Identification and management of patient deterioration—Comparing the afferent limb of Early Warning Systems

Prepared by

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Thesis

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Abstract

It is mandated that all Australian hospitals employ a means of detecting patient deterioration, and in doing so, most have chosen to adopt Early Warning Scores (EWS). Over the past three decades, many variations of EWSs have been developed and tested in larger regional/metropolitan hospitals. However, there is a paucity of evidence as to which EWS is most effective in predicting deterioration events in small, poorly resourced regional/rural hospitals. The aim of this study was to inform small, poorly resourced regional/rural hospitals on the selection of the best EWS or class of EWS, to augment patient safety within their context.

This multi-phase retrospective case-controlled study compared the efficiency of 12 existing EWSs using patient data from two small regional private hospitals (Phase 1). Outcomes from Phase 1 informed Phase 2 and the development of a new EWS for use in poorly resourced regional private hospitals. The new EWS was then validated using two independent patient cohorts from small, poorly resourced regional/rural public hospitals (n=7) and large, well-resourced public regional/metropolitan hospitals (n=6).

Results showed that in small regional private hospitals, the aggregated weighted EWS, called Compass, was most effective in identifying deteriorating patients with an Area under the Receiver Operator Characteristic Curve (AUROC) of 0.747 (CI 0.73-0.76). However, Compass had a low sensitivity of 0.44, meaning that less than 50% of the deteriorating patients achieved an emergency call score. Given the suboptimal efficiency of the 12 EWSs tested, a new, more efficient EWS was developed. The first step in developing a new EWS involved determining the ability of the vital signs in predicting patient deterioration. While vital signs are good indicators of patient deterioration, no single vital sign was found to predict patient outcomes strongly. A rapid heart rate and the need for supplementary oxygen were identified as the best indicators of an impending clinical deterioration event in this patient cohort. Based on these findings, a new combination EWS,

called MOD-6 was then developed. This was achieved by adding a single trigger component to Compass, extending the existing vital sign trigger threshold ranges and incorporating a graduated weighted scale for supplementary oxygen use. The new combination EWS, MOD-6, was 20% more effective than Compass when used in poorly resourced regional private hospitals. However, when validating the new MOD-6 using two independent patient cohorts from the public sector, the MOD-6 EWS was no more effective than existing EWSs.

This study has produced evidence that EWSs are used differently in large, well-resourced regional/metropolitan hospitals compared to poorly resourced regional/rural hospitals. In the well-resourced hospitals, there is evidence that the EWSs are being used to identify clinical deterioration events, reactively using the EWS scores to guide the escalation of patient care. At the small, poorly resourced hospitals, the EWSs appear to be used proactively to predict patient deterioration and prevent adverse patient events. At these small regional/rural hospitals, staff appear to respond early to changes in the patients' vital signs, transferring patients out to a better resource facility before triggering an emergency threshold score on the EWS. In conclusion, an aggregated weighted EWS, such as Compass, or a combination EWS such as the new MOD-6 EWS should be considered for implementation in the small, poorly resourced private hospitals. The best indicators of patients requiring transfer out to a higher level of care in this patient cohort are the use of supplementary oxygen and those with tachycardia. Findings from this research will inform nursing practice in small, poorly resourced regional/rural hospitals and positively contribute to patient safety.

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'*For it happens in this, as the physicians say it happens in hectic fever, that in the beginning of the malady it is easy to cure but difficult to detect, but in the course of time, not having been either detected or treated in the beginning, it becomes easy to detect but difficult to cure'.*
(Niccolo Machiavelli, *The Prince*)

'Sorrow is better than laughter; it may sadden your face, but it sharpens your understanding'
(Ecclesiastes 7:3)

'Remember, stars shine the brightest in the longest and darkest nights'
(Pastor Andrew Robert)

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List of Publications Originating from this Thesis

Le Lagadec, M.D., and Dwyer, T. (2017). Scoping review: The use of early warning systems for the identification of in-hospital patients at risk of deterioration. *Australian Critical Care, 30*(4), 211–22. doi:10.1016/j.aucc.2016.10.003

Le Lagadec, M.D., Dwyer, T. and Browne, M. (2020). The efficacy of twelve early warning systems for potential use in regional medical facilities in Queensland, Australia. *Australian Critical Care, 33*(1), 47–53. https://doi.org/10.1016/j.aucc.2019.03.001

Le Lagadec, M.D., Dwyer, T. and Browne, M. (2020). Patient Deterioration in Australian Regional and Rural Hospitals: Is the Queensland Adult Deterioration Detection System the Criterion Standard? *Journal of Patient Safety,* doi:10.1097/PTS.0000000000000689

List of Publications Derived from this Research

Flenady, T., Dwyer, T., Sobolewska, A., Le Lagadec, D., Connor, J., Kahl, J., . . . Browne, M. (2020). Developing a sociocultural framework of compliance: an exploration of factors related to the use of early warning systems among acute care clinicians. *BMC Health Services Research, 20*(1), 1–9. doi:10.1186/s12913-020-05615-6

List of Presentations Pertaining to this Thesis

Le Lagadec, MD (November 2018). The efficacy of twelve early warning systems for potential use in regional medical facilities in Queensland, Australia. Wide-Bay Health Research Collaborative Forum. Bundaberg, 20 November 2018

Le Lagadec, MD (August 2019). Early warning systems, how well do they work in poorly resourced regional hospitals. Three-minute thesis (3MT). CQU School of Nursing, Midwifery and Social Sciences, Brisbane (15–16 August 2019)

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Le Lagadec, MD, Dwyer, T. and Browne M (October 2019). Early warning systems, so many to choose from; which ones work best for resource-poor private regional hospitals. World Congress of Intensive Care 2019.Melbourne Convention and Exhibition Centre, Melbourne, 14–18 October 2019.

List of Acronyms and Definitions

ADDS	Adult deterioration detection system
ARC	Adult observation and response chart
AUROC	Area under the receiver operating characteristic curve
BM	Body mass index
BP	Blood Pressure
BTF	Between-the-Flags
CCU	Coronary Care Unit
Compass	National Early Warning Score System and education package
Control patients	Patients that have an uneventful hospital stay
DRG	Diagnostic Related Groups
EWS	Early Warning Score, bedside vital sign observation chart
HREC	Human Research Ethics Committee
Index patients	Patients that experience an unexpected clinical deterioration event during their hospital stay
LOS	Length of hospital stay
MADDS	Mater adult deterioration detection system
MET	Medical Emergency Team
Monitoring event	A set of patient vital signs, also referred to as ‘observations’
NEWS	National Early Warning Score
NPV	Negative predictive value
Observations	A set of patient vital signs, also referred to as a monitoring event
Parameter	Numerical range or limit of a given variable, e.g. respiration rate of 10 to 20 breaths/min.

Poorly resourced facility	Facilities with less equipment, a low staff skills mix or no established medical emergency team to manage clinical deterioration.
Q-ADDS + BP	Queensland adult deterioration detection system with systolic blood pressure scale
Q-MEWT	Queensland maternity early warning tool
RRS	Rapid Response System
SAE	Severe Adverse Event
T&T	Track and trigger
Variables	Measurable element used to describe the cohort or elements of the EWSs, e.g. vital signs, age, diagnostic groupings.

Mathematical Tests

Numerical tests used to determine EWS efficacy, their definitions and formulae. Derived from Lalkhen and McCluskey (2008) and Burgess, Herdman, Berg, Feaster and Hebsur (2009).

True positive	A patient that triggers an EWS alert and suffers an unexpected clinical deterioration event.
False positive	A patient that triggers an EWS alert but does not suffers a clinical deterioration event.
False negative	A patient that does not trigger an EWS alert but does experience an unexpected clinical deterioration event.
Sensitivity	The ability of the EWS to correctly identify patients who will suffer an SAE or an unexpected clinical deterioration event. This is a measure of an existing disease or condition: when an alarm sounds or an EWS reaches a predetermined threshold value, and the disease/condition is present, this is a true positive alarm. When an alarm sounds but the disease/condition is not present, this is a false positive alarm. The sensitivity of the EWS is dependent on the trigger threshold score; formula: True positive ÷ (true positive + false negative).
Specificity	The ability of the EWS to correctly identify patients who will not suffer an SAE or an unexpected clinical deterioration event. It is a measure of normality when the disease/condition is not present: when an alarm remains silent, or an EWS threshold value is not attained, and disease/condition is not present, this is a true negative alarm. When an alarm remains silent and disease/condition is present, this is a false negative alarm. The

	specificity of the EWS is dependent on the trigger threshold score; formula: True negative ÷ (true negative + false positive).
Odds ratio	This is a measure of the association between an exposure and a given outcome. For example, an odds ratio of two means that an index patient is twice as likely to experience an unexpected clinical deterioration event than a control patient.
Positive predictive value	The likelihood of a patient with a high EWS value experiencing an unexpected clinical deterioration event. It is dependent on the disease prevalence in the patient cohort; formula: True positives ÷ (true positives + false positives), that is the proportion of positive cases that are correctly classified.
Negative predictive value	The likelihood of a patient with a low EWS value experiencing an uneventful hospital stay, that is, no unexpected clinical deterioration event. It is dependent on the disease prevalence in the patient cohort; formula: True negatives ÷ (true negatives + false negatives), that is, the proportion of negative cases that are correctly classified.
Area under the Receiver Operator Characteristic Curve (AUROC)	Graphic display of false positives on the x-axis (1 – specificity) and true positives on the y-axis (sensitivity), represents the overall accuracy of the EWS's ability to predict an unexpected clinical deterioration event and is independent of the trigger threshold score. A perfect AUROC has a value of 1, whereas a value of 0.5 is as accurate a test as tossing a coin.

Burgess, L., Herdman, T., Berg, B., Feaster, W., & Hebsur, S. (2009). Alarm limit settings for early warning systems to identify at-risk patients. *Journal of Advanced Nursing, 65*(9), 1844–1852. doi:10.1111/j.1365-2648.2009.05048.x

Lalkhen, A., & McCluskey, A. (2008). Clinical tests: sensitivity and specificity. *Continuing Education in Anaesthesia, Critical Care & Pain, 8*(6), 221–223. doi:10.1093/bjaceaccp/mkn041

Chapter 1. General Introduction

Synopsis

Patients admitted to hospitals are often acutely ill and are at risk of clinical deterioration. If not detected early, these deterioration events may lead to increased length of stay, permanent disabilities or even death. In response to the deteriorating patient predicament, Rapid Response Systems (RRS) were introduced comprising of four limbs, one of which is the afferent, patient monitoring limb. The afferent limb typically consists of the patient's vital signs observation chart and is referred to in this study as an Early Warning Score (EWS). The EWS tracks the patient's vital signs and guides the staff's response should the patient deteriorate. Various iterations of EWSs have been implemented both nationally and internationally, but their efficacy, especially when used in small, poorly resourced regional/rural hospitals, is inadequately understood. The aim of this study is to address this gap in knowledge by investigating the efficacy of the more commonly used EWSs for possible implementation in poorly resourced Australian hospitals. This chapter introduces the patient deterioration response systems in the International and Australian context. The four limbs of the system are briefly discussed, and the three classes of EWS introduced. This chapter discusses the reason for undertaking this study, the significance of the research and the structure of the thesis.

Origins of the Study

At the time of commencing this study, the researcher was employed as a registered nurse at a small private regional hospital, one of many within the health service organisation. It was also at this time that the organisation mandated that all hospitals within the group implement a patient deterioration detection system to align with the Australian Commission on Safety and Quality recommendations (Australian Commission on Safety and Quality in Health Care [ACSQHC], 2017). It was apparent that many different EWSs (bedside observation charts) were available, and the selection of EWS implemented was left to the

discretion of each of the hospitals. This resulted in each of the hospitals within this one organisation adopting and implementing different EWS. The choice of EWS was primarily driven by personal opinion or experience. The hospital where the researcher worked implemented the chosen EWS in late 2015, albeit with some nursing and medical staff resistance. The staff had received some training in the use of the new bedside observation chart, but there was little assent by the nursing staff. Some staff questioned the efficacy of the EWS charts as they feared that the charts would undermine their nursing expertise, intuition and clinical reasoning.

Consequently, we explored the literature for evidence of the efficacy of the EWSs that had been implemented and questioned which of the EWSs, or class of EWS, would be most effective in identifying deteriorating patients in these small private hospitals.
We rationalised that if evidence of EWS efficiency were presented to the nursing staff, perhaps assent and hence, better compliance would be achieved. Also, we hoped that if the most effective EWS or class of EWS could be identified through the literature, perhaps a standardised approach would be considered throughout the organisation's multiple hospitals.
A search of the literature revealed that most EWSs were developed for and tested in, large metropolitan hospitals. Very little research, especially quantitative evaluations, has been undertaken in smaller regional/rural facilities and even less in regional private hospitals.
It became apparent to the researcher that the size of the hospital per se was not the critical factor; instead, the relevance resided in the level of resources available in these small hospitals to adequately monitor and care for the deteriorating patient. The smaller regional/rural facilities were usually poorly resourced compared to the large metropolitan hospitals (Whitehead & Quinn, 2019). The inadequate resourcing was especially true for smaller private facilities, many of which have no intensive care units or in-house doctors and few means to manage critically ill patients. In these small regional hospitals, outside of office hours, the nursing staff are wholly responsible for identifying and responding appropriately to the deteriorating patient without the support of a specialised critical care team. Yet, fewer

nursing staff in private hospitals report being trained in advanced life support skills than those in the public sector (Anstey, Bhasale, Dunbar, & Buchan, 2019). We felt that under these circumstances, it was important that the nursing staff were provided with the most effective EWS for the regional patient cohort and small hospital context. This observation motivated the study, whose overarching aim was to contribute evidence to assist poorly resourced regional/rural facility make informed decisions when selecting an EWS.

General Introduction

Unexpected in-hospital patient deterioration and severe adverse events (SAEs) gained international prominence in the early nineties when it became apparent that many of these events were preventable (Difonzo, 2017). An SAE has been defined as an unintentional event caused by poor healthcare management rather than the disease process, which may result in disability or death (Wilson et al., 1995). Like patient deterioration, SAEs can cause an increased length of hospital stay (Kyriacos, Jelsma, & Jordan, 2011). In response to preventable in-hospital patient deterioration and SAEs, in 1989, the first Medical Emergency Team (MET) was established in a Sydney hospital in Australia (Lee, Bishop, Hillman, & Daffurn, 1995). The MET replaced or supplemented the already existing Cardiac Arrest Teams (Difonzo, 2019; Lee et al., 1995). The purpose of the first MET was to bring clinical specialists to the critically ill patient before catastrophic situations or SAEs occurred, rather than after the event (Difonzo, 2017). The original MET call criteria were not well defined and were based on one of three possible conditions: facility-specific predefined conditions, physiological/pathological abnormalities or ‘urgent help needed’ (Lee et al., 1995). Shortly after that, the Rapid Response Teams were adopted in America in 1997, the Critical Care Outreach Service in the United Kingdom (UK) in 2000, and the Critical Care Response Teams in Canada in 2006 (Difonzo, 2017, 2019). The first track and trigger patient vital signs observation chart was developed in the Liverpool hospital in Australia in the early 1990s and became part of the MET concept (Cuthbertson & Smith, 2007). This track and trigger system led to the development of a broad range of similar

observation charts, which included various scoring algorithms based mainly on the patient's physiological vital signs (Cuthbertson & Smith, 2007). The evolution of the track and trigger concept resulted in the development of three broad categories or classes of patient observation charts, which became known as Earl Warning Scores (EWSs). The three classes included: the single trigger scoring system, the aggregated weighted systems and the combination systems, that is, single trigger and aggregated weighted systems (Difonzo, 2017).

In 2006 the Rapid Response System (RRS) emerged, surpassing the 'Teams' concept. The RRS incorporated four components; an afferent limb consisting of the bedside observation tract-and-trigger chart or EWS; the efferent MET response limb involving the emergency response teams made up of specially trained nurses and doctors; the administrative limb that coordinates the system components; and the governance or quality improvement limb that carries out the quality assurance and collects the resulting data (Cuthbertson & Smith, 2007; Difonzo, 2017). The RRS was a more comprehensive organisational model whose purpose was the early detection and appropriate treatment of the deteriorating patient (Difonzo, 2017). The concept of a patient deterioration response system gained international popularity, and its implementation was recommended by the Institute for Health Improvement in the USA in 2004 (Berwick, Calkins, McCannon, & Hackbarth, 2006), the Department of Health and Emergency Care in Scotland in 2005 (Johnstone, Rattray, & Myers, 2007), the Australian Commission on Safety and Quality in Health Care in Australia in 2006 (ACSQHC, 2008), the Critical Care Plan in Canada in 2007 (Ontario Ministry of Health and Long-Term Care, 2007) and the National Institute for Health and Care Excellence (NICE) in the UK in 2007 (NICE, 2007).

One of the earliest aggregated weighted EWS developed in the UK was based on five physiological parameters and was called the Modified EWS (MEWS) (Subbe, Kruger, Rutherford, & Gemmel, 2001). Together with MEWS, numerous other EWSs were introduced throughout the UK hospitals with significant variations in the physiological

parameters measured and in the staff responses evoked by the trigger thresholds (Smith, Prytherch, Meredith, Schmidt, & Featherstone, 2013). In 2007, an Acute Medical Task Force of the Royal College of Physicians of London recommended the standardisation of the EWSs for use in all National Health System hospitals in the UK (Smith et al., 2013).
As a result, the VitalPAC Early Warning Score (ViEWS) was introduced in 2010 (Prytherch, Smith, Schmidt, & Featherstone, 2010). The ViEWS trigger thresholds were primarily based on a trial-and-error approach and set to maximise the detection of patient mortality within 24 hours of exhibiting abnormal vital signs (Prytherch et al., 2010). The refinement of ViEWS, based mainly on the expert opinions of the members of the National Early Warning Score Design and Implementation Group, led to the development of the National EWS (NEWS) in 2012 (Royal College of Physicians, 2012). NEWS is currently used throughout the National Health System hospitals in England, Scotland and Wales. It has also been adopted in health care systems across Europe, India and the USA, including the US Naval Airforce (Royal College of Physicians, 2017). Despite its implementation in all National Health System hospitals, there is little evidence of the efficacy of NEWS outside of large metropolitan hospitals. NEWS has been tested in various medical settings but always within large metropolitan hospitals (Green et al., 2018; Keep et al., 2016; Pimentel et al., 2019; Smith et al., 2016). In 2017, the Royal College of Physicians reviewed NEWS, making several modifications to the vital sign weighted scores, notably introducing an oxygen saturation scoring scale for patients with chronic respiratory diseases (Royal College of Physicians, 2017). This modified EWS, NEWS2, has not yet been validated (Pimentel et al., 2019).

The initial uptake of the MET concept and the accompanying track and trigger patient monitoring system was relatively slow in Australia, with six large New South Wales hospitals and several smaller facilities having adopted the system in the decade following its introduction (Hillman, Parr, Flabouris, Bishop, & Stewart, 2001). The perceived lack of enthusiasm for the new MET concept may have been related to the scarcity of evidence

regarding the system's efficacy. To address this problem, a large, randomised control trial, the MERIT study, was conducted involving 23 hospitals; half of the hospitals adopted the new MET concept, and the other half continues to utilise their existing systems (Hillman et al., 2005). The MERIT study aimed to compare the number of unexpected hospital deaths, cardiac arrests or unplanned admissions to the intensive care unit (ICU) between the two hospital groups. Although the MERIT study failed to demonstrate the efficacy of the MET, it served to quantify the incidence of SAEs in Australian hospitals (Hillman et al., 2005). The high number of preventable SAEs in Australian hospitals led to a public outcry and spurred the Australian government into action (Rihari-Thomas, Digiacomo, Newton, Sibbritt, & Davidson, 2019). A special commission of inquiry into the NSW acute care services was undertaken, resulting in the Garling report titled, *Final report of the special commission of enquiry: Acute care services in NSW public hospitals*. The report recommended, amongst others, that increased attention be given to patient safety (Garling, 2008; Rihari-Thomas et al., 2019). The Garling report resulted in the mandatory implementation of patient deterioration detection systems in all NSW public hospitals and later in the remaining Australian hospitals (ACSQHC, 2012; Rihari-Thomas et al., 2019).

Most Australian medical facilities have implemented a track and trigger patient monitoring chart, an EWS, as part of their patient deterioration detection systems. Given the numerous deterioration detection systems that have developed over time, there is a lack of consistency in the type of EWS and the accompanying response systems implemented in hospitals throughout Australia. In an attempt to standardise these systems, several patient safety frameworks have been developed; the Compass program was adopted mainly by the Australian Capital and Northern Territories, and NSW adopted the Between-the-Flags system (Pain et al., 2017; Rihari-Thomas et al., 2019). In Queensland, the Queensland Adult Deterioration Detection System (Q-ADDS) has been adopted in most public hospitals (Wynne & Farrel, 2015). These EWSs and their response systems were developed for large

metropolitan hospitals. Their functionality in small, poorly resourced regional hospitals has yet to be ascertained.

The Rationale and Significance of the Study

The introduction above has provided an overview of the evolution of patient deterioration detection systems and their accompanying patient monitoring EWSs. Unlike England that has standardised the EWSs and implemented NEWS in all National Health Service hospitals (Royal College of Physicians, 2017), within Australia, the adoption of a single national EWS and patient deterioration detection system has not been achieved. Typically, hospitals choose patient deterioration detection systems based largely on intuition and personal preference and modifying them to suit their facilities' needs (Churpek, Yuen & Park, 2014; Cuthbertson & Smith, 2007; Jansen & Cuthbertson, 2010; Khwannimit, Bhurayanontachai, & Vattanavanit, 2019). In Chapter 2 of the thesis, an in-depth scoping review identifies quantitative studies published between 2000 and 2016 that reported on the efficiency of the afferent limb of the patient deterioration detection systems, that is, the bedside observation EWS charts. While there is good anecdotal evidence that EWS assists staff in recognising the deteriorating patient, there is little evidence that these EWSs improve patient outcomes. The review showed that although aggregated weighted EWSs appear to be most effective, no single EWS was found to be suitable for all patient cohorts.

Based on the scoping study undertaken in Chapter 2, it became apparent that most of the research into patient deterioration and EWSs have been conducted in well-resourced Metropolitan hospitals with established medical emergency teams. Still, their suitability for use in poorly resourced regional/rural facilities has attracted little attention. There are many definitions of what constitutes a resource-poor facility. In the present study, a resource-poor facility is regarded as one where the staff may have the knowledge and the skills necessary to treat the patient, but not the means (Iserson, 2018). The lack of adequate resources is especially true in smaller regional/rural hospitals. In the Australian context, a regional area is

not measured in the distance from a city but is simply defined as an area beyond the larger metropolitan cities (Regional Australia Institute, 2017). Attracting and retaining clinical staff, including nurses, to these regional/rural hospitals is difficult since there are few opportunities for promotion, and the hospitals involved are often comparatively poorly equipped (Whitehead & Quinn, 2019). It is well established that, compared to their metropolitan counterparts, people in the regional/rural areas have a more substantial burden of illness, tend to be older and have poorer health outcomes (Whitehead & Quinn, 2019). They often present at hospitals when acutely ill, which increases their risk of deterioration events (Mohr et al., 2016). Compounding this issue, when compared to metropolitan acute care facilities, these regional/rural hospitals are often poorly resourced having less equipment, a low staff skills mix and may not be well prepared to deal with deteriorating patients (Bourke, Humphreys, Wakerman, & Taylor, 2012; National Rural Health Alliance, 2016). The suitability of utilising the EWSs developed in a metropolitan hospital, in regional/rural hospitals, is unknown.

There is an urgent need to test the efficacy of these EWSs for use in small, poorly resourced hospitals. Still, there is a distinct lack of research emanating from regional/rural Australia. The lack of research funding, good leadership, and participatory opportunities makes regional/rural research unattractive (Barclay, Phillips, & Lyle, 2018). To illustrate this, it is known that despite 30% of the Australian population inhabiting regional areas, less than 2.5% of the 2014 National Health and Medical Research Council funding was directed to regional and remote focused research (Barclay et al., 2018). Regional/rural research is under-reported and under-represented, with only 220 peer-reviewed publications being generated in 2013 from regional/rural facilities compared to 1 222 publications being generated from a single South Australian metropolitan hospital in 2016 (Humphreys, Lyle, & Barlow, 2018; Moran et al., 2019). The current research aims to contribute to the under-representation of regional/rural research by undertaking a biphasic study examining the efficiency of EWSs in, and for small regional poorly resourced facilities. The overarching aim

of this study is to contribute evidence to assist poorly resourced regional/rural facility make informed decisions when selecting an EWS.

Study Aim and the Research Questions

The overarching aim of this study was to provide evidence of the efficiency of various EWSs to assist poorly resourced regional/rural hospitals make informed decisions when selecting an EWS for implementation. That is, to find an EWS with good sensitivity and specificity that can identify a deteriorating patient. It was hypothesised that one of the EWSs included in the study, or a class of EWS, would prove superior and well suited for use in small, poorly resourced regional/rural hospitals. It was hoped that if such an EWS were found, the implementation of a single EWS would help to standardise the use of a specific EWS across public and private rural and regional hospitals. In achieving this aim, the following research questions arose:

1. Which existing EWS, or class of EWS, is most effective in poorly resourced regional/rural hospitals? That is, which EWS has the highest sensitivity and specificity when tested using regional/rural patient cohort data (addressed in Chapter 4)?
2. Can an existing EWS be improved on to meet the needs of the patients in poorly resourced regional/rural hospitals, perhaps by creating a new EWS? Given that the independent variables used in EWSs are based on the patient vital signs, several sub-questions arose:
    a) Are patient vital signs good predictors of patient deterioration in the study cohort (addressed in Chapter 5)?
    b) Which vital sign(s) best predicted patient deterioration in this cohort (addressed in Chapter 5)?

c) Can the vital sign trigger ranges and weighted scores used in the EWSs be altered to create a new, more efficient EWS for poorly resourced regional private hospitals (addressed in Chapter 6)?

Structure of the Thesis

This is a thesis with publications, that is, a combination of the traditional thesis and thesis by, and with publications. It is presented in a style consistent with the directives of the CQUniversity, Australia. This multi-phase research, consisting of a series of standalone studies, is presented in this thesis as seven chapters (see Figure 1). The work is written in the third person, with references placed at the end of each chapter using the APA referring style. Each standalone study is presented either as a published manuscript or in preparation for later publication. Where appropriate, the pre-published manuscripts have been included to ensure the flow and continuity of the chapters. A synopsis and summary accompany each chapter to explain the chapter's contribution to the overarching study aim.

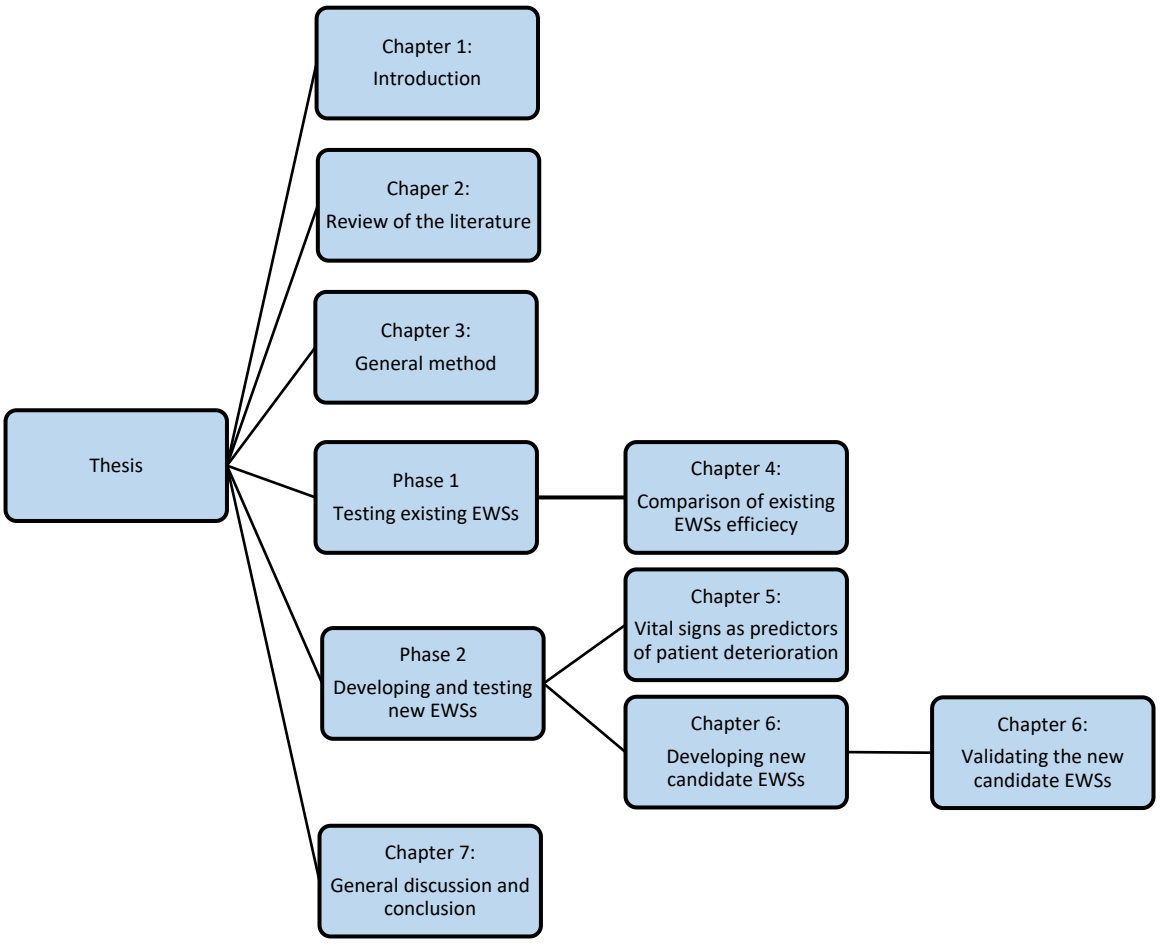

Figure 1: Schematic representation of the structure of the thesis.

Chapter 1 introduces the patient deterioration detection systems in the International and Australian context. The reason for undertaking the study is discussed, its aim and research questions are presented, and the rationale for the study and the thesis structure is given.

Chapter 2 is an in-depth scoping review of quantitative studies exploring the efficiency of EWSs for patients experiencing deterioration events in hospital wards. Consistent with the overarching conceptual framework and research methodology, the scoping review was conducted to inform the development of the research question and data abstraction tool (Gearing, Mian, Barber, & Ickowicz, 2006). The scoping review was

published in the Australian Journal of Critical Care in 2017 (Le Lagadec & Dwyer, 2017), and contemporary literature has been introduced in subsequent chapters.

Chapter 3 describes the general research methods employed throughout the study. It discusses and justifies the conceptual framework underpinning this study as well as the study design and its appropriateness. It characterises the study sites and cohort, the data collection method, synthesis and the basic statistical methods used in the data analysis.

Chapter 4 constitutes Phase 1 of the study. In this chapter, a comparison is made of the efficiency of 12 existing EWSs used in Australian hospitals. Retrospective patient data from two small, poorly resourced regional private hospitals are used in this study. This chapter addresses research question 1, ascertaining which EWS or class of EWS, is best suited for these poorly resourced regional/rural facilities. The information from this study resulted in two publications, an industry report and several oral presentations at international and local conferences and symposiums (Le Lagadec, Dwyer, & Browne, 2020a, 2020b).

Chapter 5 is the first stage of Phase 2 of the study. It addresses research question 2; can an existing EWS be improved to meet the needs of the patients in poorly resourced regional/rural hospitals. To achieve this, the intrinsic prognostic information which underpins the EWSs, the patient vital signs, was studied. This chapter explores the pattern and completeness of vital sign monitoring and undertakes a quantitative study to determine which specific vital signs are good predictors of deterioration events. The information generated from this chapter is used in the development of a more efficient EWS in Chapter 6.

Chapter 6 utilises the information derived from Chapters 4 and 5 to develop six new EWSs. This chapter represents the second stage of Phase 2 of the study. These new EWSs utilise the same set of variables, the patient vital signs, used in most existing EWSs, but the trigger thresholds and weighted scores are adapted to suit the target cohort, viz., regional/rural hospitals. Several methods of establishing the trigger thresholds are utilised

and based both on existing published literature and on methods developed in this study. The resulting EWSs are tested using the target cohort's patient data and validated using patient vital signs derived from two large independent data sets.

Chapter 7 is the concluding chapter and presents a synthesis of this biphasic study. It questions whether the study aim was achieved and offers an interpretation of the study results. The chapter addresses this biphasic study's theoretical and practical contributions and recognises the study's limitations. Suggestions are made for future research.

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Chapter 2. Scoping Review

The use of Early Warning Systems for the identification of in-hospital patient at risk of deterioration

DECLARATION OF CO-AUTHORSHIP AND CO-CONTRIBUTION

Title of Paper:

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70% - developed the concept, undertook the research, drafted the manuscript, submitted.

Nature of Co-Authors' Contributions:

30% - guided the concept development, guided the research, edited the manuscript.

Candidate's Declaration

I declare that the publication above meets the requirements to be included in the thesis as outlined in the Research Higher Degree Theses Policy and Procedure.

Synopsis

This chapter presents a scoping review of the existing literature available at the commencement of this study. Following the conceptual framework and methodology utilised in the study, it is essential to conduct a review of the literature to frame the research question and to establish appropriate operational methods of achieving the study aims (Gearing, Mian, Barber, & Ickowicz, 2006; Vassar & Holzmann, 2013). A literature review is a standardised requirement of research endeavours to identify existing knowledge and the gaps in knowledge that the current study aims to fill. Furthermore, in compliance with Gearing's conceptual framework, the review of the literature served to develop the audit tool used in the current study (Gearing et al., 2013).

The focus of the review at the commencement of the study was to ascertain the contemporary evidence examining the efficacy of patient bedside vital signs observation charts, that is, the afferent limb of the Early Warning System, in the recognition of in-hospital adult patient deterioration. Only studies involving in-hospital adult patients admitted to general wards were included. Studies involving patients in intensive care units, at the point of hospital admission (usually the Emergency or Trauma Department) or out-of-hospitals situations were omitted. Information elicited from the review was published and identified gaps used to inform the study research question and data collection processes. Ongoing evaluation of the contemporary literature continued as the study progressed, and observations were integrated into subsequent chapters.

Note: Since this chapter is a published manuscript, some of the terminology and acronyms have been adapted to suit the journal and may be inconsistent with the rest of the thesis.

Abstract

Introduction: Early Warning Systems (EWS) were developed as a means of alerting medical staff to patient clinical decline. Since 85% of severe adverse events are preceded by abnormal physiological signs, the patient bedside vital signs observation chart forms the basis of most EWS. There are three broad categories of patient observation chart EWSs: single or multiple trigger systems; aggregated weighted scoring systems; or combinations of single or multiple triggers and aggregated weighted scoring systems.

Objective: This scoping review is an overview of published studies involving the efficiency of the afferent limb of EWS in the recognition of in-hospital patient deterioration.

Method: A broad search was undertaken of peer-reviewed publications, official government websites and databases housing research theses, using combinations of keywords and phrases.

Data sources: CINAHL with full text; MedLine, PsycINFO, MasterFILE Premier, GreenFILE and ScienceDirect. Also, the Cochrane Library database, Department of Health government websites and Ethos, ProQuest and Trove databases were searched.

Exclusions: Paediatric, obstetric and intensive care studies, studies undertaken at the point of hospital admission or pre-admission, non-English publications and editorials.

Results: More than 500 publications, government documents, reports and theses were located of which 91 were considered and 21 were included in the scoping review. Of the 21 publications, eight studies compared the efficacy of various EWS and thirteen publications validated specific EWS.

Conclusions: There is low-level quantitative evidence that EWSs improve patient outcomes and strong anecdotal evidence that they augment the clinical staff's ability to recognise and respond to patient decline, thus reducing the incidence of severe adverse events. Although

aggregated weighted scoring systems are most frequently used, the efficiently of the specific EWS appears to be dependent on the patient cohort, facilities available and staff training and attitude. Most of the studies reviewed support the use of EWSs but some researchers have warned that EWSs cannot replace good clinical judgement.

Introduction

Recognising patient deterioration is a priority for most health care facilities (Jonsson, Jonsdottir, Moller, & Baldursdottir, 2011). The ability of a hospital to respond appropriately to patient clinical decline is a reflection of the facility's quality of care and can strengthen or undermine public confidence in the health care system (Goldfield, 2010; Kyriacos, Jelsma, & Jordan, 2011). Patient deterioration may be preventable and can often be attributed to human error (Kyriacos et al., 2011). Inadequate nursing skills, infrequent patient monitoring, poor documentation and a lack of timely action exacerbate patient deterioration (De Meester, Van Bogaert, Clarke, & Bossaert, 2012; Felton, 2012; Fuhrmann, Lippert, Perner, & Østergaard, 2008; Odell, Victor, & Oliver, 2009). The correct implementation of Early Warning Systems (EWSs) helps overcome subjectivity by providing clinical staff with quantitative evidence of a patient's declining clinical condition and by guiding the staffs' response (Day & Oldroyd, 2010).

Early warning systems, also known as 'track and trigger' (T&T) systems, have evolved as a means of alerting health professionals to patient clinical decline (Gao, McDonnell, et al., 2007). Since 85% of severe adverse events (SAEs) are preceded by abnormal vital signs, (Andersen et al., 2016; Devita et al., 2010; Hodgetts, Kenward, Vlachonikolis, Payne, & Castle, 2002; Kause et al., 2004) the bedside vital signs observation chart forms the basis of most EWSs. The EWS consists of both afferent and efferent limbs; the afferent limb is the use of early warning scores, as determined by the bedside observation chart, to recognise patients at risk of deterioration. The efferent limb is represented by the appropriate response and actions of the Medical Emergency Teams,

Rapid Response Systems or Critical Care Outreach Services (Devita et al., 2010; Gao, Harrison, et al., 2007). Although there has been some debate regarding the heavy reliance on abnormal vital signs in recognising patient deterioration, (Jones, Mitchell, Hillman, & Story, 2013) most EWSs continue to utilise a combination of the following physiological parameters: respiration rate, oxygen saturation level, supplementary oxygen flow rate, systolic blood pressure, heart rate, temperature, level of consciousness, and the pain score. Some also include urine output, and the Glasgow coma scale (Jonsson et al., 2011; Olsson, Terent, & Lind, 2004). All EWSs follow the same principle; a given threshold score(s) triggers a prescribed set of actions intended to escalate patient care (Day & Oldroyd, 2010). There are a variety of EWSs but most fit into three categories: (a) single or multiple trigger EWSs which prompt an intervention when a predefined threshold is reached; (b) aggregated weighted scoring systems which allocate a 'weight' to each vital sign score reflecting its level of abnormality; and (c) a combination of (a) and (b), single or multiple trigger and aggregated weighted scoring systems (Christofidis, Hill, Horswill, & Watson, 2015).

This scoping review presents a broad overview of published works related to the use of the patient bedside vital signs observation chart EWSs, that is, the afferent limb of the EWS, in the recognition of in-hospital adult patient deterioration. The aim of the review is to evaluate the reported efficacy of the various EWSs in identifying clinical deterioration of hospital patients.

Methods

A scoping review is a specific method that aims to 'map the literature' on a topic of interest to identify gaps in knowledge (Arksey & O'Malley, 2005; Armstrong, Hall, Doyle, & Waters, 2011; Peters et al., 2015). It is an appropriate approach for this review as it allows for the inclusion of a wide range of study designs, particularly in areas with emerging evidence. It differs from a systematic review in that it does not involve the assessment of the quality of the studies. Rather it summarises a range of evidence in order to report the

breadth and depth on a specific topic. The five stages as outlined by Arksey and O'Malley (2005) guided the review; (1) clarification of the purpose and search question; (2) identification of relevant studies; (3) selecting the studies; (4) presenting the data as a chart and qualitative themes, and (5) data collation, and writing a report. The search question for this review was: What is the reported efficacy of the various EWSs patient observation charts in identifying clinical deterioration of in-hospital adult patients?

We searched CINAHL with full text, MedLine, PsycINFO, MasterFILE Premier, GreenFILE, Cochrane Library and ScienceDirect databases using the search terms: Early warning systems; track and trigger systems; patient deterioration; patient deterioration and vital signs; EWSs and patient outcomes; in-hospital severe adverse events; and combinations of these terms. In addition, government websites pertaining to the Department of Health and postgraduate theses were searched through Ethos, ProQuest and Trove databases. Searches were performed without year restrictions but the following filters were applied: patient above 18 years of age; full text English language papers only; and peer reviewed journals or official government documents. When selecting the relevant studies, the researchers considered the extent and ability of the study to answer the research question (Levac, Colquhoun, & O'Brien, 2010). Inclusion criteria were publications relating to the comparison of the various EWS charts and their efficiency or validation. Relevant systematic reviews and literature reviews were also included. Additionally, studies addressing the development, use of, testing and efficacy of the bedside patient vital signs observation charts used in general medical and surgical hospital wards were considered. The exclusion criteria comprised studies pertaining to obstetric and paediatric patients, and studies involving intensive care units (ICU). These studies were excluded because they involve EWS observation charts specifically designed for that patient cohort and are not comparable with in-hospital adult EWSs. Studies involving the use of EWSs at the point of patient hospital admission were also excluded given that they are usually based on a single set of vital signs. Also excluded were EWS used in non-hospital situations as well as

editorial articles. The search was supplemented by scanning the reference lists of included studies.

Determining which studies to include in the scoping review was an iterative process predominantly lead by the lead author. While Arksey and O'Malley (2005) do not stipulate that a team approach is imperative at this stage, team discussions were conducted as an iterative process to clarify this step. Data extracted were entered onto a Microsoft Excel sheet with the final conclusions presented as tables. Emphasis was placed on quantitative studies since these statically validate the efficiency of the various EWSs. Such studies include prospective and retrospective observational studies, case-controlled studies, cross-sectional studies, before-and-after studies, and statistical validation retrospective data analysis studies. Consideration was also given to reports, qualitative and mix method studies and literature reviews of quantitative studies.

Results

Study selection

The database searches produced 520 published articles and a further 32 articles were obtained from reference lists. Eight government reports and five PhD theses pertaining to patient deterioration and EWSs were also located. Of these, 246 full text records were assessed, and 91 articles and reports were considered, of which 21 were included in the scoping review and the rest were used as background information (See Figure 2).

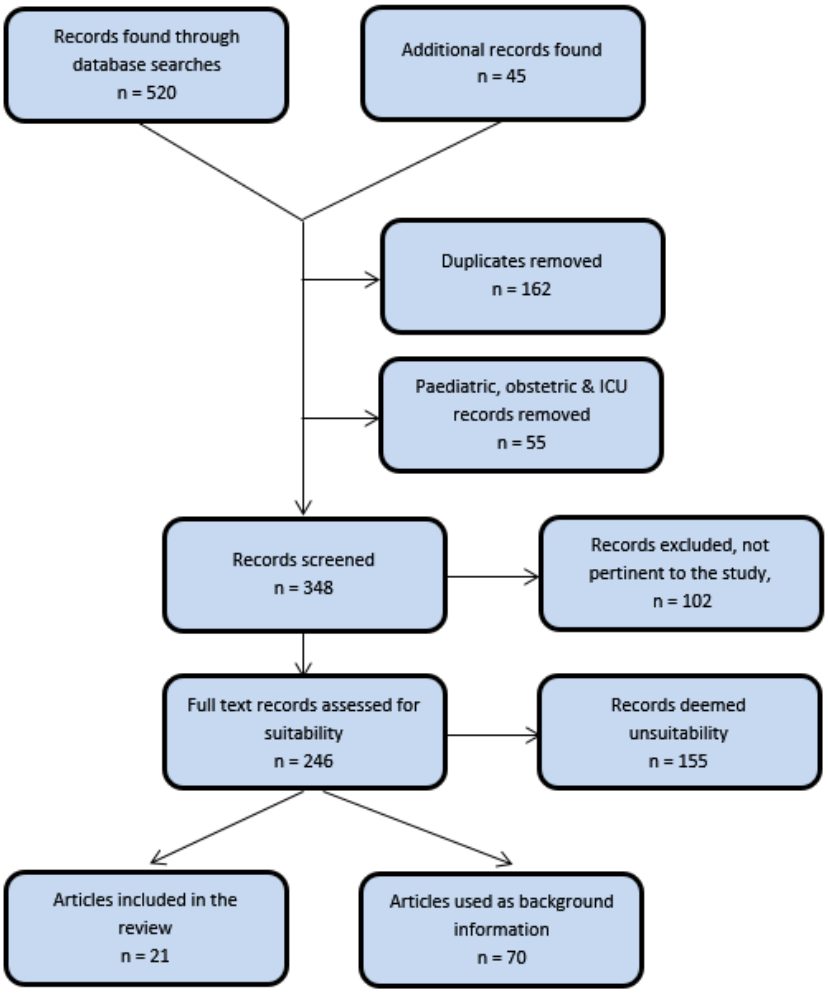

Figure 2: Flow chart of record search.

