923–33.

221. Faisal M, Richardson D, Scally AJ, Howes R, Beatson K, Speed K, et al. Computer-aided National Early Warning Score to predict the risk of sepsis following emergency medical admission to hospital: a model development and external validation study. CMAJ. 2019 Apr 8;191(14):E382–9.

222. de Groot B, Stolwijk F, Warmerdam M, Lucke JA, Singh GK, Abbas M, et al. The most commonly used disease severity scores are inappropriate for risk stratification of older emergency department sepsis patients: an observational multi-centre study. Scand J Trauma Resusc Emerg Med. 2017 Sep 11;25(1):91.

223. Corfield AR, Lees F, Zealley I, Houston G, Dickie S, Ward K, et al. Utility of a single early warning score in patients with sepsis in the emergency department. Emergency Medicine Journal. 2014 Jun;31(6):482–7.

224. Goulden R, Hoyle MC, Monis J, Railton D, Riley V, Martin P, et al. qSOFA, SIRS and NEWS for predicting inhospital mortality and ICU admission in emergency admissions treated as sepsis. Emerg Med J [Internet]. 2018 Jun;35(6):345–9. Available from: http://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,shib&db=cmedm&AN=29467173&site=ehost-live&scope=site

225. Ghanem-Zoubi NO, Vardi M, Laor A, Weber G, Bitterman H. Assessment of disease-severity scoring systems for patients with sepsis in general internal medicine departments. Crit Care. 2011;15(2):R95–R95.

226. Saeed K, Wilson DC, Bloos F, Schuetz P, van der Does Y, Melander O, et al. The early identification of disease progression in patients with suspected infection

presenting to the emergency department: a multi-centre derivation and validation study. Crit Care. 2019 Feb 8;23(1):40.

227. Innocenti F, Tozzi C, Donnini C, De Villa E, Conti A, Zanobetti M, et al. SOFA score in septic patients: incremental prognostic value over age, comorbidities, and parameters of sepsis severity. Intern Emerg Med. 2018 Apr;13(3):405–12.

228. Camm CF, Hayward G, Elias TCN, Bowen JST, Hassanzadeh R, Fanshawe T, et al. Sepsis recognition tools in acute ambulatory care: associations with process of care and clinical outcomes in a service evaluation of an Emergency Multidisciplinary Unit in Oxfordshire. BMJ Open. 2018 Apr 9;8(4):e020497–e020497.

229. Tirotta D, Gambacorta M, La Regina M, Attardo T, Lo Gullo A, Panzone F, et al. Evaluation of the threshold value for the modified early warning score (MEWS) in medical septic patients: a secondary analysis of an Italian multicentric prospective cohort (SNOOPII study). QJM. 2017 Jun 1;110(6):369–73.

230. Pong JZ, Fook-Chong S, Koh ZX, Samsudin MI, Tagami T, Chiew CJ, et al. Combining Heart Rate Variability with Disease Severity Score Variables for Mortality Risk Stratification in Septic Patients Presenting at the Emergency Department. Int J Environ Res Public Health. 2019 May 16;16(10).

231. Prabhakar SM, Tagami T, Liu N, Samsudin MI, Ng JCJ, Koh ZX, et al. Combining quick sequential organ failure assessment score with heart rate variability may improve predictive ability for mortality in septic patients at the emergency department. PLoS One. 2019 Mar 18;14(3):e0213445–e0213445.

232. Martino IF, Figgiaconi V, Seminari E, Muzzi A, Corbella M, Perlini S. The role of qSOFA compared to other prognostic scores in septic patients upon admission to the emergency department. Eur J Intern Med. 2018 Jul;53:e11–3.

233. Qin Q, Xia Y, Cao Y. Clinical study of a new Modified Early Warning System scoring system for rapidly evaluating shock in adults. J Crit Care. 2017 Feb;37:50–5.

234. Schmedding M, Adegbite BR, Gould S, Beyeme JO, Adegnika AA, Grobusch MP, et al. A Prospective Comparison of Quick Sequential Organ Failure Assessment, Systemic Inflammatory Response Syndrome Criteria, Universal Vital Assessment, and Modified Early Warning Score to Predict Mortality in Patients with Suspected Infection in Gabon. Am J Trop Med Hyg. 2019 Jan;100(1):202–8.

235. Albur M, Hamilton F, MacGowan AP. Early warning score: a dynamic marker of severity and prognosis in patients with Gram-negative bacteraemia and sepsis. Ann Clin Microbiol Antimicrob. 2016 Apr 12;15:23.

236. Samsudin MI, Liu N, Prabhakar SM, Chong SL, Kit Lye W, Koh ZX, et al. A novel heart rate variability based risk prediction model for septic patients presenting to the emergency department. Medicine. 2018 Jun;97(22):e10866–e10866.

237. Chang SH, Hsieh CH, Weng YM, Hsieh MS, Goh ZNL, Chen HY, et al. Performance Assessment of the Mortality in Emergency Department Sepsis Score, Modified Early Warning Score, Rapid Emergency Medicine Score, and Rapid Acute Physiology Score in Predicting Survival Outcomes of Adult Renal Abscess Patients in the Emergency D. Biomed Res Int. 2018 Sep 19;2018:6983568.

238. Geier F, Popp S, Greve Y, Achterberg A, Glöckner E, Ziegler R, et al. Severity illness scoring systems for early identification and prediction of in-hospital mortality in patients with suspected sepsis presenting to the emergency department. Wien Klin Wochenschr. 2013 Sep;125(17–18):508–15.

239. Asiimwe SB, Abdallah A, Ssekitoleko R. A simple prognostic index based on admission vital signs data among patients with sepsis in a resource-limited setting. Crit Care. 2015 Mar 16;19:86.

240. Hung SK, Ng CJ, Kuo CF, Goh ZNL, Huang LH, Li CH, et al. Comparison of the Mortality in Emergency Department Sepsis Score, Modified Early Warning Score, Rapid Emergency Medicine Score and Rapid Acute Physiology Score for predicting the outcomes of adult splenic abscess patients in the emergency department. PLoS One. 2017 Nov 1;12(11):e0187495–e0187495.

241. Garcea G, Jackson B, Pattenden CJ, Sutton CD, Neal CP, Dennison AR, et al. Early warning scores predict outcome in acute pancreatitis. J Gastrointest Surg. 2006 Jul;10(7):1008–15.

242. Yoo JW, Lee JR, Jung YK, Choi SH, Son JS, Kang BJ, et al. A combination of early warning score and lactate to predict intensive care unit transfer of inpatients with severe sepsis/septic shock. Korean J Intern Med. 2015 Jul;30(4):471–7.

243. Wheeler I, Price C, Sitch A, Banda P, Kellett J, Nyirenda M, et al. Early warning scores generated in developed healthcare settings are not sufficient at predicting early

mortality in Blantyre, Malawi: a prospective cohort study. PLoS One. 2013;8(3):e59830–e59830.

244. Calvert J, Desautels T, Chettipally U, Barton C, Hoffman J, Jay M, et al. High-performance detection and early prediction of septic shock for alcohol-use disorder patients. Ann Med Surg (Lond). 2016 May 10;8:50–5.

245. Awad A, Bader-El-Den M, McNicholas J, Briggs J. Early hospital mortality prediction of intensive care unit patients using an ensemble learning approach. Int J Med Inform. 2017 Dec;108:185–95.

246. Reini K, Fredrikson M, Oscarsson A. The prognostic value of the Modified Early Warning Score in critically ill patients: a prospective, observational study. Eur J Anaesthesiol. 2012 Mar;29(3):152–7.

247. Chen YC, Yu WK, Ko HK, Pan SW, Chen YW, Ho LI, et al. Post-intensive care unit respiratory failure in older patients liberated from intensive care unit and ventilator: The predictive value of the National Early Warning Score on intensive care unit discharge. Geriatr Gerontol Int. 2019 Apr;19(4):317–22.

248. Baker T, Blixt J, Lugazia E, Schell CO, Mulungu M, Milton A, et al. Single Deranged Physiologic Parameters Are Associated With Mortality in a Low-Income Country. Crit Care Med. 2015 Oct;43(10):2171–9.

249. Gök RGY, Gök A, Bulut M. Assessing prognosis with modified early warning score, rapid emergency medicine score and worthing physiological scoring system in patients admitted to intensive care unit from emergency department. Int Emerg Nurs. 2019 Mar;43:9–14.

250. Moseson EM, Zhuo H, Chu J, Stein JC, Matthay MA, Kangelaris KN, et al. Intensive care unit scoring systems outperform emergency department scoring systems for mortality prediction in critically ill patients: a prospective cohort study. J Intensive Care. 2014 Jul 1;2:40.

251. Jo S, JB L, YH J, TO J, JC Y, YK J, et al. Modified early warning score with rapid lactate level in critically ill medical patients: the ViEWS-L score. Emergency Medicine Journal. 2013 Feb;30(2):123–9.

252. Kwon JM, Lee Y, Lee Y, Lee S, Park H, Park J. Validation of deep-learning-based triage and acuity score using a large national dataset. PLoS One. 2018 Oct 15;13(10):e0205836–e0205836.

253. Usman OA, Usman AA, Ward MA. Comparison of SIRS, qSOFA, and NEWS for the early identification of sepsis in the Emergency Department. Am J Emerg Med. 2018 Nov 7;

254. Jang DH, Kim J, Jo YH, Lee JH, Hwang JE, Park SM, et al. Developing neural network models for early detection of cardiac arrest in emergency department. Am J Emerg Med. 2019 Apr 7;

255. Wei X, Ma H, Liu R, Zhao Y. Comparing the effectiveness of three scoring systems in predicting adult patient outcomes in the emergency department. Medicine. 2019 Feb;98(5):e14289–e14289.

256. Lee SB, Kim DH, Kim T, Kang C, Lee SH, Jeong JH, et al. Triage in Emergency Department Early Warning Score (TREWS) is predicting in-hospital mortality in the emergency department. Am J Emerg Med. 2019 Feb 17;

257. Singer AJ, Ng J, Thode HC, Spiegel R, Weingart S, Thode HCJ. Quick SOFA Scores Predict Mortality in Adult Emergency Department Patients With and Without Suspected Infection. Ann Emerg Med. 2017 Apr;69(4):475–9.

258. Eick C, Rizas KD, Meyer-Zürn CS, Groga-Bada P, Hamm W, Kreth F, et al. Autonomic nervous system activity as risk predictor in the medical emergency department: a prospective cohort study. Crit Care Med. 2015 May;43(5):1079–86.

259. Bulut M, Cebicci H, Sigirli D, Sak A, Durmus O, Top AA, et al. The comparison of modified early warning score with rapid emergency medicine score: a prospective multicentre observational cohort study on medical and surgical patients presenting to emergency department. Emergency Medicine Journal. 2014 Jun;31(6):476–81.

260. Kivipuro M, Tirkkonen J, Kontula T, Solin J, Kalliomäki J, Pauniaho SL, et al. National early warning score (NEWS) in a Finnish multidisciplinary emergency department and direct vs. late admission to intensive care. Resuscitation. 2018 Jul;128:164–9.

261. Eckart A, Hauser SI, Kutz A, Haubitz S, Hausfater P, Amin D, et al. Combination of the National Early Warning Score (NEWS) and inflammatory biomarkers for early risk

stratification in emergency department patients: results of a multinational, observational study. BMJ Open. 2019 Jan 17;9(1):e024636–e024636.

262. Ho LO, Li H, Shahidah N, Koh ZX, Sultana P, Hock Ong ME. Poor performance of the modified early warning score for predicting mortality in critically ill patients presenting to an emergency department. World J Emerg Med. 2013;4(4):273–8.

263. Skitch S, Tam B, Xu M, McInnis L, Vu A, Fox-Robichaud A. Examining the utility of the Hamilton early warning scores (HEWS) at triage: Retrospective pilot study in a Canadian emergency department. CJEM. 2018 Mar;20(2):266–74.

264. Liu N, Koh ZX, Goh J, Lin Z, Haaland B, Ting BP, et al. Prediction of adverse cardiac events in emergency department patients with chest pain using machine learning for variable selection. BMC Med Inform Decis Mak. 2014 Jan;14(1):75.