The publications deemed unsuitable included editorials, training manuals and studies focusing on the efferent limb of the EWSs. Also, a large number of studies focused on predicting patient deterioration at the time of patient presentation, most based on a single set of vital signs (Alam et al., 2015; Cei, Bartolomei, & Mumoli, 2009; Cıldır et al., 2013; de Pennington, Laurenson, Lebus, Sihota, & Smith, 2005; Duckitt et al., 2007; Frost et al., 2009; Geier et al., 2013; Goodacre, Turner, & Nicholl, 2006; Gottschalk, Warner, Burch, & Wallis, 2012; Groarke et al., 2008; Hosking, Considine, & Sand, 2014; Jenkins, Thompson, & Barton, 2011; Keep et al., 2016; Lam et al., 2006; Olsson et al., 2004; Paterson et al., 2006; Smith, Prytherch, Meredith, Schmidt, & Featherstone, 2013; So, Ong, Wong, Chung, & Graham, 2015; Subbe, Davies, Williams, Rutherford, & Gemmell,

2003; Subbe, Kruger, Rutherford, & Gemmel, 2001; Subbe, Slater, Menon, & Gemmell, 2006; Wang, Fang, Chen, Tsai, & Kao, 2016). These were excluded as they did not involve in-hospital ward patients and did not comply with the inclusion criteria. Articles considered included ten studies focusing on the use of EWSs in specific patient cohorts such as in oncology and haematology wards (Alrawi et al., 2013; Bailey et al., 2013; Churpek, Yuen, & Park, 2014; Cıldır et al., 2013; Cooksley, Kitlowski, & Haji-Michael, 2012; De Meester et al., 2013; Fullerton, Price, Silvey, Brace, & Perkins, 2012; Lee et al., 2008; Mulligan, 2010; Silcock, Cornfield, Gowens, & Rooney, 2015), eleven studies validated or compared EWSs based on large electronic databases of patients' vital signs, that is, electronic medical records (Alvarez et al., 2013; Badriyah et al., 2014; Bailey et al., 2013; Bellomo, 2012; Bleyer et al., 2011; Churpek et al., 2014; Escobar et al., 2012; Jarvis, Kovacs, Briggs, Meredith, Schmidt, & Featherstone, 2015; Jarvis, Kovacs, et al., 2015a; Jarvis, Kovacs, et al., 2015b; Prytherch, Smith, Schmidt, & Featherstone, 2010), and twelve systematic or literature reviews were located (Alam et al., 2014; Brabrand, Folkestad, Clausen, Knudsen, & Hallas, 2010; Elliott, Worrall-Carter, & Page, 2014; Gao, McDonnell, et al., 2007; Kyriacos et al., 2011; Massey, Aitken, & Chaboyer, 2010; McGaughey et al., 2007; McNeill & Bryden, 2013; Odell et al., 2009; Rowan, 2004; Smith, Prytherch, Schmidt, & Featherstone, 2008; Smith, Prytherch, Schmidt, Featherstone, & Higgins, 2008). Twelve studies involved the development of EWSs (Bailey et al., 2013; Christofidis et al., 2015; Christofidis, Hill, Horswill, & Watson, 2013; Escobar et al., 2012; Horswill et al., 2010; Kyriacos, Jelsma, James, & Jordan, 2014; Preece et al., 2013; Preece, Hill, Horswill, Karamatic, & Watson, 2012; Preece, Hill, Horswill, & Watson, 2012; Preece, Horswill, Hill, & Watson, 2010; Prytherch et al., 2010; Tarassenko et al., 2011), four of which focused on establishing the most appropriate trigger scores and/or the most effective parameters, while the other eight publications concentrated on the human aspect of the patient observation chart design such as ease and speed of use, minimising errors and correct interpretation of the results. Twenty-five studies looked at the human aspect of responding to patient deterioration, that is, the medical staff's ability to recognise the deteriorating patient, their reaction time in

responding to the alerts, and their attitude towards implementing EWSs (Adelstein, Piza, Nayyar, Mudaliar, & Klineberg, 2011; Buist, Harrison, Abaloz, & Van Dyke, 2007; Clarke, Kelleher, & Fairbrother, 2010; Clifton et al., 2015; De Meester et al., 2012; D. Elliott et al., 2014; Endacott, Kidd, Chaboyer, & Edington, 2007; Fox-Young & Ashley, 2010; Guinane, Bucknall, Currey, & Jones, 2013; Jonsson et al., 2011; Kolic, Crane, McCartney, Perkins, & Taylor, 2015; Ludikhuize, de Jonge, & Goossens, 2011; Massey, Aitken, & Chaboyer, 2009; Massey, Chaboyer, & Aitken, 2013; McDonnell et al., 2013; Mohammed, R, Clements, Smith, & Prytherch, 2009; Niegsch, Fabtitius, & Anhoj, 2013; Odell, 2015; Pantazopoulos et al., 2012; Parham, 2012; Pattison & Eastham, 2011; Petersen, Mackel, Antonsen, & Rasmussen, 2014; Shearer et al., 2012; Smith & Aitken, 2015; Thompson et al., 2007).

Of the twenty-one studies which answered the search question, eight publications focused on comparing various EWSs, of which five studies involved clinical trials (Abbott et al., 2015; Badriyah et al., 2014; Jarvis, Kovacs, et al., 2015a; Jarvis, Kovacs, et al., 2015b; Wheeler et al., 2013), one compared the parameters and trigger scores used in the various EWSs (Psirides, Hill, & Hurford, 2013), and two publications were systematic reviews of the literature (Gao, McDonnell, et al., 2007; McNeill & Bryden, 2013) (See Table 1).

The remaining thirteen studies focused on testing the efficiency of, or validation of EWSs of which two were systematic reviews (Alam et al., 2014; Bleyer et al., 2011; De Meester et al., 2013; Gardener-Thorpe, Love, Wrightson, Walsh, & Keeling, 2006; Kansal & Havill, 2012; Keller et al., 2010; Ludikhuize, Smorenburg, Rooij, & de Jonge, 2012; Mathukia, Fan, Vadyak, Biege, & Krishnamurthy, 2015; Mitchell et al., 2010; Moon, Cosgrove, Lea, Fairs, & Cressey, 2011; Mulligan, 2010; Patel, Jones, Jiggins, & Williams, 2011; Smith et al., 2014) (See Table 2).

Table 1: Studies comparing various Early Warning Systems (EWSs) used for in hospital patient in general wards.

Author	Aim	Method	Setting	Cohort size
Abbott et al. (2015)	Compare NEWS to PARS	Single centre, prospective observational	Medical ward, London Hospital	431 patients
Badriyah et al. (2014)	Compare NEWS to Decision-Tree EWS	Retrospective database analysis of vital signs	Acute medical admissions, UK	35 585 patients
Gao, McDonnell, et al. (2007)	Comparing 25 distinct T&T systems	Systematic review of 26 studies	31 Acute hospitals, UK	7873 patients
Jarvis, Kovacs, et al. (2015a)	Compared 35 published EWSs	Retrospective study of patient record database	Hospital group database, UK	1564,143 vital signs
Jarvis, Kovacs, et al. (2015b)	Compared standard to binary system for 36 EWSs	Retrospective study of patient record database	Hospital group database, UK	1564,153 vital signs
McNeill and Bryden (2013)	Comparing single trigger to aggregated scoring EWSs	Systematic review, 2 studies of single parameter, 4 of aggregated scoring systems	Acute hospitals, UK, USA, Australia.	677 025 patients
Psirides et al. (2013)	Compared 21 aggregated weighted EWSs	Cross-sectional study	Multi-centre, medical wards, NZ	20 district health boards
Wheeler et al. (2013)	Comparing MEWS to HOTEL—T&T	Prospective cohort study	Single centre, medical ward, Malawi	302 patients

Note: NEWS: National Early Warning Score; PARS: Patient at Risk Score; T&T: Track and Trigger; MEWS: Modified Early Warning Score; HOTEL: Hypotension, Oxygen saturation, Temperature, ECG abnormality, Loss of independence

Table 2: Studies involving the efficacy or validation of Early Warning Systems (EWS) for in-hospital patients.

Author	Aim	Method	Setting	Cohort size
Alam et al. (2014)	Impact of EWSs on patient outcomes	Systematic review of 7 studies	Acute hospitals & specialist areas, UK, Italy	486 237 patients
Bleyer et al. (2011)	Validation of MEWS & ViEWS	Retrospective study of all patient vital signs	Large, 872 bed tertiary hospital, USA	42 400 patients
De Meester et al. (2013)	Frequency of patient monitoring before-&-after MEWS implantation	Prospective observational before-&-after study	Medical & surgical wards, tertiary hospital, Antwerp, Belgium	1039 patients
Gardener-Thorpe et al. (2006)	Efficacy of NEWS	Prospective observational study	Single centre, surgical ward, UK	334 patients
Kansal and Havill (2012)	Validation of 'Between-the-Flags T&T'	Retrospective before-&-after study	Single centre, tertiary hospital, Australia	52 000 admissions
Keller et al. (2010)	Efficacy of 'Shock index' in predicting ICU admissions	Retrospective case-controlled study	Single centre Academic medical centre, Minnesota	100 patients
Ludikhuize et al. (2012)	Efficacy of MEWS and staff compliance	Retrospective observational study	Single centre, medical & surgical wards, Amsterdam	204 patients
Mathukia et al. (2015)	Efficacy of MEWS on patient outcomes	Retrospective before-&-after study	Single centre, tertiary community hospital, Pennsylvania USA	3.5 years of data, cohort size not stated
Mitchell et al. (2010)	Effect of MEWS on patient outcomes	Prospective, controlled before-&-after study	Two tertiary academic hospitals, Canberra, Australia	1157 before 985 after
Moon et al. (2011)	Effect of MEWS & CCOS on patient outcomes	Retrospective before-&-after study	Single centre, tertiary academic hospitals, UK	213 000 before 235 000 after
Mulligan (2010)	Efficacy of EWSs & standard obs chart	Prospective validation study	Single centre, Haematology unit Tertiary London hospital, UK	71 patients

Author	Aim	Method	Setting	Cohort size
Patel et al. (2011)	Effect of MEWS on patient outcomes	Retrospective before-&-after study	Single centre, trauma & orthopaedic ward, UK	32 000 patients
Smith et al. (2014)	Ability of EWSs to predict patient outcomes	Systematic review of 17 publications	Tertiary hospitals, USA, UK, Australia, Belgium	200 000 patients

Note: MEWS: Modified Early Warning Score; ViEWS: Vital PAC Early Warning Score; NEWS: National Early Warning Score; T&T: Track and Trigger; CCOS: Critical Care Outreach Service.

Comparative studies of early warning systems

Several variations of EWS have been developed with few researchers undertaking quantitative comparisons of their efficacy under clinical ward conditions. The efficiency of the Modified Early Warning Score (MEWS), widely used to predict SAE (Cei et al., 2009; Subbe et al., 2001), was compared to an easy to use EWS called HOTEL (Hypotension, Oxygen saturation, Temperature, ECG abnormality, Loss of independence) and a cohort-specific system called TOTAL (Tachypnoea, Oxygen saturation, Temperature, Alert, Loss of independence) in predicting hospital mortality (Wheeler et al., 2013). The study showed that under their conditions, HOTEL and TOTAL had a higher sensitivity and specificity than MEWS sensitivity [71% (95% CI: 56.2–82.5) and 77% (95% CI: 62.5–87.2) for HOTEL and TOTAL versus 59% (95% CI: 44.2–72.4) for MEWS, and specificity of 59% (95% CI: 53.0–65.5) and 67% (95% CI: 61.1–73.1) for HOTEL and TOTAL versus 56% (95% CI: 49.8–62.4) for MEWS]. They concluded that the simpler EWS may be better suited for resource-poor hospitals. In a study involving several well-resourced facilities, the efficacy of the UK National Early Warning Score (NEWS) was compared to an entirely algorithmically generated Decision-Tree EWS (DTEWS) using patient data from a large medical records database (Badriyah et al., 2014). Being paper-based, the NEWS is subject to human error and should thus be less reliable than the automatized DTEWS (Badriyah et al., 2014). However, the authors found that since NEWS and DTEWS are very similar in structure, DTEWS was only slightly more effective than NEWS at identifying patients at risk of SAE.

A single centre prospective observational cohort study comparing the efficiency of NEWS to a 'Patient at Risk Score' system (PARS). Abbott et al. (2015) found that the NEWS more efficiently identified medical patients at risk of unplanned ICU admission and of death than the PARS (odds ratio 1.54, $p < 0.001$ compared to 1.42, $p = 0.056$). Further, the authors suggested that the NEWS score of five which triggers a medical review could be lowered to three for that cohort of patients since a score of three or more was associated with poor outcomes. Additionally, every one-point score increase in NEWS is associated with a 55% increase in the risk of patient decline (Abbott et al., 2015).

The efficiency of an EWS is often expressed as its ability to predict an SAE within a given time frame following the monitoring of abnormal vital signs. Jarvis, Kovacs, et al. (2015a) argued that when comparing the efficiency of various EWS, the method of selecting the given set of vital signs could influence the results of the efficiency test as indicated by the Area under the Receiver Operator Characteristic curve, a statistical efficacy test.
The authors tested their theory using three vital signs sampling methods; multiple sets of vital signs; one randomly selected set of vital signs, and one set of vital signs taken at a predetermined time preceding the SAE, and applying them to efficacy testing for 35 published EWSs. They found that the sampling method had minimal impact on the results and that the most effective EWS tested for their patient cohort was NEWS (Jarvis, Kovacs, et al., 2015a). Using the data from the same patient cohort, Jarvis, Kovacs, et al. (2015b) compared 36 different aggregated weighted EWSs. Using the 36 EWSs, they tested the efficiency of calculating the aggregated weighted scores to that of simply applying binary values of zero or one for normal and abnormal vital signs. The authors concluded that the binary system was simpler to use, minimised human error and could efficiently identify at-risk patients, but added to the staff workload due to the high number of false positives which could lead to alert fatigue putting vulnerable patients at risk (Jarvis, Kovacs, et al., 2015b).

Systematic reviews of comparative studies of early warning systems

Gao, McDonnell, et al. (2007) conducted a systematic review of 25 distinct T&T systems used in the UK, of which 15 were single or multiple trigger systems and 10 were aggregated weighted scoring systems. The authors concluded that there was little evidence of the reliability or validity of the various T&T and stated that the systems were only as effective as the staff using them. They did not discourage the use of T&T systems but recommended they be used as an adjunct to good clinical judgement (Gao, McDonnell, et al., 2007). A systematic review comparing two single trigger systems to four aggregated weighted scoring systems concluded that despite the lack of good evidence, the aggregated weighted scoring systems appeared to result in fewer preventable in-hospital mortalities (McNeill & Bryden, 2013). However, the efficient of the EWSs were highly dependent on the staff response and on whether the facility was equipped with a Medical Emergency or Rapid Response Team able to manage the deteriorating patient (McNeill & Bryden, 2013). Clearly one-size does not fit all, the organisational dynamics, level of resourcing, professional skilling and the heterogeneity of the patient cohort in question, will determine the EWS best suited to specific conditions.

Validation of early warning systems

There appear to be three primary methods of validating the efficiency of EWSs: (1) by comparing the EWS scores of patients who experience SAEs with those who have had an uneventful hospital stay; (2) by performing statistical tests such as determining the sensitivity and specificity, or determining the Area Under the Receiver Operator Characteristics Curve for a given EWS; or (3) by comparing patient outcomes in ‘before-and-after’ implementation studies.

Using an electronic database of the patient’s vital signs, Bleyer et al. (2011) validated the MEWS and VitalPAC Early Warning Score (ViEWS). The authors found that patients

who had experienced an SAE had a significantly higher EWS score than those who had an uneventful hospital stay. Bleyer et al. (2011) calculated the likelihood of patient mortality for each abnormal vital sign and concluded that there was a 19 times higher probability of mortality if patients experienced three abnormal vital signs compared to those experiencing only one abnormal vital sign. Although the authors acknowledged that abnormal vital signs were most likely to occur within 48 hours of hospital admission, they stated that abnormal vital signs could occur at any time during the patient's hospital stay which justified the validation of EWS for the duration of hospitalisation.

A single centre retrospective observational study revealed that 81% of patients who experienced an SAE had an aggregated MEWS score of three or more suggesting the need for escalation of care for these patients (Ludikhuize et al., 2012). Unfortunately, the study made no mention of the number of patients with high MEWS scores that had not experienced SAEs, or the MEWS scores for patients who had an uneventful hospital stay. In a retrospective case-controlled study, the 'Shock index (SI) scores of patient who had an unplanned ICU admission was compared to those who had not needed ICU admission (Keller et al., 2010), 'Shock index', a simple system that utilises heart rate and systolic blood pressure as an indicator of left ventricular function, was developed to better identify patients at risk of an unplanned ICU admission. The authors concluded that irrespective of age, race or comorbidities, patient who experienced an unplanned ICU admission had a significantly higher SI score than those that did not ($p < 0.02$, odds ratio, 3.0) and suggested the implementation of SI as a severity of illness indicator (Keller et al., 2010).

Many of the quantitative validation studies of EWSs have been conducted using vital signs taken upon admission (de Pennington et al., 2005; Geier et al., 2013; Jenkins et al., 2011; Lam et al., 2006) or even at pre-admission (Fullerton et al., 2012), but fewer have validated EWSs for in-hospital patients. A prospective study of 334 surgical patients reported that MEWS has a 75% sensitivity and an 83% specificity for predicting unplanned ICU admissions (Gardener-Thorpe et al., 2006). This validated the use of MEWS for this surgical

cohort of patients. An EWS and a standard patient observation chart used in a Haematology ward in a London hospital were validated using all vital signs collected over three months from 71 in-hospital patient (Mulligan, 2010). During the study period, 24% of the patients experienced an SAE. Both the EWSs and the standard observation chart were found to have good sensitivity but poor specificity indication a high level of false positives. Mulligan (2010) suggested that the sensitivity of the EWS could be improved by lowering the threshold scores but that this would inevitably lead to many false alerts and increase the staff workload. The effect of escalating patient care based on a single, versus multiple abnormal vital signs, was found to increase patient deterioration detection by 3% but also increased staff workload by 40% (Jarvis, Kovacs, Briggs, Meredith, Schmidt, & Featherstone, 2015). EWSs are useful tools but they cannot be used as substitutes for good clinical judgement and an overreliance on EWSs can lead to poor decision making and overshadow accountability (Mulligan, 2010; Suokas, 2010). The sensitivity and specificity of EWSs appears to be dependent on the threshold scores implemented, the cohort of patients studied, and the outcomes being measured. In an attempt to minimise human error, Bailey et al. (2013) developed and validated an algorithm real-time-alert system for patients at risk of deterioration on the ward. Although they found that patients meeting the alert threshold were five times more likely to require transfer to ICU and nine times more likely to die, the real-time-alert system did not ultimately improve the patient outcomes. Bailey's system proved to have poor specificity leading to a high proportion of false positives and resulting in alert fatigue. One in eight at-risk patients can trigger an alert per shift, leading to alert fatigue and staff ignoring the alerts, to the detriment of the patients (Tarassenko et al., 2011). It is apparent that the efficacy of any EWS is dependent on establishing the correct threshold scores for a give patient cohort and on the implementation of the appropriate response to minimise the risk of patient deterioration.

A multi-centred 'before-and-after' study of a multi-tiered system, the Compass program which involved the introduction of an EWS, a Medical Emergency Response Team

(MET) and an intensive staff education program, found that the introduction of the system significantly improved the patient outcomes (Mitchell et al., 2010). Unplanned ICU admission decreased by 72% (21/1157 [1.8%] vs 5/985 [0.5%], $p = 0.006$) and unexpected deaths by 82% (11/1157 [1.0%] vs 2/985 [0.2%], $p = 0.03$). The number of MET reviews increased from 2.2% (25/1157) of total admissions to 3.9% (38/985, $p = 0.03$) and the frequency of patient monitoring increased significantly. Mitchell et al. (2010) concluded that the new multi-tiered system empowered nursing staff to better respond to patient deterioration and gave them the confidence to request a medical review. A similar 'before-and-after' study of the program called 'Between-the-Flags' adopted by the New South Wales public health system in 2010 (Kansal & Havill, 2012) found that the introduction of the system resulted in a 50% increase in the number of MET patient reviews and a 16% reduction in SAEs. The incidence of cardiac arrests decreased significantly but unplanned ICU admission and unexpected deaths did not decrease (Kansal & Havill, 2012).

The efficacy of MEWS in identifying at-risk patients was indirectly studied in a large tertiary hospital in Belgian in a 'before-and-after' study (De Meester et al., 2013). The study focused on the frequency of patient monitoring before and after the introduction of MEWS. The authors found that the introduction of MEWS increased patient monitoring resulting in a 40% (95% CI -0.4%–4.67%) reduction in SAEs. Similarly, an Australian study reported an increase of 210% in the frequency of patient monitoring after the introduction of an EWS (Hammond et al., 2013). Careful monitoring of patients resulted in an increase in ICU admissions and improved patient outcomes (Hammond et al., 2013). A 'before-and-after' study at a tertiary hospital in the UK analysed the incidence of SAEs after the introduction of MEWS and a critical care outreach program (Moon et al., 2011). The number of cardiac arrests and unexpected mortality almost halved after the introduction of the new program but unplanned ICU admissions increased greatly. The authors speculated that this may be due to over-cautious staff and suggested that although the system improved patient outcomes it may impact negatively on staff workload and may overtax the ICU services (Moon et al.,

2011). Similar positive outcomes were noted by Mathukia et al. (2015) who observed a doubling in the number of Rapid Response Team reviews and a halving in the incidence of cardiac arrests after the introduction of MEWS. Contrary to this, a seven year study of trauma patients (Patel et al., 2011) found that although the introduction of MEWS lowered the mortality rate in this cohort, the improvement was not statistically significant. Patel et al. (2011) speculating this could be due to the incorrect use of MEWS. Similarly, a systematic review examining the effect of EWSs on nursing proficiency in detecting patient deterioration reported that the EWSs did not have a positive impact on patient outcome (Odell et al., 2009). The authors speculating that this may be due to staff compliance issues (Odell et al., 2009). Two systematic reviews have been conducted involving EWSs and patient outcomes (Alam et al., 2014; Smith et al., 2014). Alam et al. (2014) reviewed seven publications and Smith et al. (2014) reviewed 17 studies. Both authors found that EWSs helped alert staff to patient deterioration but were unable to conclude that the EWSs had a positive impact on patient outcomes due to the heterogeneity of the studies reviewed. While EWSs enhance the medical staff's ability to identify at-risk patients and predict unexpected death and cardiac arrests, there is little evidence that they improve patient outcomes.

Discussion

The use of EWSs is a relatively recent practice with the majority of research coming from Australia, the United Kingdom and the USA. The present scoping review of the literature focuses only on the afferent limb of recognising patients at risk of deterioration. Much of the quantitative published research involves single centre studies aimed at predicting patient decline based on one set of vital signs taken upon admission (Alam et al., 2015; Cei et al., 2009; Cıldır et al., 2013; de Pennington et al., 2005; Duckitt et al., 2007; Frost et al., 2009; Geier et al., 2013; Goodacre et al., 2006; Gottschalk et al., 2012; Groarke et al., 2008; Hosking et al., 2014; Jenkins et al., 2011; Keep et al., 2016; Lam et al., 2006; Olsson et al., 2004; Paterson et al., 2006; Smith et al., 2013; So et al., 2015; Subbe et al., 2003; Subbe et al., 2001; Subbe et al., 2006; Wang et al., 2016).

Although it may be both optimal and cost-effective to identify at-risk patients at the point of admission, clinical deterioration can occur at any time during a patient's hospital stay (Bleyer et al., 2011). For this reason, this scoping review focuses on identifying patients at risk of deterioration in general hospital wards.

The result of this scoping review has shown heterogeneity in study designs, patient cohort and outcomes measured in the various studies, making direct comparisons of EWSs difficult. Clearly, the efficacy of EWSs is dependent in part on the predicted outcomes being measured. Some studies have used in-hospital mortality as the predicted outcome (Cıldır et al., 2013; Patel et al., 2011; Wheeler et al., 2013), while others have used combinations of mortality, cardiac arrests and/or admission to ICU (Abbott et al., 2015; Alam et al., 2014; Badriyah et al., 2014; Mitchell et al., 2010). The predictive ability of the various physiological parameters used in scoring systems and the efficiency of the threshold values implemented can be influenced by underlying medical condition prevalent in the population (Wheeler et al., 2013). Wheeler et al. (2013) advocate the befits of adapting EWSs to suit the patient cohort and the facilities available and suggest that EWSs are most effective in the population in which they were developed. It is apparent that EWSs are well supported by many studies (Abbott et al., 2015; Gao, McDonnell, et al., 2007; Moon et al., 2011; Wheeler et al., 2013) but it has been suggested that the system be tested for the target patient cohort prior to clinical adoption (Wheeler et al., 2013).

There have been several studies on the comparative efficiency of various EWSs, some involving clinical data (Abbott et al., 2015; Bleyer et al., 2011; Jarvis, Kovacs, et al., 2015b; Moon et al., 2011; Mulligan, 2010; Psirides et al., 2013; Wheeler et al., 2013) while others are reviews of existing published studies (Alam et al., 2014; Gao, McDonnell, et al., 2007; McNeill & Bryden, 2013; Smith et al., 2014). Although EWS may assist staff better identify at-risk patients (Alam et al., 2014; De Meester et al., 2013; Hammond et al., 2013; Smith et al., 2014), the systems are only as efficient as the staff employing them and the availability of resources within the facilities to respond to clinical deterioration (Gao,

McDonnell, et al., 2007; McNeill & Bryden, 2013). Abnormal vital signs can occur at any time during a hospital stay but patients with three or more concurrent abnormal vital signs which trigger EWS alerts have a poorer prognosis (Bleyer et al., 2011). Regardless of the system used, patients that trigger high EWS scores are more likely to suffer an SAE than patients with lower scores (Bailey et al., 2013; Keller et al., 2010; Ludikhuize et al., 2012). While the ability of EWS to identify at-risk patients can be increased by lowering the threshold scores, this may lead to many false alerts, increase staff workload and placing patients at risk due to alert fatigue (Jarvis, Kovacs, et al., 2015b; Mulligan, 2010). There is little doubt that the introduction of EWSs has improved the staff's awareness of the deteriorating patients (Kansal & Havill, 2012; Mitchell et al., 2010) which may be due partly to increased monitoring of at-risk patients (De Meester et al., 2013; Hammond et al., 2013). However, over-caution staff may lead to the overtaxing the ICU system (Moon et al., 2011) and the Rapid Response Teams (Mathukia et al., 2015).

The success of EWSs may be dependent on staff attitude (Lippert & Petersen, 2013; Parham, 2012; Pattison & Eastham, 2011; Petersen et al., 2014; Shearer et al., 2012). A multi-method study that explored the causes of failure to activate the rapid response system revealed that despite the introduction of EWSs and emergency response teams in many public hospitals, 80% of SAEs remain preventable and almost 14% of deteriorating patients are not appropriately treated (Shearer et al., 2012). The main reason for the lack of appropriate action includes staff thinking they have the situation under control; fear of reproach; inadequate patient monitoring; and poor communication (Shearer et al., 2012). A better understanding of the socio-cultural barriers within the facilities may help alleviate the problem (Shearer et al., 2012). Failures of the afferent limb in managing patient deterioration may be attributed to staff reluctance to make an MET call due to intra-professional hierarchical issues in medical facilities, as opposed to their inability to recognise patient deterioration (Lippert & Petersen, 2013; Pattison & Eastham, 2011; Tirkkonen et al., 2020). No matter how effective the EWS, 20% of MET calls are not made in a timely fashion

(Parham, 2012) and EWS protocols are not being followed in 40% of the cohort studied (Petersen et al., 2014). Since EWSs are only as effective as their operators, significant attention has been given to the human aspect of EWS chart design (Christofidis et al., 2015; Christofidis et al., 2013; Horswill et al., 2010) but without adequate staff education and buy-in, the efficiency of the EWSs remains uncertain. It takes years for such systems to be optimally utilised since the staff need time to gain an understanding of the system and confidence in its reliability (Santamaria, Tobin, & Holmes, 2010). Without doubt, EWSs are useful in aiding staff to identify at-risk patients but they cannot replace good clinical judgement and clinical skills (Fullerton et al., 2012; O'Donoghue et al., 2011). Although EWSs have been shown to reduce in-hospital SAEs (Avard et al., 2009; Bleyer et al., 2011; Hammond et al., 2013; Keller et al., 2010; Mathukia et al., 2015; Moon et al., 2011), many studies have found that EWSs have not conclusively improved patient outcomes (Bailey et al., 2013; Gao, McDonnell, et al., 2007; Kansal & Havill, 2012; Odell et al., 2009; Patel et al., 2011).

Limitations and Recommendations for Future Studies

This scoping review is a broad overview of published works involving the use of the patient bedside observation chart, the afferent limb of the EWS, to aid in the identification of clinical deterioration. It is by no means an exhaustive or in-depth review but aims to give the reader a general impression of the efficacy of such systems in minimising preventable patient deterioration. The heterogeneity of the patient cohorts and methodologies employed in the various studies considered makes direct comparisons of their results difficult and statistical analysis thereof unfeasible. Also, since no consideration was given to the efferent limb of the EWSs, this scoping study is only a partial representation of an EWS. It is recommended that a more in-depth literature review be conducted on the efficacy of the EWSs and that due consideration is given to the role of the efferent limb in the identification and treatment of the deteriorating patient.

Conclusion

There is a lot of anecdotal evidence but limited good quantitative evidence that EWSs improve in-hospital patient outcomes. Although it is not possible to identify the best EWS for all situations, aggregated weighted scoring systems appear to be most commonly used. The efficacy of EWSs, as determined through statistical testing, is highly variable since it is dependent on the threshold scores implemented, the outcomes being measured and the cohort in question. There is little doubt that the implementation of an EWS helps to identify in-hospital patients at risk of SAEs but since the efficiency of the system is dependent on its users, the contribution of the nurses and doctors must never be ignored.

Chapter Summary

The scoping review revealed numerous EWSs in use throughout the world, and there is little consensus as to which EWS is most effective. There is, however, general agreement that the EWSs do support staff in identifying deteriorating patients and guide the escalation of timely patient care. The majority of studies have been conducted in larger well-resourced settings, with limited reference to poorly resourced regional/rural facilities. Further, the review highlighted the benefits of adapting and testing existing EWSs specifically for the target patient cohort before implementing them in the clinical context. Hence, it became apparent that the lack of EWS efficiency studies for poorly resourced facilities is where the knowledge gap resides. This review guided the study's conceptualisation, the development of its overarching aim and its research questions. In response to the findings of this scoping review, the study's overarching aim was established; to provide evidence of the efficiency of various EWSs to assist poorly resourced regional/rural hospitals in making informed decisions when selecting EWSs for implementation. Since the scoping study included published literature preceding 2017, contemporary studies have been included in the successive chapters of the thesis.

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Chapter 3. General Methods

Synopsis

This chapter introduces the general method chosen to address the research questions. From the scoping review presented in Chapter 2, it is apparent that most Early Warning Scores (EWSs) were developed and tested in well-resourced metropolitan hospitals, that is, well-equipped hospitals with medical emergency teams on call 24 hours a day. In the scoping review, Chapter 2, a recommendation was made that the EWSs be tested for a specific patient cohort or facility before implementation. The current study aimed to provide evidence of the efficiency of various EWSs to assist poorly resourced regional/rural hospitals make informed decisions when selecting EWSs for implementation. This is primarily achieved by undertaking a quantitative comparative study of the efficiency of various existing EWSs using data derived from patients in two poorly resourced regional hospitals. The study design involved a retrospective chart audit with nested case-controlled studies. This chapter intends to provide the reader with a methods overview of the whole study to supplement the methods detailed within each thesis chapter. For this reason, there may be some level of content repetition.

Research Method and Appropriateness of the Study Design

This study sought to contribute evidence to assist poorly resourced regional/rural hospitals make informed decisions when choosing an EWS for implementation. This is primarily achieved by testing existing EWSs to identify which EWS or class of EWS is most efficient at triggering an alert at the appropriate time, that is, during a clinical deterioration event. The efficacy of the EWSs is tested by applying existing patient data to report the number of true and false alerts as expressed through quantitative sensitivity and specificity analyses. Sensitivity and specificity are commonly used as quantitative means of assessing EWS efficiency (Ahn et al., 2020; Churpek, Yuen, & Park, 2014; Romero-Brufau et al., 2014; Shearer et al., 2012). However, comparing the actual number of true and false alarms

generated by the EWSs is not often considered in EWS efficiency studies but is important, because it has a direct bearing on the staff workload (Jarvis et al., 2015a).

The positive paradigm adopted for this study aligned with the hypothetico-deductive model of scientific research. Simply put, the hypothetico-deductive model entails proving or disproving a hypothesis through the collection of data derived either through observation or experimentation (Sprenger, 2013). Positivism involves confirming a hypothesis, often involving a causal relationship or explanatory associations, through objective data collection, analysis, and interpretation (Park, Kong, & Artino, 2020; Ryan, 2018). In the current study, the hypothesis proposes that one of the EWSs being compared will prove superior and well suited for use in the target hospitals. Unlike qualitative studies, where a theory emerges from the data collected, in quantitative positivistic studies, the researcher commences with a hypothesis and accrues data to prove this hypothesis (McGregor, 2017). That is the intention of the current study, and thus, a quantitative study design is thought appropriate.

Unlike qualitative research, quantitative studies do not usually focus on methodologies but employ various statistical methods in analysing the data collected (McGregor, 2017). Using numerical data, the researchers distance themselves from the participants or information collected and theoretically encourage greater objectivity (Quick & Hall, 2015). Although numbers convey a sense of authenticity and accuracy, there is a risk that the data from which these numbers are derived may be invalid or unreliable (Patton, 1999). It is, therefore, imperative that the data collection method be carefully considered to maximise the quality of the end result. A prospective study would allow for real-time data collection giving the researcher good control over the quality of the data being collected, how the data is collected, and the suitability of each participant considered for inclusion in the study (Sarkar & Seshadri, 2014). Prospective studies are generally regarded as more rigorous and with less source bias than retrospective studies (Bitektine, 2008; Hess, 2004; Kaushal, 2014). Several EWS efficiency studies have utilised prospective methods, but these studies tend to involve single study sites in large tertiary hospitals (Duckitt et al., 2007;

Gardner-Thorpe, Love, Wrightson, Walsh, & Keeling, 2006; Geier et al., 2013; Gottschalk, Warner, Burch, & Wallis, 2012; Lam et al., 2006; Subbe, Kruger, Rutherford, & Gemmel, 2001). However, given the sparsity of clinical deterioration events in small regional private hospitals, the multi-site data collection and the allocated time constraints, a prospective study was not a feasible option for the current research. Since it was not viable to simultaneously test, through implementation, numerous EWSs in resource-poor hospital settings, it was considered appropriate to apply existing patient data to the various existing EWSs. Retrospective study designs are commonly used in EWS validation research, and its application will facilitate meaningful comparisons of the current study with existing published works (Forster, Housley, McKeever, & Shaw, 2018; Green et al., 2018; Keep et al., 2016). Hence, a retrospective study design using existing patient data was deemed most appropriate.

Retrospective chart reviews are commonly used for obtaining medical research data, comprising between 15% to 25% of all papers published in medical emergency journals (Siems et al., 2020). It has also been referred to in the literature as patient record reviews, chart audits, medical record reviews and health record reviews (Gearing, Mian, Barber, & Ickowicz, 2006; Madden, Lydon, Curran, Murphy, & O'Connor, 2018; Vassar & Holzmann, 2013). One of the main advantages of obtaining research data through a chart review is the relatively low cost of data abstraction since the data is readily available, having been previously collected. Retrospective chart reviews are most appropriate when there is a long latent period between disease exposure and outcomes, and in cases of rare occurrences (Gearing et al., 2006), such as unexpected clinical deterioration events. Further advantages of a retrospective study design are that such studies usually require less time to achieve results, require few resources since the data already exists, and are cheaper to run than prospective studies (Bauman, Jackevicius, Zillich, Parker, & Phillips, 2019; Kaushal, 2014). Retrospective studies minimise recall bias, reduces the need for intrusive patient

assessments, and usually allows access to large amounts of existing data (Sarkar & Seshadri, 2014).

Retrospective chart reviews have been criticised because of a potential lack of scientific rigour in the data collected (Hess, 2004, Kaushal, 2014; Sedgwick, 2014). Specifically, patient charts typically contain data that is difficult to interpret, missing or incomplete. However, since the data collected in the current study involves objective numerical values, patient vital signs, rather than subjective, descriptive information, the retrospective study design is regarded as having appropriate scientific rigour (Siems et al., 2020). A further limitation of utilising retrospective data is that cause and effect can only be hypothesised and not proven (Bauman et al., 2019). However, since the current study involves associations rather than cause and effects, a retrospective study design was well-suited to the study. Considering these identified limitations of a retrospective study design, it was important to identify a structured chart review methodology that facilitated systematic and rigorous data collection and analysis processes consistent with a positivist paradigm.

A conception framework was sought that provided consideration to the appropriateness of the data relative to the research question, the data abstraction process, the method of analyses, and in addressing data inconsistencies. A conceptual, rather than a theoretical, framework was sought since a conceptual framework describes existing knowledge, identifies knowledge gaps and defines the intended research methodology (Varpio, Paradis, Uijtdehaage, & Young, 2020). In addition, the conceptual framework explains why the research is important and how it will contribute to new knowledge (Varpio et al., 2020). As more insight is gained, the conceptual framework evolves as the research progresses. Such a conceptual framework was found in Gearing's Framework for conducting a retrospective chart review (See Table 3) (Gearing et al., 2006). Other conceptual frameworks were considered and rejected when identifying Gearings Framework as most appropriate for the current study.

Sarkar and Seshadri (2014) suggest a six-step process in conducting a clinical record review. This framework was rejected given its narrow focus on the data abstraction process and its lack of consideration in developing the study aim and research questions. Vassar and Holzmann (2013) and Gearing's frameworks are very similar. Both include conceptualising the research question, conducting a literature review to formulate the research aims and developing the research proposal. Also, both frameworks discuss developing the data abstraction protocols and tools, data abstraction, establishing the data analysis method, including defining the study cohort and sample size, and establishing methods of managing inconsistencies in the extracted data (Gearing et al., 2006; Vassar & Holzmann, 2013). The Gearing framework has the advantage of also addressing ethical approval and emphasises conducting a pilot trial (See Table 3) (Gearing et al., 2006).

Table 3: Gearing's nine steps of conducting a retrospective chart review (Gearing et al., 2006).

Steps of Gearing's Framework
1. Conceptualising the research question and generating a clear hypothesis.
2. Conducting a literature review to formulate the research aims.
3. Developing the research proposal.
4. Developing the data abstraction instrument.
5. Developing the data abstraction protocols and guidelines.
6. Data abstraction, including training the abstractors.
7. Establishing the data analysis method including defining the study cohort and sample size, develop methods of managing inconsistencies in the extracted data.
8. Obtaining ethical approval.
9. Conduct a pilot trial.

As per Gearing's first and second steps in developing a retrospective chart review for data abstraction (Gearing et al., 2006), in the current study, careful consideration was given to the research question by commencing the study with a scoping review of the literature (Le Lagadec & Dwyer, 2017). According to Vassar and Holzmann (2013), one of the possible shortcomings of a retrospective study design is a failure to develop a well-defined research question. In the current study, this was addressed by first conducting a scoping review of the

literature to identify the gaps in knowledge. Following the scoping review, the research questions were clearly defined by carefully considering whether the research questions would achieve the study aims. Establishing the research question enabled developing the research proposal, as per Gearing's third step (Gearing et al., 2006). Developing the research proposal required a good understanding of the compilation of the patient health records and the hospitals' medical records storage systems (Siems et al. 2020), made possible by the researcher's working knowledge of each hospital's documentation system. The research proposal was peer-reviewed and approved by the CQUniversity Office of Research (See Appendix A).

Steps four and five of Gearing's Framework involved developing a data abstraction protocol and tool (Gearing et al., 2006). These steps addressed the identified data collection limitations associated with retrospective chart review designs (Vassar & Holzmann, 2013). The scoping review identified data abstraction methods used in similar studies and informed their possible application in the present study. The sampling methods employed in the current study were based on those used in similar previous studies (Keller et al., 2010; Kirkland et al., 2013; Mora et al., 2016; Skaletzky, Raszynski, & Totapally, 2012). The developed data extraction tool, utilising an Excel spreadsheet, was pilot tested before the commencement of the study and validated in an independent study (Dwyer et al., 2019).

A lack of clearly defined inclusion and exclusion criteria have the potential to compromise the validity and reliability of retrospective studies (Vassar & Holzmann, 2013). Consequently, Gearing's sixth step of the retrospective chart review process involves developing rigour in the data abstraction process (Gearing et al., 2006). Therefore, the patient inclusion/exclusion criteria and a working definition of study outcomes (refer to 'Defining Unexpected Clinical Deterioration Events' below), as informed by past studies, were developed (Adelstein, Piza, Nayyar, Mudaliar, & Klineberg, 2011; Lee et al., 2008). To further minimise interpretation errors in data abstraction, a single data abstractor, the author, was used for Cohort A (See Table 4 for the patient cohort description). Since the data from

Cohorts B and C were obtained from 13 physically distant, independent hospital sites, multiple data abstractors were involved. To ensure inter-rater reliability with data abstraction across the multiple study sites, a data abstraction manual, including a video recording, was developed, and the abstractors were carefully trained to ensure consistency in data abstraction.

When determining the data analysis methods, Gearing's seventh step (Gearing et al., 2006), careful consideration was given to the study's aims, the nature of the data collected, and the analysis methods used in past EWS efficiency studies. The appropriateness of the data analysis was in accordance with similar previously published studies (Alam et al., 2015; Campbell et al., 2020; Martín-Rodríguez et al., 2020). Careful consideration was given to the study sites and patient cohorts included in the study (ee Figure 3). Retrospective patient chart reviews have limitations regarding the quality of the data available and the data abstraction process (Dworkin, 1987; Pan, Fergusson, Schweitzer, & Hebert, 2005; Vassar & Holzmann, 2013). Data quality issues can include incomplete or inaccurate documentation, the inability to verify the information recorded, and variability in the quality and interpretation of the information documented (Dworkin, 1987; Pan et al., 2005). While issues relating to inaccurate or incomplete documentation cannot be rectified retrospectively, in the present study, the impact of poor quality or missing data was reduced by optimising the data collected for each patient. Consistent with ethical approvals, hard copies of the patient vital signs observation charts and/or medical notes were collected and reviewed. Where appropriate, patient admission and outcome measures were cross-referenced using the hospitals' patient management systems and incidence reporting systems.

Before commencing the study, ethical approval and research governance were obtained for each study site (HREC/16/MHS/30, H16/04-087 HREC and HREC/17/QGC/273) as per Gearing's eighth step in conducting a retrospective chart review (Gearing et al., 2006). Gearing's ninth step involves conducting a pilot trial. Before the commencement of the current study, a pilot trial was conducted at one of the study sites

using the abstraction tool developed. A few logistical issues were identified. For example, workspace limitations in the medical records storage area required that most data collection be carried out after hours and on weekends. Other issues encountered included patients flagged as having experienced an unexpected clinical deterioration event sometimes had no documentation indicating the time and nature of the events. Decisions had to be made regarding the suitability of these patients in the study cohort. During the pilot trial, the data abstraction tool was further refined to optimise the data collection process.

Given that the current study intended to ascertain the efficiency of various EWSs by comparing the number of true and false alerts generated, the study cohort required the inclusion of both patients that experienced unexpected clinical deterioration events and those that did not. This implied conducting a case-control study. A case-control design was selected for both Phases 1 and 2 of the current study since this design is well suited to studies involving outcomes (Setia, 2016) and is commonly used in EWS efficiency studies (Cretikos et al., 2007; Keller et al., 2010; Mora et al., 2016; Skaletzky et al., 2012). The case-control study design makes the following assumptions (1) that the two patient groups, cases and controls, differ only in their outcomes, in this study, an unexpected clinical deterioration event or an uneventful hospital stay, (2) the potential for the disease (clinical deterioration) is similar in both patient groups, and (3) greater exposure amongst the cases, in this study, physiological abnormalities would increase the risk of a deterioration event (Hess, 2004). Since the current study does not involve a disease per se but an unexpected clinical deterioration event, the patient's vital signs are used to measure exposure. One of the disadvantages of the case-control study design is the risk of selection bias (Hess, 2004; Sedgwich, 2015). To minimise this risk, the study cohort must be well defined, and the cases accurately matched to the control group (Cole et al., 2011; Setia, 2016). This bias may be magnified by the rarity of the cases (Cole et al., 2011), namely, patients that suffer an unexpected clinical deterioration event in these poorly resourced private hospitals. In the present study, the cases were well defined and selected based on strict criteria. The cases,

referred to as the index patients, were carefully matched to the control patients, who had an uneventful hospital stay. Matching was based on the patient demographics and diagnostic information and by medical facility and ward. Where possible, they were also matched to a treating physician/surgeon, and their admission dates were accorded as closely as possible. Case-control studies cannot establish the prevalence/incidence of the event/condition (Setia, 2016). Since the prevalence of patient deterioration events is central to the current study, this shortcoming of the study design was circumvented by identifying and accessing the medical records of all patients in Cohort A thought to had suffered a deterioration event (index patients) at the study sites over the prescribed study period. The number of index patients in Cohort A was compared to the total hospital admissions over the same period. This comparison enabled the researcher to determine the incidence of unexpected clinical deterioration events for the study sites over the 3.5-year study period. Considering the available resources, implementing a case-controlled study using a retrospective chart review method was thought to be the most appropriate study design for Phases 1 and 2 of the current research.

Study Sites and Cohorts

The study consists of 15 independent study sites and three patient cohorts, each comprising index and control patients. All data were collected retrospectively and included both index patients, those with a documented unexpected clinical deterioration events, and matched control patients with an uneventful hospital stay. Patient data for Cohorts A, extracted from two small private hospitals, were used to test existing EWS and develop a new EWS (reported in Chapters 4, 5 and 6). Cohorts B and C, patient data from 13 public hospitals, were used to support the development and validation of the newly developed EWSs (reported in Chapter 6). These three cohorts and the study sites are presented in Figure 3 and Table 4. The final cohorts were:

- Cohort A—Small regional private hospitals (n = 331, 2 sites)
- Cohort B—Small regional/rural public hospitals (n = 288; 7 sites)
- Cohort C—Large regional/metropolitan public hospitals (n = 2278; 6 sites)

The author of this study was the data collector for the two private hospital study sites, while multiple researchers were employed as data extractors for the remaining 13 public hospital sites. The decision to enlist multiple data extractors was influenced by the logistics of costs associated with travel to the distant study sites and time required for manual data extraction and constraints of the PhD.

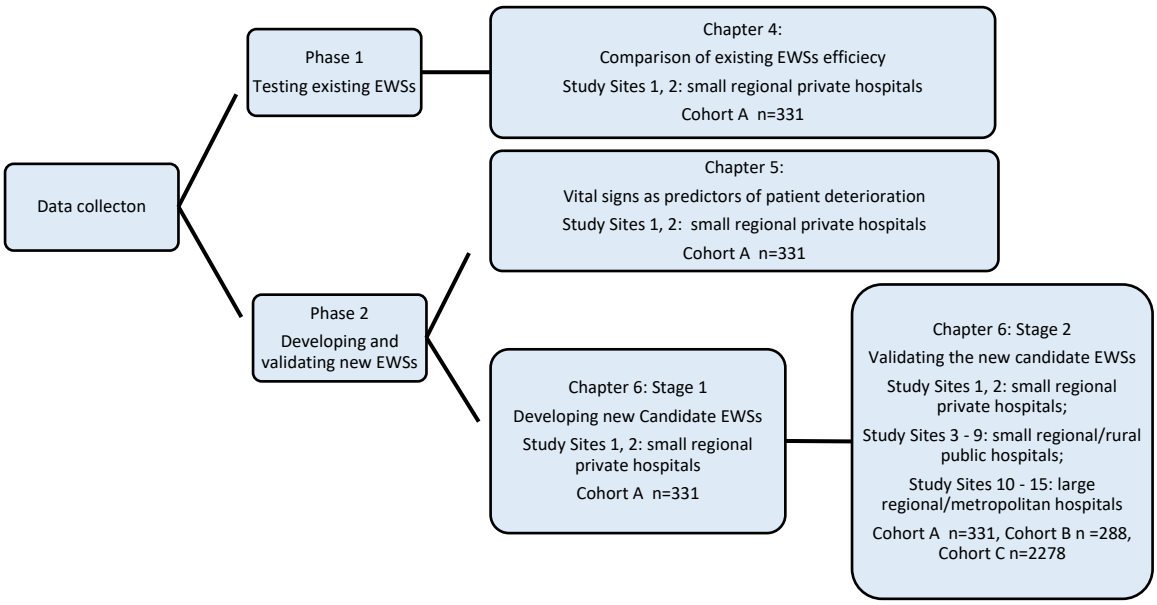

Figure 3: Data collection study sites and patient cohorts in relation to the thesis structure.

Patient Cohort A originated from two small regional private hospitals, a 59-bed hospital (Site 1) with around 6 500 admissions per year of which approximately 2 000 patients are admitted who stayed in hospital for more than 24 hours; and a 140-bed hospital (Site 2) with about 14 400 annual admissions of which 3 500 are admitted to the in-hospital wards. Study Site 1 adopted a single trigger EWS in September 2015. Site 2 trialled a combination system in some of its wards in late 2012, but the use of the EWS was intermittent, as seen in the patients' medical charts during the data collection period. These small regional hospitals have no residential medical officers, Medical Emergency Team (MET), Rapid Response Team (RRT) or similar, no emergency department and no intensive care units (ICU). Both hospitals have close observation units for severely ill patients. Patients requiring ICU care are transferred to external facilities. Because the study sites do not have a dedicated Medical Emergency or Rapid Response Team, all available nursing staff and medical officers present respond to emergency calls. The nursing staff initiates most emergency calls.

Data derived from patient Cohorts B and C were used in the second stage of Phase 2 of the study (Chapter 6) to validate newly developed EWSs (See Figure 3). These data were obtained from an independent study and not initially intended for use in the current study (Dwyer et al., 2019). Cohort B represented patient data derived from seven small regional/rural public hospitals with bed numbers ranging from fewer than 50 to 100 beds each and no ICU or medical emergency response teams. Cohort C data were obtained from six large, well-resourced regional/metropolitan, public hospitals with between 200 to more than 500 beds each, and specialised medical emergency response teams and well-appointed ICUs.

In all three patient cohorts, patients with a documented deterioration event (index patients) were demographically and diagnostically matched with control patients from the same hospital and ward who had an uneventful hospital stay. Matching was carried out by approximate age, gender, hospital, inpatient ward, primary diagnostic groupings and, where

possible, admitting medical officer and approximate admission date. For all cohorts, the study subject exclusion criteria included obstetric patients, those under 17 years of age, patients with a 'not for resuscitation' order and patients who spent less than 24 hours in a hospital.

Table 4: Characteristics of the study sites and patient cohorts used in the study

	Cohort A	Cohort B	Cohort C
Retrospective paper-based data	Yes	Yes	Yes
Data collection period	June 2014–Sept 2017	Sept 2016-Oct 2017	Sept 2016-Oct 2017
Number of hospitals	2	7	6
Patient Cohort	331 patients	288 patients	2 278 patients
Hospital size	59 and 140 beds	< 100 beds	> 200 beds
MET at facility	No	No	Yes
ICU at facility	No	No	Yes
Hospital Location	Regional	Regional/Rural	Regional/Metropolitan
Private/public sector	Private	Public	Public
Outcomes measured (Unexpected clinical deterioration event)	Emergency calls, cardiopulmonary arrest, unplanned transfer to higher level care, unexpected death	Transfer to higher level care, usually out of the facility	Medical Emergency Team Review (MET)

Defining Unexpected Clinical Deterioration Event

The current study's success depends on the accurate identification of the target patient outcome, that is, patients with a documented, in-hospital unexpected clinical deterioration event. Most studies involving EWSs utilise Severe Adverse Event (SAE) as the measurable patient outcome. However, an SAE is a broad term generally defined as iatrogenic injury/event that can result in harm or even the death of a patient (Wilson et al., 1995). Broadly, SAEs within the EWS literature are defined as; cardiac arrests (Custo & Trapani, 2020; D'Arrigo et al., 2017), unplanned transfers to an intensive care unit (ICU) (Abbott et al., 2015; Alam et al., 2015; Redfern et al., 2018), unexpected deaths (Alrawi et

al., 2013; Cetınkaya, Koksal, Sigirli, Leylek, & Karasu, 2017; Cıldır et al., 2013; Douw, Huisman-de Waal, van Zanten, van der Hoeven, & Schoonhoven, 2017; Moore et al., 2017), an emergency call (Bailey et al., 2013) or a combination of any of the above (Churpek, Yuen, & Edelson, 2013; Esmonde et al., 2006; Green et al., 2018; Hong et al., 2013; Pimentel et al., 2019). The current study describes the target outcome as having experienced an unexpected clinical deterioration event rather than an SAE. The reason being, one of the inclusion criteria for the target group is transferred to a higher level of care, which typically means transfer to another hospital as opposed to transferring to an ICU. The smaller regional/rural study sites in the current study usually have high dependency units but no ICUs. If intensive care is required, the patients are transferred to a better resourced external facility. It can be argued that transferring a patient to a higher level of care is an action taken to prevent an SAE and is not an SAE per se.

Given that small regional and rural facilities are not homogenous in relation to available resources, the outcomes criteria, unexpected clinical deterioration events, are not the same for all three patient cohorts (See Table 4). Since Cohort A included patients from two small private facilities with relatively low admission numbers, a broad definition of unexpected clinical deterioration was utilised to maximise the number of patients included in the study. This included patients who suffered a cardiopulmonary arrest, those transferred to a higher level of care, patients who experienced a medical emergency call or those that died unexpectedly. The definition of unexpected clinical deterioration for Cohorts B and C was narrower (See Table 4) given the many study sites involved, generating a sizable patient database from which the cohorts were derived. Cohort B included patients from small regional/rural public facilities with no dedicated medical emergency teams or ICUs. In such facilities, deteriorating patients are usually transferred to a higher level of care, often to a larger, better-resourced facility. Hence, for Cohort B, an unexpected clinical deterioration event was defined as patients transferred to an external facility to a higher level of care. Cohort C included patients from large regional/metropolitan hospitals with dedicated medical

emergency teams and well-appointed ICUs. The medical emergency teams respond to all emergency events, and thus an emergency call was the logical choice as the unexpected clinical deterioration event criteria for this patient cohort.

Data Collection

Patient Cohort A

Patient Cohort A was used in both Phase 1 and 2 of the study. A single data abstractor was used to identify the study cohort and collect patient data. For this cohort, the study subjects were identified using the hospitals' incidence reporting system, 'RiskMan', using the keywords: patient deterioration, deceased, emergency calls, transfer to a higher level of care and respiratory/cardiac arrest. Also, the hospitals' patient management systems, 'WebPAS' was used to identify all patients transferred to other facilities between June 2014 and December 2017 and cross-referenced with the ambulance transport request register. Also, the hospital's registry of in-hospital deaths was checked, and the events leading to the patient's demise were verified using the patient's medical records. The medical records of all potential index patients were reviewed for their inclusion suitability. The control patients were then matched to the index group using WebPAS and checked for inclusion suitability by reviewing their medical records. All patient data were de-identified and captured on a database on-site. The vital sign data was obtained from the patients' bedside observation charts as recorded by the nursing staff. The data recorded included blood pressure, heart rate, respiration rate, oxygen saturation as determined by a pulse oximeter, supplementary oxygen flow rate, body temperature, pain score using a pain scale of 0 to 10, and level of consciousness. The level of consciousness was recorded as alert (A), responding to voice (V), responding to pain (P) or unresponsive (U). Since the patients' normal baseline vital signs were not documented, the first set of vital signs collected on hospital admission or pre-admission was used. All documented vital signs were collected for approximately 72 hours preceding the unexpected clinical deterioration event for the index

patients or preceding hospital discharge for the control patients. The nature and time of a deterioration event were determined by examining the medical emergency call documentation or combining the most abnormal vital signs recorded in the patient observation chart and reviewing the patients' medical notes and pathology results. The patient's demographic data was obtained from the patient records and included age, gender, length of stay, body mass index when available, primary diagnostic groupings, comorbidities, admission and discharge dates, admitting hospital and inpatient unit. Body mass index was included as a point of interest. The primary diagnostic grouping was loosely based on the Society of Critical Care Medicine (1999). Comorbidities were scored using the Charlson comorbidity index (Charlson, Pompei, Ales, & MacKenzie, 1987; Charlson, Szatrowski, Peterson, & Gold, 1994). The Charlson comorbidity score was included to ascertain whether patients experiencing unexpected clinical deterioration events suffered more chronic illnesses than patients with uneventful hospital stays.

Patient Cohorts B and C

Cohorts B and C were used in the second stage of Phase 2 of the study (Chapter 6). Since Cohorts B and C originate from an independent study, the data collection method described below is derived from that study (Dwyer et al., 2019). Cohorts B and C were identified using the Emergency Department Information System (EDIS) and Hospital-Based Corporate Information System (HBCIS) software. The patient's medical records were tracked by their Unit Record Number (URN) and admission dates. All patient data were de-identified, and the vital sign observation chart was scanned into secure password-protected laptops to be entered into Excel spreadsheets by trained data abstractors. Multiple data abstractors were utilised in the data collection and capturing process. The abstractors were trained and provided with a procedural manual and a training video to ensure consistency of data capturing. The accuracy of the data capturing process was verified using an independent auditor. The same vital sign data and demographic data were collected for Cohorts A, B and C. However, given the multiple study sites and the large number of patient records

associated with Cohorts B and C, only four sets of vital sign data were collected per 24-hour period preceding the unexpected clinical deterioration event, in time increments as close to 6 hourly as possible.

Early Warning Scores Compared

In Phase 1 of the study (See Chapter 4), 12 existing paper-based EWS vital sign observation charts were compared (See Table 5) using patient data from small, poorly resource private facilities. These 12 EWSs were again applied in the second stage of Phase 2 of the study (See Chapter 6) to test the newly developed EWS. These 12 EWS, at the commencement of the study, represented the more commonly used EWSs in Australian medical facilities. The EWSs included in the study are used in general medical and surgical wards except for the Queensland Maternity Early Warning Tool (Q-MEWT). Q-MEWT is a specialised chart used in some post-natal wards and was included because it is one of the few EWSs that includes diastolic blood pressure as an independent trigger. Although obstetric patients were excluded from this study, Q-MEWT was included to ascertain the value of diastolic pressure as an independent trigger. Also, the Q-MEWT trigger rangers of some of the vital signs are markedly different to those used in other EWS included in this study. The British National Early Warning Score, NEWS, was included as an international comparison for the Australian EWSs and is also used in some Australian hospitals. Three of the EWSs included were single trigger EWSs, seven were combination systems—single trigger and aggregated weighted EWSs, and two EWSs, Compass and NEWS, are aggregated systems. Although Compass and NEWS have a single trigger component, the single parameter (vital sign) does not trigger an emergency call/alert but prompts a medical officer review (Avard et al., 2011). In the EWSs, the staff actions elicited by the abnormal vital signs are colour coded with increasing urgency, usually from yellow, orange, red, to purple, with the purple warranting a medical emergency team review. In the aggregated and combination EWS, the colour codes are linked to numerical values that are either used

singly or aggregated to a total score, which dictates the staff response. The vital sign ranges related to each colour code for the various EWSs are shown in Table 6.

Table 5: Early Warning Score vital sign observation charts compared in Phase 1 and in stage 2 of Phase 2 of the study.

Early Warning Score	Implementation	Type of EWS
Between-the-Flags (BTF)	New South Wales Public Hospitals, Australia	Single trigger, two-tiered response EWS
Adult Observation and Response Chart, v9 (ARC)	Mercy Health and Aged Care, Central Qld, Australia	Single trigger, four-tiered response EWS
Adult Observation and Response Chart, v2 (ARC_2)	Australian Commission on Safety and Quality in Health Care, Australia	Single trigger, two-tiered response EWS
Mater Adult Deterioration Detection System (MADDS)	Mercy Health and Aged Care, Central Qld, Australia	Single and aggregated weighted score systems, three-tiered response
Mater Adult Deterioration Detection System, v2 ($MADDS_2$)	Mercy Health and Aged Care, Central Qld, Australia	Single and aggregated weighted score systems, four-tiered response
Mater Adult Deterioration Detection System, v5 ($MADDS_5$)	Mercy Health and Aged Care, Central Qld, Australia	Single and aggregated weighted score systems, three-tiered response
Queensland maternity early warning tool, v3 (Q-MEWT)	Queensland Health Public Hospitals, Rural and remote facilities	Single and aggregated weighted score systems, four-tiered response
Queensland Adult Deterioration Detection System, v5 (Q-ADDS)	Queensland Health Public Hospitals, Tertiary and secondary facilities	Single and aggregated weighted score systems, four-tiered response
Queensland Adult Deterioration Detection System with BP scale, v6 (Q-ADDS + BP scale)	Queensland Health Public Hospitals, Tertiary and secondary facilities	Single and aggregated weighted score systems, four-tiered response
Adult Deterioration Detection System, v2 (ADDS)	Australian Commission on Safety and Quality in Health Care, Australia	Single and aggregated weighted score systems, four-tiered response
Compass (an education package with an EWS)	ACT Government Health, Australia and Northern Territory Hospitals, Australia	Aggregated weighted score systems, three-tiered response
National Early Warning Score, v2012 (NEWS)	Royal College of Physicians, British Hospitals	Aggregated weighted score systems, three-tiered response

Calculating the Early Warning Scores

Consistent with the developed data extraction protocol, an abstractor manually transposed the patients' data from the paper-based vital sign observation charts onto a Microsoft Excel spreadsheet. Each EWS included in the study was allocated a separate spreadsheet linked to the raw vital sign data spreadsheet. The vital sign weighted scores were calculated for each EWS using the Microsoft Excel logical test 'IF' function.
For example, a respiration rate of 26 breaths/min would score a 1 for Q-ADDS and a 3 for Compass. For the single trigger EWSs that utilise colour coding only (BTF, ARC and ARC_2, See Table 5), scores were allocated to the colours comparable with those used in the weighted EWSs. The highest individual vital sign weighted score for each set of observations was used for the single trigger EWS. In the aggregated EWS, the vital sign scores for each set of observations were tallied. The various EWSs were compared using the scores calculated for each set of observations. The EWS was treated as having triggered an emergency call when the score reached the appropriate value, as dictated by the individual EWS (See Table 5). The computed scores were used for the statistical analyses. Missing data were not assumed, were regarded as not being abnormal and thus scored 0.

Table 6: The vital sign ranges used in the various Early Warning Scores observation charts.

EWS	Staff response code	Score allocated	Vital sign trigger values							
			Respiration rate (breaths/ min)	SpO_2 (%)	O_2 flow rate (L/sec)	BP (mmHg)	DBP (mmHg)	Heart rate (beats/ min)	Temp (°C)	LOC
[a]BTF	Yellow	-	>25, <10	<95	-	>180, <100	-	>120, <50	>38.5, <35.5	V
	Orange	-	-	-	-	-	-	-	-	-
	Red	E	>30, <5	<90	-	>200, <90	-	>140, <40	-	P, U
	Purple	-	-	-	-	-	-		-	-
[a]ARC	Yellow	-	>19	<95	>6	>159	-	>99	>37.9	-
	Orange	-	>24	<93	>9	>169, <110	-	>109	>38.4	V
	Red	-	>29, <10	<90	>12	>199, <100	-	>119, <50	<35.5	P
	Purple	E	>34, <5	<85	-	<90	-	>139, <40	-	U
[a]ARC_2	Yellow	-	-	-	-	-	-	-	-	-
	Orange	-	-	-	-	-	-	-	-	-
	Red	-	>24, <10	<95	>12	>179, <100	-	>119, <50	>38.4, <35.5	V
	Purple	E	>29, <5	<90	-	>199, <90	-	>139, <40	-	P, U
[b]MADDS	Yellow	1	>21	<93	-	>159, <110	-	>99, <50	>37.9	V
	Orange	2	<13	<90	-	>169, <100	-	>109	>38.9, <35	-
	Red	3	-	<85	-	>199	-	>129	-	P
	Purple	≥8 (E)	>29, <8	-	-	<90	-	>139, <40	-	U
[b]$MADDS_2$	Yellow	1	>24	<94	-	>159, <110	-	>99, <50	>37.9	V
	Orange	2	-	<91	-	>169, <100	-	>109	>38.4, <35.5	-
	Red	3	>25, <13	<87	-	>199	-	>129	-	P
	Purple	≥8 (E)	>34, <8	<85	-	<90	-	>139, <40	-	U

EWS	Staff response code	Score allocated	Vital sign trigger values							
			Respiration rate (breaths/ min)	SpO_2 (%)	O_2 flow rate (L/sec)	BP (mmHg)	DBP (mmHg)	Heart rate (beats/ min)	Temp (°C)	LOC
[b]$MADDS_5$	Yellow	1	>19	<95		>159	-	>99, <50	>37.9	V
	Orange	2	>24	<93	>9	>169, <110	-	>109	>38.4	-
	Red	3	>29,<10	-	>12	>199, <100	-	>129	<35.5	P
	Purple	≥8 (E)	>34, <5	<86		<90	-	>139, <40	-	U
[b]Q-MEWT	Yellow	1	>20, <13	<95	>1	<110	>89, <60	>99	>37.4, <36	-
	Orange	2	>30	<93	>5	>139, <90	>99, <50	>109	<35.1	V
	Red	3	>34	-	>11	>149	-	>129, <50	>37.9, <35	-
	Purple	≥8 (E)	>35, <10	<91	-	>159, <80	>109, <40	>139, <40	>39.9	P,U
[b]Q-ADDS	Yellow	1	>20, <13	<95	>1	>159, <110	-	>99, <50	>37.9, <36.1	V
	Orange	2	>30	<90	>5	>169, <100	-	>109	>38.4, <35.1	-
	Red	3	>34	<85	>11	>199	-	>129	<34.1	-
	Purple	≥8 (E)	>35, <9	-	-	<90	-	>139, <40	-	P,U
[b]Q-ADDS + BP scale*	Yellow	1	>20, <13	<95	>1	*	-	>99	>37.9, <36.1	V
	Orange	2	>24	<90	>5	*	-	>109, <50	>38.4, <35.1	-
	Red	3	>29	<85	>11	*	-	>129	<34.1	C, A
	Purple	≥8 (E)	>34, <9			*	-	>139, <40	-	P, U
[b]ADDS	Yellow	1	>19	<95	>6	>159	-	>99, <50	>37.9	-
	Orange	2	>24	<93	>9	>169, <110	-	>109	>38.4	V
	Red	3	>29, <10	<90	>12	>199, <100	-	>129	<35.5	P
	Purple	≥8 (E)	>34, <5	<85	-	<90	-	>139, <40	-	U

EWS	Staff response code	Score allocated	Vital sign trigger values							
			Respiration rate (breaths/ min)	SpO_2 (%)	O_2 flow rate (L/sec)	BP (mmHg)	DBP (mmHg)	Heart rate (beats/ min)	Temp (°C)	LOC
[c]Compass	Yellow	1	<12	<96	-	<111	-	>90, <51	>38, <36.1	-
	Orange	2	>20	<94	-	>199, <101	-	>110, <41	>39	-
	Red	3	>24, <9	<92	>0	-	-	>130	<35.1	V, P, U
	Purple	-	-	-	-	-	-	-	-	-
[c]NEWS	Yellow	1	<12	<96	-	<111	-	>90, <51	>38, <36.1	-
	Orange	2	>20	<94	>0	<101	-	>110	>39	-
	Red	3	>24, <9	<92	-	>219, <91	-	>130, <41	<35.1	V, P, U
	Purple	-	-	-	-	-	-	-	-	-

Note: SpO_2: Oxygen saturation; BP: Systolic blood pressure; DBP: Diastolic blood pressure; Temp: Temperature; LOC: Level of consciousness; V: responds to voice, P: response to pain, U: unresponsive, C: newly confused, A: agitated, Score allocation; E: emergency call/alert
*Q-ADDS + BP scale utilises a variable systolic blood pressure scale based on the patients' baseline values
[a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

Statistical Analyses

For Phase 1 and 2 of the study, statistical analyses were carried out using IBM SPSS statistics 24.0 to 26.0 and MedCalc 17.9. The patients' demographic data were analysed using simple descriptive statistics, two-tailed *t*-Tests and ANOVA at 95% confidence level (or $p < 0.05$). The *t*-Test is used to establish differences between two groups, whereas the ANOVA is used when more than two groups are being compared, both tests assuming homogeneity of variance (Field, 2014). The categorical data were summarised using frequency tables and continuous data, using means and standard deviations. The unexpected clinical deterioration events were the outcomes against which the EWS efficiency was measured. For Cohort A, the various unexpected clinical deterioration event categories were grouped due to the relatively small study sample size and the heterogeneity of the unexpected clinical deterioration event categories. Unplanned transfer to a higher level of care was used as the unexpected clinical deterioration event category for Cohort B, and an emergency call was used for Cohort C (See Table 4).

In both Phase 1 and 2, the EWS efficacy testing was conducted using the Area under the Receiver Operator Characteristic Curve (AUROC), as well as sensitivity and specificity calculated from the predicted classifications. The expressions 'true and false positive alerts' and 'true and false negative alerts' are used throughout the study. The AUROC is the probability that a randomly selected index patient, who experiences an unexpected clinical deterioration event, will have a higher weighted total vital sign score than a randomly selected patient who has an uneventful hospital stay, a control patient (Jarvis et al., 2015b). The AUROC is not dependent on the decision threshold; that is, the individual EWS threshold score associated with an emergency call. Thus, the AUROC provides a 'pure' measure of the efficacy of the EWS in differentiating between the at-risk and the not at-risk patients, rather than conflating the discriminate efficacy of the EWS score with the threshold that is applied to that score to generate an alert.

Unlike the AUROC, the sensitivity and specificity are derived from the individual EWS emergency call trigger thresholds. The sensitivity of the EWS is a measure of the EWS's ability to correctly identify a deteriorating patient and can be referred to as a true positive alert (Burgess, Herdman, Berg, Feaster, & Hebsur, 2009). The specificity is a measure of the ability of a test to be appropriately selective when the EWS does not trigger an alert, and the patient is not at risk of experiencing a deterioration event (Burgess et al., 2009). This is regarded as a true negative. When a deteriorating patient does not trigger an EWS alert, it is considered a false negative, and when a control patient triggers an EWS alert, it is referred to as a false positive. The concept of true and false alarms is illustrated in Figure 4. Throughout the study, the results of the statistical analyses are tabulated and/or graphically represented. A more detailed description of the statistical methods used pertaining to specific chapters of this thesis are given in the relevant chapters.

True Positive (alert) High EWS score with an unexpected clinical deterioration event	**False Negative (no alert)** Low EWS score with an unexpected clinical deterioration event
True Negative (no alert) Low EWS score with no unexpected clinical deterioration event	**False Positive (alert)** High EWS score with no unexpected clinical deterioration event

Figure 4: Graphic representation of the concept of true and false positive and negative alerts.

Ethical Considerations

Before commencing the study, ethical approval was sought and given by the Industry partner's Human Research Ethics Committee, HREC/16/MHS/30, the Central Queensland University Human Research Ethics Committee, H16/04-087 HREC and by the Gold Coast Hospital and Health Service Human Research Ethics Committee (HREC) (HREC/17/QGC/273). Research Governance authorisation was obtained for all study sites. Since this is a retrospective study, the patient cohort was unable to consent to their information being used for research purposes. However, by signing the patient information

disclosure form upon hospital admission, the patients are agreeing to their data being used for quality improvement, auditing and research purposes. All patient data were de-identified to safeguard the patient's identity, and none of the information collected can be linked back to individual patients. The de-identified research data are stored in at least three password-protected databases: 1) the researcher's computer, 2) the secure CQUniversity data Cloudstore and OneDrive, and 3) in a secure Australian Academic and Research Network (AARNet) Cloudstore. All records and data produced in the course of this study will be retained for five years after submission of the final publication following the CQU research code of conduct (Central Queensland University, 2012) and the Australian code for responsible conduct in research, Section 2.1.1 (Australian Government, 2007).

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Chapter 4. Comparing the Efficacy of Early Warning Scores

The efficacy of twelve Early Warning Scores for potential use in small regional subcritical medical facilities in Australia

DECLARATION OF CO-AUTHORSHIP AND CO-CONTRIBUTION

Title of Paper:

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Candidate's Declaration

I declare that the publication above meets the requirements to be included in the thesis as outlined in the Research Higher Degree Theses Policy and Procedure.

DECLARATION OF CO-AUTHORSHIP AND CO-CONTRIBUTION

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Nature of Co-Authors' Contributions:

20% - guided the concept development, guided the research, edited the manuscript

Candidate's Declaration

I declare that the publication above meets the requirements to be included in the thesis as outlined in the Research Higher Degree Theses Policy and Procedure.

Synopsis

The scoping review, conducted on commencing this study (Chapter 2), recommended that Early Warning Scores (EWSs) be tested for the target patient group or facility before implementation. Since the overarching aim of this study was to provide evidence of the efficiency of various EWSs to assist poorly resourced regional/rural hospitals make informed decisions, Chapter 4 compares the effectiveness of several existing EWSs for possible implementation in these smaller hospitals.

It is apparent from the scoping study in Chapter 2 that most EWSs were developed for implementation in large, well-resourced hospitals. These large hospitals are well equipped to respond efficiently to deteriorating patients. In contrast, small private regional hospitals are often poorly resourced; they lack specialised equipment and staff suitably trained to care for critically ill or deteriorating patients. It is, therefore, important that any EWS implemented in these settings be context-specific and relevant for the target population. The ideal EWS would have good sensitivity and specificity, alerting staff to potential patient deterioration events by producing true alerts without generating unnecessary false alarms. False alarms have significant workload implications, especially in these poorly resourced facilities.

Chapter 4 represents Phase 1 of this biphasic study (see Figure1) and addresses research question 1; Which existing EWS, or class of EWS, is most effective in poorly resourced regional/rural hospitals? Therefore in this chapter, existing patient data from small regional private hospitals are applied to the three classes of commonly used EWSs to identify the most effective EWS for this patient cohort.

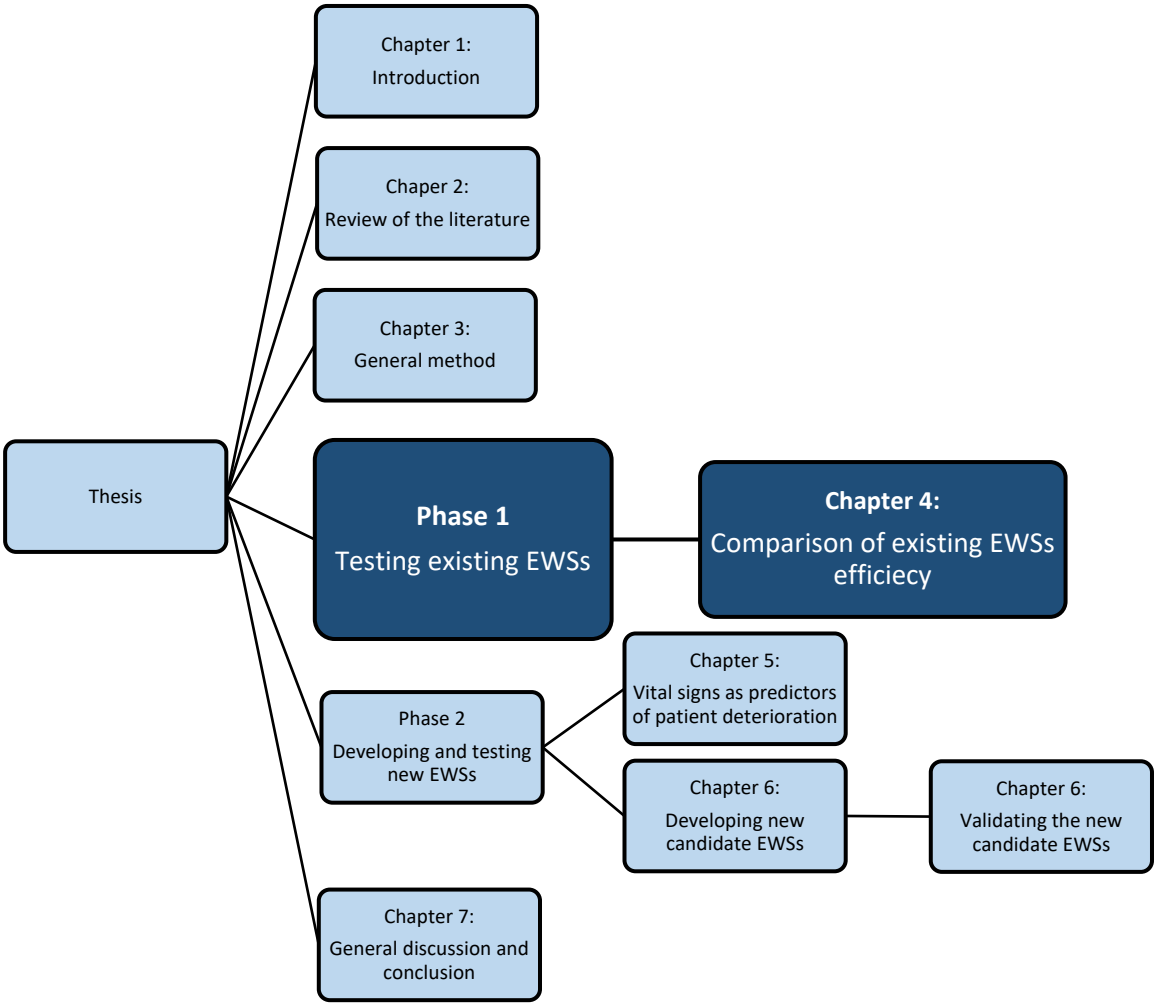

Figure 1: Schematic representation of the structure of the thesis.

While the content presented in this chapter contributed to the development of the two publications listed above, the information presented in this chapter differs from the final published manuscripts. The published works present different components of the larger population (hence different sample sizes), and terminology was adapted to suit the target audience and journal requirements. Also unique to this chapter is the inclusion of text boxes that condense and highlight the emergent findings.

Abstract

Background: It is mandatory for all medical facilities in Australia to adopt a system of identifying patients at risk of deterioration. Most facilities have chosen to adopt Early Warning Scores (EWSs) and the accompanying Rapid Response or Medical Emergency Team response system. There are three classes of EWSs: single trigger EWSs, aggregated weighted EWSs and combination EWSs. The majority of EWSs were developed in large, well-resourced metropolitan facilities and may not be suitable for use in small, poorly resourced hospitals.

Aim: This study compares 12 EWS bedside vital signs observation charts to identify the EWS, or class of EWS, best suited for potential use by a group of small regional private hospitals in Australia.

Method: This is a quantitative retrospective case-control study of patients from two regional private hospitals who experienced unexpected clinical deterioration events during their hospital stay over a 3.5-year period. In this study, an unexpected clinical deterioration event is defined as an unplanned transfer to a higher level of care, a patient for whom an emergency call is made, a cardiopulmonary arrest, or an unexpected death. The patients that experienced clinical deterioration events, referred to as index patients, were demographically and diagnostically matched with control patients who had uneventful hospital stays. All vital signs of the index and control patient cohorts, collected over 72 hours preceding the deterioration event or preceding hospital discharge, were applied to the 12 EWSs. The efficiency of the 12 EWSs were compared using the Area under the Receiver Operator Characteristic Curve (AUROC), as well as the sensitivity and specificity of each EWS. Based on the EWS sensitivity and the incidence of unexpected clinical deterioration events for this patient cohort, the hypothetical number of true and false alerts per 1 000 patients was calculated for each EWS since this directly impacts staff workload.

Results: The incidence of unexpected clinical deterioration events over the 3.5-years of data collection was 1.2% of total in-hospital admissions. Data from 159 index and 172 control patients resulting in the comparison of 5 556 sets of vital signs were collected. There were no significant differences ($p > 0.05$) in age, gender, length of hospital stay, body mass index and level of comorbidities between the index and control patients. Using the various EWSs, approximately 50% of the index patients would trigger a medical emergency call alert. On average, the emergency call would be triggered 20 hours before the deterioration event occurred. The AUROC for the 12 EWSs ranged from 0.628 to 0.747, with the single trigger EWSs having the lowest AUROC and the aggregated weighted EWSs, NEWS and Compass the highest. The sensitivity was low for all the EWSs ranging from 0.359 to 0.692. The specificity was greater than 0.9 for all the EWSs tested, meaning that the EWSs tested were efficient at identifying patients not at risk of clinical deterioration. Given the sensitivity and AUROC of the 12 EWSs tested, there is a lack of conclusive evidence of their efficacies. Based on the EWSs ability to identify patients at risk of deterioration (true alerts) and the accompanying number of false alarms, which potentially undermines staff trust in the system, the aggregated weighted and combination EWS appear most effective.

Conclusion: Since adopting a patient deterioration detection system is mandatory for all Australian medical facilities, the implementation of either an aggregated weighted or combination EWS should be considered for use in smaller regional hospitals. However, given that only half of the at-risk patients achieved an emergency call threshold score, EWSs must be used in conjunction with sound clinical judgement to identify patients in danger of deterioration.

Introduction

Patients are being admitted to hospital with increasingly complex medical conditions, multiple comorbidities and more advanced age resulting in an increased risk of in-hospital severe adverse events (SAEs) (Bell, Konrad, Granath, Ekbom, & Martling, 2006; Johnstone,

Rattray, & Myers, 2007). These SAEs, which may include cardiac or respiratory arrests and clinical deterioration resulting in an admission to a higher level of care ward, are associated with poor patient outcomes including, increased length of stay (Bellomo, Goldsmith, Russell, & Uchino, 2002; Cretikos et al., 2007), permanent disability and death (De Meester, Van Bogaert, Clarke, & Bossaert, 2012; D. Jones, Devita, & Bellomo, 2011). The estimated annual cost of SAEs in Australian hospitals is 1.7 million hospital bed-days, worth over AU$4.7 billion (Kyriacos, Jelsma, & Jordan, 2011). The risk of an in-hospital SAE is between 0.6% and 16.6% of which more than half are preventable (Buist et al., 1999; Wilson et al., 1995). Severe adverse events are frequently preceded by abnormal vital signs (Andersen et al., 2016; Schein, Hazday, Pena, Ruben, & Sprung, 1990), which, if acted upon, can prevent further patient deterioration (Considine, 2005; Elliott & Coventry, 2012). Although monitoring vital signs is regarded as the cornerstone of identifying patient clinical condition, they are not always well documented or acted on (De Meester et al., 2012; Moore et al., 2017; Pedersen et al., 2018).

Early warning scores, also referred to as track and trigger systems, are based mainly on the patient physiological vital signs. They were first introduced into the healthcare system in the mid-1990s to facilitate the recognition of the deteriorating patient (Lee, Bishop, Hillman, & Daffurn, 1995). There are now numerous variations of EWSs, most of which utilise a colour coded technique to trigger a predefined response (Roney et al., 2015). As the degree of physiological derangement increases, the response escalates according to the system's protocol (Roney et al., 2015). These EWSs help quantify patient deterioration and overcome clinical judgment subjectivity (Day & Oldroyd, 2010). In critical care environments, nurse-to-patient ratios are high; patient deterioration is more easily identifiable. In the subcritical area, such as the general hospital ward, patient deterioration is often progressive and difficult to assess (Brabrand, Folkestad, Clausen, Knudsen, & Hallas, 2010). In these subcritical environments where EWSs may be the single most important factor in identifying patient deterioration (Rattray et al., 2011). The EWS provides a simple, uniform method of

categorising the clinical needs of patients and guiding their care (Capan, Ivy, Rohleder, Hickman, & Huddleston, 2015).

The concept of EWSs and the accompanying response teams is rapidly gaining global acceptance (Gao et al., 2007). Their implementation has become mandatory in many countries, including the United Kingdom (Bonnici, Gerry, Wong, Knight, & Watkinson, 2016) and Australia (Australian Commission on Safety and Quality in Health Care, 2017). However, most EWSs were developed based on the needs of the clinical facility, or on clinical intuition, often without rigorous validation (Churpek, Yuen, & Park, 2014; Cuthbertson & Smith, 2007; Jansen & Cuthbertson, 2010).

To better identify and escalate patients at risk of deterioration in many medical facilities, multi-faceted rapid response or medical emergency team systems have been put in place (D. Jones et al., 2011). These systems usually comprise of four limbs:

- the afferent limb, which includes the EWS vital signs observation chart, triggers the appropriate staff response protocol. The afferent limb aimed at bridging the discrepancy between care given and care needed;
- the efferent limb represents the actual response, the escalation of patient care which usually involves a patient review by an intensive care response team, a medical emergency response team or a rapid response team;
- the administrative or governance limb which facilitates resources ensures adequate appropriately trained staff, oversees the planning, implementation and maintenance of the system; and
- a patient quality and safety limb which collects and analyses patient deterioration data provides feedback and develops protocols for ongoing quality care improvements (Aitken et al., 2015; DeVita et al., 2006; D. Jones et al., 2011).

The current study involves only the afferent limb of the early warning system, specifically focusing on the effects of the vital sign observation chart, herewith referred to as Early Warning Scores (EWS). There are three basic classes of EWSs; the single trigger

EWS, the aggregated weighted scoring systems, and the combination of the two systems, weighted aggregated and single trigger systems (Christofidis, Hill, Horswill, & Watson, 2015; Jansen & Cuthbertson, 2010). The single trigger EWS prompt a response based on a single or multiple abnormal vital sign(s). The weighted EWSs stratify patients by applying a numerical score based on the level of vital sign derangement. The patient's singly or aggregated scores activate a colour-coded algorithm that triggers a prescribed escalation intervention (Roney et al., 2015). The interventions are often customised to the facility's capabilities regarding skill mix and equipment availability. They are tiered to evoke an escalation in action reflective of the level of derangement of the patient's vital signs (Kyriacos et al., 2011).

This study compares the efficacy of 12 EWS vital signs observation charts belonging to the three classes of EWSs (See Chapter 3, Table 5, Appendices B–L). The efficacy of several of these EWSs has not previously been quantified. The EWSs included in the study are:

1. The single trigger EWSs:

    a) Between-the-Flags (BTF) is commonly used in hospitals in New South Wales, Australia, and was one of the first EWSs to introduce the colour-coded action prompts (Green et al., 2018; Pain et al., 2017; Rihari-Thomas, Digiacomo, Newton, Sibbritt, & Davidson, 2019). In addition, several published EWS efficiency studies have included BTF (Campbell et al., 2020; Green et al., 2018; Kansal & Havill, 2012; Khalaf, Kecskes, Georgousopoulou, & Mitchell, 2020).

    b) The Adult Observation and Response Chart (ARC) and ARC_2 (version 2) were developed in 2012 by the Australian Commission on Safety and Quality in Health Care (2019). These EWS have not previously been validated. The ARC was adopted by study Site 1 in September 2015 and implemented until November 2018.

2. The aggregated weighted EWSs:

   a) Compass was one of the first EWSs developed in Australia and originated from the Canberra Hospital, ACT, Australia (Horswill, Preece, Hill, Christofidis, et al., 2010). It is utilised mainly in hospitals in the Australian Capital and Northern Territories (Rihari-Thomas et al., 2019). Compass is the name given to the education package that accompanies the EWS (based on an EWS called ViEWS), but it is used to refer to the EWS vital signs observation chart for the present study. One previous publication included Compass, involving the effect of introducing the multi-facetted Compass program on patient outcomes (Mitchell et al., 2010).

   b) The National Early Warning Scores, NEWS, was developed by the Royal College of Physicians in 2005 and is currently used by most National Health Service hospitals in the United Kingdom (Royal College of Physicians, 2017). This EWS has been extensively studied and validated using a wide range of medical facilities, patient cohorts and hospital wards (Jarvis et al., 2015; Keep et al., 2016; Kivipuro et al., 2018; Silcock, Cornfield, Gowens, & Rooney, 2015; Smith, Prytherch, Meredith, Schmidt, & Featherstone, 2013; Spångfors, Arvidsson, Karlsson, & Samuelson, 2016).