265. Dundar ZD, Ergin M, Karamercan MA, Ayranci K, Colak T, Tuncar A, et al. Modified Early Warning Score and VitalPac Early Warning Score in geriatric patients admitted to emergency department. Eur J Emerg Med. 2016 Dec;23(6):406–12.

266. W.C. Y, C. T, Z.D. D, S.C. Y, W. J. The significance of National Early Warning Score for predicting prognosis and evaluating conditions of patients in resuscitation room. Hong Kong Journal of Emergency Medicine. 2018;25(6):324–30.

267. Naidoo DK, Rangiah S, Naidoo SS. An evaluation of the Triage Early Warning Score in an urban accident and emergency department in KwaZulu-Natal. South African Family Practice. 2014 Jan;56(1):69–73.

268. F.Y. L, J. Q, R.X. W, X.L. F, J. W, C.Y. S, et al. A prospective validation of national early warning score in emergency intensive care unit patients at Beijing. Hong Kong Journal of Emergency Medicine. 2015;22(3):137–44.

269. So SN, Ong CW, Wong LY, Chung JYM, Graham CA. Is the Modified Early Warning Score able to enhance clinical observation to detect deteriorating patients earlier in an Accident & Emergency Department? Australasian Emergency Nursing Journal. 2015 Feb;18(1):24–32.

270. Dundar ZD, Kocak S, Girisgin AS. Lactate and NEWS-L are fair predictors of mortality in critically ill geriatric emergency department patients. Am J Emerg Med. 2019 Feb 7;

271. T.S. L, P.S.K. M, W.S. S, M.Y. L, T.F. C. Validation of a Modified Early Warning Score (MEWS) in emergency department observation ward patients. Hong Kong Journal of Emergency Medicine. 2006;13(1):24–30.

272. Xie X, Huang W, Liu Q, Tan W, Pan L, Wang L, et al. Prognostic value of Modified Early Warning Score generated in a Chinese emergency department: a prospective cohort study. BMJ Open. 2018 Dec 14;8(12):e024120–e024120.

273. Cattermole GN, Mak SKP, Liow CHE, Ho MF, Hung KYG, Keung KM, et al. Derivation of a prognostic score for identifying critically ill patients in an emergency department resuscitation room. Resuscitation. 2009 Sep;80(9):1000–5.

274. CR H, JP G, Blumstein H, Case D, Messick C, CD M. Performance of the maximum modified early warning score to predict the need for higher care utilization among admitted emergency department patients. J Hosp Med. 2010 Jan;5(1):E46-52.

275. Srivilaithon W, Amnuaypattanapon K, Limjindaporn C, Imsuwan I, Daorattanachai K, Dasanadeba I, et al. Predictors of in-hospital cardiac arrest within 24 h after emergency department triage: A case-control study in urban Thailand. Emerg Med Australas. 2019 Mar 18;

276. Cattermole GN, Liow ECH, Graham CA, Rainer TH. THERM: the Resuscitation Management score. A prognostic tool to identify critically ill patients in the emergency department. Emergency Medicine Journal. 2014 Oct;31(10):803–7.

277. Najafi Z, Zakeri H, Mirhaghi A. The accuracy of acuity scoring tools to predict 24-h mortality in traumatic brain injury patients: A guide to triage criteria. Int Emerg Nurs. 2018 Jan;36:27–33.

278. Kovacs C. Outreach and early warning systems for the prevention of intensive care admission and death of critically ill adult patients on general hospital wards. Int J Nurs Pract. 2016;

279. Plate JD, Peelen LM, Leenen LP, Hietbrink F. Validation of the VitalPAC Early Warning Score at the Intermediate Care Unit. World J Crit Care Med. 2018 Aug 4;7(3):39–45.

280. Sarani B. Accuracy of an expanded early warning score for patients in general and trauma surgery wards (Br J Surg 2012; 99: 192-197). Br J Surg. 2012 Feb;99(2):197–8.

281. Hollis RH, Graham LA, Lazenby JP, Brown DM, Taylor BB, Heslin MJ, et al. A Role for the Early Warning Score in Early Identification of Critical Postoperative Complications. Ann Surg. 2016 May;263(5):918–23.

282. Gardner-Thorpe J, Love N, Wrightson J, Walsh S, Keeling N. The value of Modified Early Warning Score (MEWS) in surgical in-patients: a prospective observational study. Ann R Coll Surg Engl. 2006 Oct;88(6):571–5.

283. Garcea G, Ganga R, Neal CP, Ong SL, Dennison AR, Berry DP. Preoperative early warning scores can predict in-hospital mortality and critical care admission following emergency surgery. J Surg Res. 2010 Apr;159(2):729–34.

284. Rasmussen LJH, Ladelund S, Haupt TH, Ellekilde GE, Eugen-Olsen J, Andersen O. Combining National Early Warning Score With Soluble Urokinase Plasminogen Activator Receptor (suPAR) Improves Risk Prediction in Acute Medical Patients: A Registry-Based Cohort Study. Crit Care Med. 2018 Dec;46(12):1961–8.

285. Ghosh E, Eshelman L, Yang L, Carlson E, Lord B. Early Deterioration Indicator: Data-driven approach to detecting deterioration in general ward. Resuscitation. 2018 Jan;122:99–105.

286. Duckitt RW, Buxton-Thomas R, Walker J, Cheek E, Bewick V, Venn R, et al. Worthing physiological scoring system: derivation and validation of a physiological early-warning system for medical admissions. An observational, population-based single-centre study. BJA: The British Journal of Anaesthesia. 2007 May 22;98(6):769–74.

287. F. C, L. T, G. C, M. A, S. R, M. M, et al. The Niguarda MEWS, a new and refined tool to determine criticality and instability in Internal Medicine Ward and Emergency Medicine Unit. Italian Journal of Medicine. 2017;11(3):310–7.

288. Abbott TEF, Torrance HDT, Cron N, Vaid N, Emmanuel J. A single-centre cohort study of National Early Warning Score (NEWS) and near patient testing in acute medical admissions. Eur J Intern Med. 2016 Nov;35:78–82.

289. Graziadio S, O'Leary RA, Stocken DD, Power M, Allen AJ, Simpson AJ, et al. Can mid-regional pro-adrenomedullin (MR-proADM) increase the prognostic accuracy of NEWS in predicting deterioration in patients admitted to hospital with mild to

moderately severe illness? A prospective single-centre observational study. BMJ Open. 2019 Feb 22;8(11):e020337–e020337.

290. Jarvis SW, Kovacs C, Briggs J, Meredith P, Schmidt PE, Featherstone PI, et al. Are observation selection methods important when comparing early warning score performance? Resuscitation. 2015 May 1;90:1–6.

291. 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 1;85(4):549–52.

292. Mozaffarian D. Global Scourge of Cardiovascular Disease. J Am Coll Cardiol. 2017 Jul 4;70(1):26 LP – 28.

293. Hemingway H, Croft P, Perel P, Hayden JA, Abrams K, Timmis A, et al. Prognosis research strategy (PROGRESS) 1: A framework for researching clinical outcomes. BMJ : British Medical Journal. 2013 Feb 5;346:e5595.

294. Aragam KG, Tamhane UU, Kline-Rogers E, Li J, Fox KAA, Goodman SG, et al. Does simplicity compromise accuracy in ACS risk prediction? A retrospective analysis of the TIMI and GRACE risk scores. PLoS One. 2009 Nov 23;4(11):e7947–e7947.

295. Day T, Oxton J. The National Early Warning Score in practice: a reflection. British Journal of Nursing. 2014 Oct 23;23(19):1036–40.

296. Alhmoud B, Bonnici T, Patel R, Melley D, Williams B, Banerjee A. Performance of universal early warning scores in different patient subgroups and clinical settings: a systematic review. BMJ Open. 2021 Apr 1;11(4):e045849.

297. Hong W, Earnest A, Sultana P, Koh Z, Shahidah N, Ong MEH. How accurate are vital signs in predicting clinical outcomes in critically ill emergency department patients. European Journal of Emergency Medicine. 2013;20(1):27–32.

298. Kostakis I, Smith GB, Prytherch D, Meredith P, Price C, Chauhan A. The performance of the National Early Warning Score and National Early Warning Score 2 in hospitalised patients infected by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Resuscitation. 2021 Feb;159:150–7.

299. Hollander JE, Robey JL, Chase MR, Brown AM, Zogby KE, Shofer FS. Relationship between a clear-cut alternative noncardiac diagnosis and 30-day outcome in

emergency department patients with chest pain. Academic Emergency Medicine. 2007;14(3):210–5.

300. Manini AF, Dannemann N, Brown DF, Butler J, Bamberg F, Nagurney JT, et al. Limitations of risk score models in patients with acute chest pain. Am J Emerg Med. 2009;27(1):43–8.

301. Douw G, Huisman-de Waal G, van Zanten ARH, van der Hoeven JG, Schoonhoven L. Nurses' "worry" as predictor of deteriorating surgical ward patients: A prospective cohort study of the Dutch-Early-Nurse-Worry-Indicator-Score. Int J Nurs Stud. 2016 Jul;59:134–40.

302. Pedrosa I, Browning T, Kwon JK, Morriss M, Matsler L, Pinho MC, et al. Response to COVID-19: Minimizing Risks, Addressing Challenges and Maintaining Operations in a Complex Academic Radiology Department. J Comput Assist Tomogr. 2020;44(4):479–84.

303. Griffiths P, Jones S, Bottle A. Is "failure to rescue" derived from administrative data in England a nurse sensitive patient safety indicator for surgical care? Observational study. Int J Nurs Stud. 2013;50(2):292–300.

304. Ghaferi AA, Birkmeyer JD, Dimick JB. Hospital volume and failure to rescue with high-risk surgery. Med Care. 2011;1076–81.

305. Ede J, Jeffs E, Vollam S, Watkinson P. A qualitative exploration of escalation of care in the acute ward setting. Nurs Crit Care. 2020 May 1;25(3):171–8.

306. Mackintosh N, Watson K, Rance S, Sandall J. Value of a modified early obstetric warning system (MEOWS) in managing maternal complications in the peripartum period: an ethnographic study. BMJ Qual Saf. 2014;23(1):26–34.

307. Rocha HAL, Alcântara AC de C, Netto FC de B, Ibiapina FLP, Lopes LA, Rocha SGMO, et al. Dealing with the impact of the COVID-19 pandemic on a rapid response team operation in Brazil: Quality in practice. Int J Qual Health Care. 2021 Feb;33(1).

308. Mackintosh N, Rainey H, Sandall J. Understanding how rapid response systems may improve safety for the acutely ill patient: learning from the frontline. BMJ Qual Saf. 2012;21(2):135–44.

309. Sofaer S. Qualitative methods: what are they and why use them? Health Serv Res. 1999;34(5 Pt 2):1101.

310. Anton N, Hornbeck T, Modlin S, Haque MM, Crites M, Yu D. Identifying factors that nurses consider in the decision-making process related to patient care during the COVID-19 pandemic. PLoS One. 2021;16(7):e0254077.

311. O.J.L. M, O. D, E. Y, C. R, F. T, K. M, et al. Rapid response system adaptations at 40 US hospitals during the COVID-19 pandemic. Resusc Plus. 2021;6:100121.

312. Bardi T, Gómez-Rojo M, Candela-Toha AM, de Pablo R, Martinez R, Pestaña D. Rapid response to COVID-19, escalation and de-escalation strategies to match surge capacity of Intensive Care beds to a large scale epidemic. Rev Esp Anestesiol Reanim. 2021 Jan;68(1):21–7.

313. Mitchell OJL, Doran O, Yuriditsky E, Root C, Teran F, Ma K, et al. Rapid response system adaptations at 40 US hospitals during the COVID-19 pandemic. Resusc Plus. 2021 Jun;6:100121.

314. Berg KM, Cheng A, Panchal AR, Topjian AA, Aziz K, Bhanji F, et al. Part 7: Systems of Care: 2020 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation. 2020 Oct 20;142(16_suppl_2):S580–604.