3. The combination EWSs:

   a) Mater Adult Deterioration Detection System (MADDS) appears to be derived from the ADDS, but there is no published information on its origin. The MADDS was used by study Site 2 and was superseded by $MADDS_2$ in August 2017. A variation of this EWS, $MADDS_{5,}$ is currently used in other hospitals within the Mater Misericordiae hospital group.

   b) The Queensland Maternity Early Warning Tool (Q-MEWT) is unusual because it includes diastolic blood pressure as a contributing vital sign, hence its inclusion in

this study. This EWS is used in post-natal units in rural and remote Queensland Health facilities and has not previously been validated.

c) Queensland Adult Deterioration Detection System (Q-ADDS) and Q-ADDS with systolic blood pressure scale (Q-ADDS + BP) are based on the ADDS vital signs observation chart. The Q-ADDS and Q-ADDS + BP has recently been quantitatively and qualitatively validated (Campbell et al., 2020; Dwyer et al., 2019; Missen, Porter, Raymond, de Vent, & Larkins, 2018). Many Queensland Health public hospitals use these EWSs, Q-ADDS and Q-ADDS + BP scale.

d) Adult Deterioration Detection System (ADDS) was developed for Queensland Health public hospitals in 2010 to standardise the bedside vital sign observation chart (Horswill, Preece, Hill, & Watson, 2010). It was based on the vital signs observation chart used in the Brisbane Prince Charles Hospital and the Compass EWS chart used in the Canberra Hospital, with emphasis placed on the *human-factor* perspective of ease and accuracy of use (Christofidis et al., 2015; Preece, Hill, Horswill, Karamatic, & Watson, 2012). The effect of introducing ADDS on the emergency call rate has recently been investigated (Missen, Porter, Raymond, de Vent, & Larkins, 2018).

Most studies involving patient deterioration and EWSs have been conducted in well-equipped and appropriately staffed metropolitan tertiary hospitals with established medical emergency response teams. These facilities cater to large cohorts of acute and critically ill patients, allowing researchers access to an expansive database of potential study subjects. In contrast, there is a distinct lack of patient deterioration research conducted in smaller regional or rural medical facilities. Yet, these facilities also report patient deterioration problems often without the support of a well-equipped critical care team. This is where a gap in the best evidence resides. The regional/rural population generally experience poorer health than their metropolitan counterparts, primarily due to issues accessing

appropriate medical services (AMA, 2017; Whitehead & Quinn, 2019). Also, per capita, the regional health sector receives substantially less federal funding than its metropolitan counterparts (Armstrong, Gillespie, Leeder, Rubin, & Russell, 2007). Another issue compounding access to services is that Australian regional/rural medical facilities have difficulty attracting and retaining clinical staff due to the distance from the cities, a lack of funding and the complex and heavy workloads (Bourke, Humphreys, Wakerman, & Taylor, 2012). Insufficient staffing levels and inadequate skills mix in regional facilities are associated with increased length of hospital stay (LOS) and poor patient outcomes (Aiken et al., 2016; Liang, Chen, Lee, & Huang, 2012; Lim, O'Connell, & Heller, 1999). The problem is often magnified in private hospitals, which receive little government subsidies and are funded exclusively based on their performance, exacerbating staffing issues (Australian Institute of Health and Welfare, 2019; Bloom, 2002).

According to a British nationwide hospital review of acute health care, validating the various EWSs would be the single most important factor in improving patient hospital care (NICE, 2007). Although a given EWS may be effective at one medical facility, it may not be appropriate for another patient cohort. It is, therefore, essential that EWSs be validated for a specific facility type and patient group before implementation (Wheeler et al., 2013). The overarching aim of this study was to provide evidence of the efficiency of various EWSs to assist poorly resourced regional/rural hospitals make informed decisions when selecting EWSs for implementation.

Method

Study design and patient cohort

The study design and patient cohort (Cohort A), data collection method, EWSs compared and ethic approvals are discussed in Chapter 3. This retrospective case-control study was conducted in two small regional private hospitals in Australia. Study Site 1 is a 59-bed hospital, and Site 2 is a 140-bed facility. Patient data (Cohort A) were collected from

June 2014 to December 2017. Patients with a documented unexpected clinical deterioration event (index patients) were demographically and diagnostically matched to patients who had an uneventful hospital stay (control patients). The patients' demographic data and all documented vital signs for 72 hours preceding the deterioration event (index patients) or preceding hospital discharge (control patients) were extracted and applied to the 12 EWSs (See Chapter 3, Table 5, Appendices B–L).

Statistical analyses

The general statistical methods employed, using IBM SPSS statistics 24.0 and MedCalc 17.9, are discussed in Chapter 3. The patient demographic data from the two study sites were compared using descriptive statistics. Comparisons were also made between the calendar day of patient admission, the occurrence of the unexpected clinical deterioration events, and the per diem timing of the deterioration events. Where appropriate, the weighted EWS scores were calculated, and statistical analyses were conducted. All statistical analyses were carried out using two EWS threshold values; the emergency call threshold score and a moderate threshold score, the second-highest response tier score dictated by the EWS response protocol. The two threshold scores were used in the analyses to ascertain whether lowering the trigger thresholds would result in more efficient EWSs. The threshold scores were not the same for all 12 EWSs (See Table 7) but were determined by the EWS protocols. The various unexpected clinical deterioration event categories used in this study: cardiopulmonary arrest, unplanned transfer to a higher level of care ward, an emergency call and unexpected death, were grouped due to the small sample size.

Table 7: The trigger scores used in determining EWSs sensitivity, specificity and the number of false and true alerts.

EWS	Emergency alert threshold EWS score	Moderate threshold EWS score
[a]BTF	Red	Yellow
[a]ARC	Purple	Red
[a]ARC_2	Purple	Red
[b]MADDS	8	4
[b]$MADDS_2$	8	6
[b]$MADDS_5$	8	4
[b]Q-MEWTS	8	6
[b]Q-ADDS	8	4
[b]Q-ADDS + BP	8	6
[b]ADDS	8	6
[c]Compass	7	4
[c]NEWS	7	5

Note: [a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

The efficiencies of the 12 EWSs were compared using the Area under the Receiver Operator Characteristic Curve (AUROC), sensitivity and specificity, true and false positive alerts and true and false negative alerts. All vital signs collected over 72 hours preceding an unexpected clinical deterioration event for the index patients or preceding hospital discharge for the control patients were used to calculate the AUROC. The significant differences, at a 95% confidence interval ($p < 0.05$) between the AUROC of the various EWSs, were compared through pairwise comparisons using the nonparametric Mann-Whitney U-statistic method created by DeLong (DeLong, DeLong, & Clarke-Pearson, 1988). The Mann-Whitney U-statistic ranks the data and compares the median, not the mean of the data. The sensitivity and specificity for each EWS were calculated using the final set of vital signs preceding an unexpected clinical deterioration event or, for the control patients, the equivalent set of vital signs derived from the time of admission. On average, index patients experienced a deterioration event 94.98 (124.48) hours (CI: 75.48–114.48) after admission. Therefore, the set of vital signs collected approximately 95 hours post-admission was used for the control group to calculate the EWS sensitivity and specificity.

Results

Demographics

More than 800 patient records were examined, with 331 eligible patient records included (159 index patients and 172 matched control patients) and 5 556 sets of vital signs extracted. Site 1 produced 78 index and 90 control patients and from Site 2, 81 index and 82 control patients were recorded. Approximately 40% of the index patients were identified using Riskman, the hospital's incidence reporting system; the rest were selected via WebPAS, the hospital's patient management system. No additional index patients were obtained from the deceased register or the ambulance transport request register. Since the index and control patients were matched, there were no significant differences in the demographics between the two groups (See Tables 8 and 9). Seventy per cent of the patients in this study were over 70 years of age. Patients from Site 1 were on average seven years older than those of Site 2 (Site 1: 76.6 [13.2] years, CI: 73.6–79.6; Site 2: 69.6 [17.55] years, CI: 65.8–73.5; $p = 0.001$, F = 10.71, [See Figure 5]). This notable difference in patient ages may reflect the general population of these two regions, with 19.2% of Site 1's and 13.3% of Site 2's inhabitants being over 65 years of age (Australian Bureau of Statistics, 2017).

Table 8: Patient demographics for the index and control groups for the two study sites combined. Values are given as averages (standard deviation).

	Index	Control	p
Gender (male)	52.8%	53.3%	0.963
Age (years) (range)	73.01 (15.8) (17 - 104)	72.15 (14.46) (17 - 94)	0.603
BMI# (kg/m^2) (range)	27.56 (6.61) (10.76 - 45.11)	27.29 (6.74) (15.56 - 53.01)	0.759
LOS* (days) (range)	6.55 (8.1) (1 - 48)	6.95 (5.82) (1 - 41)	0.602
Charlson score (range)	5.54 (2.42) (0 - 15)	5.65 (2.53) (0 - 14)	0.712

Note: #BMI: Body Mass Index
*LOS: length of stay

Table 9: Patient demographics for the index patients comparing the two study sites. Values are given either as percentages or as average (standard deviation).

	Study Site 1	Study Site 2	p
Gender (male)	51.9%	53.7%	0.767
Ward (medical)	70.1%	71.6%	0.764
Age (years)	76.6 (13.2)	69.6 (17.6)	0.001
BMI# (kg/m^2)	25.3 (5.1)	29.5 (7.4)	0.0001
LOS* (days)	5.8 (4.8)	7.7 (8.6)	0.013
Charlson score	5.4 (2.8)	5.5 (2.4)	0.954

Note: #BMI: Body Mass Index
*LOS: length of stay

There was no significant correlation between the patients' ages and the EWS scores for their final set of vital signs (p = 0.534, R^2 = 0.034) and no significant differences between patient age and admission to the ward (p > 0.05).

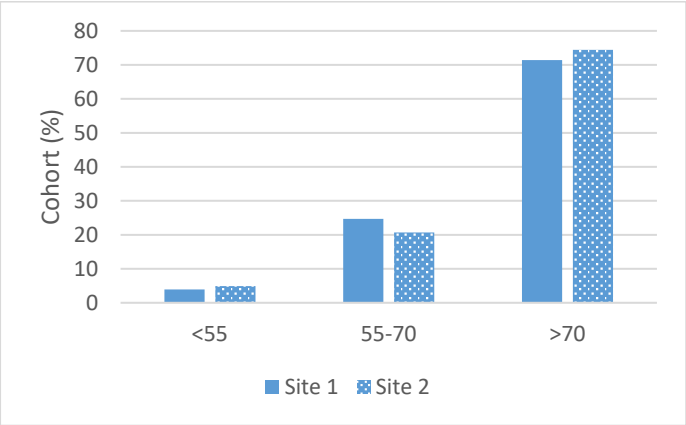

Figure 5: Patient age categories for the two study sites. Index and control patients are combined.

For both study sites, over 70% of the patients were from the medical ward, and the rest were surgical patients. Although there was no significant difference between the index and control patients' body mass indexes (BMI: p = 0.759, F = 0.094), the patients from Site 2 had significantly higher BMI than Site 1 patients (Site 1: 25.33 [5.1] kg/m^2, CI: 24.4–26.3, and Site 2: 29.49 [7.4] kg/m^2, CI: 28.1–30.88; p < 0.0001, F = 23.8, [See Figure 6]). Overall, approximately 6% of patients were underweight (BMI < 18.4 kg/m^2), 39% were within normal BMI (18.4–24.9 kg/m^2), 23.5% were overweight (25–29.9 kg/m^2) and 31.5% were obese or morbidly obese (BMI > 30 kg/m^2).

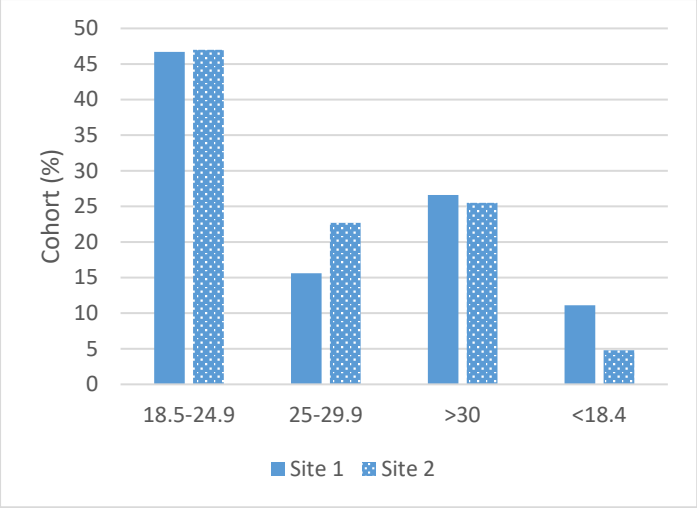

Figure 6: Body mass index (BMI) categories for the two study sites. Index and control patients are combined.

The average length of stay (LOS) for patients at Site 1 was significantly shorter (5.8 [4.8] days, CI: 5.1–6.6) than at Site 2 (7.7 [8.6] days, CI: 6.4–9.1; $p = 0.013$, F = 6.2). However, the average LOS for index and control groups for the two study sites combined did not differ significantly ($p = 0.602$, F = 0.272). There was no significant correlation between the LOS and the patients' EWS scores for any of the EWSs tested (Pearson 2-tailed correlation $p = 0.880–0.157$); however, there was a weak but significant positive correlation between LOS and patients' ages ($p = 0.0001$, F = 26.95, $R^2 = 0.076$). When index patients that were transferred to an external higher care facility were omitted from the comparison, the LOS for the index patients at both study sites was statistically longer than the control patients (index: 8.63 [9.1] days, control: 6.95 [5.8] days; $p = 0.008$, F = 3.095). The primary diagnostic groups shown in Figure 7, loosely based on diagnostic grouping as per the Society of Critical Care Medicine (1999), was similar for both study sites. The Charlson comorbidity index was not significantly different for patients from the two sites, ($p = 0.954$, F = 0.003) or between the index and control groups ($p = 0.712$, F = 0.137).

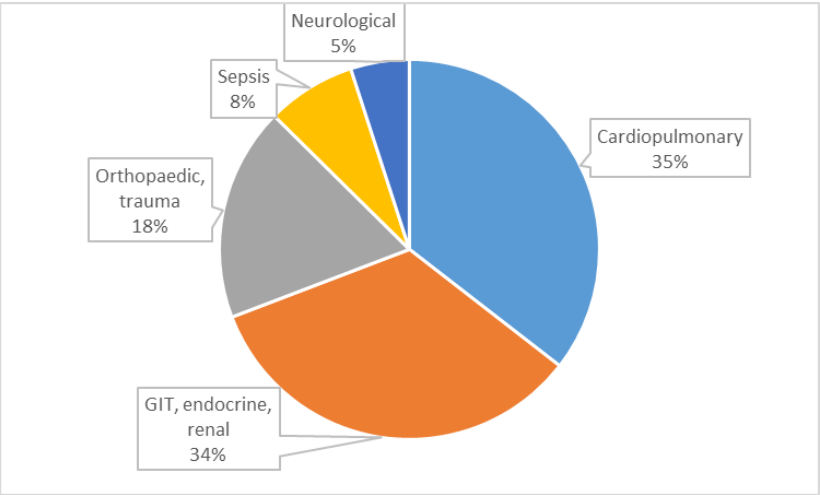

Figure 7: The primary diagnostic groups of patients (total cohort).

Seventy per cent of the cohort were over 70 years old, and their length of hospital stay was positively correlated to their age.

The text boxes emphasise the most important findings of this study.

Most patients with a documented unexpected clinical deterioration event at Site 1 (75.3% of index patients) were transferred to a higher level of care, either within the facility or externally to another hospital. Some of the index patients at both sites (5.2%) experienced an unspecified clinical deterioration event, the nature of the deterioration event not being documented, which was classed as unspecified deterioration events. Two categories of clinical deterioration events are always well documented at both study sites: an emergency call and patient demise, since both mandate the completion of appropriate documentation in the patient records. Thus, these two deterioration event categories are clearly distinguishable. There was no significant difference in unexpected deaths between the two study sites (Site 1: 9.1%, Site 2: 8.5%, $p = 0.922$), but there was a significantly higher incidence of emergency calls at Site 2 (29.3%) compared to Site 1 (3.9%, $p < 0.0001$). Also, there were significantly more patients transferred to a higher level of care at Site 1 (75.3%) compared to Site 2 (26.8%, $p < 0.0001$, [See Table 10]). Study Site 2 is the largest of the two hospitals and may be better resourced. It is conceivable that staff were more

frequently alerted to patient deterioration at Site 2, and these patients were then treated on the ward rather than being transferred to a higher level of care.

> Site 2 adopted an EWS, albeit intermittently, several years before Site 1 and had a significantly higher number of emergency calls and fewer patients transferred to a higher level of care than Site 1.

Table 10: Categories of unexpected clinical deterioration events for the index patients comparing the two study sites.

Clinical deterioration event	Site 1	Site 2	*p*
Unspecified deterioration	5.2%	19.5%	0.006
Emergency call	3.9%	29.3%	< 0.0001
Cardiopulmonary arrest	6.5%	15.9%	0.050
Transfer to higher level care	75.3%	26.8%	< 0.0001
Unexpected death	9.1%	8.5%	0.922

The study resulted in 5 556 sets of vital signs extracted from the 331 patient records for the 72 hours. Over the 72-hour data collection period, an average of seven more sets of vital signs were collected for the index patient than for the control patients (index: 20.7 [14.5], range: 5–116 sets of vital signs per patient; control: 13.48 [4.95], range: 4–41 sets of vital signs per patient; $p < 0.0001$, F = 30.78). There were no significant differences in the average number of vital signs taken per patient for the two study sites (Site 1: index, 22.1 [19.04], range: 5–116, control, 12.31 [3.43], range: 6–24; Site 2: index, 19.54 [8.19], range: 6–36, control, 14.72 [5.86], range: 4–41; $p = 0.632$, F = 0.230). The incidence of unexpected clinical deterioration events for the two study sites was approximately 0.34% (Site 1: 0.48%, Site 2: 0.21%) of all admissions, including short-stay patients (day-surgery), and 1.2% (Site 1: 1.58%, Site 2: 0.83%) of in-hospital patients.

Incidence of unexpected clinical deterioration event was 1.2% of in-hospital admissions, that is, 1.2 unexpected clinical deterioration events per 100 ward admissions

Index patients were monitored significantly more often than the control patients.

Timing of severe adverse events

Almost 60% of the index and control patients from study Sites 1 and 2 were admitted to hospital early in the week, and 56.7% of unexpected clinical deterioration events occurred from Wednesday to Friday (See Figure 8). The median time from admission to unexpected clinical deterioration event was 50.4 hours, although the average time to unexpected clinical deterioration event from admission was 94.98 (124.48) hours. Approximately 47% of unexpected clinical deterioration events occurred between 08:00 and 16:30, 29% between 16:30 and 24:00, and 24% between 24:00 and 08:00.

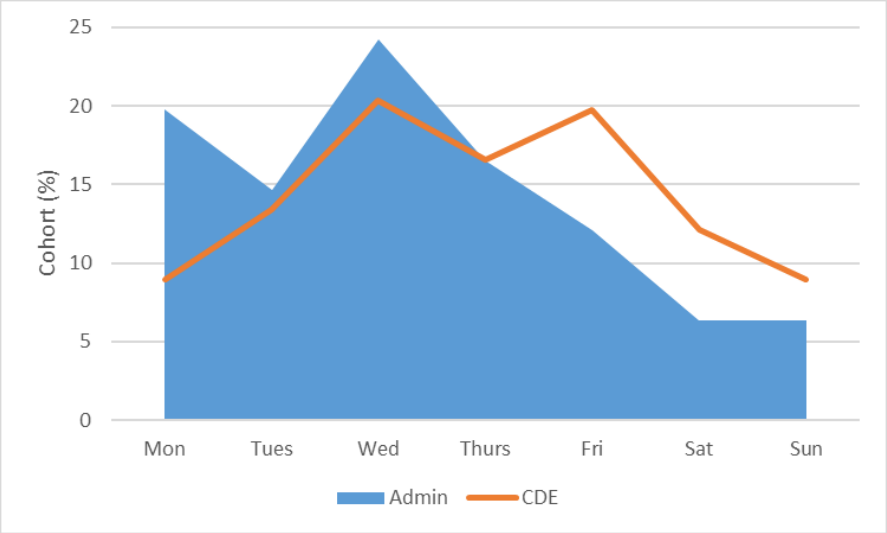

Figure 8: Weekly distribution of patient admissions and unexpected clinical deterioration event (CDE).

Most unexpected clinical deterioration events occurred during office hours on weekdays, approximately 50 hours after admission.

The index patients reached the EWSs emergency call threshold score on average 20.06 (22.67) hours preceding the documented unexpected clinical deterioration event. The few control patients (1.3% of the control cohort) that would theoretically have triggered emergency calls, that is, their EWSs reached the emergency threshold score, did so 42.53 (18.9) hours preceding their hospital discharge. The time to first alert was significantly different between the index and control groups for all the EWSs ($p < 0.05$) except for the aggregated weighted EWSs, Compass (index: 20.89 [20.59] hours, control: 23.71 [24.91] hours; $p = 7.49$, F = 0.103) and NEWS (index: 18.34 [19.8] hours, control: 18.08 [25.21] hours; $p = 0.986$, F = 0.001). The Q-MEWT alerted significantly earlier than the other EWS ($p < 0.001$), 34.07 (27.0) hours preceding an unexpected clinical deterioration event and 48.96 (21.29) hours preceding discharge for the control group (See Figure 9). At a moderate trigger threshold score, that is, at a lower tier as per the EWSs protocol (See Table 10), the average time to alert preceding a deterioration event for all the EWS was 25.58 (24.28) hours and 48.27 (21.56) hours preceding discharge for the control group (See Figure 10). Again, Q-MEWT triggered significantly sooner than all the other EWS ($p < 0.05$) except ARC_2. For the index patients, both Q-MEWT and ARC_2 alerted approximately 36.5 hours preceding an unexpected clinical deterioration event compared to approximately 22 hours for the other EWSs, and approximately 55 hours preceding discharge for the control group compared to an average of 42 hours for the remaining EWSs. When the control patients trigger alerts, these are false positive alerts. Meaning, their vital signs are abnormal, resulting in high EWS scores, but there is no documented evidence that the patients experienced clinical deterioration events.

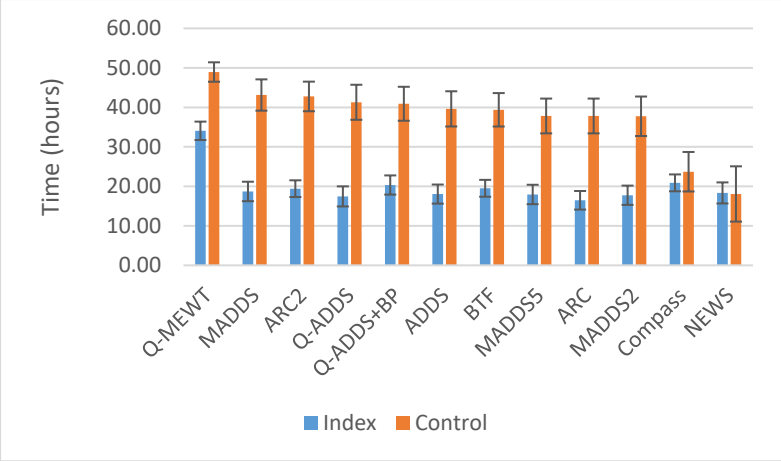

Figure 9: Time (hours) to alert preceding clinical deterioration events or hospital discharge, at the emergency threshold score. Bars indicate SE of the mean.

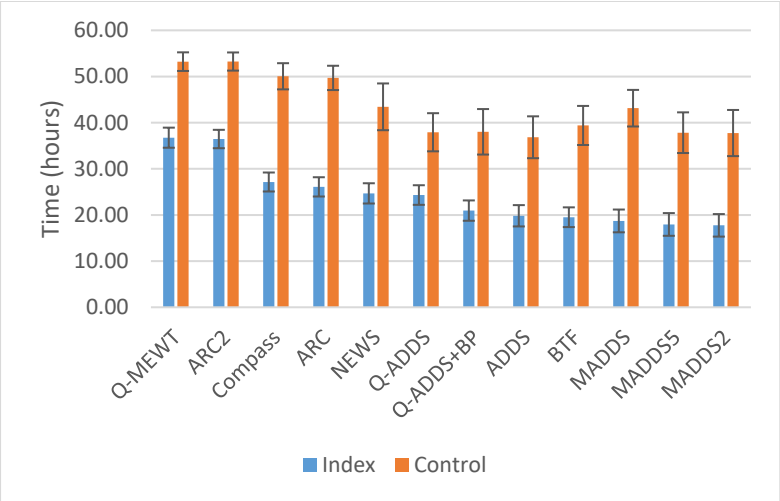

Figure 10: Time (hours) to alert preceding clinical deterioration events or hospital discharge, at the moderate threshold score. Bars indicate SE of the mean.

Number of alerts in 72 hours

At the emergency call threshold score, the index patients alerted 2.25 (range: 0–33) times in the 72 hours preceding an unexpected clinical deterioration event. Q-MEWT alerted significantly more frequently ($p < 0.001$, F = 6.72) than all the other EWSs, 4.55 (5.59) times for Q-MEWT compared to 2.05 (3.61) for the other EWSs. Among the control patients, at the emergency threshold score, the various EWSs triggered 0.31 (range: 0–29) times over the 72 hours preceding discharge. Q-MEWT again produced a significantly higher number of alerts, 1.62 (3.13) times, compared to the other EWSs, 0.19 (0.84) times, ($p < 0.0001$, F = 20.87). The various EWSs alerted 4.55 (range: 0–68) times over the 72 hours for the index patients at the moderate threshold score. On average, the control patients alerted 1.07 (range: 0–37) times in the 72 hours preceding their discharge from hospital. The percentage

of vital sign sets collected that triggered alerts at two EWS threshold scores over a 72-hour period is shown in Table 11. The single trigger EWSs; BTF, ARC and ARC_2, as well as the aggregated weighted EWSs; Compass and NEWS showed the greatest increase in the number of alerts when the threshold score was lowered. Although the single trigger and aggregated weighted EWSs more effectively identified patients at risk of deterioration, they also produced high numbers of false alarms, that is, triggered alerts for patients that did not suffer clinical deterioration events.

Index patients reached an emergency threshold score approximately 20 hours preceding the unexpected clinical deterioration event and alerted 2.25 times in 72 hours preceding the deterioration event.

Table 11: The percentage of sets of vital signs collected that triggered an alert at two EWS threshold scores for index and control patients in the 72 hours preceding unexpected clinical deterioration events or hospital discharge (n = 5037 sets of vital signs). The EWSs threshold scores used are given in Table 7.

EWS	Sets of vital signs triggered at an emergency threshold score (%)		Sets of vital signs triggered at a moderate threshold score (%)	
	Index patients	Control patients	Index patients	Control patients
[a]BTF	13.24%	2.07%	45.02%	22.72%
[a]ARC	10.18%	1.31%	28.00%	8.49%
[a]ARC_2	13.70%	2.15%	46.90%	23.40%
[b]MADDS	10.33%	1.35%	16.34%	2.03%
[b]$MADDS_2$	10.62%	1.31%	12.16%	1.39%
[b]$MADDS_5$	11.34%	1.31%	21.95%	3.13%
[b]Q-MEWT	26.20%	11.66%	30.91%	12.84%
[b]Q-ADDS	10.04%	1.18%	12.63%	1.56%
[b]Q-ADDS + BP scale	11.51%	1.73%	14.57%	1.77%
[b]ADDS	11.48%	1.35%	14.65%	1.82%
[c]Compass	15.58%	0.68%	44.44%	9.97%
[c]NEWS	10.94%	0.34%	26.63%	3.25%

Note: [a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

Based on the results shown in Table 11, the number of hypothetical true and false alerts per 100 patients over 24 hours is shown in Table 12. Given a 1.2% incidence of unexpected clinical deterioration events for this cohort, that is, 1.2 patients per 100 would suffer an unexpected clinical deterioration event, and 98.8 patients would have an uneventful hospital stay. This implies that, at the emergency threshold score, Q-MEWT would trigger 1.26 true alerts (26.2% of 1.2 patients multiplied by four sets of vital signs per day) and 46.08 false alerts in 24 hours (11.66% of 98.8 patients multiplied by four sets of vital signs per day). The number of false alarms would have a significant impact on staff workload.

Table 12: The hypothetical number of true and false alerts per 100 patients over a 24-hour period for two EWS threshold scores. Based on the data in Table 11 and assuming four sets of vital signs are monitored per 24 hours; 1.2% incidence of unexpected clinical deterioration events. The EWSs threshold scores used are given in Table 7.

EWS	Number of hypothetical alerts at the emergency threshold score		Number of hypothetical alerts at a moderate threshold score	
	True alerts	False alerts	True alerts	False alerts
[a]BTF	0.64	8.18	2.16	89.79
[a]ARC	0.49	5.18	1.34	33.55
[a]ARC_2	0.66	8.50	2.25	92.48
[b]MADDS	0.50	5.34	0.78	8.02
[b]$MADDS_2$	0.51	5.18	0.58	5.49
[b]$MADDS_5$	0.54	5.18	1.05	12.37
[b]Q-MEWT	1.26	46.08	1.48	50.74
[b]Q-ADDS	0.48	4.66	0.61	6.17
[b]Q-ADDS + BP scale	0.55	6.84	0.70	7.00
[b]ADDS	0.55	5.34	0.70	7.19
[c]Compass	0.75	2.69	2.13	39.40
[c]NEWS	0.53	1.34	1.28	12.84

Note: [a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

Identifying at-risk patients, the incidence of true and false alerts

Using the most recent set of vital signs preceding the unexpected clinical deterioration event and the equivalent set of vital signs from the time of admission for the control patients, approximately half (49.04%; range: 35.9%–69.2%) of the index patients (true positive alerts), and 1.3% (range: 0–7.65%) of the control patients (false positive alerts) would theoretically have triggered an alert at the emergency call threshold score (See Table 13). Therefore, for this patient cohort, the EWSs tested would not have triggered an emergency call for approximately half of the patients that suffered an unexpected clinical deterioration event. The NEWS achieved the lowest number of true alerts amongst the index patients (35.9%) but also produced no false alarms amongst the control patients (false positives). In comparison, Q-MEWT had the highest number of index patient emergency calls (69.2%) and the highest percentage of false alarms in the control group (7.7%). If the

threshold score was lowered to a more moderate score (See Table 13), the percentage of true positives (true alerts) improved for all 12 EWSs averaging 68.56% (13.7%). However, the number of false alarms also increased, averaging 5.33% (6.2%) for the 12 EWS. The single trigger EWSs; BTF, ARC and ARC_2, as well as the aggregated weighted EWS Compass, produced a greater than 30% improvement in true positive alerts when the moderate threshold score was implemented with only BTF and ARC_2 producing more than a 10% increase in the number of false positive alerts. Based on the data in Table 13 and on a 1.2% incidence of unexpected clinical deterioration events, the hypothetical number of patients per 100 ward admissions that would correctly or incorrectly trigger an EWS alert is shown in Table 14.

Table 13: The percentage of patients categorised as true positive, false positive, true negative and false negative at two alert threshold scores for the 12 EWSs.

EWS		Index patients (n = 159)		Control patients (n = 171)	
	High & moderate Threshold scores	True positive (%)	False negative (%)	True negative (%)	False positive (%)
[a]BTF	Red (E)	55.35	44.65	98.82	1.18
	Yellow	92.45	7.55	81.76	18.24
[a]ARC	Purple (E)	42.77	57.23	99.41	0.59
	Red	74.21	25.79	95.88	4.12
[a]ARC_2	Purple (E)	58.49	41.51	98.82	1.18
	Red	93.08	6.92	81.76	18.24
[b]MADDS	≥8 (E)	44.65	55.35	99.41	0.59
	≥4	59.12	40.88	99.41	0.59
[b]$MADDS_2$	≥8 (E)	45.28	54.73	99.41	0.59
	≥6	49.69	50.31	99.41	0.59
[b]$MADDS_5$	≥8 (E)	47.80	52.20	99.41	0.59
	≥4	69.18	30.82	97.65	2.35
[b]Q-MEWT	≥8 (E)	69.18	30.82	92.35	7.65
	≥6	74.21	25.79	91.18	8.82
[b]Q-ADDS	≥8 (E)	46.54	52.2	99.41	0.59
	≥4	52.83	47.17	99.41	0.59
[b]Q-ADDS + BP scale	≥8 (E)	50.94	49.06	98.41	1.59
	≥6	60.38	39.62	98.41	1.59
[b]ADDS	≥7 (E)	47.54	52.20	99.41	0.59
	≥6	56.60	43.40	98.82	1.18

EWS	High & moderate Threshold scores	Index patients (n = 159) True positive (%)	Index patients (n = 159) False negative (%)	Control patients (n = 171) True negative (%)	Control patients (n = 171) False positive (%)
[c]Compass	≥7 (E)	44.03	55.97	100	0.00
	≥4	77.36	22.64	94.71	5.29
[c]NEWS	≥7 (E)	35.85	64.15	100	0.00
	≥5	63.52	36.48	97.65	2.35

Note: E: the score at which an emergency call is triggered, [a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

Table 14: The number of true and false alerts per 100 hospital admissions at two threshold scores, for the 12 EWSs. Incidence of unexpected clinical deterioration event is 1.2% of in-hospital patients, i.e. 1.2 unexpected clinical deterioration event patients and 98.8 uneventful hospital stay patients.

EWS	High & moderate Threshold scores	True alerts per 100 pts	False alerts per 100 pts
[a]BTF	Red (E)	0.66	1.17
	Yellow	1.11	18.02
[a]ARC	Purple (E)	0.51	0.59
	Red	0.89	4.07
[a]ARC_2	Purple (E)	0.70	1.17
	Red	1.12	18.02
[b]MADDS	≥8 (E)	0.54	0.58
	≥4	0.71	0.58
[b]$MADDS_2$	≥8 (E)	0.54	0.58
	≥6	0.60	0.58
[b]$MADDS_5$	≥8 (E)	0.57	0.58
	≥4	0.83	2.32
[b]Q-MEWT	≥8 (E)	0.83	7.56
	≥6	0.89	8.71
[b]Q-ADDS	≥8 (E)	0.56	0.58
	≥4	0.63	0.58
[b]Q-ADDS + BP scale	≥8 (E)	0.61	1.57
	≥6	0.72	1.57
[b]ADDS	≥7 (E)	0.57	0.58
	≥6	0.68	1.17
[c]Compass	≥7 (E)	0.53	0.00
	≥4	0.93	5.23
[c]NEWS	≥7 (E)	0.43	0.00
	≥5	0.76	2.32

Note: E: the score at which an emergency call is triggered; pts: patients
[a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

For the EWSs tested, on average, only approximately 50% of the index patients would trigger an emergency call and 1.3% of the control patients would falsely trigger emergency calls.

Comparing the efficiency of the EWSs using the AUROC

The AUROC was calculated to assess the efficacy of the numeric EWS indicator rather than any particular trigger threshold score. The AUROC is calculated from the raw EWS scores using patient status (index/control) as a criterion. For the 12 EWSs assessed, the AUROC range from 0.628 to 0.747 (See Table 15, Figures 11 and 12). The AUROC gave rise to three rough groupings: the single trigger EWSs, BTF and ARC_2 had the lowest AUROC; the aggregated weighted EWSs, Compass and NEWS had the highest AUROC; and the combination EWS and the single trigger EWS, ARC formed an intermediate group (See Figure 12).

Table 15: The AUROC for the 12 EWS in the study.

EWS	AUROC	SE[∞]	95% CI
[a]BTF	0.628	0.008	0.61 - 0.64
[a]ARC	0.689	0.007	0.67 - 0.70
[a]ARC_2	0.635	0.008	0.62 - 0.65
[b]MADDS	0.698	0.007	0.68 - 0.71
[b]$MADDS_2$	0.697	0.007	0.68 - 0.71
[b]$MADDS_5$	0.705	0.007	0.69 - 0.72
[b]Q-MEWT	0.690	0.007	0.68 - 0.70
[b]Q-ADDS	0.723	0.007	0.71 - 0.74
[b]Q-ADDS + BP scale	0.696	0.007	0.68 - 0.71
[b]ADDS	0.701	0.007	0.69 - 0.71
[c]Compass	0.747	0.007	0.73 - 0.76
[c]NEWS	0.741	0.007	0.73 - 0.75

Note: [∞] (DeLong et al., 1988)
[a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

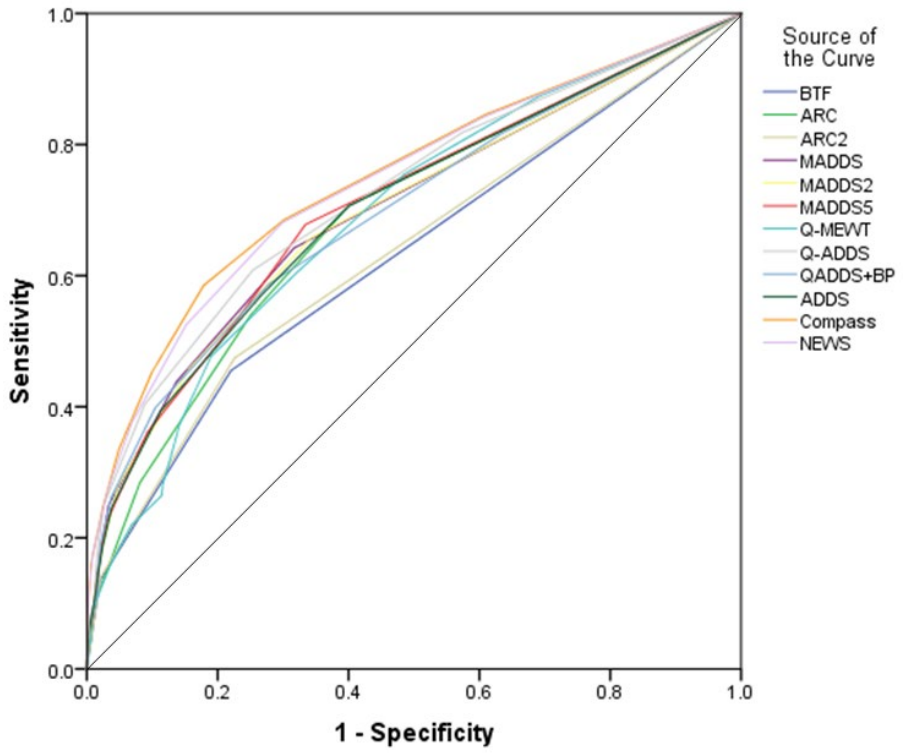

Figure 11: AUROC for the 12 EWSs.

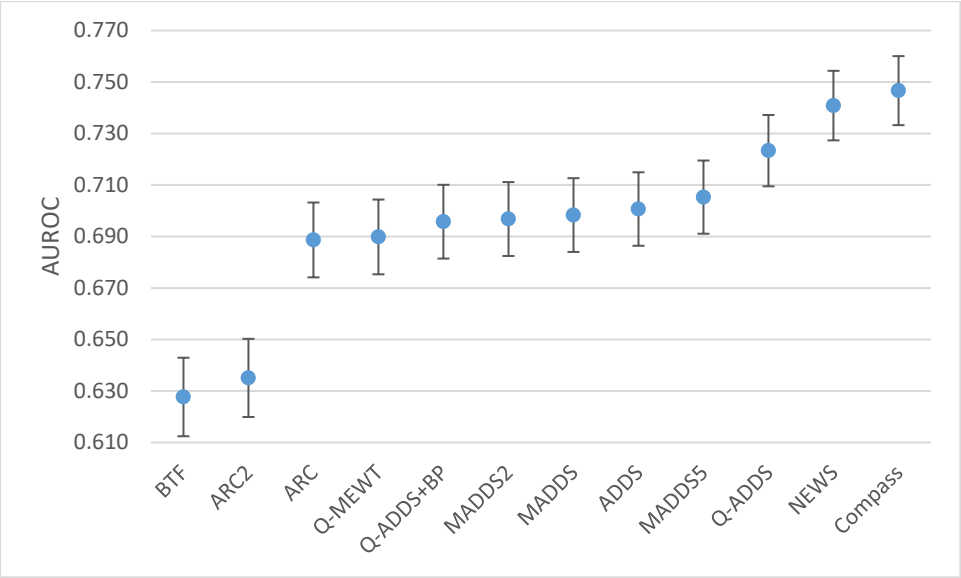

Figure 12: AUROC for the 12 EWSs with error bars indicating the confidence intervals.

Sensitivity and specificity of the 12 EWSs

The sensitivity and specificity of the EWSs reflect the percentage of true positives alerts and true negatives (non-alerts), respectively (See Table 16). At the emergency call threshold score (E), the sensitivities of the EWSs were relatively poor, ranging from 0.359 (CI: 0.28–0.44) for NEWS to 0.692 (CI: 0.61–0.76) for Q-MEWT. The specificity ranged from 0.92 (CI: 0.87–0.96) for Q-MEWT to 0.999 (CI: 0.98–1) for NEWS and Compass. This indicates that at the emergency threshold score, the EWSs tested are very efficient at identifying patients that were not at risk of deterioration but are less efficient at identifying those at risk of unexpected clinical deterioration events. At the more moderate threshold score, the sensitivity of all the EWSs increased with the single trigger EWSs, BTF, ARC and ARC_2, as well as the aggregated weighted EWSs, Compass and NEWS showing the greatest improvement in sensitivity (See Table 16, Figure 13).

Of the single trigger EWSs, ARC_2 appeared to be the most efficient, having the highest sensitivity and specificity at the emergency threshold score. The sensitivity of ARC_2 is surpassed only by the Q-MEWT, the combination EWS. Unfortunately, Q-MEWTS also has the lowest specificity resulting in its poor discriminatory ability. At the emergency threshold score, NEWS and Compass, the two aggregated weighted EWSs, produced the highest specificity with no false positives (false alerts). Thus, every patient that triggered an emergency alert using these aggregated weighted EWSs suffered an SAE. Unfortunately, this comes at the cost of reduced sensitivity, with a high false negative toll, meaning that these EWSs were not able to identify a large proportion of the patients that were truly at risk of deterioration.

Table 16: The sensitivity and specificity with a 95% confidence level, for the 12 EWSs at two threshold scores.

EWS	High & moderate Threshold score	Sensitivity	Specificity
[a]BTF	Red (E)	0.550 (0.47 - 0.63)	0.988 (0.96 - 1.00)
	Yellow	0.925 (0.87 - 0.96)	0.819 (0.75 - 0.87)
[a]ARC	Purple (E)	0.428 (0.35 - 0.51)	0.994 (0.97 - 1.00)
	Red	0.742 (0.67 - 0.81)	0.959 (0.92 - 0.98)
[a]ARC_2	Purple (E)	0.585 (0.50 - 0.66)	0.990 (0.96 - 1.00)
	Red	0.930 (0.88 - 0.97)	0.818 (0.75 - 0.87)
[b]MADDS	≥8 (E)	0.447 (0.37 - 0.53)	0.992 (0.97 - 1.00)
	≥4	0.591 (0.51 - 0.67)	0.994 (0.97 - 1.00)
[b]$MADDS_2$	≥8 (E)	0.453 (0.37 - 0.53)	0.994 (0.97 - 1.00)
	≥6	0.572 (0.49 - 0.65)	0.994 (0.97 - 1.00)
[b]$MADDS_5$	≥8 (E)	0.478 (0.40 - 0.56)	0.994 (0.97 - 1.00)
	≥4	0.692 (0.61 - 0.76)	0.977 (0.94 - 0.99)
[b]Q-MEWT	≥8 (E)	0.692 (0.61 - 0.76)	0.920 (0.87 - 0.96)
	≥6	0.742 (0.67 - 0.81)	0.912 (0.86 - 0.95)
[b]Q-ADDS	≥8 (E)	0.465 (0.39 - 0.55)	0.990 (0.97 - 1.00)
	≥6	0.623 (0.54 - 0.70)	0.994 (0.97 - 1.00)
[b]Q-ADDS + BP scale	≥8 (E)	0.510 (0.43 - 0.59)	0.990 (0.96 - 1.00)
	≥6	0.742 (0.67 - 0.81)	0.988 (0.96 - 0.99)
[b]ADDS	≥8 (E)	0.478 (0.40 - 0.56)	0.990 (0.97 - 1.00)
	≥6	0.566 (0.49 - 0.64)	0.988 (0.96 - 0.99)
[c]Compass	≥7 (E)	0.440 (0.36 - 0.52)	0.999 (0.98 - 1.00)
	≥4	0.774 (0.70 - 0.84)	0.947 (0.90 - 0.98)
[c]NEWS	≥7 (E)	0.359 (0.28 - 0.44)	0.999 (0.98 - 1.00)
	≥5	0.635 (0.56 - 0.71)	0.977 (0.94 - 0.99)

Note: [a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

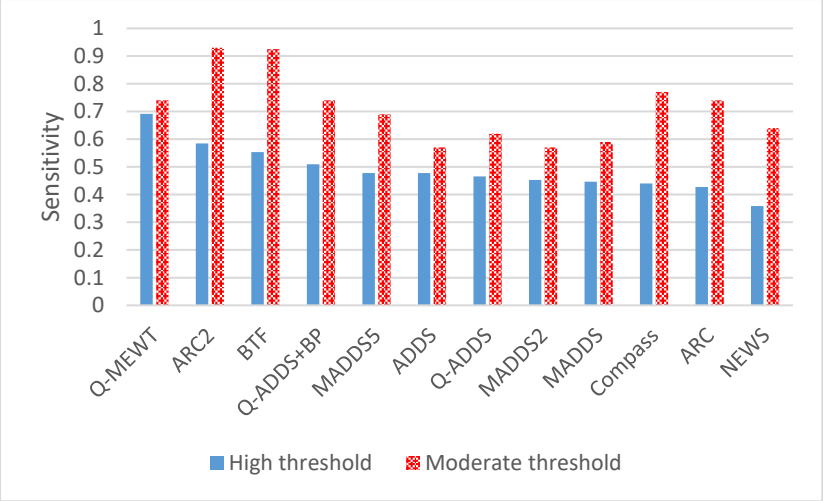

Figure 13: Sensitivity of the 12 EWSs at the high (emergency) and moderate threshold scores.