315. Levy N, Zucco L, Ehrlichman RJ, Hirschberg RE, Hutton Johnson S, Yaffe MB, et al. Development of Rapid Response Capabilities in a Large COVID-19 Alternate Care Site Using Failure Modes and Effect Analysis with In Situ Simulation. Anesthesiology. 2020 Nov;133(5):985–96.

316. Reeves JJ, Hollandsworth HM, Torriani FJ, Taplitz R, Abeles S, Tai-Seale M, et al. Rapid response to COVID-19: health informatics support for outbreak management in an academic health system. J Am Med Inform Assoc. 2020 Jun;27(6):853–9.

317. Kuckertz A, Brändle L, Gaudig A, Hinderer S, Morales Reyes CA, Prochotta A, et al. Startups in times of crisis – A rapid response to the COVID-19 pandemic. Journal of Business Venturing Insights. 2020;13:e00169.

318. CDC. Considerations for Alternate Care Sites. 2020.

319. T. B, M. GR, A.M. CT, R. de P, R. M. Rapid response to COVID-19, escalation and de-escalation strategies to match surge capacity of Intensive Care beds to a large scale epidemic. Rev Esp Anestesiol Reanim. 2020;

320. Montagna E, Donohoe J, Zaia V, Duggan E, O'Leary P, Waddington J, et al. Transition to clinical practice during the COVID-19 pandemic: a qualitative study of young doctors' experiences in Brazil and Ireland. BMJ Open. 2021;11(9):e053423.

321. Kamble R, Scantling-Birch Y, Samarth G, Larsson E, Maden C, Kamble R. P67 Integrated surgical teaching for juniors: surgical education during COVID-19. BJS Open. 2021;5(Supplement_1):zrab032-066.

322. Abrahamson SD, Canzian S, Brunet F. Using simulation for training and to change protocol during the outbreak of severe acute respiratory syndrome. Crit Care. 2005;10(1):1–6.

323. Fregene TE, Nadarajah P, Buckley JF, Bigham S, Nangalia V. Use of in situ simulation to evaluate the operational readiness of a high-consequence infectious disease intensive care unit. Anaesthesia. 2020;75(6):733–8.

324. Carr E, Bendayan R, Bean D, Stammers M, Wang W, Zhang H, et al. Evaluation and improvement of the National Early Warning Score (NEWS2) for COVID-19: a multi-hospital study. BMC Med. 2021 Dec 1;19(1).

325. Dana PE, Comilla S, Paul SC. Interim Guidance for Basic and Advanced Life Support in Adults, children, and neonates with suspected or confirmed COVID-19. Circulation. 2020;141:e933-43.

326. P. A, A. H, M. N, D. B, L. P, J. B, et al. Addressing Operational Challenges Faced by COVID-19 Public Health Rapid Response Teams in Non-United States Settings. Disaster Med Public Health Prep. 2021;

327. Carayon P, Hundt AS, Karsh BT, Gurses AP, Alvarado CJ, Smith M, et al. Work system design for patient safety: the SEIPS model. BMJ Qual Saf. 2006;15(suppl 1):i50–8.

328. Holden RJ, Carayon P, Gurses AP, Hoonakker P, Hundt AS, Ozok AA, et al. SEIPS 2.0: a human factors framework for studying and improving the work of healthcare professionals and patients. Ergonomics. 2013;56(11):1669–86.

329. Grant S. Limitations of track and trigger systems and the National Early Warning Score. Part 1: areas of contention. British Journal of Nursing. 2018 Jun 12;27(11):624–31.

330. Grant S, Crimmons K. Limitations of track and trigger systems and the National Early Warning Score. Part 2: sensitivity versus specificity. British Journal of Nursing. 2018 Jun 28;27(12):705–10.

331. Russell S, Stocker R, Barker RO, Liddle J, Adamson J, Hanratty B. Implementation of the National Early Warning Score in UK care homes: a qualitative evaluation. British Journal of General Practice. 2020 Nov 1;70(700):e793 LP-e800.

332. Petersen JA, Rasmussen LS, Rydahl-Hansen S. Barriers and facilitating factors related to use of early warning score among acute care nurses: a qualitative study. BMC Emerg Med. 2017;17(1):36.

333. Petersen JA, Mackel R, Antonsen K, Rasmussen LS. Serious adverse events in a hospital using <em>early warning score</em> – What went wrong? Resuscitation. 2014 Dec 1;85(12):1699–703.

334. Khanna AK, Hoppe P, Saugel B. Automated continuous noninvasive ward monitoring: future directions and challenges. Crit Care. 2019;23(1):194.

335. Stafseth SK, Grønbeck S, Lien T, Randen I, Lerdal A. The experiences of nurses implementing the Modified Early Warning Score and a 24-hour on-call Mobile Intensive Care Nurse: An exploratory study. Intensive Crit Care Nurs. 2016;34:33–41.

336. Jensen JK, Skår R, Tveit B. Hospital nurses’ professional accountability while using the National Early Warning Score: A qualitative study with a hermeneutic design. J Clin Nurs. 2019 Dec 1;28(23–24):4389–99.

337. Bigham BL, Chan T, Skitch S, Fox-Robichaud A. Attitudes of emergency department physicians and nurses toward implementation of an early warning score to identify critically ill patients: qualitative explanations for failed implementation. CJEM. 2018/06/14. 2019;21(2):269–73.

338. Jensen JK, Skår R, Tveit B. Introducing the National Early Warning Score – A qualitative study of hospital nurses’ perceptions and reactions. Nurs Open. 2019 Jul 1;6(3):1067–75.

339. Cherry PG, Jones CP. Attitudes of nursing staff towards a Modified Early Warning System. British Journal of Nursing. 2015 Sep 10;24(16):812–8.

340. Jensen JK, Skår R, Tveit B. The impact of Early Warning Score and Rapid Response Systems on nurses' competence: An integrative literature review and synthesis. Journal of Clinical Nursing (John Wiley & Sons, Inc). 2018 Apr;27(7–8):e1256–74.

341. Mitchell OJL, Neefe S, Ginestra JC, Baston CM, Frazer MJ, Gudowski S, et al. Impact of COVID-19 on inpatient clinical emergencies: A single-center experience. Resusc Plus. 2021 Jun;6:100135.

342. Liu SY, Kang XL, Wang CH, Chu H, Jen HJ, Lai HJ, et al. Protection procedures and preventions against the spread of coronavirus disease 2019 in healthcare settings for nursing personnel: Lessons from Taiwan. Aust Crit Care. 2021 Mar;34(2):182–90.

343. Spina S, Marrazzo F, Migliari M, Stucchi R, Sforza A, Fumagalli R. The response of Milan's Emergency Medical System to the COVID-19 outbreak in Italy. Vol. 395, Lancet (London, England). 2020. p. e49–50.

344. Zandieh SO, Yoon-Flannery K, Kuperman GJ, Langsam DJ, Hyman D, Kaushal R. Challenges to EHR Implementation in Electronic- Versus Paper-based Office Practices. J Gen Intern Med. 2008;23(6):755–61.

345. Gui X, Chen Y, Zhou X, Reynolds TL, Zheng K, Hanauer DA. Physician champions' perspectives and practices on electronic health records implementation: challenges and strategies. JAMIA Open. 2020 Apr 1;3(1):53–61.

346. Kostakis I, Smith GB, Prytherch D, Meredith P, Price C, Chauhan A. Impact of the coronavirus pandemic on the patterns of vital signs recording and staff compliance with expected monitoring schedules on general wards. Resuscitation. 2021 Jan;158:30–8.

347. Burke C, Conway Y. Factors that influence hospital nurses' escalation of patient care in response to their early warning score: A qualitative evidence synthesis. J Clin Nurs. 2022 Mar 25;n/a(n/a).

348. Petersen JA. Early warning score. Challenges and opportunities in the care of deteriorating patients Dan Med J. 2018;65:1–13.

349. Petersen JA. Early Warning Score-Challenges and Opportunities in the Care of Deteriorating In-hospital Patients: Phd Thesis. University of Copenhagen, Faculty of Health and Medical Sciences; 2016.

350. Pivovarov R, Elhadad N. Automated methods for the summarization of electronic health records. Journal of the American Medical Informatics Association. 2015;22(5):938–47.

351. Mick J. Data-driven decision making: a nursing research and evidence-based practice dashboard. JONA: The Journal of Nursing Administration. 2011;41(10):391–3.

352. Beasley JW, Wetterneck TB, Temte J, Lapin JA, Smith P, Rivera-Rodriguez AJ, et al. Information chaos in primary care: implications for physician performance and patient safety. The Journal of the American Board of Family Medicine. 2011;24(6):745–51.

353. Jeffs L, Beswick S, Lo J, Lai Y, Chhun A, Campbell H. Insights from staff nurses and managers on unit-specific nursing performance dashboards: a qualitative study. BMJ Qual Saf. 2014;23(12):1001–6.

354. LAHEY T, NELSON W. A Dashboard to Improve the Alignment of Healthcare Organization Decisionmaking to Core Values and Mission Statement. Cambridge Quarterly of Healthcare Ethics. 2019/12/20. 2020;29(1):156–62.

355. Reisman M. EHRs: The Challenge of Making Electronic Data Usable and Interoperable. P T. 2017 Sep;42(9):572–5.

356. Meszaros J, Ho C hsing. Building trust and transparency? Challenges of the opt-out system and the secondary use of health data in England. Med Law Int. 2019 Jun 1;19(2–3):159–81.

357. KAPLAN B. How Should Health Data Be Used?: Privacy, Secondary Use, and Big Data Sales. Cambridge Quarterly of Healthcare Ethics. 2016/03/09. 2016;25(2):312–29.

358. O.J.L. M, S. N, J.C. G, C.M. B, M.J. F, S. G, et al. Impact of COVID-19 on inpatient clinical emergencies: A single-center experience. Resusc Plus. 2021;6:100135.

359. NHS. Records Management Code of Practice 2021. Nhs. 2021;(August).

360. Janitz ME. Document control. Qual Prog. 2003;36(6):104.

361. Brand JW, Morrice DJ, Patteril M V, Mackay JH. National Early Warning Score 2 (NEWS2) to identify inpatient COVID-19 deterioration: The importance of pO<sub>2</sub>:FiO<sub>2</sub> ratio. Clinical Medicine. 2021 May 1;21(3):e315 LP-e316.

362. Lockwood JM, Thomas J, Martin S, Wathen B, Juarez-Colunga E, Peters L, et al. AutoPEWS: Automating Pediatric Early Warning Score Calculation Improves Accuracy Without Sacrificing Predictive Ability. Pediatr Qual Saf. 2020 Mar 25;5(2):e274–e274.

363. NHS DIgital. Electronic Prescribing and Medicines Administration (EPMA) Data. 2012.

364. Ludikhuize J, de Jonge E, Goossens A. Measuring adherence among nurses one year after training in applying the Modified Early Warning Score and Situation-Background-Assessment-Recommendation instruments. Resuscitation. 2011;82(11):1428–33.

365. McGregor C. Improving time to antibiotics and implementing the "Sepsis 6" BMJ Qual Improv Rep. 2014 Jan 1;2(2):u202548.w1443.

366. Duffy JR, Brewer BB. Feasibility of a multi-institution collaborative to improve patient-nurse relationship quality. JONA: The Journal of Nursing Administration. 2011;41(2):78–83.

367. St Pierre J. Staff nurses' use of report card data for quality improvement: first steps. J Nurs Care Qual. 2006;21(1):8–14.

368. Davidson E, Heslinga D. Bridging the IT adoption gap for small physician practices: An action research study on electronic health records. Information Systems Management. 2006;24(1):15–28.

369. Borycki E, Kushniruk A, Armstrong B, Joe R, Otto T. Integrating electronic health records into health professional and health informatics education: A continuum of approaches. 2010;

370. Chapman SM, Maconochie IK. Early warning scores in paediatrics: an overview. Arch Dis Child. 2019 Apr 1;104(4):395 LP – 399.

371. Horton DJ, Graves KK, Kukhareva P V, Johnson SA, Cedillo M, Sanford M, et al. Modified early warning score-based clinical decision support: cost impact and clinical outcomes in sepsis. JAMIA Open. 2020 Jul 1;3(2):261–8.

372. Bedoya AD, Clement ME, Phelan M, Steorts RC, O'Brien C, Goldstein BA. Minimal Impact of Implemented Early Warning Score and Best Practice Alert for Patient Deterioration. Crit Care Med. 2019 Jan;47(1):49–55.

373. Van Citters AD, Gifford AH, Brady C, Dunitz JM, Elmhirst M, Flath J, et al. Formative evaluation of a dashboard to support coproduction of healthcare services in cystic fibrosis. Journal of Cystic Fibrosis. 2020;19(5):768–76.

374. Kovacs C. Outreach and early warning systems for the prevention of intensive care admission and death of critically ill adult patients on general hospital wards. Int J Nurs Pract. 2016;

375. McGaughey J, Alderdice F, Fowler R, Kapila A, Mayhew A, Moutray M. Outreach and Early Warning Systems (EWS) for the prevention of Intensive Care admission and death of critically ill adult patients on general hospital wards. Cochrane Database of Systematic Reviews. 2007 Jul 18;(3).

376. Boudou M, ÓhAiseadha C, Garvey P, O'Dwyer J, Hynds P. Modelling COVID-19 severity in the Republic of Ireland using patient co-morbidities, socioeconomic profile and geographic location, February to November 2020. Sci Rep. 2021 Sep;11(1):18474.

377. Bunkenborg G, Poulsen I, Samuelson K, Ladelund S, Åkeson J. Mandatory early warning scoring—implementation evaluated with a mixed-methods approach. Applied Nursing Research. 2016;29:168–76.

378. Johnston MJ, Arora S, King D, Bouras G, Almoudaris AM, Davis R, et al. A systematic review to identify the factors that affect failure to rescue and escalation of care in surgery. Surgery. 2015;157(4):752–63.

379. Johnston M, Arora S, King D, Stroman L, Darzi A. Escalation of care and failure to rescue: A multicenter, multiprofessional qualitative study. Surgery. 2014;155(6):989–94.

380. Elnitsky CA, Powell-Cope G, Besterman-Dahan KL, Rugs D, Ullrich PM. Implementation of Safe Patient Handling in the U.S. Veterans Health System: A Qualitative Study of Internal Facilitators' Perceptions. Worldviews Evid Based Nurs. 2015 Aug 1;12(4):208–16.

381. Brangan E, Banks J, Brant H, Pullyblank A, Le Roux H, Redwood S. Using the National Early Warning Score (NEWS) outside acute hospital settings: a qualitative study of staff experiences in the West of England. BMJ Open. 2018 Oct 1;8(10):e022528.

382. Cassidy CE, MacEachern L, Best S, Foley L, Rowe ME, Dugas K, et al. Barriers and Enablers to Implementing the Children's Hospital Early Warning Score: A Pre- and Post-Implementation Qualitative Descriptive Study. J Pediatr Nurs. 2019;46:39–47.

383. Wood C, Chaboyer W, Carr P. How do nurses use early warning scoring systems to detect and act on patient deterioration to ensure patient safety? A scoping review. Int J Nurs Stud. 2019;94:166–78.

384. Rattray JE, Lauder W, Ludwick R, Johnstone C, Zeller R, Winchell J, et al. Indicators of acute deterioration in adult patients nursed in acute wards: a factorial survey. J Clin Nurs. 2011;20(5-6):723–32.

385. Currey J, Allen J, Jones D. Critical care clinician perceptions of factors leading to medical emergency team review. Australian critical care. 2018;31(2):87–92.

386. Frederix I, Caiani EG, Dendale P, Anker S, Bax J, Böhm A, et al. ESC e-Cardiology Working Group Position Paper: Overcoming challenges in digital health implementation in cardiovascular medicine. Eur J Prev Cardiol. 2019 Jul 1;26(11):1166–77.

387. Bakken S. Informatics is a critical strategy in combating the COVID-19 pandemic. Journal of the American Medical Informatics Association. 2020 Jun 1;27(6):843–4.

388. Reeves JJ, Pageler NM, Wick EC, Melton GB, Tan YHG, Clay BJ, et al. The Clinical Information Systems Response to the COVID-19 Pandemic. Yearb Med Inform. 2021/09/03. 2021 Aug;30(1):105–25.

389. Pullinger R, Wilson S, Way R, Santos M, Wong D, Clifton D, et al. Implementing an electronic observation and early warning score chart in the emergency department: a feasibility study. European Journal of Emergency Medicine. 2017;24(6):e11–6.

390. Mestrom E, De Bie A, Steeg M van de, 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;14(5):e0213402.

391. Greenhalgh T, Russell J. Why do evaluations of eHealth programs fail? An alternative set of guiding principles. PLoS Med. 2010;7(11):e1000360.

392. Walpole S, Taylor P, Banerjee A. Health informatics in UK Medical Education: an online survey of current practice. JRSM Open. 2016;8(1):2054270416682674.

393. Madhavan S, Bastarache L, Brown JS, Butte AJ, Dorr DA, Embi PJ, et al. Use of electronic health records to support a public health response to the COVID-19 pandemic in the United States: a perspective from 15 academic medical centers. Journal of the American Medical Informatics Association. 2021 Feb 1;28(2):393–401.

394. Osborne TF, Veigulis ZP, Arreola DM, Röösli E, Curtin CM. Automated EHR score to predict COVID-19 outcomes at US Department of Veterans Affairs. PLoS One. 2020;15(7):e0236554.

395. Jidkov L, Alexander M, Bark P, Williams JG, Kay J, Taylor P, et al. Health informatics competencies in postgraduate medical education and training in the UK: a mixed methods study. BMJ Open. 2019 Mar 1;9(3):e025460.

# Appendices

## Appendix 1. NEWS recording form

| NEWS key | FULL NAME | |
|---|---|---|
| 0 1 2 3 | DATE OF BIRTH | DATE OF ADMISSION |

| Parameter | | Score | |
|---|---|---|---|
| | DATE | | DATE |
| | TIME | | TIME |
| **A+B Respirations** Breaths/min | ≥25 | 3 | ≥25 |
| | 21–24 | 2 | 21–24 |
| | 18–20 | | 18–20 |
| | 15–17 | | 15–17 |
| | 12–14 | | 12–14 |
| | 9–11 | 1 | 9–11 |
| | ≤8 | 3 | ≤8 |
| **A+B $SpO_2$ Scale 1** Oxygen saturation (%) | ≥96 | | ≥96 |
| | 94–95 | 1 | 94–95 |
| | 92–93 | 2 | 92–93 |
| | ≤91 | 3 | ≤91 |
| **$SpO_2$ Scale 2†** Oxygen saturation (%) Use Scale 2 if target range is 88–92%, eg in hypercapnic respiratory failure | ≥97 on $O_2$ | 3 | ≥97 on $O_2$ |
| | 95–96 on $O_2$ | 2 | 95–96 on $O_2$ |
| | 93–94 on $O_2$ | 1 | 93–94 on $O_2$ |
| | ≥93 on air | | ≥93 on air |
| | 88–92 | | 88–92 |
| †ONLY use Scale 2 under the direction of a qualified clinician | 86–87 | 1 | 86–87 |
| | 84–85 | 2 | 84–85 |
| | ≤83% | 3 | ≤83% |
| **Air or oxygen?** | A=Air | | A=Air |
| | $O_2$ L/min | 2 | $O_2$ L/min |
| | Device | | Device |
| **C Blood pressure** mmHg Score uses systolic BP only | ≥220 | 3 | ≥220 |
| | 201–219 | | 201–219 |
| | 181–200 | | 181–200 |
| | 161–180 | | 161–180 |
| | 141–160 | | 141–160 |
| | 121–140 | | 121–140 |
| | 111–120 | | 111–120 |
| | 101–110 | 1 | 101–110 |
| | 91–100 | 2 | 91–100 |
| | 81–90 | 3 | 81–90 |
| | 71–80 | | 71–80 |
| | 61–70 | | 61–70 |
| | 51–60 | | 51–60 |
| | ≤50 | | ≤50 |
| **C Pulse** Beats/min | ≥131 | 3 | ≥131 |
| | 121–130 | 2 | 121–130 |
| | 111–120 | | 111–120 |
| | 101–110 | 1 | 101–110 |
| | 91–100 | | 91–100 |
| | 81–90 | | 81–90 |
| | 71–80 | | 71–80 |
| | 61–70 | | 61–70 |
| | 51–60 | | 51–60 |
| | 41–50 | 1 | 41–50 |
| | 31–40 | 3 | 31–40 |
| | ≤30 | | ≤30 |
| **D Consciousness** Score for NEW onset of confusion (no score if chronic) | Alert | | Alert |
| | Confusion | 3 | Confusion |
| | V | | V |
| | P | | P |
| | U | | U |
| **E Temperature** °C | ≥39.1° | 2 | ≥39.1° |
| | 38.1–39.0° | 1 | 38.1–39.0° |
| | 37.1–38.0° | | 37.1–38.0° |
| | 36.1–37.0° | | 36.1–37.0° |
| | 35.1–36.0° | 1 | 35.1–36.0° |
| | ≤35.0° | 3 | ≤35.0° |
| **NEWS TOTAL** | | | TOTAL |
| | Monitoring frequency | | Monitoring |
| | Escalation of care Y/N | | Escalation |
| | Initials | | Initials |

Appendix 2. Ethics approval

Ymchwil Iechyd a Gofal Cymru
Health and Care Research Wales

NHS
Health Research Authority

Dr Amitava Banerjee
222 Euston Road Institute of Health Informatics
University College London
NW1 2DA

Email: approvals@hra.nhs.uk
HCRW.approvals@wales.nhs.uk

28 September 2020

Dear Dr Banerjee

**HRA and Health and Care Research Wales (HCRW) Approval Letter**

| | |
|---|---|
| **Study title:** | **Early warning scores in individuals with cardiac disease: a mixed-methods study** |
| **IRAS project ID:** | **277254** |
| **REC reference:** | **20/PR/0286** |
| **Sponsor** | **UCL** |

I am pleased to confirm that **HRA and Health and Care Research Wales (HCRW) Approval** has been given for the above referenced study, on the basis described in the application form, protocol, supporting documentation and any clarifications received. You should not expect to receive anything further relating to this application.

Please now work with participating NHS organisations to confirm capacity and capability, in line with the instructions provided in the "Information to support study set up" section towards the end of this letter.

**How should I work with participating NHS/HSC organisations in Northern Ireland and Scotland?**

HRA and HCRW Approval does not apply to NHS/HSC organisations within Northern Ireland and Scotland.

If you indicated in your IRAS form that you do have participating organisations in either of these devolved administrations, the final document set and the study wide governance report (including this letter) have been sent to the coordinating centre of each participating nation. The relevant national coordinating function/s will contact you as appropriate.

Please see IRAS Help for information on working with NHS/HSC organisations in Northern Ireland and Scotland.

**How should I work with participating non-NHS organisations?**
HRA and HCRW Approval does not apply to non-NHS organisations. You should work with your non-NHS organisations to obtain local agreement in accordance with their procedures.

**What are my notification responsibilities during the study?**

The standard conditions document "*After Ethical Review – guidance for sponsors and investigators*", issued with your REC favourable opinion, gives detailed guidance on reporting expectations for studies, including:

- Registration of research
- Notifying amendments
- Notifying the end of the study

The HRA website also provides guidance on these topics, and is updated in the light of changes in reporting expectations or procedures.

**Who should I contact for further information?**
Please do not hesitate to contact me for assistance with this application. My contact details are below.

Your IRAS project ID is **277254**. Please quote this on all correspondence.