The 12 EWSs tested had an AUROC of 0.628–0.747, and a sensitivity of 0.36–0.69.

Discussion

Most patients in the study cohort were of advanced age with multiple comorbidities, characteristic of the regional/rural population (Australian Bureau of Statistics, 2017; Australian Institute of Health and Welfare, 2018). A recent study in a large regional hospital in Victoria, Australia, found that the mean age of patients requiring emergency medical reviews was 70 to 89 years old (Porter, Peck, McNabb, & Missen, 2020). In comparison, patients in metropolitan hospitals requiring emergency calls are much younger, in their early to mid-60s (Churpek et al., 2014; Forster, Housley, McKeever, & Shaw, 2018; Ljunggren, Castren, Nordberg, & Kurland, 2016; Mora et al., 2016). Age is a known risk factor of patient health deterioration and is closely linked to a higher incidence of cardiac arrests and death (Green et al., 2018; Kellett & Deane, 2006; Prytherch, Smith, Schmidt, & Featherstone, 2010; Ljunggren et al., 2016; Quarterman, Thomas, McKenna, & McNamee, 2005; Smith, Prytherch, Schmidt, & Featherstone, 2008). Despite the advanced age of the patients, the incidence of unexpected clinical deterioration events was reasonably low, 1.2%, compared to previous studies that have reported SAE incidences of between 2% and 16% (Anderson,

Davis, Hanna, & Vincent, 2013; Buist, Bernard, Nguyen, Moore, & Anderson, 2004; Goldhill & McNarry, 2004; Hamilton, Globerd, & Harrison, 2014). This may be due to the low risk, subcritical patients frequenting these small private regional hospitals. In the present study, age was not related to the patients' EWS scores but did affect their LOS. Some studies have shown that age has no significant impact on the EWS's predictive power (D'Arrigo et al., 2017; Petersen, Antonsen, & Rasmussen, 2016), while others have found that it does make a small contribution to the efficacy of the EWSs (Prytherch et al., 2010; Quarterman et al., 2005). According to Prytherch et al. (2010), the inclusion of age adds complexity to the EWS and can raise ethical issues that are not justified by the small contribution that age adds to the EWS efficiency. With advanced age, the number of comorbidities tends to increase and could be expected to be a predictor of SAEs (Bleyer et al., 2011; Frost, Alexandrou, Bogdanovski, Salamonson, Davidson, et al., 2009; Frost, Alexandrou, Bogdanovski, Salamonson, Parr, et al., 2009; Kellett, Woodworth, Wang, & Huang, 2013; Kyriacos, Jelsma, & Jordan, 2014). However, there was no significant difference in the number of comorbidities in the current study, as determined using the Charlson comorbidity index, between the index and control groups, indicating that comorbidities were not a predictor of unexpected clinical deterioration events for this patient cohort.

The reliability of any diagnostic tool, in this case, an EWS, is dependent on the outcome measured (Altman & Royston, 2000), and since patient outcomes are fluid, characterising the SAEs can be challenging (Tarassenko et al., 2011). In the current study, unexpected clinical deterioration events were broadly defined to include several categories of patient outcomes. This was done not only because of the fluidity of patient outcomes but also because the patient cohort size was too small to allow for subclassification of the unexpected clinical deterioration events. As with several other studies, the dominant SAE was 'transferred to a higher level of care', which strictly speaking is not an SAE but a consequence thereof (Churpek, Yuen, & Edelson, 2013a; Churpek et al., 2013b; Cretikos et al., 2007; Ludikhuize, Smorenburg, Rooij, & de Jonge, 2012; Massey, Aitken, & Chaboyer,

2015). The only irrefutable clinical deterioration event was morality which represented approximately 9% of the index patient outcomes in the current study. The mortality rate of index patients in this study was similar to the findings of Subbe, Davies, Williams, Rutherford, and Gemmell (2003), 9.7% mortality rate, and Smith, Prytherch, Schmidt, and Featherstone (2008), 8.4% mortality, but both are lower than those of other studies, 14.8% to 32.2% (Cildir et al., 2013; Ludikhuize et al., 2012; Tirotta et al., 2017; Wheeler et al., 2013).

Since patient admissions at the study sites are either planned or at the discretion of the admitting physician, most admissions occurred early in the week, Monday to Wednesday. Weekend admissions are rare, possibly due to the lack of regional specialist care and auxiliary medical services on weekends. In the current study, the unexpected clinical deterioration events manifested around 50 hours post-admission and occurred most frequently between Wednesday and Friday during office hours. Some studies have shown that SAEs often occur after hours and on weekends when staff numbers are lower, and patient monitoring is less frequent (Peberdy et al., 2008). In the present study, there was no after-hours spike in unexpected clinical deterioration events. Being resource-poor facilities, the nursing staff are wholly responsible for monitoring and responding to deteriorating patients in the absence of resident doctors and medical emergency teams. Although it was not within the scope of this study to explore the reasons for the diurnal pattern of unexpected clinical deterioration events, it is possible that nursing staff respond early to high-risk patients to minimise SAEs occurring after hours.

In the 72 hours preceding the unexpected clinical deterioration events, approximately half of the index patients had severely abnormal vital signs, which would have achieved an emergency call EWS threshold score. Yet emergency calls were made for only 3.9% and 29.3% of the patients at Site 1 and Site 2, respectively (See Table 10). The difference in the incidence of emergency calls between the two study sites may, at least in part, be due to the early adoption of EWSs in Site 2 compared to Site 1. Before introducing the EWS,

emergency calls were made based chiefly on nurse intuition rather than a prescribed EWS protocol. This may be anecdotal evidence that implementing an EWS at study Site 2 helped staff recognise and respond to the deteriorating patient.

In the present study, patients with a documented unexpected clinical deterioration event first reached an emergency threshold score approximately 20 hours preceding the deterioration event. Other studies have shown that EWS scores increase steadily from approximately 20 hours preceding the deterioration event and reached an emergency threshold score approximately 8 hours preceding the deterioration event (Zografakis-Sfakianakis et al., 2018). According to Cuthbertson and Smith (2007), EWSs have poor discriminatory abilities since most patient deterioration is only detectable about 15 minutes before an SAE. Yet Smith, Prytherch, Schmidt, and Featherstone (2008) believe that patient deterioration is often detectable 24 hours before the SAE, giving staff ample opportunity to react appropriately. Several studies have shown that EWSs can alert an SAE more than 24 hours before the event (Green et al., 2018; Kellett et al., 2013; Ludikhuize et al., 2012; Mora et al., 2016; Prytherch et al., 2010; Subbe, Kruger, Rutherford, & Gemmel, 2001) or at least several hours preceding the event (Bleyer et al., 2011; Buist et al., 1999; Lighthall, Markar, & Hsiung, 2009; Nurmi, Harjola, Nolan, & Castren, 2005; Stoffel-Lowis, 2011). This serves to illustrate the heterogeneity of EWS efficiencies depending on the patient cohort, the facility and the EWS being tested.

Between one and eight at-risk patients trigger an alert per shift (Tarassenko et al., 2011) and some at-risk patients will experience multiple episodes of physiological instability preceding an SAE (Andersen et al., 2016; Buist et al., 1999). The risk of patient deterioration increases with increasing incident and number of abnormal vital signs (Fuhrmann, Lippert, Perner, & Østergaard, 2008; Goldhill & McNarry, 2004). Based on a review of 15 published studies, between 26 and 56 emergency calls are made per 1 000 patients (D. Jones, Bellomo, & Devita, 2009) and given that not all patients reaching the emergency threshold score are medically reviewed, this may be an underestimation. On average, in the current

study, index patients reached emergency call thresholds 2.25 times in the 72 hours preceding an unexpected clinical deterioration event, with Q-MEWT, the EWS with diastolic blood pressure, triggering most frequently, more than four times per index patient. Although Q-MEWT may appear to be a better predictor of patient deterioration, it also triggered about eight times more false alerts than the other EWSs. The theoretical number of alerts at the emergency threshold score per 100 patients per day (See Table 12) shows that Q-MEWT's ability to correctly trigger an alert is approximately twice that of the other EWSs. Also, Q-MEWT would correctly identify almost 70% of patients at risk of unexpected clinical deterioration (See Table 13), whereas the other EWS correctly identify 36% to 58% of at-risk patients. However, Q-MEWT also produced the highest number of false alarms, 46 false alarms per 100 patients per day and incorrectly flagged almost 8% of the control patients as being at risk of deterioration. There is a clear trade-off between correctly identifying at-risk patients and the threat of staff alarm fatigue due to false alerts. As a comparison, if NEWS was implemented, there would be 0.53 true alerts per day per 100 patients, which is similar to the other EWSs tested, excluding Q-MEWT, and only 1.34 false alerts. Unfortunately, NEWS correctly identified less than 36% of the at-risk patients. If the emergency threshold was lowered to the more moderate score, on average, the EWSs' ability to correctly identify at-risk patients would increase by almost 40%, but the number of false alerts would increase by over 300%. The choice of EWS implemented would have far-reaching ramifications on staff workload and patient safety.

An EWS with good sensitivity produces few false negative results; that is, most patients at risk of deterioration reach the emergency threshold score (Mulligan, 2010). If few not at-risk patients trigger emergency calls (a low incidence of false positives), the EWS has a high specificity (Mulligan, 2010). Few of the control patients in the current study reached emergency threshold scores resulting in all EWSs having good specificities, > 0.9. Thus, for this patient cohort, these EWSs were highly efficient at identifying low-risk patients. However, the numerous false negatives imply that many at-risk patients did not trigger alerts

and would remain unnoticed if the staff relied entirely on the EWS scores when assessing a patient's medical condition. This is why it has been suggested that EWSs should always be used in conjunction with other clinical results, empiric medical knowledge of the patient and good nurse intuition (Grant & Crimmons, 2018; D Jones, Mitchell, Hillman, & Story, 2013; O'Donoghue et al., 2011; Silcock et al., 2015).

According to Odell (2015), the implementation of EWSs is an oversimplified solution to a very complex problem. In the current study, the large number of false negatives (index patients that did not attain an emergency threshold score) resulted in low EWS sensitivities, with Q-MEWT having the highest sensitivity of 0.692 and NEWS the lowest, 0.359. These EWS sensitivities are in accord with previous studies (Ghosh, Eshelman, Yang, Carlson, & Lord, 2018; Green et al., 2018; Mulligan, 2010; Romero-Brufau et al., 2014; Sharpley & Holden, 2004; Smith, Prytherch, Schmidt, Featherstone, & Higgins, 2008) resulting in some researchers concluding that clinical reliance on EWSs is questionable (Gao et al., 2007). Recent EWS validation studies involving NEWS and BTF produced sensitivities even lower than those in the current studies: 15.3% for NEWS at a threshold score ≥ 5; and 27.5% for BTF at the emergency threshold score (red zone on the vital sign observation chart) (Ghosh et al., 2018; Green et al., 2018). If the trigger thresholds were lowered, the sensitivity would increase to 22.2% for NEWS at a threshold score of ≥ 3; and 64.9% for BTF in the moderate threshold score (yellow zone) (Ghosh et al., 2018; Green et al., 2018). The current NEWS emergency threshold score is ≥ 7. The Royal College of Physicians (2017) has recognised that this threshold score may be too stringent and has recommended that patients with a score ≥ 5 be considered for urgent medical review, but the emergency threshold score currently remains unchanged at ≥ 7. The sensitivity of the EWSs (the ability of the EWS to correctly identify at-risk patients) can be improved by lowering the trigger threshold scores, but this comes at the cost of increasing the number of false alerts. In the current study, if the trigger threshold is lowered, the sensitivity of all the EWSs increase, averaging 0.71, but the number of false alarms escalates almost four-fold. This results in an increased staff workload

which could lead to alarm fatigue and a failure to respond to deteriorating patients (Burgess, Herdman, Berg, Feaster, & Hebsur, 2009; Currey, Allen, & Jones, 2018; Roney et al., 2015; Wang, Fang, Chen, Tsai, & Kao, 2016).

The AUROC is commonly used as a measure of EWS efficiency because it is independent of the EWS trigger thresholds. It is merely an indication of the likelihood of a deteriorating patient triggering an alert compared to a patient not at risk of deterioration. The average AUROC for the 12 EWSs tested was 0.7, with the aggregated weighted EWSs, Compass and NEWS having the highest AUROC at 0.74. Among the combination EWSs, Q-ADDS was the most efficient, with an AUROC of 0.72. The single trigger EWSs, BTF and ARC_2 had the lowest AUROC of 0.628 and 0.635, respectively. An AUROC of 0.7 is considered reasonable, and an AUROC exceeding 0.8 is regarding as having good discriminatory abilities (Prytherch et al., 2010; Smith, Prytherch, Schmidt, Featherstone, & Higgins, 2008). Most EWSs previously validated have AUROC of between 0.6 and 0.9, indicating that the EWS tested in the current study fall within the published range and can be regarded as reasonably effective (Fullerton, Price, Silvey, Brace, & Perkins, 2012; Green et al., 2018; Keep et al., 2016; Kivipuro et al., 2018; Moore et al., 2017; Opio, Nansubuga, & Kellett, 2013; Prytherch et al., 2010; Smith et al., 2013; Smith et al., 2014; Spångfors et al., 2016).

Given the ambiguous and often contradictory results generated by the various mathematical EWS validation tests, there has been some discussion about how EWS efficiency should be quantified. Romero-Brufau, Huddleston, Escobar, and Liebow (2015) suggested that the AUROC and specificity are not suitable measures of a test's efficiency since they do not consider the prevalence of the disease/condition in the patient cohort. They argue that the AUROC is a measure of an EWS tool itself and does not consider the pre-test probability of patient deterioration. In the current study, we argued that AUROC is a good measure of EWS efficiency because it is not reliant on the EWS trigger thresholds but simply reflects the likelihood of an index patient having a higher score than that of a control

patient. Romero-Brufau et al. (2015) suggest that sensitivity is a better measure of EWS efficiency. There have also been suggestions that trigger thresholds be individually established based on the patient's pre-existing condition (Capan et al., 2015). Such real-time EWS have been tested, with critical EWS threshold scores set based on the individual's medical condition on admission (Capan et al., 2015). The system may be viable but is not practical given its high resource requirement. Yet another suggestion is that the EWS thresholds be altered to suit a given facility or patient cohort (Gao et al., 2007). Cuthbertson and Smith (2007) proposed that distinction be made between early and late signs of unexpected clinical deterioration and that EWS threshold scores be altered accordingly. The use of sensitivity has also been criticised since it is a single measure in time. Grant and Crimmons (2018) argue that patient deterioration is often a gradual change in clinical condition and that the vital signs trends should be considered rather than a single set of vital signs at a given time. According to Morgan and Wright (2007), the original developers of the first track and trigger system, EWSs were not designed to predict patient outcomes since patient outcomes are dependent on many factors of which vital signs is only one. These systems were developed to track the patient's clinical condition and help inexperienced staff identify patient deterioration (Morgan & Wright, 2007).

This study has shown that the higher the number of alerts over a given time, the higher the sensitivity of the EWS. However, high sensitivity comes at the expense of poor discriminatory ability, which means many of the alerts were false alarms. Poor discriminatory ability is expressed as a low AUROC, which is why Q-MEWT had the highest number of alerts, the highest sensitivity, but a poor AUROC. Whereas NEWS had few alerts, thus a low sensitivity, having missed 65% of the deteriorating patients, but very few false alerts (false positives). Therefore, almost every alert generated by NEWS indicated an unexpected clinical deterioration event which resulted in NEWS having a high AUROC. Thus, there is a trade-off between adopting an EWS that is highly efficient at identifying at-risk patients without overtaxing staff with superfluous false alarms.

The question remains, of the 12 EWSs tested, which system would best suit the study cohort? There have been some arguments in support of the single trigger systems given that these systems are simple to implement and minimise the risk of calculation and documentation errors, a major cause for EWS failure (Churpek et al., 2013b; D. Jones et al., 2011; Subbe, Gao, & Harrison, 2007). Thus, single trigger EWS may be well suited for poorly resourced hospitals. Also, there is evidence that even a single deranged vital sign may be indicative of a potential SAE (Andersen et al., 2016; Baker et al., 2015; Bleyer et al., 2011) with some vital signs such as heart rate and respiratory rate being independent predictors of patient deterioration (Chaboyer, Thalib, Foster, Ball, & Richards, 2008). However, since vital signs monitoring is usually intermittent, a single abnormal vital sign is easily missed (Smith, Prytherch, Schmidt, Featherstone, Kellett, et al., 2008). While BTF is the most simplistic of the EWSs evaluated, having only two tiers of action, yellow indicating at-risk patients and red allocated to patients requiring urgent emergency medical review, it may be over-simplistic. Although a simple system may be considered well suited for non-critical medical facilities, many of the patients in the study cohort experienced a gradual clinical deterioration that may not have been identified using a two-tiered system.

Also, studies have shown that the potential of experiencing an SAE increases as the number of abnormal vital signs increase (Baker et al., 2015; Elliott et al., 2017; Royal College of Physicians, 2017). Combinations of abnormal vital signs are thought to be a better indicator of patient clinical decline (Considine, Berry, Johnson, & Sands, 2017; Goldhill & McNarry, 2004). Several studies have compared various classes of EWSs and found the aggregated weighted systems are more effective at identifying at-risk patients than the single trigger EWSs (Churpek et al., 2013b; Churpek et al., 2014; de Pennington, Laurenson, Lebus, Sihota, & Smith, 2005; Green et al., 2018; Jarvis et al., 2015; McNeill & Bryden, 2013).

In the current study, the aggregated EWSs, NEWS and Compass, produce the best AUROC with the lowest number of false alerts but had the lowest sensitivity and failed to alert over 60% of the unexpected clinical deterioration events. On the other hand, Q-MEWT had the highest number of true positive alerts and the highest incidence of false alerts, which would

probably make this EWS impractical to implement. Thus, based on existing literature and the current study's findings, it may be prudent to recommend adopting either one of the aggregated weighted EWSs or a combination EWSs such as Q-ADDS. Furthermore, given that most Queensland public hospitals utilise combination EWS to standardise the EWS implemented, private medical facilities may consider adopting a combination EWS. While it is generally agreed that EWSs contribute towards the identification of patients at risk of deterioration, it is inconclusive as to whether they can alter the patient outcomes (Chan, Jain, Nallmothu, Berg, & Sasson, 2010; Esmonde et al., 2006; Smith et al., 2014). No matter which EWS is adopted, they should probably be regarded as tools that assist in decision making and should not replace good clinical judgement and nursing assessment.

Conclusion

Despite the simplicity of implementing the single trigger EWSs, their efficiency was low, and their implementation is not recommended. Of the 12 EWSs compared, Q-MEWT proved to have the highest sensitivity, alerting staff to deteriorating patient. However, Q-MEWT generated many false alerts, increasing the staff workload and making this EWS impractical to implement. Based on the EWSs sensitivity and AUROC there is a lack of conclusive evidence of the efficacy of the 12 EWSs tested. However, since it is now mandatory that all Australian medical facilities implement a system of identifying patients at-risk of deterioration, it may be advisable to consider adopting an aggregated weighted or a combination EWS. Given that only half of patients that suffered an unexpected clinical deterioration event reached an emergency call threshold score, it is imperative that staff clinical judgement and good nursing assessment be used in combination with EWS.

Chapter Summary

This chapter compared the efficiency of 12 existing EWS intending to identify a system that could be recommended for use in the smaller, more poorly resourced regional/rural hospitals. These EWSs, with reasonably good sensitivities, that is, the ability to identify a deterioration patient, also proved to have poor specificities, potentially generating many false alerts and increasing staff workloads in these already resource-poor facilities. Although no single EWS was ideally suited for this patient cohort, the aggregated EWSs could better detect deteriorating patients when compared to the single trigger EWSs. The outcomes of Chapter 4 prompted the modification of existing EWS to determine their efficacy in meeting the needs of patients in poorly resourced regional/rural hospitals. To do so, Chapter 5 will ascertain which of the vital signs best predicts patient deterioration to utilise this information to develop a new, more efficient EWS.

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Chapter 5. Patient Vital Signs

Patient monitoring patterns and vital signs as predictors of patient deterioration

Synopsis

The overarching aim of this two-phase study was to provide evidence of Early Warning Score (EWS) efficiencies to assist small regional/rural hospitals make informed choices when selecting an EWS suited for implementation. To achieve this aim, Phase 1 compared the efficacy of 12 existing EWSs using patient data from small regional private hospitals (Chapter 4). Although the aggregated EWSs called Compass had the best AUROC, only around half of the deteriorating patients reached the emergency threshold score. Thus, many at-risk patients in these settings would not have triggered an EWS alert and would have remained undetected if staff relied solely on the EWSs. Since no single EWS demonstrated optimal efficacy for this patient cohort, Phase 2 sought to optimise this information by developing and validating a new EWS. The initial step in developing a new EWS was to identify the individual contribution of each vital sign predicting clinical deterioration and determine which of these parameters could be adapted to improve the specificity and sensitivity of the EWSs (See Figure 1 below).

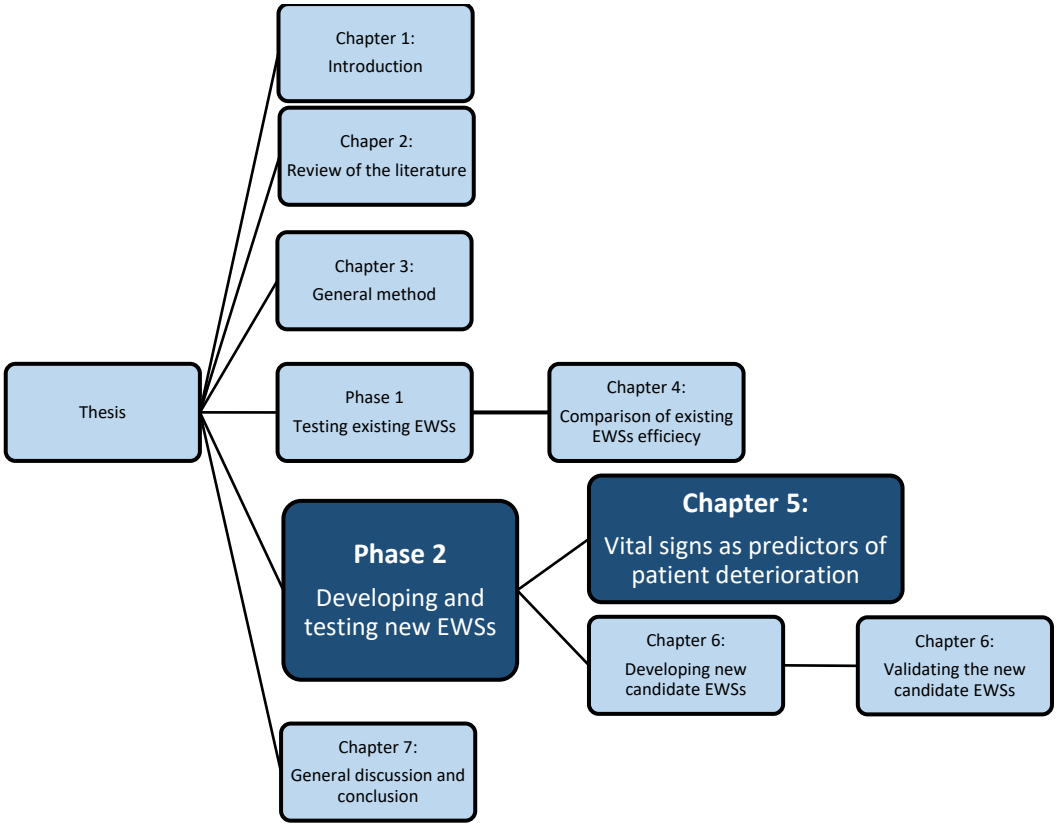

Figure 1: Schematic representation of the structure of the thesis.

The study presented here, in Chapter 5, investigates the pattern of vital sign monitoring in the target cohort to better understand the nature of patient monitoring at these smaller hospitals. Specifically, this study aims to determine whether the patient vital signs are good indicators of patient deterioration in the study cohort (Research Question 1a) and which vital signs best predict a deterioration event (Research Question 1b). This information is then used to develop and test new regional/rural context-specific EWS (presented in Chapter 6).

Abstract

Background: Patient vital signs are regarded as a measure of wellness but are only of use if the patient is monitored regularly and if the vital sign normality range is known. Early Warning Scores (EWSs) used in hospitals to help staff identify deteriorating patients are based on patient vital signs. This study investigates whether vital signs are good indicators of patient deterioration and which vital sign best predicts an unexpected clinical deterioration event.

Aim: This study aims to explore the pattern and completeness of vital sign monitoring of patients that experienced unexpected clinical deterioration events (index group) and those who had uneventful hospital stays (control group). Also, the contribution of each vital sign in predicting unexpected clinical deterioration events is investigated.

Method: A retrospective case-controlled study design was undertaken to compare vital sign data from patients who experienced unexpected clinical deterioration events and those who had an uneventful hospital stay. Patient data, extending over 3.5-years, were collected from two small regional private hospitals. The pattern and completeness of vital sign monitoring in the patient groups were compared using *t*-Tests and ANOVA with logistical transformation used for vital signs with skewed distributions. The contribution of each vital sign in predicting unexpected clinical deterioration events was determined using AUROC, odds ratios, sensitivity, specificity and binary logistical regression analysis.

Results: In the 72 hours preceding the unexpected clinical deterioration event or preceding hospital discharge, index patients were monitored more frequently (16.46 [13.12] sets of observations per patient) than control patients (13.74 [6.0] sets per patient). However, the completeness of vital sign documentation was higher in the control (82%) than in the index patients (61.4%). The most frequently omitted vital signs were level of consciousness (LOC), pain score and body temperature. Approximately 97% of the index patients and 70% of the control patients exhibited abnormal vital signs in the 24 hours preceding the unexpected

clinical deterioration event or hospital discharge, of which 63.8% of the index patients and 8.2% of the control patients experienced severely abnormal vital signs. The incidence of clinical deterioration events was positively linked to the frequency of abnormal vital signs and the number of abnormal vital signs per set (AUROC: 0.872 and 0.867, respectively).
No single vital sign was found to strongly predict patient outcomes. However, based on the odds ratios and AUROC, the use of supplementary oxygen > 3 L/min and heart rate > 120 beats/min were the best predictors of unexpected clinical deterioration events. According to the linear regression analysis results, all vital signs except SpO_2 made a small but significant contribution to predicting an unexpected clinical deterioration event. The most influential contributors were supplementary oxygen flow rate and heart rate.

Conclusion: Deteriorating patients are monitored more frequently than those not at risk of deterioration events, and vital signs appear to be good indicators of unexpected clinical deterioration events. Although no individual vital sign strongly predicts unexpected clinical deterioration events, supplementary oxygen flow rate and heart rate were the best predictors of such events.

Introduction

Early Warning Scores (EWSs) to assist staff in recognising and responding to patient deterioration has become commonplace and even mandatory in many developed counties (Bellomo, 2012; Churpek, Yuen, & Edelson, 2013; Prytherch, Smith, Schmidt, & Featherstone, 2010). The efficacy of these EWSs depends on abnormal vital signs preceding a clinical deterioration event. However, this is only of use if the vital signs' normality ranges can be established. Doing so has proved controversial given that factors such as age, morbidity, environment, body mass and level of fitness can individualise vital sign norms (Grant & Crimmons, 2018; Hong et al., 2013). According to Cuthbertson and Smith (2007), the vital sign normality range is commonly based on intuition rather than hard evidence, and derangement in vital signs often occur only a few minutes before the severe

adverse event (SAE), rending the EWS ineffective. In some cohorts, such as young children, vital signs are not a good indicator of clinical deterioration due, in part, to a lack of clear normality guidelines and consensus of monitoring methods (Van Kuiken & Huth, 2016). Also, there is no consensus regarding the optimal frequency of vital sign monitoring (Evans, Hodgkinson, & Berry, 2001). The lack of consensus is problematic, given that standardising the patient monitoring plan would help unify the detection of, and response to, the deteriorating patient (Royal College of Physicians, 2017). It has been suggested that the frequency of vital sign monitoring should be based on the patient's condition (Van Kuiken & Huth, 2016). Still, it is often dictated by facility policies, staff workloads and workplace traditions (Smith, Recio-Saucedo, & Griffiths, 2017).

The use of vital signs in Early Warning Systems

Monitoring patients' vital signs are routinely conducted in most health care facilities and are recognised as a physiological indicator of patient wellness (Hong et al., 2013). A basic set of vital signs usually includes recording the respiration rate (RR), heart rate (HR), blood pressure (BP), body temperature, and peripheral capillary oxygen saturation (SpO_2). According to Hong et al. (2013), any measurement or observation that indicates patient wellness or illness may be regarded as a vital sign. These may include urine output, mental state, that is, level of consciousness (LOC) or Glasgow Coma Scale (GCS), capillary refill, pain score, blood sugar levels, and blood gases (Hong et al., 2013; Sebat, Vandegrift, Oldroyd, Kramer, & Sebat, 2020). There have also been suggestions to include nutritional status, skin colour, spirometry, mobility and smoking status (Evans et al., 2001; Wheeler et al., 2013). However, since many of these variables are not routinely monitored, they are not usually included in the patient's EWS observation charts. Many EWSs include a weighted score for the patient's LOC or GCS. Some EWSs emphasise new confusion or agitation (Q-ADDS v6, NEWS2) since this is an important sign of clinical decline (Royal College of Physicians, 2017). Change in the LOC may be a more significant indicator of clinical decline

than the actual LOC (Royal College of Physicians, 2017), and thus frequent monitoring of patients is essential.

Despite an abundance of literature on the efficacy of EWSs (Abbott et al., 2015; Badriyah et al., 2014; Bleyer et al., 2011; Le Lagadec & Dwyer, 2017) and their extensive clinical implementation, patient deterioration remains a major concern for most medical facilities (Credland, Dyson, & Johnson, 2018). This may be partly due to patient cohort-specific variations, which have led to developing and testing cohort-specific EWSs (Cooksley, Kitlowski, & Haji-Michael, 2012; Mulligan, 2010; Wheeler et al., 2013). According to Watkinson, Pimentel, Clifton, and Tarassenko (2018), an EWS's efficacy depends on the patient database used in its development and testing. Most EWSs were developed in and for large metropolitan hospitals and are not necessarily well suited for use in smaller regional or rural facilities (Le Lagadec, Dwyer, & Browne, 2019). The patient demographics, the severity of patient illness, staff skill mix, and resources available in smaller regional/rural facilities often differ greatly from metropolitan tertiary hospitals. It is, therefore, prudent to utilise an EWS that suits the regional and rural context. To implement the best EWS or modify an existing system for a given cohort, it would be helpful to identify the vital signs that most frequently trigger EWS alerts or that best predict clinical deterioration events for that patient cohort.

This study aims to examine the pattern and completeness of vital sign monitoring in the 72 hours preceding an unexpected clinical deterioration event or hospital discharge. Also, to establish the contribution of each vital sign in identifying at-risk patients and determining which vital sign(s) best predict patient outcomes. These aims will be achieved by answering the following questions:

- Are there differences in the vital sign monitoring patterns of index and control patients?

- Are there differences in the completeness of vital sign documentation between the index and control groups?
- Does the statistical distribution of vital signs differ between the index and control groups?
- Do multiple abnormal vital signs increase the risk of unexpected clinical deterioration events?
- Which vital sign(s) best predicts patient outcomes, using as evaluation criteria:
    - Odds ratios;
    - Area under the Receiver Operating Characteristic Curve (AUROC);
    - Sensitivity and Specificity of each vital sign; and
    - Regressions.

The information gained in this study will be used later to inform on the development of a new, more efficient EWS better suited to the patient cohort in poorly resourced regional/rural medical facilities.

Method

Data collection

The cohort selection, data gathering, and data processing are described in Chapter 3. This study involves patient Cohort A, patients from two small regional private hospitals.

Statistical analysis

The categorical data were summarised using frequency tables, and for continuous data, mean and standard deviations were calculated. Raw vital sign data from the index and control groups were compared using simple *t*-Tests and analysis of variance (ANOVA) using 95% confidence intervals and a threshold for statistical significance of $p < 0.05$. Since *t*-Test and ANOVA assumes a normal distribution of the residuals (Clarke, 1980), SpO_2 and

supplementary oxygen flow rate, having a skewed distribution, were logarithmically transformed for analysis.

Establishing the normal range of individual vital signs is contentious, and this study was based on the approximate ranges used in the 12 EWSs discussed in Chapter 4. The vital sign ranges used are shown in Table 17.

Table 17: Vital sign ranges depicting the severity of the abnormality.

Vital signs	Normal range	Moderately abnormal	Severely abnormal
Respiration Rate (breaths/min)	10–20	6–9, 21–29	< 6, > 29
SpO_2 (%)	95–100	91–94	< 91
O_2 flow rate (L/min)	0–3	4–10	> 10
Systolic BP (mmHg)	110–160	90–109, 161–198	< 90, > 199
Heart rate (beats/min)	50–100	40–49, 101–139	< 40, > 139
Body temperature (^oC)	35.5–37.9	< 35.5, 38.0–39.9	> 39.9

Note: Vital sign ranges approximated from the EWS trigger thresholds (See Chapter 4). Diastolic BP is not included, given its omission from most EWSs.

The frequency of vital signs monitoring and the time interval between monitoring events were calculated for the index and control groups over the 72 hours of data collection. Also, the completeness of vital signs monitoring and the most frequently omitted vital signs were determined. The distribution of each vital sign was plotted using only the final 24 hours of vital signs data, preceding unexpected clinical deterioration events or hospital discharge for the control group. Vital sign abnormalities are most common 24 hours preceding the unexpected clinical deterioration event (See Chapter 4). The percentage of observations and patients with abnormal vital signs in the moderate and severe range was calculated using the data collected 24 hours preceding the unexpected clinical deterioration events or hospital discharge. The relationship between the abnormal vital signs and the associated unexpected clinical deterioration event was graphically represented by overlaying the frequency distribution of each vital sign and the corresponding incidence of unexpected clinical deterioration events. Using linear regressions and the AUROC, the relationship between

unexpected clinical deterioration events and the number of abnormal vital signs was evaluated.

Following Cretikos et al. (2007), the usefulness of the vital sign thresholds in classifying index and control patients was assessed by calculating the odds ratios (OR), the AUROC, and the sensitivity and specificity of each vital sign. The OR was calculated to determine the increased likelihood of an unexpected clinical deterioration event occurring when a given vital sign was within a certain level of derangement. The AUROC was used to identify the vital signs which best predicted unexpected clinical deterioration events. The AUROC is the probability that a patient who experiences an unexpected clinical deterioration event will have abnormal vital sign(s) compared to those who have uneventful hospital stays. An important feature of the AUROC is that it does not refer to any particular decision threshold. Setting the threshold higher or lower can significantly impact sensitivity and specificity, but not on the AUROC. Thus, the AUROC is useful because it provides a 'pure' measure of the ability of a vital sign in discriminating the two groups of patients. The AUROC was calculated using all sets of vital signs collected over 24 hours. Also, to determine whether the vital signs' predictive power increased with the forthcoming deterioration event, the AUROC was employed using a single set of vital signs per patient in six-hour increments preceding the deterioration event, that is, at -24 hours, -18 hours, -12 hours, -6 hours and 0 hours. The question 'What is the ideal vital sign threshold?' is distinct from the amount of discriminant information available in the vital sign that the AUROC captures. The significant differences at a 95% confidence interval ($p < 0.05$) between the AUROC of the index and control cohorts were compared through pairwise comparisons using the nonparametric Mann-Whitney U-statistic method of DeLong (DeLong, DeLong, & Clarke-Pearson, 1988). The Mann-Whitney U-statistic ranks the data and compares the median, not the mean of the data.

As an additional measure of the contributions of the vital signs in predicting unexpected clinical deterioration events, binary logistical regressions were performed for

each vital sign. This was undertaken using the final set of observations pre-clinical deterioration and the time equivalent set for the control patients, measured from when the patient was admitted to hospital. The vital signs with two-tailed distributions, RR, HR, BP and temperature, were centred and scaled using a Z-score equation before being transformed (their values squared) to compensate for their quadratic nature. This is a fact-heavy chapter, and therefore, the most important findings have been placed in text boxes for emphasis.

Results

Monitoring vital signs

Over the 72-hour monitoring period, 5 556 sets of vital signs were collected; 2 989 sets for the 159 index patients and 2 567 for the 172 control patients. Significantly more sets of vital signs were collected for the index patients (16.46 [13.12] sets/patient) than for the control patients (13.74 [6.0] sets/patient; $p = 0.001$, $F = 11.16$). The time interval between patient monitoring differed greatly over the 72 hours (See Table 18). On average, vital signs were monitored every 3.79 (2.65) hours for the index patients and every 6.11 (2.52) hours for the control patients ($p < 0.001$, $F = 66.34$). In the time interval, -72 hours to -49 hours, that is, 72 hours to 49 hours preceding the unexpected clinical deterioration event or hospital discharge, the number of monitoring events and the time interval between monitoring events were similar for the index and control groups ($p > 0.05$). Thereafter, the number of monitoring events increased over time for the index group, and the intervals between the events shortened significantly ($p < 0.05$). In the control group, although there were statistical differences in the number of and the time between the monitoring events, the trend was not as noticeable as in the index group (See Table 18, Figures 14 and 15).

Table 18: The average number of monitoring events (observations) per patient and the time interval between events (h) for the index and control groups. Letters associated with means (SD) pertain to statistical differences ($p < 0.05$).

		-72h to -49h	-48h to -25h	-24h to 0h	p#	F#
Number of observations taken	Index	5.79 (5.46)[a]	6.5 (5.3)[a]	9.58 (7.02)[c]	<0.001	13.74
	Control	5.32 (3.33)[ab]	4.08 (2.65)[d]	4.93 (2.66)[b]	<0.001	7.84
	p*	0.413	<0.001	<0.001		
	F*	0.673	25.61	64.67		
Time interval between observations (h)	Index	4.93 (2.47)[wx]	5.57 (4.84)[w]	3.08 (2.07)[y]	<0.001	20.904
	Control	5.51 (3.14)[x]	7.45 (4.25)[z]	5.64 (2.27)[x]	<0.001	17.46
	p*	0.144	<0.001	<0.001		
	F*	2.15	11.98	113.19		

Note:# pertains to intra-grouping statistical significance test (differences between time intervals within index or control cohort, reading from left to right)
* pertains to inter-grouping statistical significance test (differences between index and control cohort for a given time interval, reading from top to bottom)

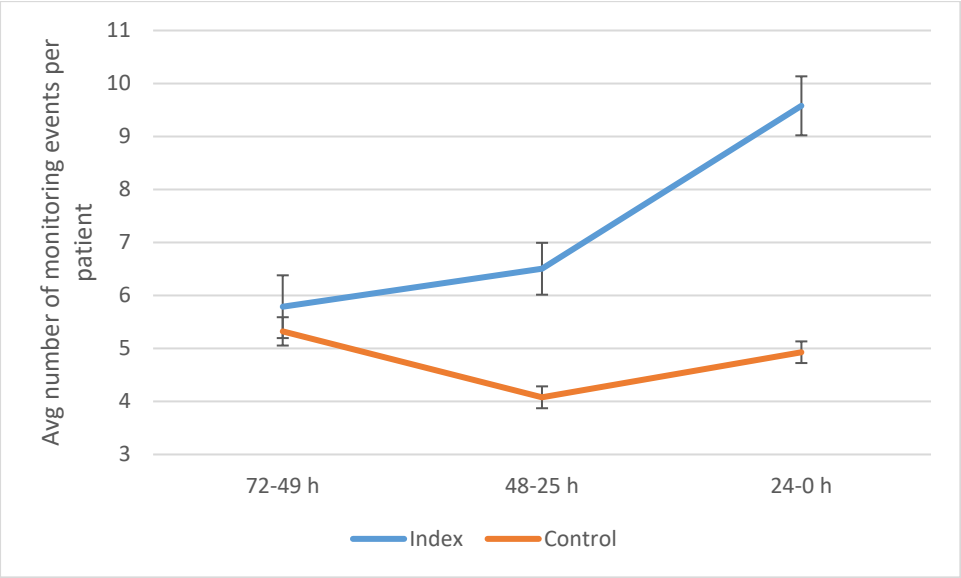

Figure 14: The average number of monitoring events per patient per 24-hour interval. Vertical bars indicate standard errors of the mean.

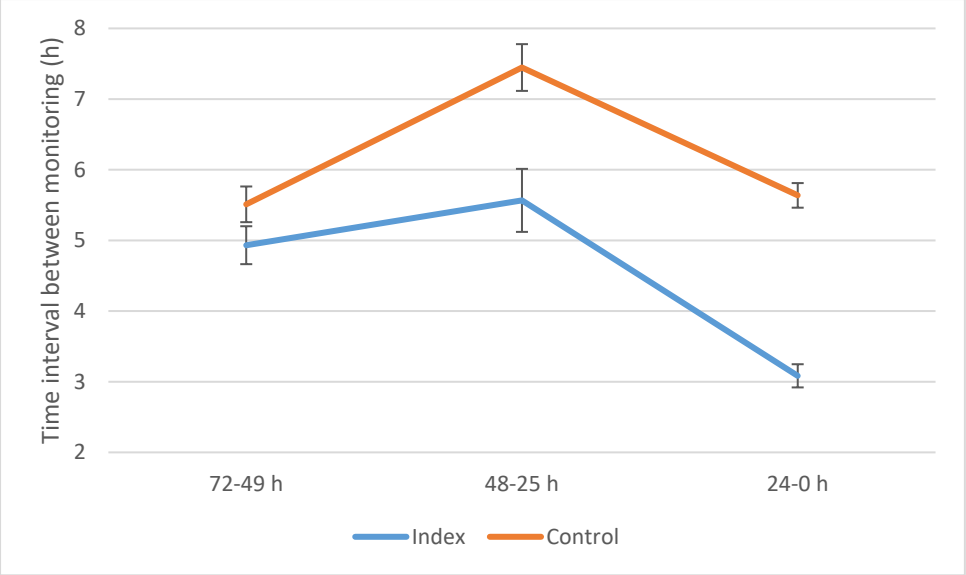

Figure 15: The average time interval (hours) between monitoring events over the 72 hours. Vertical bars indicate standard errors of the mean.

Completeness of Vital Sign Documentation

Of the 5 556 sets of vital signs collected, only 38.6% were complete. However, the two study sites used several different vital sign observation charts over the 3.5-year data collection period, and not all charts included the LOC and pain score. If these two variables are not considered, 70.7% of the observation sets can be considered complete. For the 159 index patients, 2 989 sets of vital signs were recorded, of which only 61.4% were complete (ignoring LOC and pain score), and 82% of the 2 567 sets of vital signs documented for the 172 control patients were complete. The completeness of vital signs was significantly different for the index and control patients ($p < 0.001$, $F = 106.69$). The most commonly omitted vital signs were pain score (53% omission for index and 43% for the control group); temperature (33.5% omission for index and 14% for the control group), and LOC (20% omission for index and 14% for the control group). Although less than 5% of the cohort monitoring events omitted RR, there is some doubt about the accuracy of this vital sign documentation. Respiration rate is known to be the first indication of patient deterioration (NICE, 2007). Yet, RR mainly remained unchanged for many index patients despite the other vital signs showing increasingly abnormal values.

More vital signs were taken for the index than the control patients, but fewer of these vital sign sets were complete.

The distribution range of vital signs

In the 24 hours preceding the unexpected clinical deterioration events or hospital discharge, 2 404 sets of vital signs were recorded. The distribution range of the various vital signs was significantly different in the index and control groups ($p < 0.05$) except for BP. Although there was a high degree of overlap in all the vital sign distributions between the two groups, the index patients displayed a more extensive distribution at both ends of the normality range (See Figures 16–22). The wide distribution range indicates more abnormal vital signs documented for the index than the control patients. The high degree of overlap shows the weak discriminatory power of any one individual vital sign. The incidence of unexpected clinical deterioration events superimposed on the vital sign distribution range (See Figures 16–22) suggests that unexpected clinical deterioration events are most prominent in the extremes of the vital sign ranges. However, only a small proportion of the cohorts exhibited extreme abnormal vital signs. For example, although 97% of patients with RR ≥ 35 breaths/min suffered an unexpected clinical deterioration event, only 5.7% of the patient cohort were documented as having RR within this range (See Figure 16). Only 3.8% of the patient cohort required more than 6 L/min of supplementary oxygen, but all these patients suffered an unexpected clinical deterioration event (See Figure 18). Approximately 6% of the patients had heart rates of ≥139 beats/min, of which 96% experienced a deterioration event (See Figure 21).

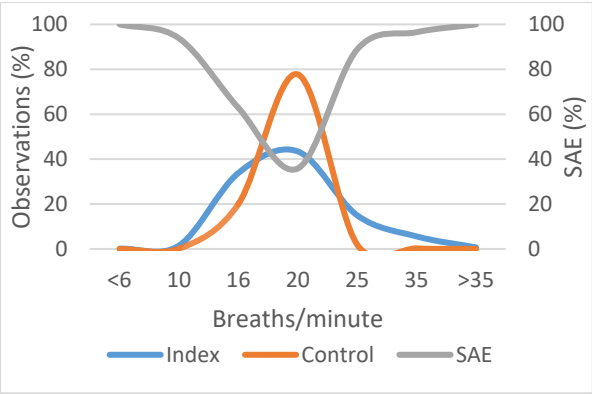

Figure 16: Distribution of respiration rate (breaths/min) for the index and control patients ($p < 0.001$, $F = 3.1$); and the associated incidence of clinical deterioration events.

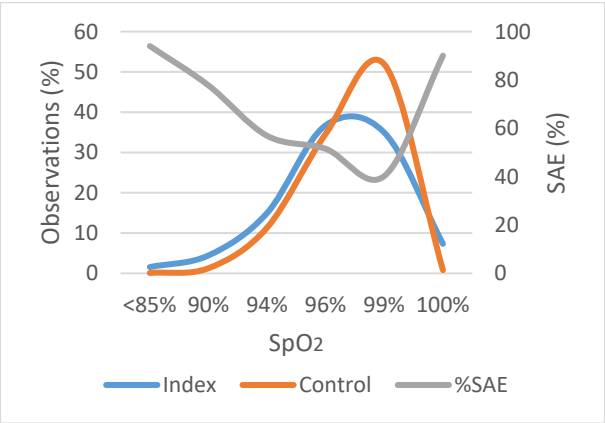

Figure 17: Distribution of oxygen saturation (%) for the index and control patients. Data was logarithmically transformed for *t*-Test ($p = 0.01$, $F = 6.67$); and the associated incidence of clinical deterioration events.

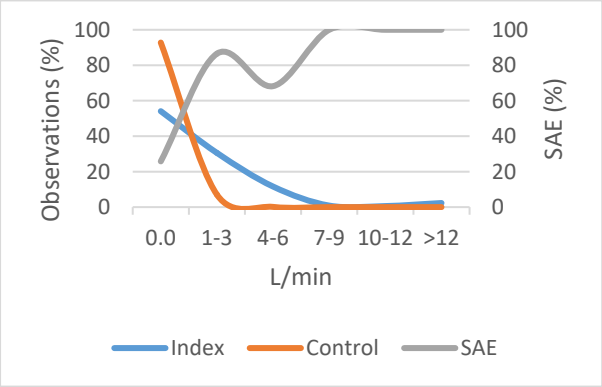

Figure 18: Distribution of supplementary oxygen flow rate (L/min) for the index and control patients. Data was logarithmically transformed for *t*-Test ($p < 0.001$, $F = 118.68$); and the associated incidence of clinical deterioration events.

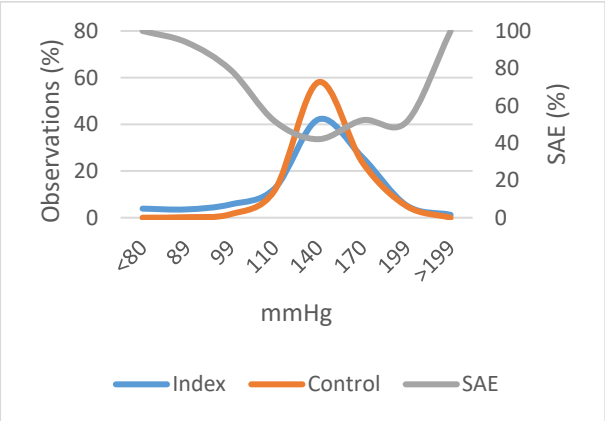

Figure 19: Distribution of systolic blood pressure (mmHg) for the index and control patients ($p = 0.074$, $F = 3.2$); and the associated incidence of clinical deterioration events.

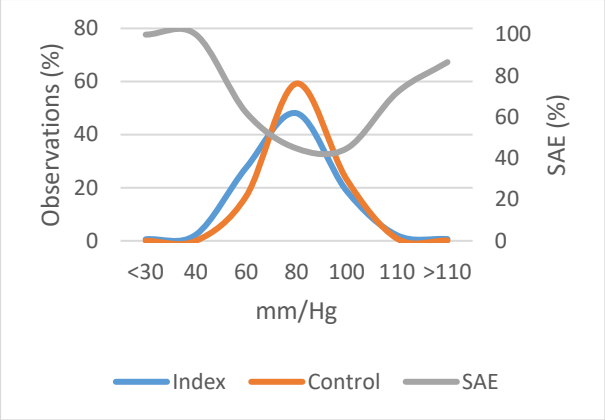

Figure 20: Distribution of diastolic blood pressure (mmHg) for the index and control patients (p = 0.142, F = 2.16); and the associated incidence of clinical deterioration events.

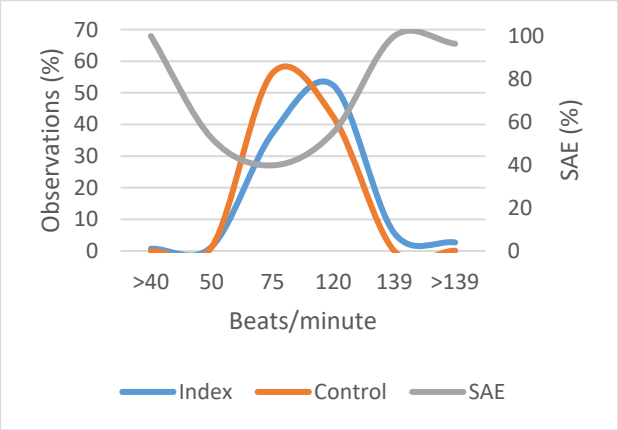

Figure 21: Distribution of heart rate (beats/min) for the index and control patients (p < 0.001, F = 98.32); and the associated incidence of clinical deterioration events.

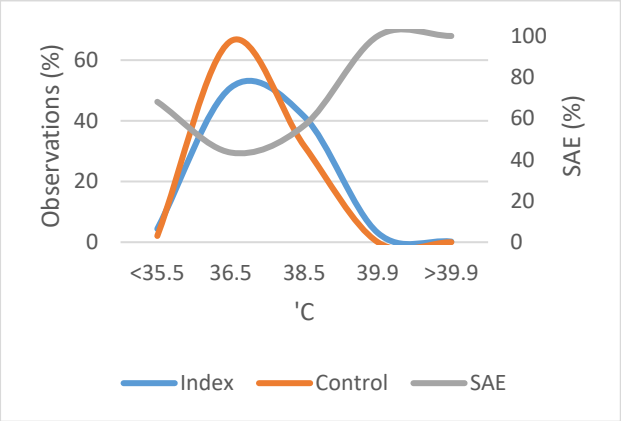

Figure 22: Distribution of body temperature (°C) for the index and control patients (p < 0.001, F = 21.27); and the associated incidence of clinical deterioration events.

Table 19: The percentage of monitoring events (observations) in 24 hours, with abnormal vital signs within the noted range.

Vital signs	Range	Index cohort		Control cohort	
		Sets of observations within this range	Patients with observations within this range	Sets of observations within this range	Patients with observations within this range
Respiration rate (breaths/min)	< 10, > 20	21.9%	54.1%	2.1%	7.6%
	< 6, > 29	3.2%	15.1%	0.1%	1.7%
SpO_2	< 95%	21.0%	57.9%	12.7%	27.9%
	< 90%	6.0%	28.3%	1.4%	4.7%
O_2 flow rate (L/min)	> 3	15.4%	33.3%	0.1%	0.6%
	> 9	2.9%	10.7%	0%	0%
Systolic BP (mmHg)	< 110, > 160	33.8%	88.1%	21.0%	47.7%
	< 90, > 199	8.7%	25.8%	0.6%	1.7%
Heart rate (beats/min)	< 50, > 100	24.1%	48.5%	4.6%	14.0%
	< 40, > 139	3.4%	11.3%	0.1%	0.6%
Body temp (°C)	< 35.5, > 37.9	9.4%	33.3%	2.0%	6.4%
	> 39.9	0.2%	0.6%	0%	0%

Note: Diastolic BP is not included because there are no set abnormality ranges for this vital sign.

There were significantly more index patients with abnormal sets of vital signs than control patients ($p < 0.001$, $F = 111.9$) (See Table 19). Systolic BP was the most common abnormal vital sign both in the index and control cohorts. Within the index group, 96.9% of the patients had a least one set of observations with abnormal vital signs in the 24 hours preceding the unexpected clinical deterioration event, and 63.8% of these were in the severely abnormal range. In comparison, 70.4% of the control patients had a least one set of anomalous observations, and 8.2% were within the severely abnormal range. In addition, patients that suffered unexpected clinical deterioration events were significantly more likely to exhibit signs of rapid breathing (> 20 breaths/min), required more than 6 L/min of supplementary oxygen and showed rapid heart rates (> 100 beats/min).

Patients that suffered unexpected clinical deterioration events tended to exhibit signs of rapid breathing, required more than 6 L/min of supplementary oxygen and exhibited rapid heart rates.

Abnormal vital signs and the risk of severe adverse events

On average, each index patient had 8.4 ([6.8], range 0–34) sets of observations with abnormal vital signs in the 24 hours preceding the unexpected clinical deterioration event, and 53.2% of the observations had more than one abnormal vital sign per set. Also, 63.5% of the index patients had at least one severely abnormal vital sign in 24 hours, of which 3% had multiple severely abnormal vital signs per set. On average, in the control group, each patient had 2.27 ([2.3], range 0–26) sets of abnormal observations, of which 12.4% had more than one abnormal vital sign per set. Also, 8.1% of the control patients had severely abnormal vital signs, but none had multiple severely abnormal vital signs per set. Using unexpected clinical deterioration events as the target outcome, the AUROC for the number of abnormal sets of observations (frequency of abnormal observations) per patient was 0.872. This indicates that patients with multiple sets of abnormal observations were more likely to suffer an unexpected clinical deterioration event than patients with fewer abnormal observations. Likewise, patients who had multiple abnormal vital signs per set of observations were more likely to suffer an unexpected clinical deterioration event than those with only one or no abnormal vital signs per set of observations (AUROC = 0.867). There was a positive correlation between the number of abnormal sets of observations per patients and the incidence of unexpected clinical deterioration events ($R = 0.504$, $R^2 = 0.254$, $F(1,329) = 111.91$, $p < 0.001$). Patients with multiple sets of abnormal observations were more likely to suffer unexpected clinical deterioration than patients with only one or no sets of observations with abnormal vital signs. Also, there was a weaker but significant correlation between the number of monitoring events per patients with multiple abnormal vital signs and the incidence of unexpected clinical deterioration events ($R = 0.471$, $R^2 = 0.222$, $F(1,329) = 94.04$, $p < 0.001$). Therefore, the number of abnormal sets of observations per patient had a greater impact on the incidence of unexpected clinical deterioration events than the number of abnormal vital signs per sets of observations.

Patients with multiple sets of abnormal vital signs were at increased risk of a deterioration event.

Vital signs predicting patient outcomes

Having determined that the frequency and number of abnormal vital signs are correlated to the incidence of unexpected clinical deterioration events, it is useful to establish which vital sign has the greatest predictive power. This was established using a variety of statistical analyses.

Odds ratios

The most prominent odds ratio (OR) results were for supplementary oxygen flow rate > 3 L/min (OR = 146.35 [CI 20.49–1045.34]), HR > 120 beats/min (OR = 77.13 [CI 10.76–552.71]), body temperature > 37.9^{o}C, (OR = 43.17 [CI 5.98–311.46]), and RR > 29 breaths/min, (OR = 26.97 [CI 3.7–195.77]). The other vital signs produced odd rations below 1.5 and were not considered remarkable.

AUROC of individual vital signs, sensitivity and specificity

The AUROC for the various vital signs collected over 24 hours was poor, ranging from 0.408 to 0.663 (See Figure 23 and Table 20). An AUROC of below 0.7 is regarded as having poor predictive abilities and between 0.7 and 0.8 as having reasonable predictive abilities (Prytherch et al., 2010). To illustrate, an AUROC of 0.8 indicates that a randomly selected index patient's score on the indicator was more extreme than 80% of control patients. However, an AUROC of 0.5 means the index patient's score was more extreme than 50% of control patients. Thus, 0.5 indicates no better than chance, and 1.0 means perfect separability of the two classes of patients. Based only on the AUROC, no single vital sign appears to adequately predict unexpected clinical deterioration events. Still, of the nine vital signs measured, the highest AUROC was obtained for supplementary oxygen flow rate

followed by HR. Although this may not appear to be a relevant result, it does provide some indication of the contribution of each vital sign in the unexpected clinical deterioration event.

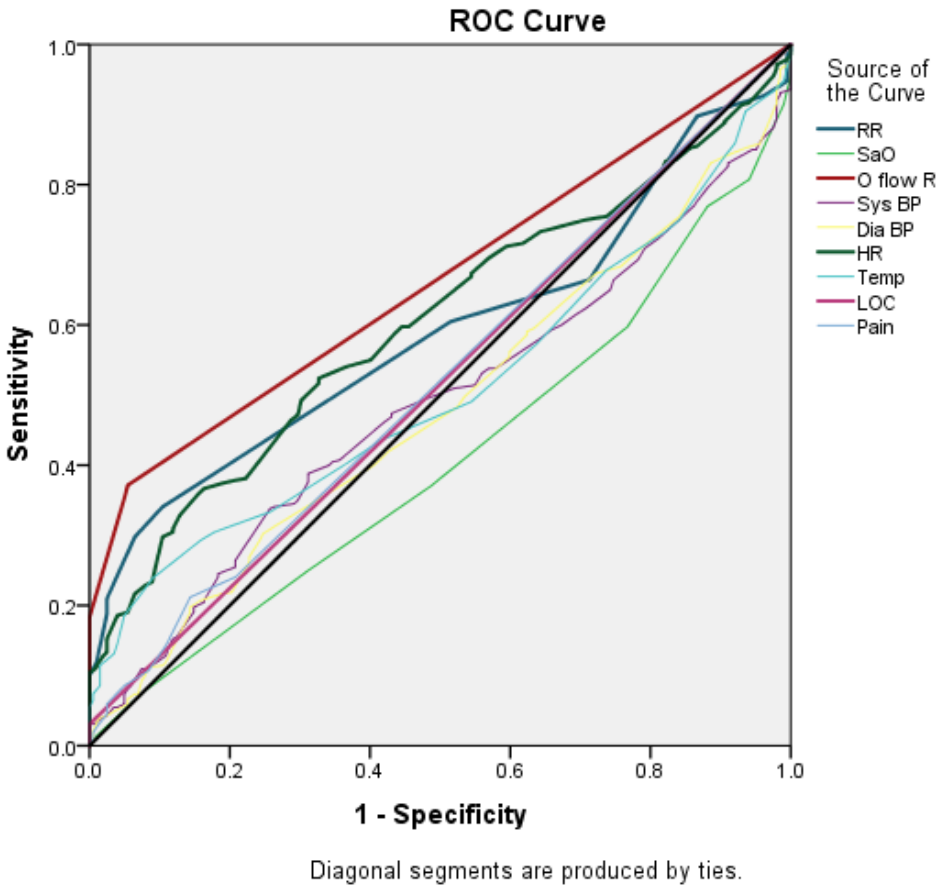

Figure 23: The AUROC for patient vital signs using all sets of observations collected over 24 hours preceding the unexpected clinical deterioration event or hospital discharge.

Table 20: The AUROC for each vital sign using all sets of vital signs collected over 24 hours.

Vital signs	AUROC	Confidence Interval (95%)	p
Respiration rate	0.589	0.55 - 0.63	< 0.001
SpO_2	0.408	0.36 - 0.45	< 0.001
O_2 flow rate	0.663	0.62 - 0.71	< 0.001
Systolic BP	0.487	0.44 - 0.53	0.586
Diastolic BP	0.480	0.43 - 0.53	0.417
Heart rate	0.603	0.56 - 0.65	< 0.001
Body temp.	0.507	0.46 - 0.55	0.771
LOC	0.515	0.47 - 0.56	0.532
Pain score	0.521	0.47 - 0.57	0.399

Based on the AUROC, no individual vital sign appears to adequately predict unexpected clinical deterioration events.

It has been suggested that the discriminatory ability of vital signs increases with the approaching SAE (Smith, Prytherch, Schmidt, & Featherstone, 2008). Using the current data set, the AUROC was calculated to test this theory, using a single set of vital signs collected at approximately 6-hour time increments (See Figure 24 and Table 21).

Table 21: The AUROC (CI at 95%) for each vital sign with unexpected clinical deterioration events as the predicted outcome, using a single set of vital signs per patient in six-hour increments; 0 hours is the final set of vital signs preceding the deterioration event; p indicates significant differences (i.e. AUROC significantly greater than 0.5) between the index and control groups.

Vital Signs	-24 hour	-18h	-12h	-6h	0h
Respiration rate	0.593 (0.51 - 0.68) p < 0.001*	0.571 (0.49 - 0.66) p = 0.001	0.531 (0.45 - 0.61) p = 0.157	0.575 (0.50 - 0.65) p = 0.001	0.596 (0.53 - 0.67) p < 0.001
SpO_2	0.35 (0.27 - 0.43) p < 0.001	0.409 (0.33 - 0.49) p = 0.538	0.360 (0.28 - 0.44) p = 0.026	0.328 (0.26 - 0.40) p = 0.007	0.386 (0.32 - 0.45) p < 0.001
O_2 flow rate	0.589 (0.51 - 0.67) p < 0.001	0.646 (0.57 - 0.73) p < 0.001	0.627 (0.55 - 0.70) p < 0.001	0.606 (0.54 - 0.68) p < 0.001	0.728 (0.67 - 0.79) p < 0.001
Systolic BP	0.546 (0.47 - 0.63) p = 0.109	0.521 (0.44 - 0.61) p = 0.231	0.421 (0.34 - 0.50) p = 0.149	0.483 (0.41 - 0.56) p = 0.548	0.475 (0.41- 0.54) p = 0.262
Diastolic BP	0.477 (0.40 - 0.56) p = 0.524	0.456 (0.37 - 0.54) p = 0.221	0.403 (0.33 - 0.48) p = 0.061	0.466 (0.39 - 0.54) p = 0.206	0.456 (0.39 - 0.52) p = 0.216
Heart rate	0.625 (0.55 - 0.70) p < 0.001	0.603 (0.52 - 0.69) p < 0.001	0.607 (0.53 - 0.69) p = 0.001	0.627 (0.56 - 0.70) p < 0.001	0.658 (0.59 - 0.72) p < 0.001
Body temp.	0.593 (0.52 - 0.67) p = 0.001	0.552 (0.47 - 0.64) p = 0.192	0.580 (0.50 - 0.66) p = 0.012	0.539 (0.47 - 0.61) p = 0.054	0.578 (0.51 - 0.65) p = 0.003
LOC	0.511 (0.44 - 0.59) p = 0.072	0.522 (0.44 - 0.61) p = 0.03	0.520 (0.50 - 0.66) p = 0.018	0.531 (0.46 - 0.60) p = 0.007	0.565 (0.50 - 0.63) p < 0.001
Pain score	0.493 (0.42 - 0.57) p = 0.806	0.490 (0.41 - 0.57) p < 0.001	0.490 (0.44 - 0.60) p = 0.739	0.481 (0.41 - 0.55) p = 0.906	0.532 (0.47 - 0.60) p = 0.089

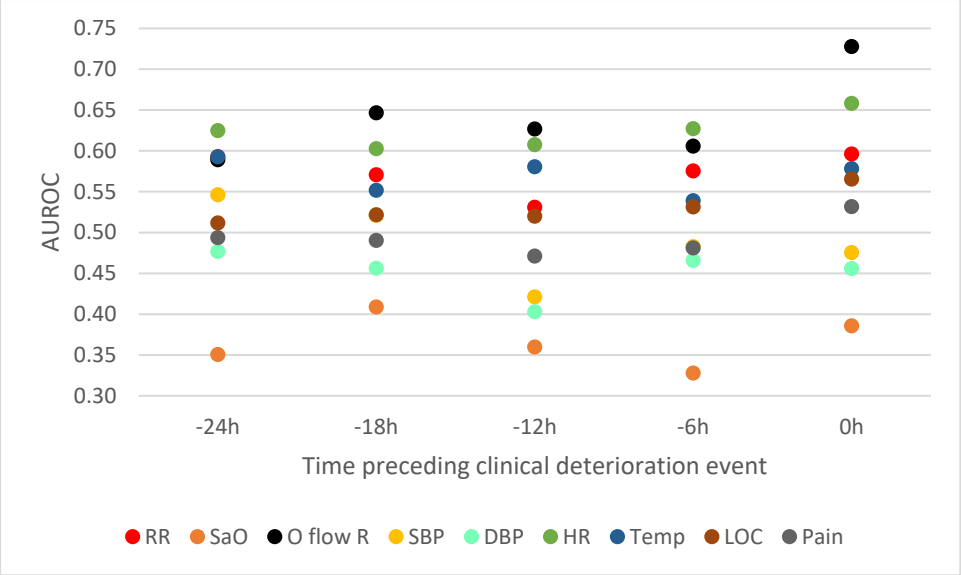

Figure 24: The AUROC for each vital sign at 6-hour increments. A single set of vital signs was used per patient for each time interval.

There is a tendency towards the improved predictive ability of patient outcomes from -24 hours to 0 hours, with 0 hours being the time of the unexpected clinical deterioration event. Once more, based on the AUROC, the best predictors of unexpected clinical deterioration events were supplementary oxygen flow rate (black dots), HR (green dots) and, to a lesser extent, RR (red dots).

As an additional test of the vital sign's ability to predict patient outcomes, the sensitivity and specificity were calculated using the final set of vital signs preceding the unexpected clinical deterioration event or hospital discharge, based on the threshold values given in Table 17 (See Figures 25–31). The highest sensitivities were seen in SpO_2 < 96%, 0.73; and supplementary oxygen flow rate > 0 L/min, 0.61. This implies that 73% of patients that suffered an unexpected clinical deterioration event (index patients) experienced SpO_2 < 96% before the event (See Figure 26). However, in this study, sensitivity is not a good measure of unexpected clinical deterioration events because many control patients also had SpO_2 < 96% yet did not suffer a clinical deterioration event (See Figure 26). It is, therefore, also important to consider specificity. A SpO_2 < 85% had a specificity of 0.99, indicating that almost none of the control patients had an oxygen saturation level below 85%. Almost all

patients with oxygen saturation below 85% suffered an unexpected clinical deterioration event (See Figure 26). Likewise, all patients on more than 6 L/min of supplementary oxygen suffered an unexpected clinical deterioration event (specificity = 1) (See Figure 27). Yet, the sensitivity for a supplementary oxygen flow rate of > 6 L/min was only 0.145, meaning that only 14.5% of patients that suffered an unexpected clinical deterioration event needed supplementary oxygen at > 6 L/min. Using this approach, the vital signs that most efficiently identified at-risk patients, with specificities = 1, including a respiration rate of > 35 breaths/min, supplementary oxygen flow rate of > 6 L/min, SBP > 199 mmHg or < 80 mmHg; DBP < 30 mmHg; HR < 40 beats/min and body temperature of > 38.9°C. Therefore, by process of elimination, patients with vital signs within these ranges all suffered unexpected clinical deterioration events, but the converse is not true: not all patients who suffered an unexpected clinical deterioration event had vital signs within these ranges. This is further evidence that no single vital sign is a good predictor of unexpected clinical deterioration events.

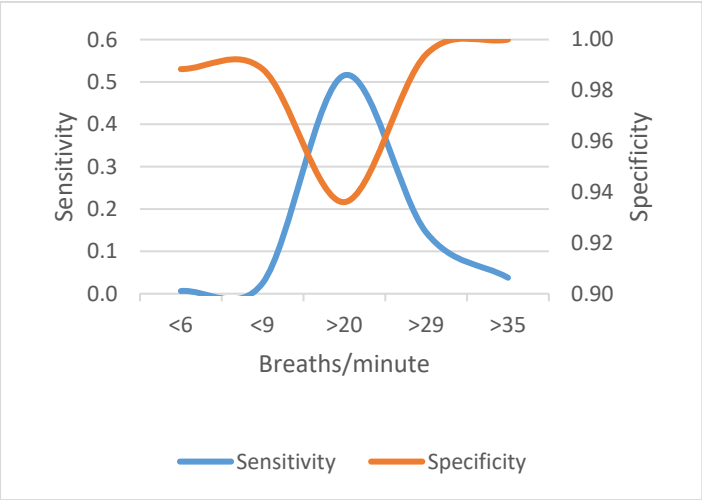

Figure 25: Respiration rate, sensitivity and specificity.

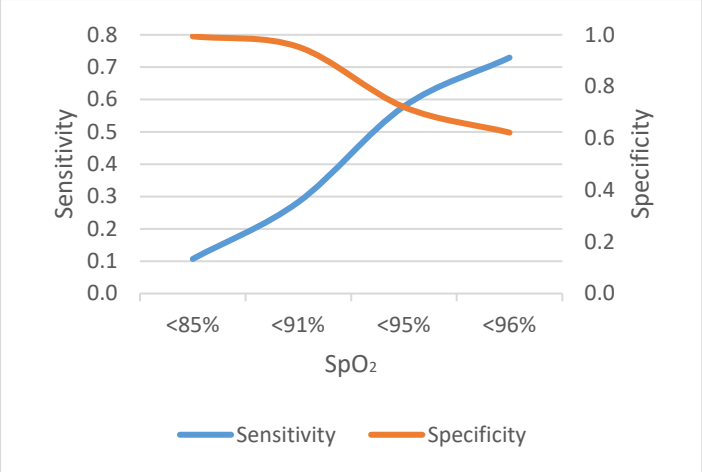

Figure 26: Oxygen saturation, sensitivity and specificity.

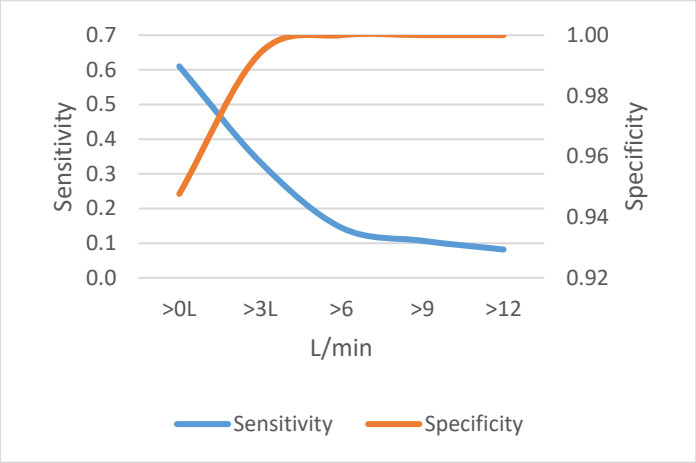

Figure 27: Supplementary oxygen flow rate, sensitivity and specificity.

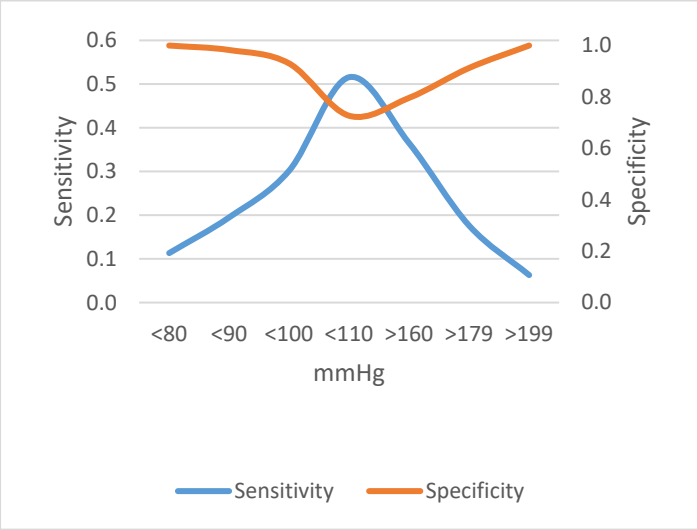

Figure 28: Systolic blood pressure, sensitivity and specificity.

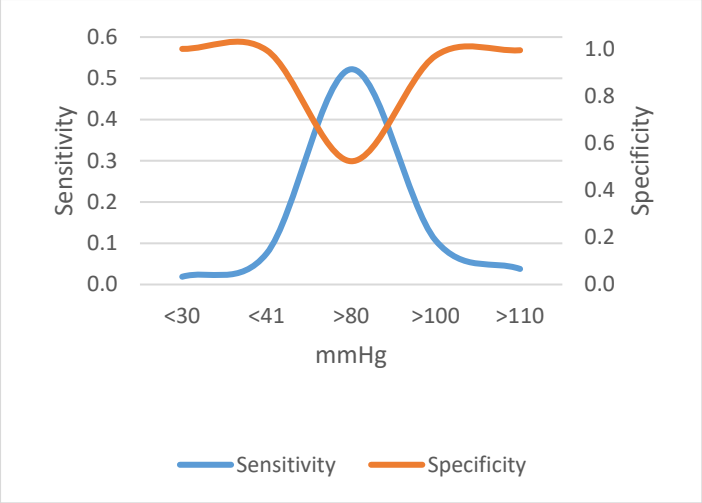

Figure 29: Diastolic blood pressure, sensitivity and specificity.

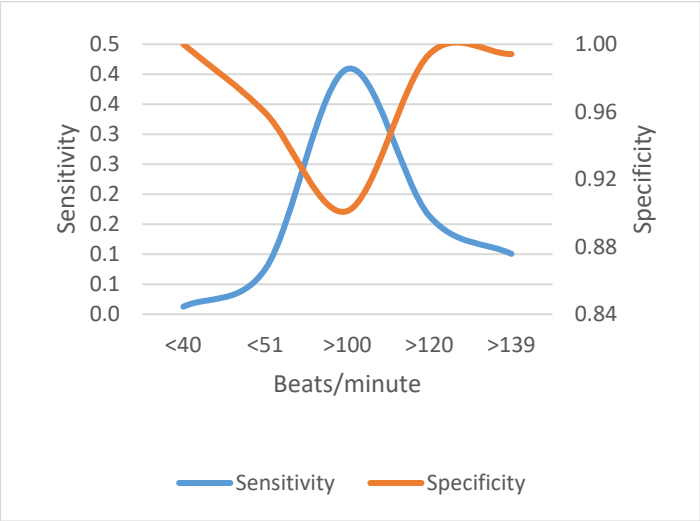

Figure 30: Heart rate, sensitivity and specificity.

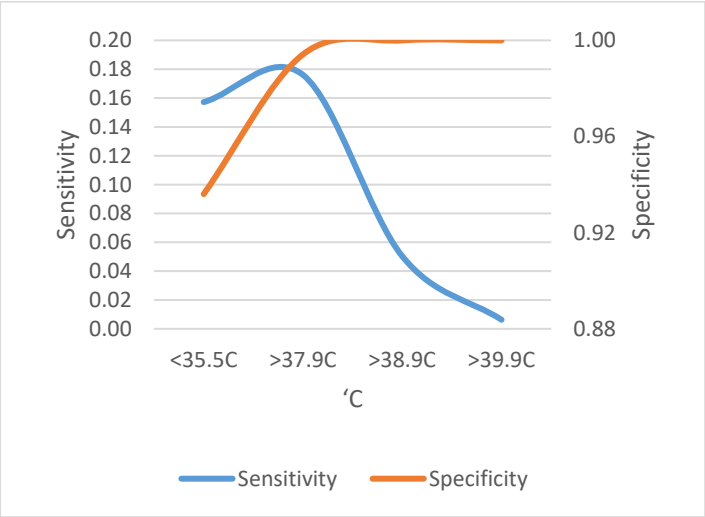

Figure 31: Body temperature, sensitivity and specificity.

Regressions

All vital signs, except for SpO_2, were predictors of patient outcomes ($p < 0.05$), but the pseudo-R^2 was weak. Pseudo-R^2 indicates the ability of a variable/model to predict the outcome measured for a given cohort (Field, 2014). The variable or model with the highest pseudo-R^2 is best able to predict the outcome. Supplementary oxygen flow rate had the highest pseudo-R^2 and the highest ß coefficient, followed by HR (See Table 22). The ß coefficient indicates the degree of change in the outcome measured for every unit of change in the predictor variable; in this case, the vital sign was measured (Field, 2014).

Table 22: Binary logistical regression of the vital signs with unexpected clinical deterioration events as the dependent variable. The vital signs with two-tailed distribution were centred.

Vital signs	Nagelkerke R^2	ß coefficient	Exp (ß)	p
Respiration rate#	0.188	-0.761	0.467	<0.001
SpO_2	0.021	0.05	1.051	0.056
O_2 flow rate	0.338	-0.949	0.387	<0.001
Systolic BP#	0.213	-0.827	0.437	<0.001
Diastolic BP#	0.104	-0.475	0.662	<0.001
Heart rate#	0.187	-0.867	0.42	<0.001
Body temp. #	0.067	-0.311	0.733	0.002
LOC	0.142	-0.313	0.044	0.002

Note: #Means were centred, variance standardised and scaled using a Z-score, then squared

Based on the regression results, supplementary oxygen and HR made a significant contribution in predicting patient outcomes.

Discussion

If it were possible to determine the vital sign(s) that best predicted a deterioration event, it may enhance the clinical staffs' abilities to identify at-risk patients and escalate their care early. However, this knowledge would only be helpful if patients were adequately monitored and all vital signs accurately documented.

Despite the multitude of possible wellness indicators, vital signs remain the cornerstone of most EWSs, but there is little consistency regarding the recommended frequency of patient monitoring (Cardona-Morrell, Prgomet, Turner, Nicholson, & Hillman, 2016; Devita et al., 2010). Monitoring vital signs is fundamental in assessing the patient's physiological state and gauging the risk of clinical deterioration, but patient monitoring adds greatly to the routine nursing workload (Cardona-Morrell et al., 2016). For this reason, the frequency of patient monitoring is often inadequate and can range from intermittent to continuous, depending on medical facility policies, available resources, tradition and nurse intuition (Cardona-Morrell et al., 2016; Smith et al., 2017). The advent of EWSs, with the accompanying escalation of care protocols, has provided guidelines in this respect and has, in some cases, improved the frequency of patient monitoring (Chen et al., 2009). While monitoring frequency has little impact on patient outcomes (Cardona-Morrell et al., 2016), regular monitoring has been shown to improve the early detection of at-risk patients (Mitchell et al., 2010).

The present study shows that monitoring frequency was adjusted to suit the patient's medical condition. In the first 24 hours of monitoring, that is, -72 hours to -49 hours, there was no significant difference in monitoring intervals between index and control patients. Both groups were monitored approximately every five hours. As patients in the index group deteriorated, the frequency of monitoring increased, while in the control group, monitoring intervals remained mostly unchanged over the 72-hour data collection period. Given that much of the data collected in this study precedes the adoption of EWSs, it can be assumed that the change in monitoring frequency in the index group was not guided by an EWS protocol but by nurse intuition or workplace tradition and policy. There is a tendency to monitor geriatric patients less frequently than younger patients, perhaps because staff do not want to disturb or cause undue anxiety amongst their older patients (Smith & Aitken, 2015). Infrequent monitoring of geriatric patients is unfortunate because older patients often have more comorbidities and are at higher risk of deterioration. In the present study, the average

age of the cohort was over 70 years old, putting them in the high-risk category. Understanding the staff decision making regarding monitoring frequency warrants further study.

The frequency and completeness of vital sign documentation have bearings on the staff's ability to recognise at-risk patients (Smith et al., 2017). Neglecting to document all vital signs is common in healthcare and has been shown to vary between 0% complete records (Kyriacos, Jelsma, & Jordan, 2014) to 90% complete (Griffiths et al., 2018). A large survey of 1.15 million sets of vital signs found that only 72% were complete (Bleyer et al., 2011). Although the five basic vital signs, RR, SpO_2, BP, HR and temperature, are present in most patient observation charts, supplementary oxygen flow rate, LOC/GCS and pain score are not included in all bedside observation charts. Therefore, in some instances, their absence may not be due to staff remissness. As with the current study, in many medical facilities, observation charts are not standardised throughout the hospital, let alone throughout a healthcare system. The omission of a given vital sign may be due to its absence on the patient observation chart rather than due to staff inattentiveness. The present study includes patient records that span over 3.5-years, involving four hospital wards at two study sites. Several observation charts were employed in the various wards over the study period. The primary vital signs, RR, BP, HR, SpO_2, temperature and supplementary oxygen flow rate, were recorded in approximately 71% of the patient monitoring events. Though included on most of the observation charts employed over the study period, pain score and LOC were often not emphasised and thus frequently omitted. Interestingly, there were more omitted vital signs in the index group than in the control group. This is perhaps due to the increased frequency of patient monitoring in the index group, some being monitored as often as every 15 minutes with body temperature being recorded intermittently. Chen et al. (2009) noted that the introduction of EWSs increased the frequency of patient monitoring but not the completeness of the vital sign documentation. According to Chen et al. (2009), 77% of patients in their study had at least one missing vital

sign immediately before the SAE. Apart from vital sign omissions, the implausibility of recordings can also severely jeopardise the ability of staff to recognise patient deterioration. In a survey of over 2 million sets of observations, Pedersen et al. (2018) found that 0.2% of observations were implausible, believed to have been 'fudged' to fall below the EWS alert threshold. Improbable vital signs were suspected in the present study, especially regarding RR, with patients showing clear signs of deterioration, but their RR remained virtually unchanged throughout the monitoring period.

Despite RR being well recognised as the most frequent omitted vital sign (Chen et al., 2009; Cretikos et al., 2007; Endacott, Kidd, Chaboyer, & Edington, 2007; Hogan, 2006) in the current study, only 5% of patient monitoring events lacked RR, but the accuracy of the documentation was at times doubtful. The most frequently omitted vital sign, apart from LOC and pain score, was body temperature. Temperature is a commonly missed vital sign, with studies showing its omission being between 17% and 59% (Bleyer et al., 2011; Endacott et al., 2007; Jonsson, Jonsdottir, Moller, & Baldursdottir, 2011; Ludikhuize, Smorenburg, Rooij, & de Jonge, 2012). Other frequently missed vital signs include LOC being omitted up to 94% of the time (Endacott et al., 2007; Jonsson et al., 2011; Ludikhuize et al., 2012), pain score omitted in 30% to 90% of cases (Elliott et al., 2017), and SpO_2 omitted from 17% to 66% of patient records (Bleyer et al., 2011; Jonsson et al., 2011; Ludikhuize et al., 2012). Heart rate and supplementary oxygen flow rate are also frequently omitted (Ludikhuize et al., 2012; Pedersen et al., 2018). Although BP is one of the most recorded vital signs (Ludikhuize et al., 2012), it is noted in some studies that it is a poor indicator of patient deterioration (Hong et al., 2013; Luís & Nunes, 2018).

Abnormal vital signs are common in hospital patients and can be associated with the disease process, narcosis, stress and environmental or emotional stimuli (Bleyer et al., 2011; Hong et al., 2013; Ludikhuize et al., 2012). In the current study, many patients, both in the index and the control groups, had at least one abnormal vital sign in the 24 hours preceding the unexpected clinical deterioration event or hospital discharge. Consistent with

other studies (Cuthbertson, Boroujerdi, McKie, Aucott, & Prescott, 2007), there were significantly more abnormal vital signs in the index patients than among the control patients, especially in the severely abnormal vital sign range (See Table 19). In the index group, approximately 64% of patients had severely abnormal vital signs that could have warranted a medical emergency call. This implies that the remaining 36% of the index patients did not have vital signs sufficiently abnormal to warrant an emergency call. If the staff relied only on the patient's vital signs to alert them to clinical decline, more than one-third of the index group would suffer unexpected clinical deterioration events without early detection. Abnormal vital signs do not always precede clinical deterioration. An audit of 165 000 sets of vital signs showed that 31% of patients that suffered an SAE did not trigger an alert (Foster, Housley, Hatton, & Shaw, 2016). Similarly, a study of 6 000 SAEs revealed that 40% of the patients had no severally abnormal vital signs before the event (Kause et al., 2004). A large multi-centred study found that one in eight patients admitted to ICU or dying unexpectedly in hospital had vital signs deemed within the normal range (Tirkkonen et al., 2020). In a chart audit of post-operative patients, Kyriacos et al. (2014) found that 9% of deteriorating patients have no abnormal vital signs and Santiano et al. (2009) noted that only 50% of patients suffering a cardiac arrest showed signs of abnormal vital signs before the event. Therefore, although vital signs are good indicators of the patient's physiological state, sometimes clinical deterioration events are unavoidable and can occur suddenly without detectable warning signs.

Deteriorating patients often display several simultaneous abnormal vital signs (Royal College of Physicians, 2017). The current study shows a positive correlation between the prevalence of unexpected clinical deterioration events and the number and frequency of abnormal vital signs. The frequency of abnormal vital signs, that is, the number of abnormal sets of observations, was more indicative of the impending unexpected clinical deterioration event than the actual cumulative number of abnormal vital signs over the 24-hour monitoring period. This implies that most of the index patients experienced a gradual clinical

deterioration rather than a sudden SAE. It is common for deteriorating patients to reach an EWS emergency threshold score several times before an SAE and for multiple vital signs to contribute to the EWS emergency scores (Smith & Aitken, 2015). In a study involving 1.5 million sets of vital signs, Bleyer et al. (2011) noted a 19 times greater mortality risk if three or more deranged vital signs occurred than a single abnormal vital sign. Like the present study, several studies have shown a good association between the incidence of SAEs and the number of, or the repeated occurrence of, abnormal vital signs (Andersen et al., 2016; Lighthall, Markar, & Hsiung, 2009).

The early detection of patient deterioration may be enhanced if it is possible to identify the vital sign(s) that best predicts the clinical deterioration event for a given patient cohort. The weighted scores of the aggregated EWS strive to achieve this by allocating a higher weighting to vital signs regarded as indicators of patient deterioration. However, the vital sign thresholds used are often based on intuition rather than hard evidence (Cuthbertson & Smith, 2007). Therefore, despite the small cohort size in the current study, it was hoped that the vital signs which best predict patient deterioration would become evident.

Respiration rate, a recognised indicator of patient deterioration (Flenady, Dwyer, & Applegrath, 2017; Royal College of Physicians, 2017), is not necessarily a reflection of lung function. Tachypnoea can indicate patient distress, pain or sepsis, while bradypnoea may indicate narcosis or central nervous system depression (Royal College of Physicians, 2017). In the current study, only 3.6% of the total patient cohort were found to have RR < 10 breaths/min. There was no significant difference in the incidence of bradypnoea between the index and control patients ($p = 0.358$, $F(1, 329) = 0.85$). Tachypnoea (RR > 20 breaths/min) was more prevalent in the study cohort, with 56.6% of the index and 6.4% of the control patients having at least one episode of tachypnoea in the 24 hours ($p < 0.001$, $F(1, 329) = 110.94$). However, based on the odds ratio and AUROC, RR was not a good predictor of unexpected clinical deterioration events, possibly due to inaccurate documentation.

Oxygen saturation gauges cardiopulmonary function (Royal College of Physicians, 2017). It is a vital sign that should be interpreted with caution, given that patients with chronic respiratory disorders will have a different set of SpO_2 norms than healthy non-respiratory compromised patients (Royal College of Physicians, 2017). Some studies have found SpO_2 to be a good indicator of patient deterioration (Buist, Bernard, Nguyen, Moore, & Anderson, 2004; Lighthall et al., 2009), and in the current study, $SpO_2 < 90\%$ was more prevalent among the index than the control patients ($p < 0.001$, $F(1, 329) = 38.12$). Forty-three per cent of all patients, index and control, had $SpO_2 < 95$, and 16% were documented as having at least one set of observations with $SpO_2 < 90\%$. Of these, 28% suffered an unexpected clinical deterioration event, but many were treated with supplementary oxygen, thus artificially elevating their oxygen saturation level. Oxygen saturation is a vital sign that can easily be manipulated by altering the patient's respiratory pattern or applying or removing supplementary oxygen. Therefore, this vital sign's usefulness as a wellness indicator should be considered with caution. Also, the primary diagnosis of approximately 35% of the present study cohort involved cardiopulmonary complaints, of which chronic obstructive pulmonary disease featured prominently (See Chapter 4). Many of the index and control patients had multiple comorbidities, including chronic respiratory ailments. Poor oxygen saturation levels were common in this patient cohort and did not necessarily indicate a deterioration event.