Yours sincerely,
Kathryn Davies

Approvals Specialist

Email: approvals@hra.nhs.uk

*Copy to:* *Ms Suzanne Emerton*

Appendix 3. Systematic review search strategy for MEDLINE

1- EWS OR early warning score* OR early warning system* OR rapid response system* OR MEWS OR modified early warning score* OR modified early warning system* OR news OR national early warning score OR news2 OR national early warning score 2 OR ( track and trigger system* )
2- (MH "Intensive Care Units")
3- ICU OR intensive care unit* OR critical care unit* OR critical care
4- 2 OR 3
5- 1 AND 4
6- (MH "Nervous System Diseases")
7- neurological disorder* OR neurological disease OR neurological condition*
8- 6 OR 7
9- 1 AND 8
10- MH "Cardiovascular Diseases") OR (MH "Cardiology")
11- (MH "Thoracic Surgery")
12- cardiovascular disease* OR cardiovascular disorder* OR heart disease* OR cardiology* OR cardiac surgery OR thoracic surgery
13- 10 OR 11 OR 12
14- 1 AND 13
15- (MH "Musculoskeletal Diseases") OR (MH "Orthopedics")
16- orthopedic disease* OR orthopedic surgery
17- 15 OR 16
18- 1 AND 17
19- (MH "Kidney Diseases, Cystic") OR (MH "Kidney Failure, Chronic") OR (MH "Polycystic Kidney Diseases") OR (MH "Renal Insufficiency, Chronic")
20- renal disease* OR renal failure OR kidney disease*
21- 19 OR 20
22- 1 AND 21
23- (MH "Hematologic Diseases")
24- hematologic disorder* OR hematologic disease* OR hematology
25- 23 OR 24
26- 1 AND 25
27- (MH "Respiratory Tract Diseases")
28- respiratory disease* OR respiratory disorder*
29- 27 OR 28
30- 1 AND 29
31- (MH "Gastroenterology")
32- gastrointestinal disorder* OR gastrointestinal disease* OR gastroenterology OR hepatology
33- 31 OR 32
34- 1 AND 33
35- (MH "Medical Oncology") OR (MH "Surgical Oncology")
36- oncology OR cancer OR chemotherapy
37- 35 OR 36
38- 1 AND 37
39- (MH "Wounds and Injuries") OR (MH "Emergency Medicine")
40- emergency department* OR emergency OR emergency room* OR trauma*
41- 39 OR 40
42- 1 AND 41
43- (MH "Sepsis") OR (MH "Infection")
44- INFECTION* OR INFECTIOUS DISEASE* OR SEPSIS

45- 43 OR 44
46- 1 AND 45
47- (MH "Obstetrics")
48- (obstetrics and gynecology) OR OBSTETRIC*
49- 47 OR 48
50- 1 AND 49
51- (MH "Allergy and Immunology")
52- immunological disease* OR immunological disorder*
53- 51 OR 52
54- 1 AND 53
55- (MH "Internal Medicine")
56- medical ward*
57- 55 OR 56
58- 1 AND 57
59- (MH "General Surgery")
60- surgical ward*
61- 59 OR 60
62- 1 AND 61
63- 5 OR 9 OR 14 OR 18 OR 22 OR 26 OR 30 OR 34 OR 38 OR 42 OR 46 OR 50 OR 54 OR 58 OR 62

Appendix 4. Systematic review search strategy for CINAHL

1- EWS OR early warning score* OR early warning system* OR rapid response system* OR MEWS OR modified early warning score* OR modified early warning system* OR news OR national early warning score OR news2 OR national early warning score 2 OR (track and trigger system* )
2- (MH "Intensive Care Units")
3- ICU OR intensive care unit* OR critical care unit* OR critical care
4- 2 OR 3
5- 1 AND 4
6- (MH "Nervous System Diseases")
7- neurological disorder* OR neurological disease OR neurological condition*
8- 6 OR 7
9- 1 AND 8
10- (MH "Heart Diseases") OR (MH "Cardiovascular Diseases")
11- (MH "Heart Surgery")
12- cardiovascular disease* OR cardiovascular disorder* OR heart disease* OR cardiology* OR cardiac surgery OR thoracic surgery
13- 10 OR 11 OR 12
14- 1 AND 13
15- (MH "Orthopaedic Surgery") OR (MH "Musculoskeletal Diseases")
16- orthopaedic disease* OR orthopaedic surgery
17- 15 OR 16
18- 1 AND 17
19- (MH "Kidney, Cystic") OR (MH "Kidney Diseases")
20- renal disease* OR renal failure OR kidney disease*
21- 19 OR 20
22- 1 AND 21
23- (MH "Hematologic Diseases")
24- (MH "Lymphatic Diseases")
25- hematologic disorder* OR hematologic disease* OR haematology
26- 23 OR 24 O 25
27- 1 AND 26
28- (MH "Respiratory Tract Diseases")
29- respiratory disease* OR respiratory disorder*
30- 28 OR 29
31- 1 AND 30
32- (MH "Digestive System Diseases")
33- gastrointestinal disorder* OR gastrointestinal disease* OR gastroenterology OR hepatology
34- 32 OR 33
35- 1 AND 34
36- (MH "Cancer Patients") OR (MH "Oncology")
37- oncology OR cancer OR chemotherapy
38- 36 OR 37
39- 1 AND 38
40- (MH "Wounds and Injuries") OR (MH "Trauma")
41- emergency department* OR emergency OR emergency room* OR trauma*
42- 40 OR 41
43- 1 AND 42
44- (MH "Infection")
45- INFECTION* OR INFECTIOUS DISEASE* OR SEPSIS
46- 44 OR 45
47- 1 AND 46
48- (MH "Obstetric Emergencies") OR (MH "Obstetric Patients")
49- ( obstetrics and gynaecology ) OR OBSTETRIC*
50- 48 OR 49
51- 1 AND 50

52- (MH "Internal Medicine")
53- (MH "Allergy and Immunology")
54- medical ward
55- immunological disease* OR immunological disorder*
56- 52 OR 53 OR 54 OR 55
57- 1 AND 56
58- (MH "Surgical Patients")
59- surgical ward*
60- 58 OR 59
61- 1 AND 60
62- 5 OR 9 OR 14 OR 18 OR 22 OR 27 OR 31 OR 35 OR 39 OR 43 OR 47 OR 51 OR 57 OR 61

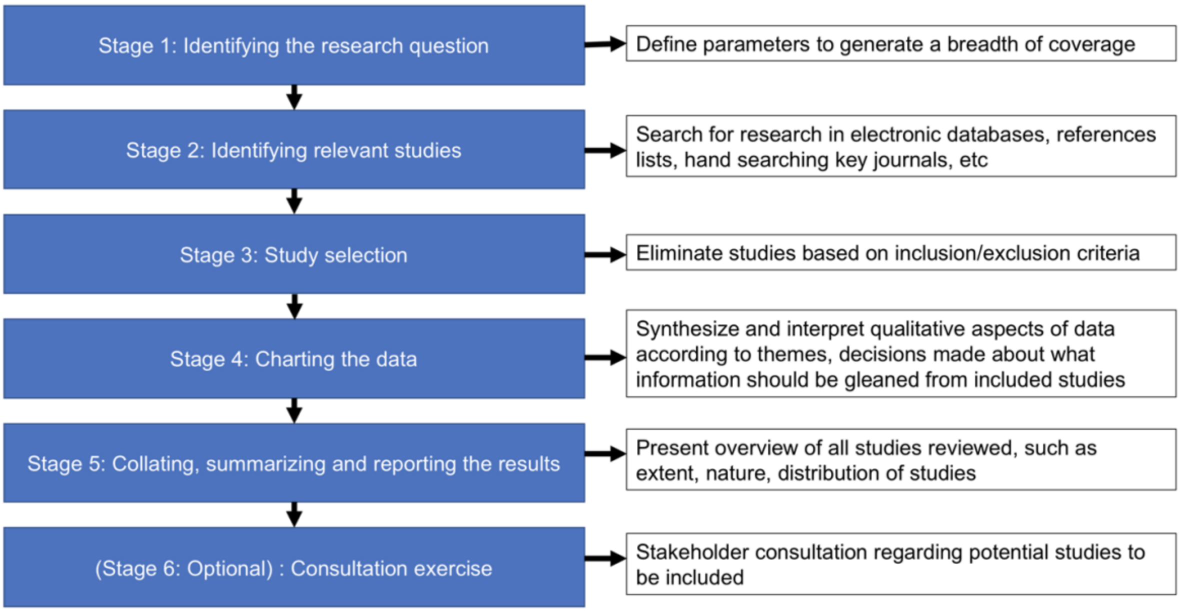
Appendix 5. Patients' subgroups in systematic review

1- Cardiology patients
2- Neurology patients
3- Orthopaedic patients
4- Renal patients
5- Haematology patients
6- Respiratory patients
7- Gastroenterology patients
8- Oncology patients
9- Emergency patients
10- Infection patients
11- Medical patients
12- Surgical patients
13- Intensive care patients

Appendix 6. STARD checklist.

| Section & Topic | No | Item | Reported on page # |
|---|---|---|---|
| **TITLE OR ABSTRACT** | | | |
| | **1** | Identification as a study of diagnostic accuracy using at least one measure of accuracy (such as sensitivity, specificity, predictive values, or AUC) | |
| **ABSTRACT** | | | |
| | **2** | Structured summary of study design, methods, results, and conclusions (for specific guidance, see STARD for Abstracts) | |
| **INTRODUCTION** | | | |
| | **3** | Scientific and clinical background, including the intended use and clinical role of the index test | |
| | **4** | Study objectives and hypotheses | |
| **METHODS** | | | |
| *Study design* | **5** | Whether data collection was planned before the index test and reference standard were performed (prospective study) or after (retrospective study) | |
| *Participants* | **6** | Eligibility criteria | |
| | **7** | On what basis potentially eligible participants were identified (such as symptoms, results from previous tests, inclusion in registry) | |
| | **8** | Where and when potentially eligible participants were identified (setting, location and dates) | |
| | **9** | Whether participants formed a consecutive, random or convenience series | |
| *Test methods* | **10a** | Index test, in sufficient detail to allow replication | |
| | **10b** | Reference standard, in sufficient detail to allow replication | |
| | **11** | Rationale for choosing the reference standard (if alternatives exist) | |
| | **12a** | Definition of and rationale for test positivity cut-offs or result categories of the index test, distinguishing pre-specified from exploratory | |
| | **12b** | Definition of and rationale for test positivity cut-offs or result categories of the reference standard, distinguishing pre-specified from exploratory | |
| | **13a** | Whether clinical information and reference standard results were available to the performers/readers of the index test | |
| | **13b** | Whether clinical information and index test results were available to the assessors of the reference standard | |
| *Analysis* | **14** | Methods for estimating or comparing measures of diagnostic accuracy | |
| | **15** | How indeterminate index test or reference standard results were handled | |
| | **16** | How missing data on the index test and reference standard were handled | |
| | **17** | Any analyses of variability in diagnostic accuracy, distinguishing pre-specified from exploratory | |
| | **18** | Intended sample size and how it was determined | |
| **RESULTS** | | | |
| *Participants* | **19** | Flow of participants, using a diagram | |
| | **20** | Baseline demographic and clinical characteristics of participants | |
| | **21a** | Distribution of severity of disease in those with the target condition | |
| | **21b** | Distribution of alternative diagnoses in those without the target condition | |
| | **22** | Time interval and any clinical interventions between index test and reference standard | |
| *Test results* | **23** | Cross tabulation of the index test results (or their distribution) by the results of the reference standard | |
| | **24** | Estimates of diagnostic accuracy and their precision (such as 95% confidence intervals) | |
| | **25** | Any adverse events from performing the index test or the reference standard | |
| **DISCUSSION** | | | |
| | **26** | Study limitations, including sources of potential bias, statistical uncertainty, and generalisability | |
| | **27** | Implications for practice, including the intended use and clinical role of the index test | |
| **OTHER INFORMATION** | | | |
| | **28** | Registration number and name of registry | |
| | **29** | Where the full study protocol can be accessed | |
| | **30** | Sources of funding and other support; role of funders | |

Appendix 7. Arksey and O'Malley framework.