Notably, all patients given supplementary oxygen at > 6 L/min, and the majority that required more than 3 L/min, suffered unexpected clinical deterioration events (See Figure 27). Significantly more index than control patients were given supplementary oxygen during the 24 hour of monitoring ($p < 0.001$, $F(1, 329) = 27.46$, for $O_2 > 0$ L/min). Based on the odds ratio and AUROC, supplementary oxygen flow rate appears to be linked to unexpected clinical deterioration events, but is the need for supplementary oxygen an indicator of patient deterioration or does it contribute to the deterioration event? Clinical staff are often eager to administer oxygen therapy to alleviate hypoxaemia but rarely consider the dangers of

hyperoxaemia (McEvoy, 2018). According to Chu et al. (2018), 15% of patients admitted to UK hospitals are put on supplementary oxygen, of which 50% to 84% experience hyperoxaemia. Many healthcare professionals regard supplementary oxygen as harmless and beneficial, even in the absence of hypoxaemia (Chu et al., 2018). Excess oxygen can lead to increased cellular metabolic activity, cellular damage, inflammation, and place oxidative stress on the cardiovascular, pulmonary, and neurological systems (Chu et al., 2018; McEvoy, 2018), thus exacerbating clinical deterioration. The injudicious use of supplementary oxygen has been linked to an increased risk of organ failure and mortality (Chu et al., 2018; Girardis et al., 2016; Hofmann et al., 2017), and the serious threat of hypercapnia in chronic respiratory disorder patients (Royal College of Physicians, 2017). In a recent study, Ahn et al. (2020) found that patients that died following an emergency call tended to be tachycardiac and on supplementary oxygen. In the current study, patients on more than 3 L/min of supplementary oxygen had an almost 150 times greater risk of suffering an unexpected clinical deterioration than patients not on supplementary oxygen (OR = 146.35). Few studies consider supplementary oxygen as an indicator of patient deterioration. But Luís and Nunes (2018) noted a strong correlation between supplementary oxygen and the incidence of SAEs. According to Watkinson et al. (2018), by adding supplementary oxygen to the EWS they tested greatly improved the EWS's ability to predict patient deterioration. Still, the authors warned that this is a medical intervention that may affect the other vital signs. Spångfors, Arvidsson, Karlsson, and Samuelson (2016) found that supplementary oxygen greatly contributed to the EWS score but was not a predictor of SAEs.

Abnormal SBP is frequently seen in patients that suffer an SAE (Herod, Frost, Parr, Hillman, & Aneman, 2014; Kause et al., 2004; Lighthall et al., 2009; Smith & Aitken, 2015) and was the most common abnormal vital sign in the current study. Hypotension is usually a better indicator of patient deterioration than hypertension (Andersen et al., 2016; Buist et al., 2004; Hong et al., 2013; Smith & Aitken, 2015). In the current study, 1.2% of index patients

registered SBP > 199 mmHg while 7.5% of patients had SBP < 90 mmHg of which 94% suffered a clinical deterioration event. Although significantly more index patients experienced hypotension than did the control patients ($p < 0.001$, $F(1, 329) = 31.32$ for SPB < 100 mmHg), over the 24-hour monitoring period, the distribution range of SBP was similar in the index and control patients rendering this vital sign ineffective as a predictor of patient deterioration. Diastolic BP is not usually included in EWSs, possibly because it is closely correlated to SBP, and the normality range for DBP has not been established. The index patients had more sets of observations with DBP > 80 mmHg or DBP < 40 mmHg than the control patients, but over the 24-hour monitoring period, the distribution of DBP was not significantly different for the two groups.

Changes in HR is often associated with patient deterioration (Royal College of Physicians, 2017). Bradycardia has not been found to be a good indicator of deterioration, but tachycardia often is (Andersen et al., 2016; Herod et al., 2014; Smith & Aitken, 2015). The same is true in the current study. Few index and control patients experienced HR < 40 beats/min but significantly more index than control patients had HR > 100 beats/min ($p < 0.001$, $F(1, 329) = 46.81$). Based on the odds ratio and AUROC, as in other studies (Hodgetts, Kenward, Vlachonikolis, Payne, & Castle, 2002; Hong et al., 2013; Luís & Nunes, 2018), HR was found to be a relatively good predictor of SAEs.

Both pyrexia and hypothermia are indicators of physiological disturbances and contribute to most EWSs scores (Royal College of Physicians, 2017). However, measuring body temperature is sometimes poorly carried out or omitted (Bleyer et al., 2011; Evans et al., 2001; Pedersen et al., 2018) and in several studies has not been found to be a good indicator of clinical deterioration (Duckitt et al., 2007; Luís & Nunes, 2018). In the current study, although severe pyrexia (body temp. > 39.9^{o}C) was an indicator of clinical deterioration events, only 0.6% of the index cohort exhibited higher body temperature > 39.9^{o}C.

The ‘worried’ criterion is often used to trigger an emergency alert (Cioffi, Conway, Everist, Scott, & Senior, 2010; Mohammed Iddrisu, Considine, & Hutchinson, 2018) and is frequently linked to the patient’s LOC. According to Kause et al. (2004), a two-point change in the GCS is a good indicator of patient deterioration. In the current study, the poor documentation of LOC placed doubt on the usefulness of this vital sign as a deterioration indicator. However, the situation could change if the documentation of LOC improved, perhaps through ongoing staff education.

Using sensitivity and specificity, yet another measure of efficiency to ascertain the vital signs’ prognostic power, did not prove useful in this study. The low sensitivity of the vital signs is perhaps evidence of individual vital sign’s poor predictive potential. However, the specificity proved helpful in identifying patients not at risk of deterioration, and as expected, the specificity increased with the increasing level of the vital sign derangement. Meaning that few, if any, of the control patients recorded severely abnormal vital signs.

Studies have found that the ability of vital signs and EWSs to predict impending patient deterioration peaks in the time interval of -12 hours to -8 hours, and -8 hours to -4 hours preceding the SAE (Cuthbertson et al., 2007; Zografakis-Sfakianakis et al., 2018). This may be cohort dependent. In the current study, the predictive ability of the individual vital signs tends to improve over time from -72 hours to 0 hours (See Table 21, Figure 24). As the clinical deterioration event approaches, the increasing predictive power of the vital signs raises the question of whether these vital signs can be used as early indicators of patient deterioration instead of late indicators of deterioration. It is easy to identify an at-risk patient at the time of or after a deterioration event. The usefulness of a predictive system is the early identification and prevention of an SAE. If the vital signs cannot fulfil this requirement individually, perhaps they can do so collectively.

Using logistic regressions, it was evident that all the vital signs, except SpO_2, were weak but significant predictors of patient outcomes. The best individual contributors in

predicting outcomes were supplementary oxygen flow rate and HR. Given the current study results, it may be worth considering altering the existing EWSs to better suit the regional patient cohort. More 'weight' could be given to the most predictive vital signs; supplementary oxygen flow rate, HR, RR and possibly LOC. Also, the vital signs' trigger thresholds may need to be adjusted to alert staff early to an impending clinical deterioration event. Since the monitoring of RR may be inaccurately executed and LOC is often omitted, continuous staff education is highly recommended. Although the use of EWSs is sometimes met with staff resistance and compliance continues to be poor (Credland et al., 2018), EWSs remains a useful tool in identifying at-risk patients. The use of the EWS is mandatory in all Australian healthcare facilities (Cardona-Morrell et al., 2016); thus, its correct implementation should be encouraged through ongoing staff education and regular chart audits.

Conclusion

Vital signs appear to be good indicators of patient deterioration. The patients in small regional private hospitals that suffered an unexpected clinical deterioration event, the index patients, had noticeably more abnormal sets of vital signs than patients with an uneventful hospital stay, that is, the control patients. Also, there was a significant positive relationship between the number and frequency of abnormal vital signs and the incidence of unexpected clinical deterioration events. The various statistical tests employed have shown that the distribution of most vital signs was significantly different for the index and control patients. Based on the odds ratio and AUROC, although no single vital sign adequately predicted the impending unexpected clinical deterioration event, supplementary oxygen flow rate and heart rate had the highest predictive abilities. Collectively, almost all the vital signs were significantly correlated to patient outcomes. The binary logistic regression analysis showed that the most significant predictors of patient outcomes were supplementary oxygen flow rate and heart rate. It is suggested that this knowledge be used to modify an existing EWS or to develop a new EWS to better suit the study patient cohort.

Chapter Summary

The study contained in this chapter sought to identify the vital sign(s) which best predicts unexpected patient deterioration for a regional cohort of private hospital patients. In so doing, the pattern and completeness of vital sign monitoring were also investigated. The study showed that monitoring vital signs is a good indicator of unexpected clinical deterioration events in these smaller resource facilities. Furthermore, the study showed that patients experiencing clinical deterioration were monitored more frequently and had more abnormal vital signs documented than patients who did not have a deterioration event. This indicates that the nursing staff were using the vital signs to gauge the patient's clinical progress. This chapter ascertained that no individual vital sign strongly predicted an impending unexpected clinical deterioration event or SAE. However, supplementary oxygen and rapid heart rate were the best independent indicators of unexpected clinical deterioration. Therefore, these vital signs will inform the optional trigger thresholds when developing the new EWS presented in Chapter 6.

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Chapter 6. Developing a New Early Warning Score

Designing an efficient Early Warning Score for resource-poor regional/rural hospitals

Synopsis

It was established in Chapter 4 that in the regional/rural context, the Early Warning Scores (EWSs) only identified approximately half of the patients at risk of unexpected clinical deterioration events. Although the aggregated weighted EWS Compass was the most effective, having the highest AUROC, it had relatively poor sensitivity and was not ideally suited for the target patient cohort. Most EWSs were developed for use in larger well-resourced metropolitan hospitals and not tested for implementation in small, poorly resourced hospitals. The small regional/rural hospitals do not usually have the specialised equipment or critical care staff to respond in a timely manner to the severely ill, deteriorating patients. It is important that these poorly resourced hospitals employ the most suitable EWS to help the staff achieve an early response to high-risk patients.

Since the overarching aim of the study was to provide evidence of the efficiency of EWSs in poorly resourced regional/rural hospitals, and the commonly used EWSs compared in Chapter 4 have not produced a satisfactory solution, the next step is to develop and test a new EWS specifically for the regional/rural context. Having identified that the need for supplementary oxygen and tachycardia are the best predictors of unexpected clinical deterioration events in the target population (Chapter 5), the study presented in Chapter 6 utilises this new knowledge to develop a new, more efficient EWS that is better suited for the regional/rural patient cohort (Figure 1 below). Next, the newly developed EWS is validated using two independent patient cohorts; small poorly resourced regional/rural public hospitals (n=7) and large well-resourced regional/metropolitan public hospitals (n=6).

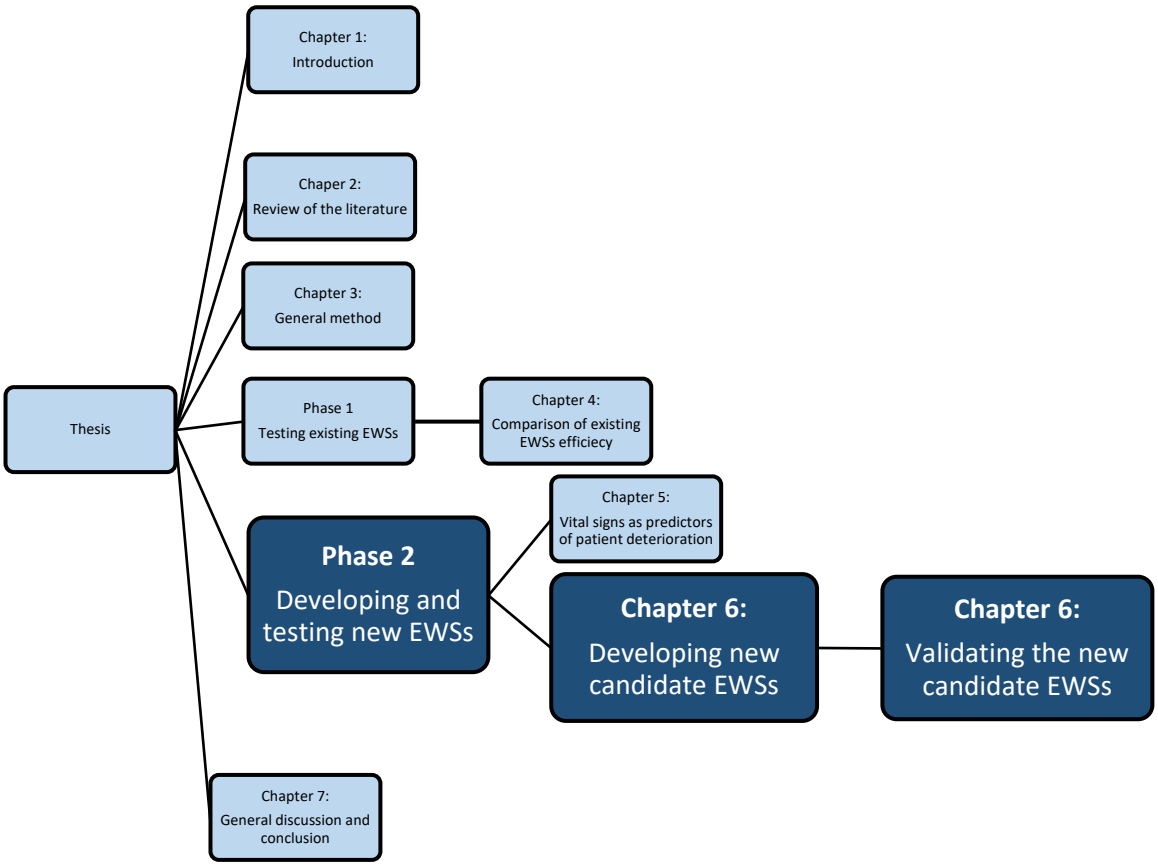


Figure 1: Schematic representation of the structure of the thesis.

Abstract

Background: Early Warning Scores (EWSs) were developed in and for large, well-resourced metropolitan hospitals. These EWSs, based on patient vital signs, have not been found to be very efficient in identifying at-risk patients in small, poorly resourced regional/rural hospitals.

Aim: The aim of this study was to develop and validate a new EWS that would efficiently identify patients at risk of experiencing unexpected clinical deterioration events in small, poorly resourced regional/rural hospitals.

Method: This retrospective case-control study collected patient vital sign data from three patient cohorts; Cohort A, patients from two small regional private hospitals; Cohort B, patients from seven small, poorly resourced regional/rural public hospitals; and Cohort C, patients from six large well-resourced public hospitals. Each cohort consisted of two groups; patients that suffered unexpected clinical deterioration events and matched patients that had uneventful hospital stays.

Firstly, new candidate EWSs were developed by altering the trigger ranges and weighted scores of the vital signs that contribute to the existing EWSs. This was achieved using various methods, including a centile-based process, broadening the vital sign trigger ranges and converting an aggregated EWS, Compass, to a combination EWS. This resulted in the development of six new candidate EWSs, MOD-1 to MOD-6. Next, the efficiency of the six new candidate EWSs were tested using AUROC, sensitivity, specificity and the ratio of false to true alerts using three trigger threshold scores. Lastly, the new candidate EWSs were validated using two independent patient cohorts, Cohorts B and C.

Results: Six new candidate EWSs were developed, MOD-1 to MOD-6. The final candidate EWS, MOD-6 at an emergency trigger threshold score of 6, increased the sensitivity of an existing EWS, Compass, by 20% for patients from the small regional private hospitals (Cohort A). MOD-6 differs from Compass in that a single trigger component has been added

to the EWS, some of the vital sign trigger thresholds have been broadened, supplementary oxygen flow rate was allocated a graduated weighted scale, and the emergency threshold score has been lowered from seven to six. The AUROC increase from 0.78 for Compass, the best performing existing EWS, to 0.81 for MOD-6 (Cohort A). The validation of the newly developed candidate EWSs using the independent cohorts produced disappointing results, yielding AUROC of less than 0.6 and 0.7 for Cohorts B and C, respectively.

Conclusion: Although the new candidate EWS, MOD-6, is more effective at identifying deteriorating patients in the cohort for which it was developed, patients from the small regional private hospitals, it cannot be universally recommended. In general, the relatively poor EWS efficiency implied that staff should not substitute good clinical judgement with a diagnostic tool. Any EWS tool adopted for use within similar facilities should be tested before implementation and should be used as a tool to support clinical decision making.

Introduction

Early Warning Scores (EWSs) were developed as the afferent arm of the rapid response system to detect and respond to patient deterioration by tracking their physiological state (De Bie et al., 2019). Despite being implemented internationally, there is little evidence that EWSs improve patient outcomes (Gao et al., 2007; Hillman et al., 2005; Subbe, Davies, Williams, Rutherford, & Gemmell, 2003). Consequently, user confidence is sometimes poor, and up to 70% of stakeholders believe EWSs fail to identify all deteriorating patients, and 88% believe they lead to unnecessary patient reviews (Foster, Housley, McKeever, & Shaw, 2018). The lack of universal EWS efficiency has resulted in the development and adoption of numerous EWSs. An EWS is a collection of measurable variables, usually vital signs, to which scores or colours are allocated based on the level of the variable derangement. As such, any change to the existing EWS may constitute a *new* EWS. This may include changes to the trigger threshold scoring system (Bell, Konrad, Granath, Ekbom, & Martling, 2006; Burgess, Herdman, Berg, Feaster, & Hebsur, 2009;

Tarassenko et al., 2011; Watkinson, Pimentel, Clifton, & Tarassenko, 2018), to the variables included (Luís & Nunes, 2018; Olsson & Lind, 2003; Olsson, Terent, & Lind, 2004), or to the prescribed staff response (Cheung & Concord Medical Emergency Team, 2019). Most new EWSs stem from merely altering the vital sign trigger ranges. However, since there is little consensus as to what constitutes a normal vital sign range (Grant, 2018; Hong et al., 2013), setting abnormal ranges for EWS trigger thresholds can be problematic. For this reason, many EWSs utilise vital sign trigger ranges and weighted scores based on expert intuition and historical data (Burgess et al., 2009; Cuthbertson, Boroujerdi, McKie, Aucott, & Prescott, 2007; Cuthbertson & Smith, 2007; Tarassenko et al., 2011).

Several systematic methods of selecting the EWS vital sign trigger ranges have been suggested. According to Cuthbertson and Smith (2007), to develop an effective EWS, the vital signs that predict or are associated with a deterioration event must first be identified, the vital sign trigger range established, and the new EWS must be validated before implantation. As an alternative, a centile technique based on the statistical distributions of the vital signs for a given target cohort has been suggested (Tarassenko et al., 2011; Watkinson et al., 2018). This method assumes that the vital signs of critically ill patients will reside in the extremes of the variable's distribution range (Tarassenko et al., 2011; Watkinson et al., 2018). Another technique of improving the efficacy of EWSs is by lowering the aggregated trigger threshold scores and thus increasing the EWS's sensitivity. However, this inevitably leads to a decrease in the EWS specificity (Fullerton, Price, Silvey, Brace, & Perkins, 2012; Gardner-Thorpe, Love, Wrightson, Walsh, & Keeling, 2006; Green et al., 2018; Jenkins, Thompson, & Barton, 2011; Le Lagadec, Dwyer, & Browne, 2020). Poor specificity increases the number of false alerts which leads to increased staff workload taking staff away from their regular duties and possibly placing patients at risk (Cheung & Concord Medical Emergency Team, 2019; Grant & Crimmons, 2018). Although all three techniques have successfully been employed to improve EWSs efficacies for their target patient cohort none have gained universal acceptance.

It has been suggested that EWSs are most effective when used in the facility or patient cohort for which they were designed (Watkinson et al., 2018). The 12 EWSs presented in Chapter 4 were developed in and for large, well-resourced tertiary hospitals. When testing these EWSs using patient data from poorly resourced regional facilities, their efficiency was relatively low with AUROCs ranging from 0.628 to 0.747. Only approximately half of the deteriorating patients were identified as critically ill (See Chapter 4). This implies that the EWSs developed for use in large metropolitan hospitals are not ideally suited for the smaller, poorly resourced regional hospitals. Therefore, there is a need to develop an EWS that is better suited for poorly resourced regional hospitals. This chapter aims to develop EWSs that efficiently identify patients at risk of deterioration in small regional private hospitals. A variety of methods will be used to create the new EWSs, some of which will be based on the results from Chapters 4 and 5. Validating prognostic tools, including EWSs, employing the same database utilised in its development is subject to bias (Altman & Royston, 2000). Therefore, the newly developed EWSs will be validated using a prospective method as described by Duckitt et al. (2007) using independent patient cohorts. For comparative purposes, the 12 EWSs discussed in Chapter 4 will be included in the validation study. Since it is beyond the scope of this study to test the newly developed EWS in a clinical setting, they will be referred to as ‘candidate’ EWSs.

Method

Using a retrospective case-controlled study design, the development of the new EWSs was carried out in two stages. Stage 1 involved developing the candidate EWSs using the vital sign database obtained from the patient from the small regional private hospitals (Cohort A) (See Table 23). The efficacy of the candidate EWSs are tested using AUROC, a recognised method of testing EWSs efficacy (Badriyah et al., 2014; Ghosh, Eshelman, Yang, Carlson, & Lord, 2018; Green et al., 2018; Malycha et al., 2019) as well as their sensitivity and specificity. In stage 2, the candidate EWSs are validated using two independent patient cohorts, Cohorts B and C (See Table 23). Cohort B included 288 patients from seven small

regional/rural public hospitals; six of these hospitals have fewer than 50 beds each, and the seventh, fewer than 100 beds. Cohort C included 2 278 patients derived from four metropolitan and two large regional public hospitals with more than 200 beds. In all three cohorts, A, B and C, patients who experienced an unexpected clinical deterioration event, index patients, were demographically and diagnostically matched with patients who had an uneventful hospital stay, that is, control patients. A description of the data collection method is given in Chapter 2.

Table 23: Characteristics of the study sites and patient cohorts used in the study.

	Cohort A	Cohort B	Cohort C
Retrospective paper-based data	Yes	Yes	Yes
Data collection period	June 2014–Sept 2017	Sept 2016-Oct 2017	Sept 2016-Oct 2017
Number of hospitals	2	7	6
Hospital size	59 and 140 beds	< 100 beds	>200 beds
Hospital context	Private	Public	Public
MET at facility	No	No	Yes
ICU at facility	No	No	Yes
Hospital Location	Regional	Rural/Regional	Regional/Metropolitan
Unexpected cinical deterioration event	Emergency call, unplanned transfer to higher level care, cardiopulmonary arrest, unexpected death	Transfer to higher level care, usually out of the facility	Medical Emergency Review (MET)

Stage 1: Development of candidate Early Warning Scores

Using the vital sign data from the patients from the small private regional hospitals (Cohort A), six candidate versions of ‘combination’ EWSs, referred to as MOD-1 to MOD-6, were developed (See Figure 32). The seven variables used in these six candidate EWSs,

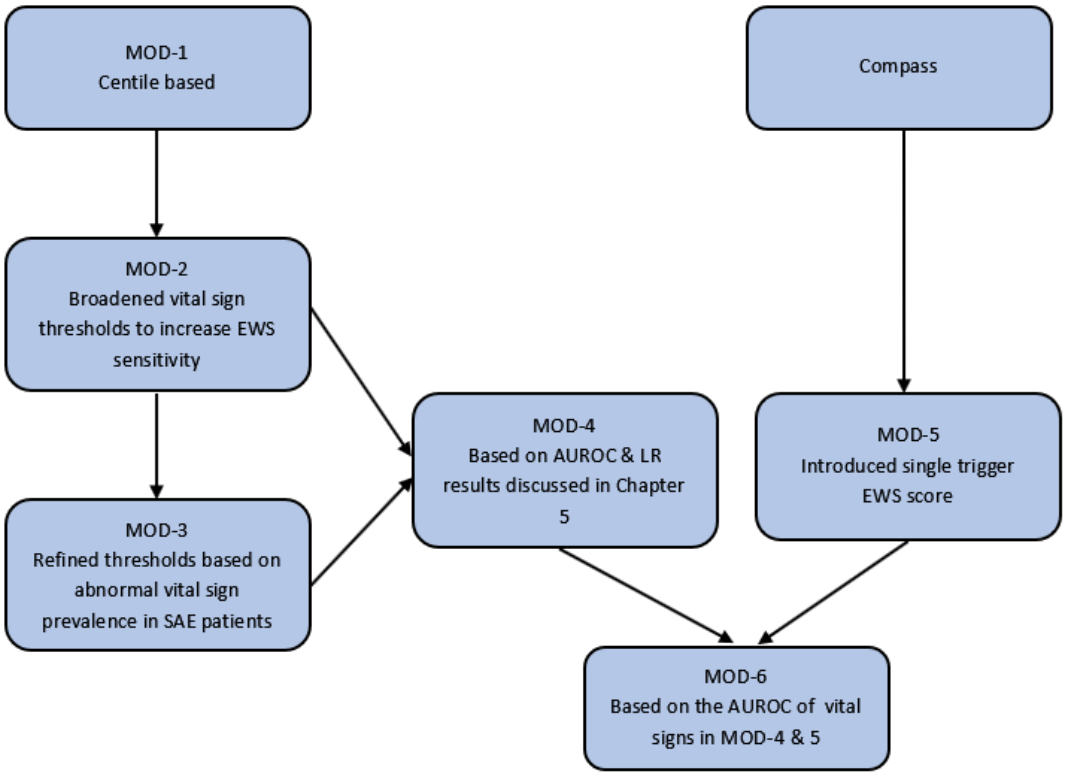
that is, the five standard vital signs plus supplementary oxygen flow rate and level of consciousness (LOC), remained unchanged. However, the trigger ranges and the weighted score allocations to each vital sign were altered. The individual vital signs weighted scores ranged from 0 to 3 or E (8) depending on the level of derangement. The variables used in the candidate EWSs included: respiration rate (RR), oxygen saturation (SpO_2), supplementary oxygen flow rate (O_2 flow rate), systolic blood pressure (SBP), heart rate (HR), body temperature (temp) and LOC. The binary patient outcome employed was unexpected clinical deterioration events or uneventful hospital stay.

The first candidate EWS, MOD-1, was centile-based as per the method of Tarassenko et al. (2011) and Watkinson et al. (2018). Using the vital sign data from the patients from the small regional private hospitals (Cohort A), the distribution curves of the vital signs were plotted for all sets of observations collected over 24 hours preceding the unexpected clinical deterioration event, and the EWS scores were allocated according to the vital sign percentile (See Table 24). The distinction was made between one- and two-sided vital sign distribution curves. Vital signs with a one-sided distribution are regarded as abnormal at one end of their distribution range. These include high values for O_2 flow rate and LOC, and low values for SpO_2. Vital signs with a two-sided distribution are regarded as abnormal at both ends of their distribution range, that is, both at low and high values. Two-sided distribution vital signs include RR, SBP, HR and body temperature.

Table 24: EWS weighted scores allocated to vital signs within a given cumulative distribution range (centile), based on the normalised distribution of the vital sign.

EWS score	Two-sided distribution centile range (RR, SBP, HR, Temp)	One-sided distribution centile range (SpO_2, O_2 flow rate, LOC)
E	$<1^{st}$, $>99^{th}$	$>98^{th}$ or $<2^{nd}$
3	$1^{st} – 2^{nd}$, $98^{th} – 99^{th}$	$95^{th} – 98^{th}$ or $2^{nd} – 5^{th}$
2	$2^{nd} – 5^{th}$, $95^{th} – 98^{th}$	$90^{th} – 95^{th}$ or $5^{th} – 10^{th}$
1	$5^{th} – 10^{th}$, $90^{th} – 95^{th}$	$80^{th} – 90^{th}$ or $10^{th} – 20^{th}$
0	$>10^{th}$, $<90^{th}$	$<80^{th}$ or $>20^{th}$

The candidate EWS, MOD-2 was derived from MOD-1 with the vital sign trigger ranges extended to increase the sensitivity of the EWS (See Table 25). In MOD-3, derived from MOD-2, the vital sign trigger ranges were modified based on informed intuition and the prevalence of these abnormal vital signs in the index patients (Cohort A), similar to the method used by Buist, Bernard, Nguyen, Moore, and Anderson (2004). Using the trigger thresholds in MOD-2 and 3, MOD-4 was developed with higher weighted scores assigned to the vital signs, which best predicted the unexpected clinical deterioration event as determined by the AUROC. This is a method of developing EWSs similar to that of Cuthbertson and Smith (2007). Emphasis was placed on supplementary oxygen flow rate and tachycardia because these were found to best predicted an unexpected clinical deterioration event (See Chapter 5). MOD-5 was derived from the aggregated weighted EWS, Compass, one of the top-performing EWS mentioned in Chapter 4. For MOD-5, the Compass vital sign trigger ranges remained largely unchanged, but a 'single trigger threshold score' (*E*) was added for each vital sign to create a combination EWS.
That is, an EWS that triggered an alert due to either a single severely abnormal vital sign or a combination of moderately abnormal vital signs. MOD-6 was created from MOD-4 and 5 based on the AUROC calculated for the weighted vital sign scores derived from MOD-4 and MOD-5. The vital sign threshold triggers for the six candidate EWSs are shown in Table 25. The candidate EWSs were regarded as having triggered an emergency call when a single vital sign achieved an *E* threshold score or when the aggregated score of multiple vital signs was ≥ 8. The efficiency of the various EWSs was based on the AUROC of the aggregated weighted EWS scores and on the system's sensitivity and specificity.



Note: AUROC: Area under the receiver operator characterise curve; LR: logistical regression; MOD: newly developed candidate EWSs

Figure 32: Development of the candidate EWSs.

Table 25: The vital sign ranges and weighted EWS scores used in the candidate EWS, MOD-1 to Mod-6.

EWS score		MOD-1	MOD-2	MOD-3	MOD-4	MOD-5	MOD-6
RR	E	<11, >34	<12, >29	<8, >29	<10, >29	<8, >29	<12, >29
	3	<12, >32	<15, >25	<10, >25	>27	<9, >24	<14, >25
	2	<14, >26	>22	>24	<12, >24	>20	>22
	1	>23	>20	>20	>20	<12	>20
SpO_2	E	<86	<89	<80	<89	<85	<85
	3	<91	<91	<90	<91	<92	<92
	2	<93	<94	-	<94	<94	<94
	1	<95	<96	<95	<96	<96	<96
O_2 flow	E	>14	>6	>6	>6	>2	>6
	3	>5	>3	>3	>3	>0	>3
	2	-	>1	>1	>1	-	>1
	1	>2	>0	>0	>0	-	>0

EWS score		MOD-1	MOD-2	MOD-3	MOD-4	MOD-5	MOD-6
SBP	E	<68, >204	<85, >199	<80	<85	<85	<90
	3	<74, >189	<90, >180	<85, >199	<90, >199	<91	>199
	2	<83, >174	<100, >170	<90	<100, >170	<101, >199	>169, <100
	1	<96, >163	<110, >160	<100	<110, >160	<111	>159, <110
HR	E	<43, >154	<45, >139	>139	>150	>139	>139
	3	<51, >142	<51, >130	>130	>130	>130	>130
	2	<56, >129	<56, >120	<45, >120	<41, >110	<41, >110	<41, >110
	1	<59, >117	<61, >100	<50, >110	<51, >100	<51, >90	<51, >90
Temp	E	<35.1, >39.1	<35.2, >39.0	>39.9	>39.0	<34.5, >39.0	>39.0
	3	<35.4, >38.7	<35.4, >38.5	<35.0, >38.9	<35.0, >38.5	<35.1	<35.0, >38.5
	2	<35.6, >38.1	<35.6, >37.9	>38.5	>37.9	-	>37.9
	1	<35.8, >37.6	<35.8, >37.5	<35.5, >38.0	<35.5, >37.5	<36.1, >38.0	<35.5, >37.5
LOC	E	P/U	P/U	P/U	P/U	P/U	P/U
	3	-	-	V	-	-	-
	2	-	-	-	-	V	V
	1	V	V	-	V	-	-

Note: V = voice; P = pain; U = unresponsive; E = emergency call

Stage 2: Validation of the candidate Early Warning Scores

The efficiencies of the six new candidate EWSs were tested using a prospective validation method as described by Duckitt et al. (2007) using the aggregated EWS values ≥ 6, ≥ 7 and ≥ 8. The vital sign data from the independent patient cohorts, Cohorts B and C, were applied to the six candidate EWSs, MOD-1 to 6, and to the original 12 EWSs discussed in Chapter 4. The original 12 EWSs were included as a baseline comparison due to the inclusion of the two independent patient cohorts, Cohorts B and C. The vital sign data from the patients from the small regional private hospitals, Cohort A, were also applied to the six candidate EWSs for comparative reasons. As an additional test of efficiency, the ability of the EWSs to predict patient mortality was tested using a subset of Cohort A, patients that had died unexpectedly, labelled Cohort A-subset. The EWS scores were obtained for the 18 EWSs (six new candidate EWSs and the12 existing EWSs) for all sets of vital signs

collected over the 24-hour period preceding the unexpected clinical deterioration event or hospital discharge. Over 15 000 sets of vital signs were included in this EWS validation study. Data from each patient cohort was independently analysed. Using the aggregated weighted scores derived from all sets of vital signs collected over the 24-hour period, the AUROC was calculated from each EWS for each cohort. The significant difference between the AUROCs was determined using the DeLong test (DeLong, DeLong, & Clarke-Pearson, 1988). The sensitivity and specificity of the EWSs were calculated for each patient cohort using the final set of vital signs preceding the deterioration event or preceding hospital discharge. Also, the ratio of false to true alerts was calculated for each cohort at an unexpected clinical deterioration event incidence of 1.2% (See Chapter 4). A clinical deterioration event rate of 1.2% implies that for every 1000 patients, 12 patients suffer an unexpected clinical deterioration event, and 988 have an uneventful hospital stay. The sensitivity, specificity and ratio of false to true alert were calculated for *E* score as dictated by the EWS protocol and for *E - 1* and *E - 2* to ascertain whether lowering the EWS score trigger threshold should be considered (See Table 26). Data analysis was conducted using IBM SPSS Statistics 26.0. Since this is a fact-heavy chapter, the most important findings have been placed in text boxes for emphasis.

Table 26: The trigger scores used in determining EWS sensitivity, specificity and the ratio of false to true alerts.

EWS	*E* score	E - 1	E - 2
[a]BTF*	Red	-	Yellow
[a]ARC	Purple	Red	Orange
[a]ARC_2*	Purple	Red	-
[b]MADDS	8	7	6
[b]$MADDS_2$	8	7	6
[b]$MADDS_5$	8	7	6
[b]Q-MEWTS	8	7	6
[b]Q-ADDS	8	7	6
[b]Q-ADDS + BP	8	7	6
[b]ADDS	8	7	6
[c]NEWS	7	6	5

EWS	*E* score	E - 1	E - 2
[c]Compass	7	6	5
[b]MOD-1	8	7	6
[b]MOD-2	8	7	6
[b]MOD-3	8	7	6
[b]MOD-4	8	7	6
[b]MOD-5	8	7	6
[b]MOD-6	8	7	6

Note: *BTF and ARC_2 have two tiers of response
[a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

Results

Patient demographics

Stage 1, the development of the candidate EWSs (See Figure 32), was based on 2 505 sets of vital signs gathered from Cohort A, patients from the two small regional private hospitals. Stage 2, validating the candidate EWSs, was based on 15 429 sets of vital signs from Cohorts A, B, C and A-subset (See Table 27). Although the age of the index and control patients were not significantly different within the cohorts ($F(1, 2910) = 0.767$, $p = 0.381$), there were significant differences in patient age between the various cohorts ($F(3,2910) = 10.67$, $p > 0.001$). Cohort B, patients from the small public regional/rural hospitals, had the youngest patient group 67.6 (15.0) years while Cohort A-subset were significantly older than the other patient cohorts, 79.1 (14.6) years ($p < 0.05$). Patients from Cohorts A and C were similarly aged, 72.6 (15.1) and 71.3 (15.0) years, respectively, ($p > 0.05$). There were significantly more males in Cohort A-subset ($F(1, 2937) = 5.86$, $p = 0.016$) than the other three cohorts, which all had a similar number of male patients ($F(2, 2937) = 2.33$, $p = 0.072$).

Table 27: Patient demographics for Cohorts A, B, C and A-subset.

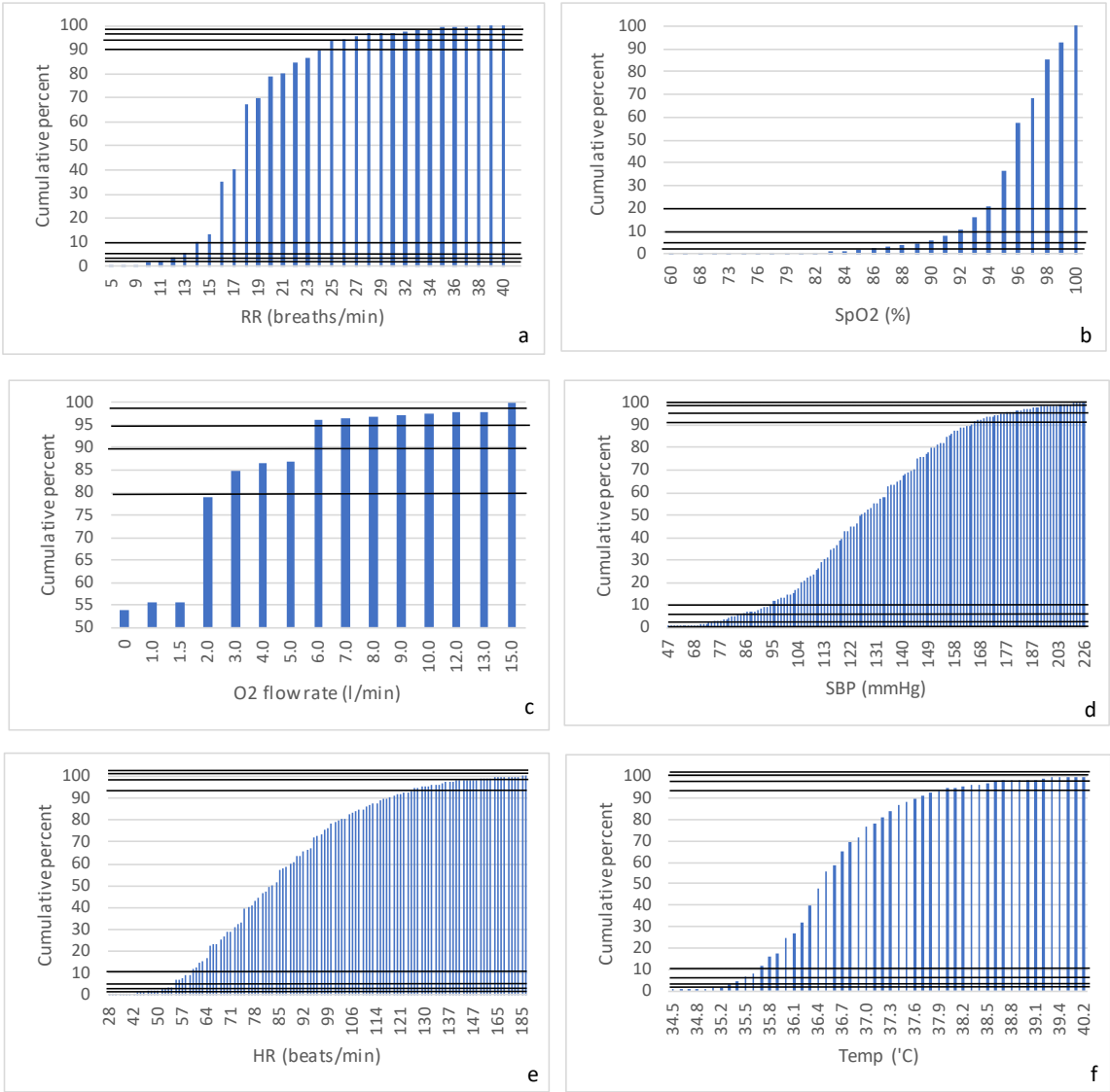
	Cohort A Small regional private hospitals	Cohort B Small regional/rural public hospitals	Cohort C Large regional/ metropolitan public hospitals	Cohort A subset Patients in Cohort A died unexpectedly
Number of patients	331 (159 index)	288 (118 index)	2278 (1165 index)	45 (15 index)
Sets of vital signs	2 505	1 302	11 380	242
Avg patient age	72.6 (15.1)	67.6 (15.0)	71.3 (15.0)	79.1 (14.6)
Gender (male)	53.1%	56.1%	52.6%	64.4%

Stage 1: Development of candidate Early Warning Scores

The cumulative distribution of each vital sign was used to establish the trigger scores in MOD-1 (See Figure 33). The horizontal lines indicate the centile values of the vital signs. For example, the EWS of *E* for respiration rate (RR) would be a value in the 1st percentile, that is, < 11 breaths/min, and in the 99e percentile, > 34 breaths/min (See Figure 33a, Tables 24 and 25). An EWS score of 3 would be in the 2nd percentile, < 12 breaths/min, and in the 98th percentile, > 32 breaths/min. For the one-sided vital signs, such as oxygen saturation (SpO_2), an EWS score of *E* represented the 98th percentile, SpO_2 < 86%, while an EWS score of 3 would be in the 95th percentile, SpO_2 < 91%. When testing the centile EWS, MOD-1, using vital sign data from Cohort A, MOD-1 was significantly less efficient than the existing EWSs, Compass and NEWS (p = 0.002 and p = 0.01 respectively).
The AUROC for MOD-1 was 0.740 (95% CI, 0.721–0.759), for NEWS, 0.775 (CI, 0.757-0.793), and for Compass, 0.783 (CI, 0.765–0.801).

The new centile-based EWS, MOD-1, was less effective than the existing EWSs, NEWS and Compass.

The efficacy of the candidate EWS, MOD-1, was improved by extending the vital sign trigger values resulting in the development of MOD-2 (See Table 25). MOD-2 (AUROC, 0.788, CI, 0.771–0.806) proved to be more efficient than MOD-1 (AUROC, 0.740, CI, 0.721-0.759, $p < 0.001$) but not significantly better than Compass (AUROC, 0.783, CI, 0.765–0.801, $p = 0.668$). The vital sign trigger values were further refined based on their prevalence in the Cohort A's index patients, giving rise to MOD-3. MOD-3 (AUROC, 0.780, CI, 0.763–0.798) was more effective than MOD-1 ($p = 0.003$) but slightly less effective than MOD-2 ($p = 0.520$). MOD-4, derived from MOD-2 and 3, differed very little in the vital sign thresholds. Yet, the efficiency of this EWS was improved (AUROC, 0.799, CI, 0.782–0.816), making it slightly more effective than Compass and NEWS, but not significantly so ($p = 0.200$ and $p = 0.058$ respectively).



Note: The 1st, 2nd, 5th, 10th, 90th, 95th, 98th, 99th centiles are shown as horizontal lines for Figures a, d, e and f; the 2nd, 5th,10th, 20th centiles are shown for Figure b; and the (80th, 90th, 95th, 98th) centiles are shown for Figure c.

Figure 33: Cumulative distribution plot of the vital signs for the index patients (Cohort A); (a) respiration rate (RR), (b) oxygen saturation (SpO_2), (c) supplementary oxygen flow rate, (d) systolic blood pressure (SBP), (e) heart rate (HR), (f) body temperature (Temp).

To improve the efficiency of Compass, the most effective EWS for Cohort A (See Chapter 4), an *E* trigger score was added, converting Compass from an aggregated weighted EWS to a combination EWS. This candidate EWS, MOD-5, was found to be only marginally more effective than Compass (AUROC, MODE-5: 0.787, CI, 0.769–0.804, Compass: 0.783, CI, 0.765–0.801, p = 0.765). Using the AUROC for the weighted EWS scores for each vital sign range used in MOD-1 to MOD-5 and Compass, MOD-6 was

developed (See Table 28). MOD-6 proved to be the most effective EWS for Cohort A (AUROC, 0.812, CI, 0.795–0.829).

The new candidate EWS, MOD-6 proved to be the most effective EWS for patients from small, poorly resourced regional private hospitals.

Table 28: The AUROC (95% CI) for the weighted EWS scores of the vital signs in MOD-1 to MOD-6.