Appendix 8. Scoping review search terms

A. *Cochrane*

1- ''Escalation of care''or''rapid response''or''calling for help''or''patient deteriorat*''or “medical emergency team"
2- "early warning score"or"national early warning score “or ews or news or news2
3- covid or ''corona virus'' or covid19
4- 1 and 2 and 3 (0 results)
5- 1 and 3 (18)
6- limited to 2011-2021 (10)i/ reviews (3)
7- 1 and 2 (24)
8- limited to 2011-2021 (20)/ reviews (6)

B. *Medline And Cinahl*

1- ((((("escalation of care") or ("rapid response")) or ("critical care outreach")) or ("calling for help")) or ("patient deteriorat*")) or ("medical emergency team")
2- (((("early warning score") or ("national early warning score")) or (ews)) or (news)) or (news2)
3- ((covid) or (covid19)) or ("corona virus")
4- 1 and 2 (285)
5- + full text + 2011-2021 +English language only: (239 studies)
6- 1 and 3 (448)
7- +full text + 2011-2021 +English language only: (437 studies)
8- 1 and 2 and 3 (13)
9- +full text +2011-2021+english language only: (13 studies)

C. *Emcare*

1- ''Escalation of care''or''rapid response''or''calling for help''or''patient deteriorat*''or “medical emergency team"
1- "Early warning score"or"national early warning score “or ews or news or news2
2- covid or ''corona virus'' or covid19
3- *limited to 2011-2021*
4- 1 and 2 and 3 (6)
5- 1 and 2 (174)
6- 1 and 3

Appendix 9. Scoping review data synthesis information

key information to chart for each paper:

- Author(s)
- Year of publication
- Origin/country of origin (where the study was published or conducted)
- Aims/purpose
- Study population and sample size (if applicable)
- Methodology/methods
- Intervention type/duration, comparator, outcome measures (if applicable)
- Key findings that relate to the scoping review question/s

Appendix 10. CASP tool for Scoping review critical appraisal

| Study ID | A1. Are the results valid: 1. Was there a clear statement of the aims of the research? | A1. 2. Is a qualitative methodology appropriate? | A2. Is it worth continuing: 3. Was the research design appropriate to address the aims of the research? | A2. 4. Was the recruitment strategy appropriate to the aims of the research? | A2. 5. Was the data collected in a way that addressed the research issue? | A2. 6. Has the relationship between researcher and participants been adequately considered? | B. What are the results: 7. Have ethical issues been taken into consideration? | B. 8. Was the data analysis sufficiently rigorous? | B. 9. Is there a clear statement of findings? | C: Will the results help locally: 10. How valuable is the research? |
|---|---|---|---|---|---|---|---|---|---|---|
| Anton 2021 | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Mitchell 2021 | Yes | Yes | Yes | Can't tell | Yes | Yes | Yes | Yes | Yes | Yes |
| Bardi 2021 | Yes | Yes | Yes | Can't tell | Can't tell | Yes | Non | Can't tell | Yes | Yes |

Appendix 11.a

Interview domains and questions

Domains: (i)Condition (ii)Value preposition, (iii)Adopters, (iv)Organisation (v)Adaptation over time

(i)Experience of implementing NEWS2 in the clinical setting:

- - Have you used NEWS2 for escalation of care while caring for patients? How common is it to receive an alarm for a patient in need for critical care?
- - How do you respond to an alarm by NEWS2? (ii)The value of NEWS2

- - How valuable is NEWS2 as a tool presented to you by the developers who implemented it in EHRs?
- - How Simple was NEWS2 understanding and use?
- - Does it bring you the value it was supposed to? Did it improve the efficacy and safety of patients?

(iii)The adoption to utilizing NEWS2

- - How did this implementation change your practice in escalating care?
- - How did this change affect patients care and safety?

(iv) The organisational capacity

- How supported is early warning scores in the organisation? Do you think the hospital systems is ready for utilizing NEWS2 digitally?

(iv)Adapting over time:

- - How resilient is the organisation and staff to adapt to the escalation of care using NEWS2?
- - Have you faced issues around the process of escalation using NEWS2 and technology? How much scope is there to resolve that may arise over time?

Appendix 11.b

Survey domains and questions

Domains: (i) Condition, (ii)Technology, (iii)Wider system

1- The information generated by NEWS2; including score and alarms; are easy to understand
2- The implementation of digital recording of NEWS2 in EHRs helped in recording patients' parameters and NEWS2
3- The implementation of digital recording of NEWS2 in EHRs helped in improving the escalation of care when needed
4- The presented model of NEWS2 in the EHRs is simple and practical. (EHR Electronic health records)/
5- There is a clear policy on the application of NEWS2 in patients care in your hospital

| Answer: Strongly agree Agree. Neither agree nor disagree. Disagree strongly disagree |
|---|

6- . How often patients have complex conditions. i.e., comorbidities, metabolically unstable, or poorly understood condition (Excluding Covid)
7- How often patients cared for were diagnosed with Covid-19
8- How often patients have socioeconomic factors i.e. family, income, house condition, education, affecting their prognosis
9- The need for help in understanding NEWS2 and who to refer to

| Answer: | Often. | Occasionally. | Sometimes. | Almost never. | I don't know |
|---|---|---|---|---|---|

10- Attending networking session with regard to NEWS2 and routine monitoring i.e. updates, or team meetings.

| Answer: internally in the department - Organised hospital sessions - Informal discussions with colleagues - Yes, I checked the materials we have or online resources. - I haven't participated or attended any updates or networking sessions |
|---|

11- Training offered to understand and utilise NEWS2.

| Answer: Informatics staff/ tech experts/superusers Manuals and resources online. Orientation by ward staff or manager Self- practice |
|---|

Appendix 12. Dashboard evaluation interview questions

Introduction

Deteriorating dashboard is an EHR-integrated tool to audit the completion and percentage of staff recording of the assessment when patients deteriorating. Including vital signs, patients with high NEWS2, sepsis assessment by nurses and doctors, and sepsis 6 prescribing.

We would like to evaluate this tool as a QI project. This is the first cycle.

We are assessing the performance in numbers as showing in the dashboard as shown in historical view and interviewing some staff who utilise it to give us their opinion.

we hope after this assessment we will conduct any improvement needed, then re-evaluate in a few months.

Questions:

1. What is your job role?
2. How do you utilise the dashboard in your work?
3. Was there a training or orientation for you to use the dashboard? how was it?
4. Is there an induction or training for current or future users?
5. What was your expectation of the dashboard? Were they met?
6. How beneficial is the dashboard for the purpose it's designed for? How valuable?
7. The dashboard is meant to audit decline or improvement in assessment, if detected, how well was this handled or coordinated?
8. Do you notice an improvement that took place? How or where?
9. If so, why do you think this change happened?
10. Did you notice any deterioration in the performance of staff?
11. If so, why do you think this happened?
12. Out of the data you got from the dashboard, is there any plan for improvement in staff practice or workflow strategy as a result of the dashboard?
13. -What are the downsides or negative aspects of the dashboard that needs to be improved?
14. -Is there anything that you would like to add to the dashboard?
15. If so, what would it be?

Appendix 13. Risk of bias assessment results using PROBAST tool.

| Study | Validation | Quality | |
|---|---|---|---|
| | | Risk of bias | Applicability |
| Kellett, 2012 (S1) | External | Low | Low |
| Kim, 2017 (S2) | External | Unclear | Unclear |
| Bozkurt, 2015 (S3) | External | High | High |
| Seak, 2017 (S4) | External | High | High |
| Hu, 2016 (S5) | Internal | Unclear | High |
| Liljehult, 2016 (S6) | External | Unclear | High |
| Mulligan, 2010 (S7) | External | High | High |
| Cooksley, 2012 (S8) | External | Unclear | Unclear |
| Vaughn, 2018 (S9) | External | High | High |
| Young, 2014 (S10) | External | High | High |
| von Lilienfeld-Toal, 2007 (S11) | External | Unclear | High |
| Pedersen, 2018 (S12) | External and Internal | Low | Low |
| Forster, 2018 (S13) | External | Low | Low |
| Pimentel, 2018 (S14) | External | Low | Unclear |
| Sbiti-rohr, 2016 (S15) | | Unclear | High |
| Brabrand, 2017 (S16) | External | Unclear | Unclear |
| Jo, 2016 (S17) | External | High | High |
| Barlow, 2007 (S18) | External | Low | Unclear |
| Bilben, 2016 (S19) | External | Unclear | Unclear |
| Delahanty, 2019 (S20) | Internal | Low | Low |
| Redfern, 2018 (S21) | External | Low | Low |
| Churpek, 2017 (S22) | External | High | High |
| Faisal, 2019 (S23) | External | Low | Low |
| Churpek 2017 (S24) | External | Low | Low |
| Henry, 2015 (S25) | Internal | Low | Low |
| Brink 2019 (S26) | External | Unclear | Unclear |
| De Groot, 2014 (S27) | External | Unclear | Unclear |

| Study | Validation | Quality | |
|---|---|---|---|
| | | Risk of bias | Applicability |
| Corfield, 2014 (S28) | External | Low | Low |
| Goulden, 2018 (S29) | External | Unclear | Unclear |
| Khwannimit, 2019 (S30) | External | Unclear | Unclear |
| Ghanem-Zoubi, 2011 (S31) | External | Unclear | Unclear |
| Saeed, 2019 (S32) | Internal | Unclear | Unclear |
| Innocenti, 2018 (S33) | External | Unclear | Unclear |
| Camm, 2018 (S34) | External | Unclear | Unclear |
| Tirotta, 2017 (S35) | External | Unclear | Unclear |
| Pong, 2019 (S36) | Internal | Unclear | Unclear |
| Prabhakar, 2019 (S37) | Internal | Unclear | Unclear |
| Martino, 2018 (S38) | External | Unclear | Unclear |
| Vorwerk, 2009 (S39) | External | Unclear | Unclear |
| Qin, 2017 (S40) | External | Unclear | Unclear |
| Schmedding, 2019 (S41) | External | Unclear | Unclear |
| Albur, 2016 (S42) | External | Unclear | Unclear |
| Cildir, 2013 (S43) | External | Unclear | Unclear |
| Chiew, 2019 (S44) | External | Unclear | Unclear |
| Samsudin, 2018 (S45) | Internal | Unclear | Unclear |
| Chang, 2018 (S46) | External | Unclear | High |
| Geier, 2013 (S47) | External | Unclear | Unclear |
| Asiimwe, 2015 (S48) | Internal | Unclear | Unclear |
| Hung, 2017 (S49) | External | Unclear | High |
| Garcea, 2006 (S50) | External | Unclear | High |
| Yoo, 2015 (S51) | External | Unclear | Unclear |
| Siddiqui, 2017 (S52) | External | Unclear | Unclear |
| Calvert, 2016 (S53) | Internal | Low | Unclear |
| Awad, 2017 (S54) | Internal | Low | Low |
| Reini, 2012 (S55) | External | Unclear | Unclear |

| Study | Validation | Quality | |
|---|---|---|---|
| | | Risk of bias | Applicability |
| Chen, 2019 (S56) | External | Unclear | High |
| Baker, 2015 (S57) | External | Unclear | Unclear |
| Gök, 2019 (S58) | External | Low | Unclear |
| Moseson, 2014 (S59) | External | Unclear | Unclear |
| Jo, 2013 (S60) | External | Unclear | Unclear |
| Kwon, 2018 (S61) | External and Internal | Unclear | Unclear |
| Usman, 2019 (S62) | External | High | High |
| Jang, 2019 (S63) | Internal | Low | Low |
| Wei, 2019 (S64) | External | High | High |
| Lee, 2019 (S65) | Internal | Low | Low |
| Singer, 2017 (S66) | External | Unclear | Unclear |
| Eick, 2015 (S67) | External | Unclear | Unclear |
| Bulut, 2014 (S68) | External | Unclear | Unclear |
| Kivipuro, 2018 (S69) | External | Unclear | Unclear |
| Eckart, 2019 (S70) | External | Unclear | Unclear |
| Ho, 2013 (S71) | External | Unclear | Unclear |
| Skitch, 2018 (S72) | External | Unclear | Unclear |
| Liu, 2014 (S73) | Internal | Low | Unclear |
| Dundar, 2016 (S74) | External | Unclear | High |
| Yuan, 2018 (S75) | External | Unclear | High |
| Naidoo, 2014 (S76) | External | Unclear | Unclear |
| Liu, 2015 (S77) | External | Low | Unclear |
| So, 2015 (S78) | External | Unclear | Unclear |
| Dundar, 2019 (S79) | External | Unclear | High |
| Lam, 2006 (S80) | External | Unclear | Unclear |
| Xie, 2018 (S81) | External | Unclear | Unclear |
| Cattermole, 2009 (S82) | Internal | Unclear | Unclear |
| Heitz, 2010 (S83) | External | High | Unclear |

| Study | Validation | Quality | |
|---|---|---|---|
| | | Risk of bias | Applicability |
| Srivilaithon, 2019 (S84) | Internal | Unclear | Unclear |
| Cattermole, 2014 (S85) | External | Unclear | Unclear |
| Najafi, 2018 (S86) | External | Unclear | High |
| Bartkowiak, 2019 (S87) | External | Unclear | Unclear |
| Kovacs, 2016 (S88) | External | Low | Low |
| Plate, 2018 (S89) | External | Low | Low |
| Sarani, 2012 (S90) | External | Low | Low |
| Hollis, 2016 (S91) | External | Unclear | Unclear |
| Gardner-Thorpe 2006 (S92) | External | Unclear | Unclear |
| Garcea, 2010 (S93) | External | High | High |
| Cuthbertson, 2007 (S94) | External | High | Unclear |
| Prytherch, 2010 (S95) | Internal | Low | Low |
| Smith, 2013 (S96) | External | Low | Low |
| Rasmussen, 2018 (S97) | External | Unclear | Unclear |
| Ghosh, 2018 (S98) | Internal | Low | Low |
| Duckitt, 2007 (S99) | Internal | Low | Low |
| Colombo, 2017 (S100) | External | High | High |
| Abbot, 2016 (S101) | External | High | High |
| Wheeler, 2013 (S102) | External | Unclear | Unclear |
| Graziadio, 2019 (S103) | External | Unclear | Unclear |

Appendix 14. Early warning scores used in studies of patients' sub-populations and settings

| Study | EWS name | HR | SBP | RR | Temp | APVU/ LOC | O2 Sat | Supp O2 | Urine OP | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| Kellett, 2012 (S1) | VIEWS | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ | ✗ |
| Seak, 2017 (S4) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Bozkurt, 2015 (S3) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Kim, 2017 (S2) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Hu, 2016 (S5) | VIEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Mulligan, 2010 (S7) | EWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Liljehult, 2016 (S6) | EWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Cooksley, 2012 (S8) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ |
| Cooksley, 2012 (S8) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Vaughn, 2018 (S9) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Von Lilienfeld-Toal, 2007 (S11) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Young, 2014 (S10) | MEWS | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ | ✓ |
| Barlow, 2007 (S18) | EWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ |
| Bilben, 2016 (S19) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Brabrand, 2017 (S16) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Forster, 2018 (S13) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ |
| Jo, 2016 (S16) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Pedersen, 2018 (S12) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Pimentel, 2018 (S14) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Pimentel, 2018 (S14) | NEWS2 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ |
| Sbiti-rohr, 2016 (S15) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Henry, 2015 (S25) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Innocenti, 2018 (S33) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Garcea, 2006 (S50) | EWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ |
| Qin, 2017 (S40) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |

| Study | EWS name | HR | SBP | RR | Temp | APVU/ LOC | O2 Sat | Supp O2 | Urine OP | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| Albur, 2016 (S42) | EWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ |
| Asiimwe, 2015 (S48) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Brink 2019 (S26) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Camm, 2018 (S34) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Chang, 2018 (S46) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Chiew, 2019 (S44) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Chiew, 2019 (S44) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Churpek, 2017 (S22) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Churpek, 2017 (S22) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Churpek, 2017 (S24) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Churpek, 2017 (S24) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Cildir, 2013 (S43) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Corfield, 2014 (S28) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| De Groot, 2014 (S27) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| De Groot, 2014 (S27) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Delahanty, 2019 (S20) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Delahanty, 2019 (S20) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Faisal, 2019 (S23) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Geier, 2013 (S47) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Ghanem-Zoubi, 2011 (S31) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Goulden, 2018 (S29) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Hung, 2017 (S49) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Khwannimit, 2019 (S30) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Khwannimit, 2019 (S30) | SOS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ |
| Khwannimit, 2019 (S30) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Martino, 2018 (S30) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |

| Study | EWS name | HR | SBP | RR | Temp | APVU/ LOC | O2 Sat | Supp O2 | Urine OP | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| Pong, 2019 (S36) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Pong, 2019 (S36) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Prabhakar, 2019 (S37) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Prabhakar, 2019 (S37) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Redfern, 2018 (S21) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Saeed, 2019 (S32) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Samsudin, 2018 (S45) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Samsudin, 2018 (S45) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Schmedding, 2019 (S41) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Siddiqui, 2017 (S52) | EWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ |
| Tirotta, 2017 (S35) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Vorwerk, 2009 (S39) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Yoo, 2015 (S51) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Awad, 2017 (S54) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Baker, 2015 (S57) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Calvert 2016 (S53) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Gök, 2019 (S58) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Chen, 2019 (S56) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Jo, 2013 (S60) | HOTEL | ✗ | ✓ | ✗ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ |
| Jo, 2013 (S60) | VIEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Moseson, 2014 (S59) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Reini, 2012 (S55) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Bulut, 2014 (S68) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Cattermole, 2009 (S82) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Cattermole, 2014 (S85) | WORTHING | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ |
| Cattermole, 2014 (S85) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Cattermole, 2014 (S85) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |

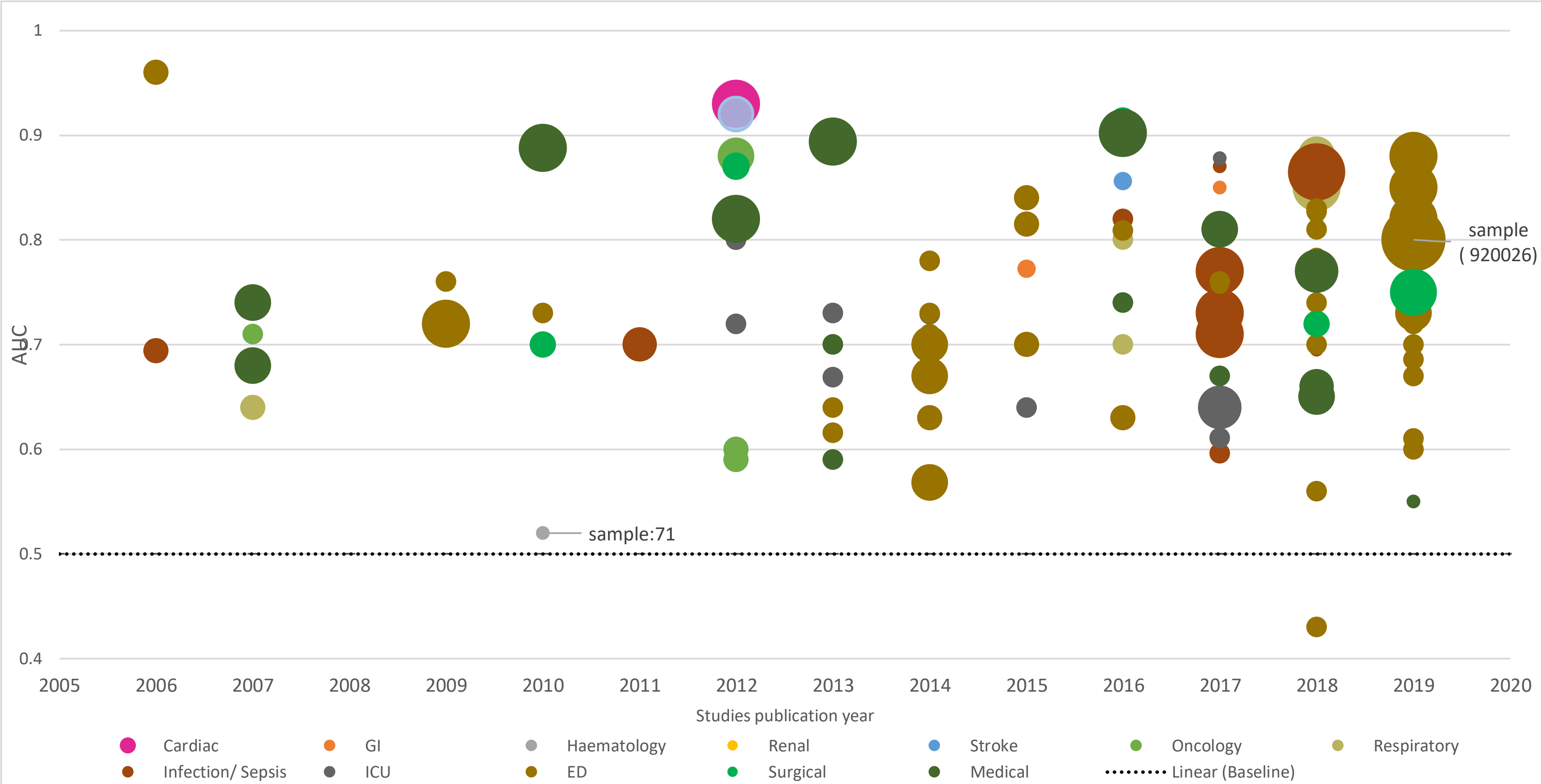
| Study | EWS name | HR | SBP | RR | Temp | APVU/ LOC | O2 Sat | Supp O2 | Urine OP | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| Heitz, 2010 (S83) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Dundar, 2016 (S74) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Dundar, 2016 (S74) | VIEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Dundar, 2019 (S79) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Eckart, 2019 (S70) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Eick, 2015 (S67) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Liu, 2015 (S77) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Liu, 2015 (S77) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Ho, 2013 (S71) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Jang, 2019 (S63) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Kivipuro, 2018 (S69) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Kwon, 2018 (S61) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Liu, 2014 (S73) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Lee, 2019 (S65) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Lee, 2019 (S65) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Lee, 2019 (S65) | TREWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✓ |
| Naidoo, 2014 (S76) | TREWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✓ |
| Najafi, 2018 (S86) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Singer, 2017 (S66) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Skitch, 2018 (S72) | HEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Skitch, 2018 (S72) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| So, 2015 (S78) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Srivilaithon, 2019 (S84) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Lam, 2006 (S80) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Usman, 2019 (S62) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Yuan, 2018 (S75) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Yuan, 2018 (S75) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |

| Study | EWS name | HR | SBP | RR | Temp | APVU/ LOC | O2 Sat | Supp O2 | Urine OP | Other |
|---|---|---|---|---|---|---|---|---|---|---|
| Wei, 2019 (S64) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Xie, 2018 (S81) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Bartkowiak, 2019 (S87) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Bartkowiak, 2019 (S87) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ |
| Cuthbertson, 2007 (S94) | EWS | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| Cuthbertson, 2007 (S94) | MEWS | ✓ | ✓ | ✓ | ✓ | ✗ | ✓ | ✗ | ✗ | ✗ |
| Garcea, 2010 (S50) | EWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ |
| Gardner-Thorpe 2006 (S92) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ |
| Hollis, 2016 (S91) | EWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ |
| Kovacs, 2016 (S88) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Plate, 2018 (S89) | VIEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Sarani, 2012 (S90) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Abbott, 2016 (S101) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Duckitt, 2007 (S99) | WPC | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ |
| Duckitt, 2007 (S99) | EWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Colombo, 2017 (S100) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Ghosh, 2018 (S98) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Ghosh, 2018 (S98) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |
| Graziadio, 2019 (S103) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Prytherch, 2010 (S95) | VIEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Rasmussen, 2018 (S97) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Smith, 2013 (S96) | NEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ |
| Wheeler, 2013 (S102) | Hotel | ✓ | ✗ | ✓ | ✗ | ✓ | ✓ | ✗ | ✗ | ✓ |
| Wheeler, 2013 (S102) | MEWS | ✓ | ✓ | ✓ | ✓ | ✓ | ✗ | ✗ | ✗ | ✗ |

| Total | 133 |
|---|---|

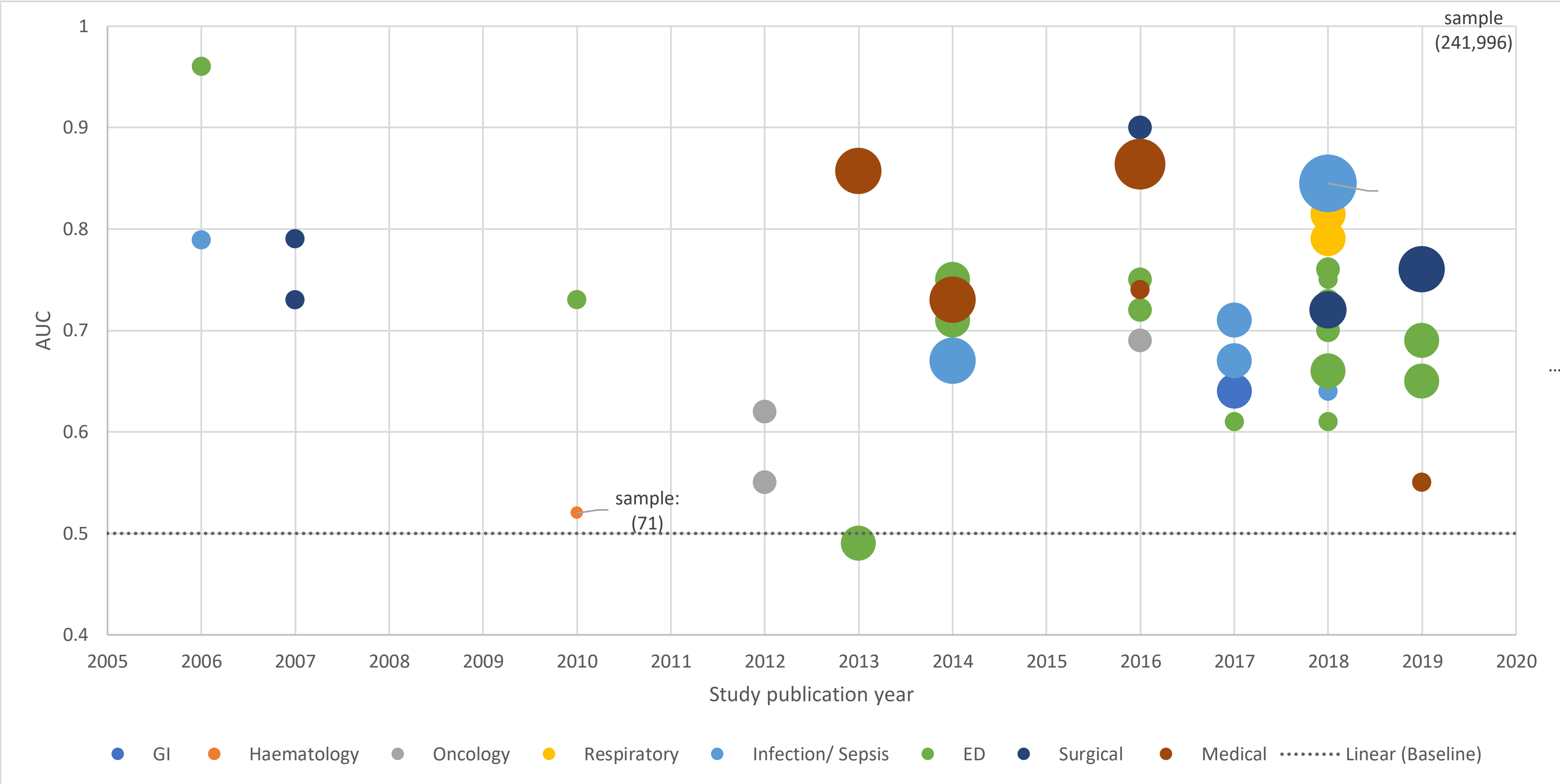
Abbreviations: HR: heart rate, SBP: systolic blood pressure, RR: respiratory rate, Temp: temperature, AVPU/LOC: alert, verbal response, physical response, unresponsive score or level of consciousness, O2 sat: Oxygen saturation, Supp O2: supplemental oxygen, Urine OP: urine output, Other: other parameters, i.e., blood biomarkers. VIEWS: Vital pack early warning score, MEWS: modified early warning score, EWS: early warning score, NEWS: national early warning score, NEWS2: national early warning score 2, SOS: Search Out Severity score, Worthing: Worthing physiological scoring system, HOTEL: Hypotension, Oxygen saturation, Temperature, ECG abnormality, Loss of independence score, TREWS: Triage in Emergency department Early Warning Score, HEWS: Hamilton early warning score.

Appendix 15. Predictive performance of early warning scores for mortality in studies from 2005 to 2020 for different disease subgroups and clinical settings



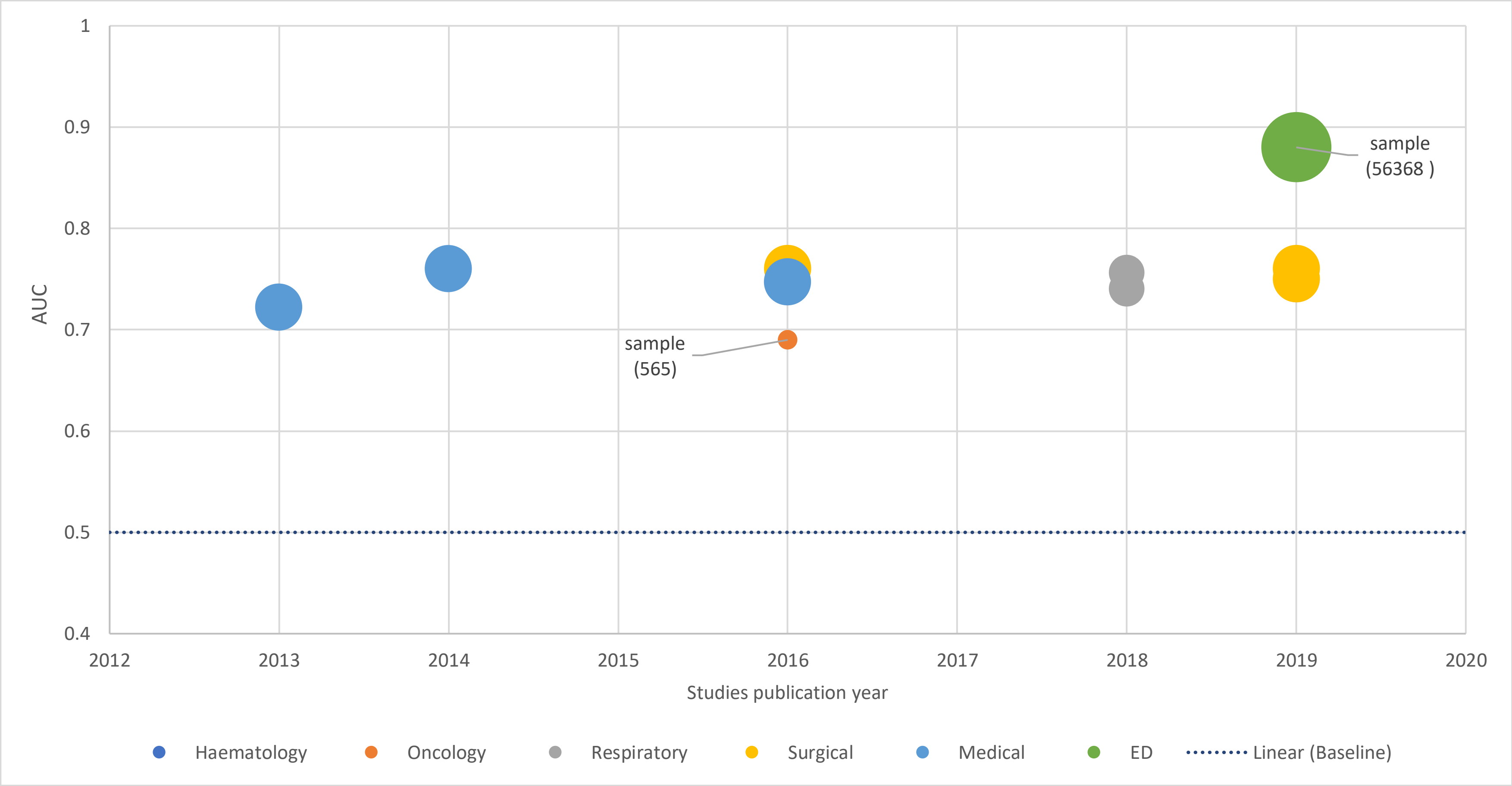

Abbreviations: AUC: Area Under the Curve; ED: Emergency Department; GI: Gastrointestinal diseases; ICU: Intensive Care Unit. Note: Bubbles sizes represents the sample size in each study.

Appendix 16. Predictive performance of early warning scores for intensive care admission in studies from 2005 to 2020 for different disease subgroups and clinical settings




Abbreviations: AUC: Area Under the Curve; ED: Emergency Department; GI: Gastrointestinal diseases. Note: Bubbles sizes represents the sample size in each study.

Appendix 17. Predictive performance of early warning scores for cardiac arrest in studies from 2012 to 2020 for different disease subgroups and clinical settings




Abbreviations: AUC: Area Under the Curve; ED: Emergency Department; GI: Gastrointestinal diseases. Note: Bubbles sizes represents the sample size in each study.

Appendix 18. EWS documentation Status Summary for all observations taken in each hospital in Barts Health Trust.

| Site Summary | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sep-19 | | | Oct-19 | | | Nov-19 | | | Dec-19 | | | Jan-20 | | |
| Location | Complete | Incomplete | % Complete Status | Complete | Incomplete | % Complete Status | Complete | Incomplete | % Complete Status | Complete | Incomplete | % Complete Status | Complete | Incomplete | % Complete Status |
| Newham University Hospital | 872 | 229 | 79% | 1147 | 319 | 78% | 9995 | 6493 | 61% | 32418 | 16017 | 67% | 19127 | 8387 | 70% |
| Royal London Hospital | 9679 | 1917 | 83% | 13498 | 3148 | 81% | 57585 | 19174 | 75% | 73852 | 21654 | 77% | 41128 | 11012 | 79% |
| St Bartholomew's Hospital | 6047 | 961 | 86% | 10213 | 1521 | 87% | 15747 | 2859 | 85% | 27804 | 5486 | 84% | 15668 | 2249 | 87% |
| Whipps Cross Hospital | 3308 | 241 | 93% | 33882 | 6835 | 83% | 62051 | 9231 | 87% | 66052 | 7860 | 89% | 37593 | 3858 | 91% |
| **Grand Total** | **19906** | **3348** | **86%** | **58740** | **11823** | **83%** | **145378** | **37757** | **79%** | **200126** | **51017** | **80%** | **113516** | **25506** | 82% |

Appendix 19. Dashboard development stages

1- Developing began with initially creating a simple Vitals data table
2- A broader generation of vitals data is added.
3- Transforming the table into a thorough and more robust data visualisation of NEWS2, assessment and escalation of deteriorating patients via Qlik Sins.
4- Data of around 1.2 million recordings of 110,000 admissions from August to October 2020 were extracted from the Datawarehouse of Barts trust hospitals; pulled from EHR (Cerner Millennium®).
5- The dashboard metrics are indicators of the status of patients who needed escalation of care, such as vital signs and sepsis scoring and time of entry and by whom.
6- Post-development, data are pulled continuously until the present time. Dashboards were produced using SQL and final views were developed using a QVD table in the Qlik Sense® Server.
7- Validation of data was done by NK by evaluating 100 metrics accuracy and independently screened by NK and a quality officer.
8- Front end screening was conducted by nursing informatics to check the validity of presented data.

The dashboard was approved by the informatics lead, quality improvement and chief nursing information officer