	Candidate Early Warning Scores						
Vital sign	Compass	MOD-1	MOD-2	MOD-3	MOD-4	MOD-5	MOD-6
RR	0.602 (.58-.63)	0.602 (.58-.62)	0.629 (.61-.65)	0.596 (.57-.62)	0.604 (.58-.63)	0.604 (.58-.63)	0.619 (.60-.64)
SpO_2	0.578 (.56-.60)	0.539 (.52-.56)	0.579 (.56-.60)	0.538 (.52-.56)	0.569 (.55-.59)	0.580 (.56-.60)	0.580 (.56-.60)
O_2 flow rate	0.673 (.65-.69)	0.675 (.65-.70)	0.679 (.66-.70)	0.679 (.66-.70)	0.679 (.66-.70)	0.681 (.66-.70)	0.680 (.66-.70)
SBP	0.562 (.54-.59)	0.565 (.54-.59)	0.578 (.56-.60)	0.558 (.54-.58)	0.578 (.56-.60)	0.562 (.54-.59)	0.580 (.58-.60)
HR	0.641 (.62-.66)	0.543 (.52-.57)	0.581 (.56-.61)	0.570 (.55-.59)	0.597 (.57-.62)	0.641 (.62-.66)	0.642 (.62-.66)
Temp.	0.467 (.44-.49)	0.527 (.50-.55)	0.527 (.50-.55)	0.521 (.50-.55)	0.535 (.51-.56)	0.466 (.44-.49)	0.534 (.51-.56)

Stage 2: Validation of the candidate Early Warning Scores

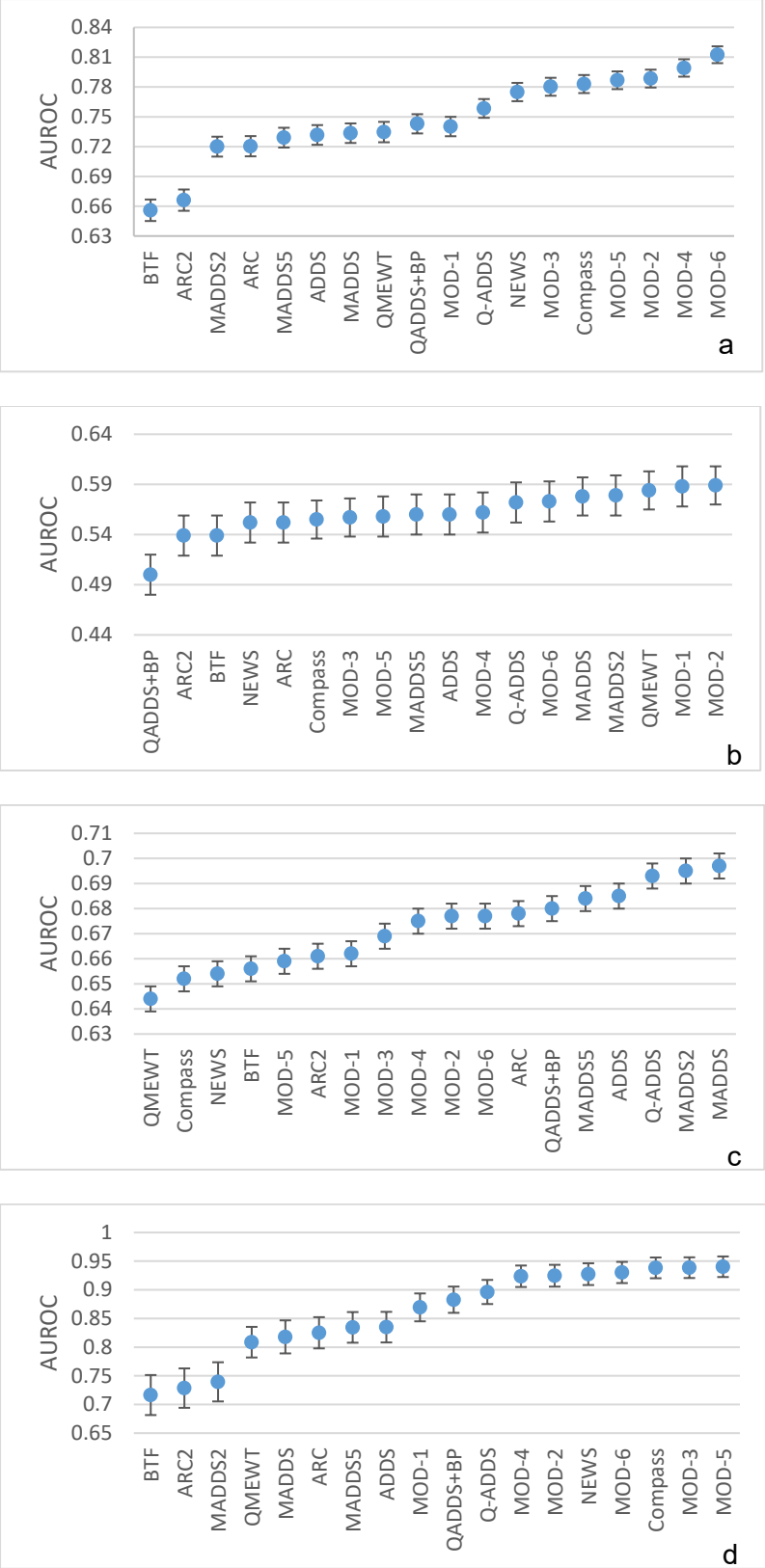
AUROC

The candidate EWSs, MOD-1 to 6 and the 12 existing EWSs studied previously (See Chapter 4), were tested using Cohorts A, B and C. Based on the AUROC, MOD-6 (AUROC, 0.812, CI, 0.795–0.829), was the most efficient EWS for Cohort A, the patient cohort from the small regional private hospitals. MOD-6 was significantly better than Compass (p = 0.018) (See Figure 34a) and differed from Compass in that it is a four-tiered combination EWS with altered weighted vital sign scores and trigger threshold ranges.

However, when applied to Cohort B, patients from the small public regional/rural hospitals, MOD-6 was not significantly better than the other EWSs ($p > 0.05$, AUROC, 0.573, CI, 0.532–0.615) (See Figure 34b). For Cohort B, all the EWSs tested were poor predictors of patient deterioration, having AUROC < 0.6 with the candidate EWSs not being significantly better or worse than the existing 12 EWSs ($p > 0.05$).

When applying the candidate EWSs, MOD-1 to 6 to Cohort C, patients from large public regional and metropolitan hospitals, the candidate EWSs produced mediocre AUROC of between 0.659 and 0.677 (See Figure 34c). For Cohort C, the best AUROC were obtained from Q-ADDS (0.693, CI, 0.683–0.703), $MADDS_2$ (0.695, CI, 0.686–0.705) and MADDS (0.697, CI, 0.688–0.707). The EWSs Compass and NEWS, which had effectively predicted patient deterioration for Cohort A, were not good predictors of patient deterioration for Cohorts B or C. When applying the EWSs to Cohort A-subset, patients from Cohort A that had died unexpectedly, the overall AUROC was greatly improved with MOD-2 to 6, NEWS and Compass having similar AUROC of 0.927 to 0.930. To summarise, based on the AUROC of the 18 EWSs compared for Cohort A, which were the patients from the small private regional hospitals, MOD-6 was the most effective. For Cohort B, the small public regional/rural hospitals, none of the EWSs tested were good predictors of patient deterioration, while for Cohort C, the large public regional/metropolitan hospitals, Q-ADDS, $MADDS_2$ and MADDS were the most effective EWSs. Of the 18 EWSs tested, there was no single 'stand-out' EWS that was superior in predicting a patient deterioration event in all three patient groups. However, it is apparent that in all three patient cohorts, the class of combination EWSs was the most effective.

The class, combination EWS, proved most efficient at predicting patient deterioration events in all three patient cohorts and can predict unexpected mortality with about 90% accuracy (AUROC > 0.9).



Note: The scale of the Y-axis differs in Figures 34 a–d.

Figure 34: AUROC for the 18 EWS for each patient cohort with error bars indicating the confidence intervals; (a) Cohort A, (b) Cohort B, (c) Cohort C, (d) Cohort A-subset.

Sensitivity and specificity

The sensitivity and specificity of the EWSs were tested for three trigger scores *E*, *E - 1* and *E - 2* to ascertain whether lowering the trigger scores would produce more effective EWSs. In all patient cohorts, as the EWS trigger threshold score was reduced from *E* to *E - 1* and *E - 2,* the sensitivity of the EWSs increased, but the specificity decreased, resulting in a higher incidence of both true and false alerts (See Tables 29–32, Figures 35–37).

Using a lower EWS trigger threshold score resulted in higher sensitivities but low specificities, producing many false alerts.

Using the trigger score *E*, the EWS Q-MEWT had the highest sensitivity in Cohorts A, B and C but also the lowest specificity resulting in many false alerts. For Cohort A, patients from the small private regional hospitals, among the candidate EWSs, MOD-2 had the highest sensitivity but a relatively low specificity, resulting in a comparatively high ratio of false to true alerts (See Figure 37a). MOD-6, at an EWS trigger score of *E - 2*, had a sensitivity of 71.07% for Cohort A (See Table 29) and a false to true alert ratio of fewer than 5 false alerts for every true alert; a reasonable result compared to some of the other EWSs tested for this cohort (See Figure 37a). The sensitivity of all the EWSs was low when applied to Cohort B, patients from small regional/rural public hospitals, with a median of 10.7% for trigger score *E*. Even at an EWS trigger score of *E - 2*, the sensitivity remained below 40% (See Table 30), and the ratio of false to true alerts was unacceptably high (See Figure 37b). For Cohort C, the large public hospitals, MOD-2 at an EWS trigger score of *E - 2* had good sensitivity (75.8%) but low specificity resulting in a false to true alert ratio of 11.4:1 (See Figure 37c). When applying the candidate EWSs to Cohort A-subset, patients that had died unexpectedly in the small private hospitals, the EWS sensitivities were slightly lower than for Cohort A, but the specificity was excellent, resulting in a false to true alert ratio of 0 (See

Figure 37d). For Cohort A-subset, MOD-5, Compass and NEWS at an EWS trigger score of *E - 2,* produced good sensitivities and successfully identified 86.7% of the at-risk patients.

The sensitivity of all EWSs tested was reasonably low; around 10%, for patients in small regional/rural public hospitals but was higher for patients from small regional private hospitals and those from large metropolitan hospitals (about 53% and 60%, respectively).

Table 29: Sensitivity and Specificity of 18 EWSs at three trigger scores for Cohort A (small private regional hospitals).

	E Score		E - 1		E - 2	
EWS	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
[a]BTF	55.23	95.29	-	-	92.93	81.53
[a]ARC	44.03	95.29	77.99	51.18	94.34	47.06
[a]ARC_2	57.86	97.06	91.82	80.59	-	-
[b]MADDS	44.69	99.22	44.69	97.65	45.91	97.65
[b]MADDS2	45.28	97.06	47.17	97.06	50.31	97.06
[b]MADDS5	47.54	96.47	47.54	96.47	50.94	96.47
[b]Q-MEWT	72.84	68.82	76.73	67.65	78.62	65.29
[b]Q-ADDS	43.51	97.65	44.65	97.65	46.54	97.65
[b]Q-ADDS+ BP	49.17	96.47	51.57	96.47	57.86	95.88
[b]ADDS	47.28	97.06	50.31	97.06	54.09	95.29
[c]NEWS	40.25	99.41	54.72	97.06	67.30	91.76
[c]Compass	51.57	96.47	62.26	95.88	68.55	91.18
[b]MOD-1	48.73	96.39	51.27	96.34	55.70	95.80
[b]MOD-2	70.44	93.53	74.21	92.35	79.25	90.59
[b]MOD-3	47.80	98.82	49.69	98.82	57.86	98.24
[b]MOD-4	59.12	95.88	60.38	99.22	64.15	95.88
[b]MOD-5	66.04	95.88	68.55	95.29	72.33	94.12
[b]MOD-6	61.64	97.06	65.41	96.47	71.07	95.88

Note: [a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

Table 30: Sensitivity and Specificity of 18 EWSs at three trigger scores for Cohort B (small public regional/rural hospitals).

	E Score		E - 1		E - 2	
EWS	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
[a]BTF	15.48	97.50	-	-	34.52	70.00
[a]ARC	10.71	100.0	22.62	91.25	39.29	60.00
[a]ARC_2	15.48	97.50	35.71	70.00	-	-
[b]MADDS	9.52	100.0	9.52	100.0	9.52	100.0
[b]$MADDS_2$	10.71	100.0	10.71	100.0	13.10	100.0
[b]$MADDS_5$	10.71	100.0	11.90	98.75	13.10	98.75
[b]Q-MEWT	34.52	72.50	34.52	72.50	36.90	72.50
[b]Q-ADDS	9.52	98.75	9.52	98.75	10.71	98.75
[b]Q-ADDS+ BP	8.33	95.00	8.33	93.75	10.71	92.50
[b]ADDS	10.71	100.0	11.90	98.75	13.10	98.75
[c]NEWS	7.14	97.50	13.10	95.00	23.81	90.00
[c]Compass	13.10	96.25	17.86	91.25	28.57	87.50
[b]MOD-1	10.71	100.0	10.71	100.0	11.90	100.0
[b]MOD-2	15.48	97.50	16.67	97.50	22.62	97.50
[b]MOD-3	9.52	98.75	9.52	98.75	11.90	97.50
[b]MOD-4	13.10	97.50	13.10	97.50	16.67	97.50
[b]MOD-5	21.43	95.00	23.81	93.75	25.00	88.75
[b]MOD-6	15.48	98.75	16.67	97.50	21.43	97.50

Note: [a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

Table 31: Sensitivity and Specificity of 18 EWSs at three trigger scores for Cohort C (large public metropolitan/regional hospitals).

	E Score		E - 1		E - 2	
EWS	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
[a]BTF	62.27	96.53	-	-	88.29	63.59
[a]ARC	53.77	98.81	79.79	90.42	90.29	61.13
[a]ARC_2	69.30	96.08	88.90	62.96	-	-
[b]MADDS	56.63	98.36	58.11	98.36	60.28	98.18
[b]MADDS2	56.98	98.81	59.15	98.81	61.75	98.18
[b]MADDS5	59.76	98.54	63.05	97.90	66.00	97.26
[b]Q-MEWT	79.79	75.09	81.01	74.64	82.83	72.90
[b]Q-ADDS	53.25	98.72	57.50	98.36	62.88	97.81
[b]Q-ADDS+ BP	59.76	98.45	63.40	98.27	66.61	97.81
[b]ADDS	60.10	98.63	63.23	97.99	66.35	97.26

	E Score		E - 1		E - 2	
EWS	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
[c]NEWS	47.61	94.62	56.98	90.33	66.61	84.58
[c]Compass	53.60	90.78	62.36	85.86	69.12	78.10
[b]MOD-1	43.19	98.27	47.27	97.90	51.86	96.44
[b]MOD-2	69.99	94.80	72.59	93.34	75.80	89.78
[b]MOD-3	52.04	97.17	54.47	96.99	58.80	96.08
[b]MOD-4	57.94	95.89	60.88	94.62	66.18	91.97
[b]MOD-5	68.52	87.59	70.16	84.85	73.11	82.03
[b]MOD-6	68.00	95.35	69.99	93.52	73.20	89.87

Note: [a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

Table 32: Sensitivity (%) and Specificity (%) of 18 EWSs at three trigger scores for Cohort A-subset (small private regional hospitals, unexpected deaths).

	E Score		E - 1		E - 2	
EWS	Sensitivity	Specificity	Sensitivity	Specificity	Sensitivity	Specificity
[a]BTF	40.0	100	-	-	80.0	90.0
[a]ARC	26.7	100	60.0	100	86.7	83.3
[a]ARC_2	40.0	100	86.7	90.0	-	-
[b]MADDS	20.0	100	20.0	100	20.0	100
[b]MADDS2	26.7	100	33.3	100	40.0	100
[b]MADDS5	33.3	100	40.0	100	46.7	100
[b]Q-MEWT	46.7	96.7	46.7	93.3	60.0	90.0
[b]Q-ADDS	26.7	100	46.7	100	33.3	100
[b]Q-ADDS+ BP	33.3	100	26.7	100	60.0	100
[b]ADDS	33.3	100	46.7	100	46.7	100
[c]NEWS	53.3	100	73.3	100	86.7	100
[c]Compass	66.7	100	86.7	100	86.7	100
[b]MOD-1	33.3	100	33.3	100	40.0	100
[b]MOD-2	60.0	100	73.3	100	80.0	100
[b]MOD-3	40.0	100	53.3	100	60.0	100
[b]MOD-4	46.7	100	53.3	100	73.3	100
[b]MOD-5	66.7	100	73.3	100	86.7	100
[b]MOD-6	60.0	100	73.3	100	80.0	100

Note: [a]Single trigger EWS, [b]Combination EWS, [c]Aggregated weighted EWS

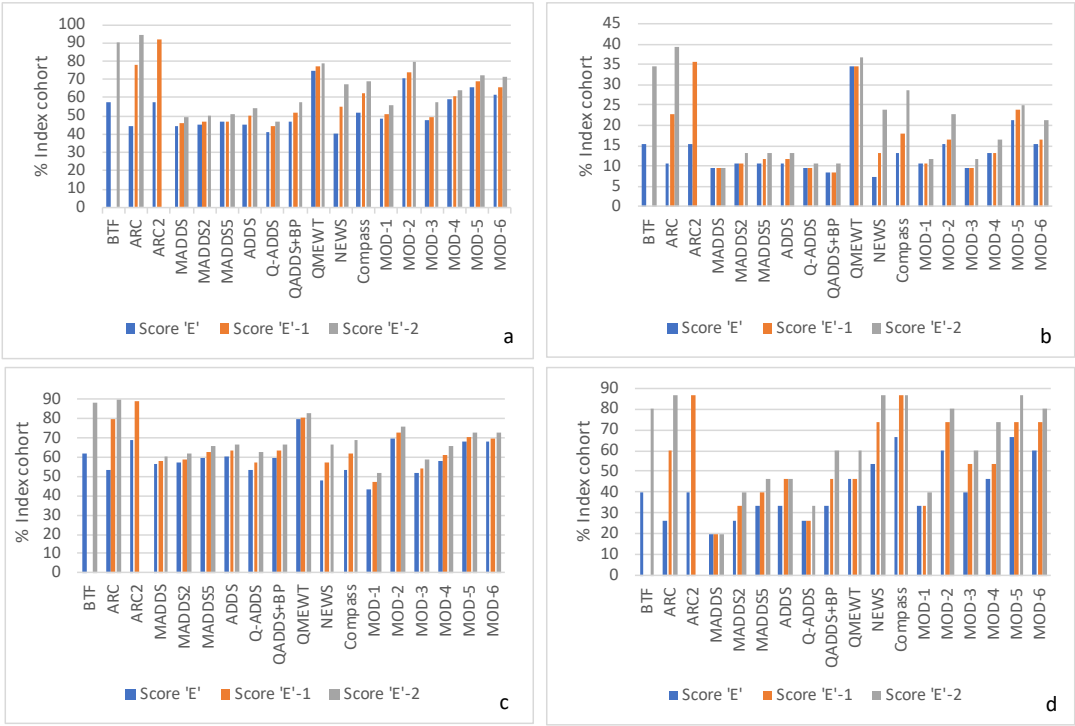


Figure 35: The percentage of true positive alerts (sensitivity) for the 18 EWS for each patient cohort; (a) Cohort A, (b) Cohort B, (c) Cohort C, (d) Cohort A-subset.

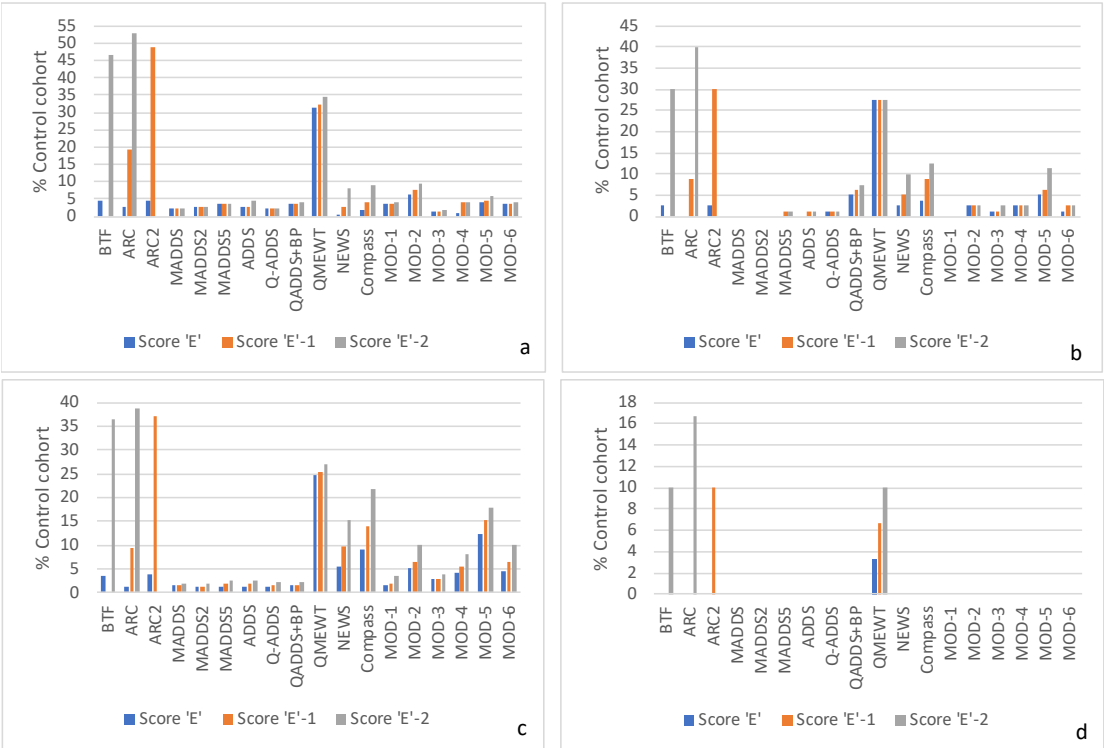


Figure 36: The percentage of false positive alerts (100-specificity) for the 18 EWS for each patient cohort; (a) Cohort A, (b) Cohort B, (c) Cohort C, (d) Cohort A-subset.

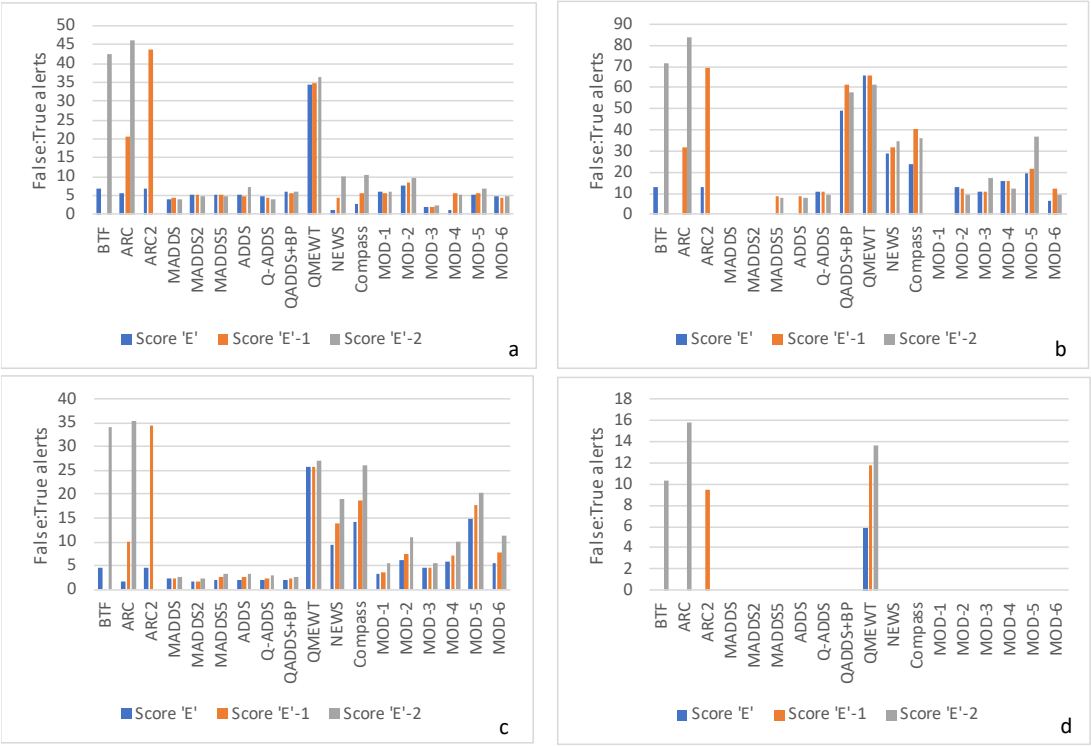


Figure 37: The ratio of false to true alerts per 1000 patients at an unexpected clinical deterioration event rate of 1.2%, for the 18 EWS for each patient cohort; (a) Cohort A, (b) Cohort B, (c) Cohort C, (d) Cohort A-subset.

Discussion

Previous studies have cast doubt on the efficacy of EWSs in identifying deteriorating patients (Grant, 2018; 2019; Grant & Crimmons, 2018; Le Lagadec et al., 2020; Wheeler et al., 2013). For this reason, six new candidate EWSs were developed to improve patient safety in poorly resourced regional hospitals in Australia. The candidate EWSs were based on the same measurable variables (vital signs) used in most existing EWSs. These variables, vital signs, are routinely monitored, and therefore, their inclusion in the candidate EWSs should not increase the staff workload or necessitate staff retraining; thus, potentially minimising compliance issues. For the candidate EWSs, only the vital sign trigger ranges and the resulting EWS weighted scores were altered while the staff response to the EWS alerts was not addressed. The staff response may be altered to suit the health facilities' available resources and policies.

Using the AUROC as a measure of EWS efficiency only considers the binary outcomes of patients, that is, an unexpected clinical deterioration event or an uneventful hospital stay. Some patients may deteriorate or improve without intervention; some will deteriorate despite intervention (Tarassenko et al., 2011). Several studies have shown that some patients suffer SAEs without displaying abnormal vital signs or triggering an EWS alert (Foster, Housley, Hatton, & Shaw, 2016; Le Lagadec et al., 2020). Tarassenko et al. (2011) argue that since patient outcomes are fluid and not predestined, using AUROC is inadequate when testing an EWS efficiency. An alternative measure of efficiency is to use EWS sensitivity and specificity. However, the sensitivity and specificity are dependent on the EWS trigger alerts values set by the system developer and often lacks scientific rigour (Romero-Brufau, Huddleston, Escobar, & Liebow, 2015). Therefore, in the current study, emphasis is placed on the AUROC when assessing the EWS efficiency, but due consideration was also given to the EWSs sensitivity and specificity. Since this is a retrospective study, the patient outcomes are known, and a binary system is justified.

Developing a centile-based EWS, MOD-1 assumes that all vital signs are normally distributed with the index patients' data, residing at the extremes of the distribution range (Tarassenko et al., 2011). This was not strictly true for patients from the small private regional hospitals (Cohort A), given that the AUROC of the centile-based MOD-1 showed no improvement in efficiency compared to the existing EWSs (See Figure 34a). Broadening the vital sign alarm range in MOD-2 increased the AUROC and the EWS sensitivity but decreased the specificity resulting in a relatively high ratio of false to true alerts (See Table 29 and Figure 37a). This was not unexpected given that numerous studies have shown that increasing EWS sensitivity can lead to an increased staff workload due to high numbers of false alarms (Bell et al., 2006; Burgess et al., 2009; Grant & Crimmons, 2018). False alarms can lead to compliance issues putting critically ill patients at risk (Burgess et al., 2009; Grant & Crimmons, 2018). Refining the vital sign alarm range in MOD-3 did not improve the EWS efficiency. Still, it did result in higher specificity and a lower

sensitivity implying that MOD-3 was better able to exclude not-at-risk patients (See Table 29) but was less effective at identifying at-risk patients. High specificity resulted in few false alarms, but this is of little benefit if the EWS cannot adequately identify the at-risk patients. This can be especially disconcerting if clinical staff develop a heavy reliance on EWSs to guide their patient care instead of utilising clinical judgement (Grant, 2019; Massey, Chaboyer, & Anderson, 2017).

A predictive tool such as an EWS is reliable if it is based on good intrinsic prognostic information (Altman & Royston, 2000), in this case, the vital signs. If the prognostic information is a weak predictor of patient outcomes, the EWS may not be effective. Not all vital signs are equally good predictors of patient deterioration (Cuthbertson et al., 2007; Duckitt et al., 2007; Luís & Nunes, 2018). Therefore, a candidate EWS was developed, emphasising those vital signs that best predicted patient outcomes (See Chapter 5) for the target cohort, that is, patients from small regional private hospitals. When higher graduated weighted scores were allocated to supplementary O_2 flow rate, tachycardia, and tachypnoea, the resulting MOD-4, had a higher AUROC but not significantly better than the most effective existing EWS, Compass (See Figure 34a). This method of developing EWSs, based on the most predictive vital signs, has been suggested as an alternative to the traditional best-guess method of setting the physiological ranges and EWS weighted score (Duckitt et al., 2007). The method was successfully used to develop the Aberdeen Warning of Critical Illness Score system and the Worthing Physiological Scoring System for emergency care medical patients (Cuthbertson et al., 2007; Duckitt et al., 2007). It has been suggested that vital signs that do not predict patient outcomes be omitted from the EWS to reduce staff workload and improve staff compliance (Luís & Nunes, 2018). In the current study, SBP, body temperature and SpO_2 contributed little to predicting patient deterioration (See Chapter 5). Their omission would potentially have minimal impact on the statistical EWS efficiency, as determined by the AUROC. However, despite there being scant empiric evidence of their

contributing value in an EWS (Cuthbertson et al., 2007; Luís & Nunes, 2018), they are indicators of patient wellness and their exclusion would undoubtedly be met with opposition.

Combination EWSs, EWS that function both via a single vital sign trigger and an aggregated weighted vital sign score, are commonly used in Australian hospitals. The researcher aimed to improve the efficiency of the most effective EWS in the current study, Compass, by converting it from an aggregated weighted EWS to a combination system, which was labelled MOD-5. When applying the vital sign data of patients from the small regional private hospitals (Cohort A) to the newly developed MOD-5, the EWS sensitivity was greatly improved (See Table 29). However, the AUROC remained similar to that of Compass (See Figure 34a). Further refinement of the EWS resulted in MOD-6, which produced the best AUROC and good sensitivity for the patients admitted to the small regional private hospitals. Decreasing the emergency call trigger score of MOD-6 from a score of 8 to 6 (*E* - 2) increased the system's sensitivity from 61.6% to 71% without increasing the ratio of false to true alerts (4.7:1). Therefore, if MOD-6 was implemented using an EWS trigger score of equal to or greater than six, as the emergency call score, there would be a 20% increase in the number of at-risk patients identified compared to when Compass is implemented at its current emergency trigger threshold of seven. Although MOD-6 appears to be well suited to small regional private facilities, it is not assured that it will be equally effective if applied to other hospital cohorts. Testing the efficacy of a system using the same patient database utilised in its development is a weak validity test, subject to bias and overoptimism (Altman & Royston, 2000). Therefore, the candidate EWSs were tested against independent external patient cohorts.

The independent patient cohorts used to validate the candidate EWSs included patients from seven small regional/rural public hospitals and six large regional/metropolitan hospitals. Given the similarity in geographical location and facility size, it was anticipated that the efficacy of the EWSs would be comparable for the small private and public regional/rural hospitals (Cohorts A and B). However, when applied to the patient data from the small public

hospitals, all the EWSs tested, both the existing 12 EWSs and the six new candidate EWSs, proved equally inefficient. Their AUROCs were well below 0.7, the level generally regarded as acceptable in predicting patient outcomes (Prytherch, Smith, Schmidt, & Featherstone, 2010; Smith, Prytherch, Schmidt, Featherstone, & Higgins, 2008), and their sensitivity averaging 10%. This implies that these EWSs would only trigger an emergency call for approximately 10% of the deteriorating patients. The dissimilarities in EWS efficiency between the small regional public and private facilities may indicate that it is not the size of the hospital that is significant, but perhaps the organisational response to deteriorating patients.

Given that transfer to a higher level of care was the measured outcome for the small regional/rural public hospitals (Cohort B), the apparent lack of EWS sensitivity might be related to the staff responding early to signs of patient deterioration. Since these small facilities do not have the specialist teams or resources to care for critically ill patients, the staff may be pre-empting potential deterioration events (Stanley et al., 2019). Patients may be transferred to a high level of care before their EWS values reached the emergency call score. Given that the EWS sensitivity is dependent on an emergency score being attained, early response to patient deterioration will result in poor EWS sensitivity. A recent study comparing the efficacy of Q-ADDS in small regional/rural and large metropolitan public hospitals showed similar results. Index patients at smaller facilities achieved much lower Q-ADDS scores than those in metropolitan hospitals. Thus, Q-ADDS produced an AUROC of only 0.54 in the small hospitals compared to 0.91 for the well-resourced metropolitan hospitals (Dwyer et al., 2019). This does not necessarily imply that EWSs are not efficient in small, poorly resourced facilities; it may indicate that the staff in these small facilities are more alert to potential deterioration events and respond sooner than do staff in large, well-resourced metropolitan hospitals. If this is the case, it implied that staff in poorly resourced hospitals utilise EWSs as predictors of deterioration events. Those in well-resourced hospitals may be using the EWS as indicators of deterioration events, responding when an

emergency call score is achieved. This would account for the statistical differences observed in the EWS efficiency between the small, poorly resourced and the well-resourced hospitals.

A diagnostic tool, such as an EWS, yields a measure of statistical prediction based on observed outcomes (Altman & Royston, 2000). In the current study, the level of agreement between the predictability and the observed patient outcome was compared. If, however, the observed outcome is inappropriate, calculating the resulting EWS efficiency would not be accurate. The efficiency of the EWS in the current study is dependent on the validity of the unexpected clinical deterioration event as the measurable outcome. Since this is a retrospective study based on existing patient data, the classification of patient outcomes, unexpected clinical deterioration events and uneventful hospital stay is a subjective measure, open to interpretation by the clinical staff. It is possible that some of the deteriorating patients in the index group may have been erroneously classified and that their condition may not have eventuated in SAEs. All index patients in the small regional/rural public facility cohort and 71% of index patients in the small private facility cohort were transferred to a higher level of care either within the facility or to an external facility. Whether these patient transfers were warranted or not is unknown. Once transferred to an external facility, the patient outcomes are not followed up and thus not documented in their medical charts. These patients could have recovered without further intervention and may, therefore, not have suffered a clinical deterioration event. This is a study limitation. However, since the same patient data was applied to all the EWSs compared in the current study, the same degree of downward bias would apply to all the EWSs tested. The differences observed in the EWSs efficiencies are therefore believed to be valid.

The most irrefutable unexpected clinical deterioration event is patient mortality. Approximately 9% of the index patients in the small regional private hospital cohort died unexpectedly. Using the vital sign data of patients who had died unexpectedly to validate the EWSs produced excellent AUROC (See Figure 34d). Most of the aggregated weighted EWSs, including the new candidate EWSs, produced specificities of 100%. This means that

the aggregated weighted EWSs would raise no false alarms if used to predict unexpected patient mortality. Although unexpected death constitutes a small sample, it is representative of the regional private hospital cohort. Validating an EWS using a subset of the original patient cohort is subject to positive bias (Altman & Royston, 2000). Ideally, the EWS should be tested using mortality as the unexpected clinical deterioration event for the patients from the small regional/rural and the large regional/metropolitan public hospitals (Cohorts B and C). Unfortunately, this datum is not currently available.

Of the 18 EWSs tested in the current study, no single EWS proved superior for both well and poorly resourced private and public hospitals. It is, therefore, apparent that a single universal EWS would not suit all facilities. According to Watkinson et al. (2018), an EWS's efficiency depends on the database (patient cohort) used in its development. This is evident in the current study. The candidate EWS, MOD-6, was the most effective EWS when applied to patient data from the small private facilities for which this EWS was developed. However, MOD-6 was less effective when applied to patient data from public hospitals. This study has shown that improving EWS efficiency by developing a new EWS is viable but is most effective when applied to the patient cohort for which it was developed. It may be prudent to recommend a class of EWS rather than a specific, individual EWS. The current study has shown that the combination EWSs are most effective in identifying deteriorating patients in both private and public, regional/rural and metropolitan hospitals. It is important to note that these EWSs are merely tools that alert staff to changes in the patient's physiological status and guide patient care. They do not detect an SAE but merely identify signs of a potential deterioration event (Burgess et al., 2009). De Bie et al. (2019) and Grant (2019) cautioned that overreliance on objective tools, such as EWSs, may compromise patient safety if staff relying on them at the expense of intuition and expert knowledge. Given the lack of good evidence regarding the ability of these EWSs to correctly identify at-risk patients, it is prudent for nursing staff not to become over-reliant on EWSs but to utilise them together with sound clinical judgement.

Conclusion

It was hoped that modifying or developing new EWSs would improve patient safety by better identifying at-risk patients for small, poorly resourced medical facilities. The newly developed candidate EWS, MOD-6 at an emergency trigger score of six, improved the distinction between index and control patients by 20% in the cohort for which it was developed. Unfortunately, the efficiency of the candidate EWSs could not be validated using the independent patient cohorts. This indicates that a universal EWS would probably not be suitable for all medical facilities. However, it was apparent that the class 'combination EWS' appears to be the most effective for both small and large public and private hospitals. Based on the sensitivity and AUROC of the 18 EWSs test, it appears that staff in poorly resourced public hospitals may be using EWS to predict and thus prevent deterioration events. In contrast, staff in well-resourced hospitals use EWSs as indicators of patient deterioration, allowing patients to attain higher EWS threshold scores before responding. Although EWSs may be effective tools in tracking the patients' physiological status, their use as indicators of patient deterioration and SAEs should be implemented with caution and probably only as an adjunct to good clinical judgement.

Chapter Summary

In determining the EWS most suited to small resource-poor facilities, we found that while the EWS called Compass performed best, none of the existing, commonly adopted EWSs (Chapter 4) are ideally suited for this patient cohort. Therefore, six new candidate EWSs were explicitly created for the small regional private hospital context. One new candidate EWSs, labelled MOD-6, proved to be 20% more effective than the best performing existing EWS, Compass. When validating these six new EWSs using patient vital sign data from independent cohorts, the new candidate EWSs did not prove to be any more efficient than the existing ones. Still, it was ascertained that overall, the combination EWSs was the most effective class of EWSs.

As shown previously in Chapter 4, the current study confirmed that EWSs developed for a particular cohort of patients are not necessarily effective when applied to an alternative patient group. An important finding of the current study is that EWSs may be used differently in poorly resourced versus well-resourced hospitals. It appears that in poorly resourced hospitals, the EWSs may be used to predict patient deterioration, with staff responding early to prevent further deterioration. In contrast, in large, well-resourced facilities, it appears that the EWSs may be used as indicators of clinical deterioration events. That is, the staff may be utilising the EWS protocol to guide their response to patient deterioration. This would enable patients to reach higher EWS values before staff activated a MET alert. This information may be useful when investigating how EWSs are being utilised in well-resourced compared to poorly resourced hospitals.

The overarching aim of this study was to provide evidence of the efficiency of various EWSs to assist poorly resourced regional/rural hospitals make informed decisions when selecting EWSs for implementation. The evidence produced in this chapter indicates that a combination EWS with an emergency trigger score lowered from eight to six may be best suited for these small private hospitals. An emergency response score of six may allow sufficient time for the staff to escalate patient care and prevent an unexpected clinical deterioration event. However, it is strongly recommended that the EWS being considered for implementation should be tested for the target cohort before adoption.

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Chapter 7. General Discussion and Conclusion

Synopsis

The previous chapters, Chapters 4 to 6, presented three related but separate studies involving the afferent limb of the Early Warning System, the Early Warning Scores (EWSs). These chapters contributed to the study's overarching aim: to provide evidence of the efficiency of various EWSs to assist poorly resourced regional/rural hospitals in making informed decisions when selecting an EWS for implementation. Of the existing EWS tested, an aggregated EWS called Compass was best suited for the small regional/rural hospitals. However, Compass had poor sensitivity prompting a medical review for less than half of the deteriorating patients. Therefore, a new EWS called MOD-6 was developed that was well suited for this patient cohort. However, when MOD-6 was validated using two independent patient cohorts, it was not superior to existing EWSs. This confirmed a recommendation made in the scoping review, Chapter 2, that EWSs should be tested for the target patient cohort before implementation.

This final chapter combines the evidence from these smaller studies to articulate how the overarching recommendation for optional EWS was reached. In addition, we analyse the emergent themes from each chapter that potentially contribute to a practical solution in select an EWS best suited to their patient cohort and the available resources in these small hospitals. Finally, in this chapter, the study limitations are noted, and suggestions are made for future research consideration.

Recapitulation of the Objectives and Results

The overarching aim of this study was to provide evidence of the efficiency of various EWSs to assist poorly resourced regional/rural hospitals make informed decisions when selecting EWSs for implementation. The steps taken to achieve this aim included a review of the literature, comparing the efficiency of existing EWSs using patient data from the target

facilities, and finally, developing and validating a new EWS specifically for use in the target hospitals.

The literature review in Chapter 2 showed good evidence that EWSs may help staff recognise and respond to deteriorating patients (Alam et al., 2014; De Meester et al., 2013; Hammond et al., 2013). Still, there is little quantitative evidence that the EWSs improve patient outcomes (Bailey et al., 2013; Le Lagadec & Dwyer, 2017). Most of the research involving EWS efficiency was conducted in large, well-resourced metropolitan hospitals. There is a distinct gap in the literature regarding EWS efficiency for small, poorly resourced regional/rural hospitals. This is prudent given that many smaller regional/rural facilities, especially in the private sector, have no resident doctors, and the responsibility rests entirely on the nursing staff to identify and respond to deteriorating patients (Considine et al., 2020; Le Lagadec, Dwyer, & Browne, 2020b). In contrast, in the larger well-resourced hospitals, although the nurses are responsible for identifying the deteriorating, they have the support of the Rapid Response or Medical Emergency Teams to manage the crisis situation (Difonzo, 2019; Flenady et al., 2020). In principle, any Early Warning Score (EWS) or tool that can assist the nursing staff in their clinical decision making should augment patient safety. Based on previous studies which compared single trigger EWSs to aggregated weighted EWSs, it is generally agreed that the latter is the most effective in identifying deteriorating patients (Churpek, Yuen, & Edelson, 2013a; Churpek, Yuen, & Park, 2014; Green et al., 2018; Le Lagadec, Dwyer, & Browne, 2020a; Le Lagadec et al., 2020b). However, the efficiency of any EWS appears to be dependent on the patient cohort, facilities available, staff training, and the culture of the organisation (Lippert & Petersen, 2013; Rosero, Romito, & Joshi, 2020; Shearer et al., 2012; Watkinson, Pimentel, Clifton, & Tarassenko, 2018). The need to provide the best evidence of the EWS efficiencies for a specific patient cohort type is the fundamental reason for undertaking the current study. Studies reviewed in Chapter 2 generally supported the use of EWSs in larger acute care facilities while cautioning that EWSs should be used as an adjunct to, and not as a replacement for, good clinical intuition

and critical judgement (Forster, Housley, McKeever, & Shaw, 2018; Grant, 2018; Grant, 2019).

In the two small regional private hospitals included in this study (Cohort A, See Chapter 4), 1.2% of hospital ward admissions experienced an unexpected clinical deterioration event. That is 12 unexpected clinical deterioration events per 1 000 patient admissions. The number of unexpected clinical deterioration events is important because it directly impacts staff workload, the length of hospital stay, and the cost of patient care (Cretikos et al., 2007; Najjar, Nafouri, Vanhaecht, & Euwema, 2015). A recent study showed that according to the staff, the greater the workload, the less staff could monitor their patients and track their illness (Ede et al., 2021). This implies that a high workload may reduce the staffs' ability to identify patients that deteriorate (Ede et al., 2021). In addition, the increased workload has been linked to failure to rescue and, therefore, negatively impacts patient quality care and safety (Johnston et al., 2015; Mushta, Rush, & Andersen, 2018; Shever, 2011). One of the measures taken to improve patient safety in all Australian medical facilities is implementing a patient deterioration detection system that provides staff with a tool to communicate their patient concerns (Australian Commission on Safety and Quality in Health Care, 2017; Ede et al., 2021). There is some evidence that introducing an EWS at one of the two study sites in the current study increased the incidence of medical emergency calls and decreased the number of patients transferred to a higher level of care. Although this evidence is weak, it does indicate that using an EWS at this facility may have improved patient safety by helping staff identify the deteriorating patients, escalate their care and thus prevent the necessity of transfer to a high care ward (HDU or ICU).

When comparing the efficiency of 12 existing EWSs (See Chapter 4), we found that the single trigger EWSs were the least effective. Although single trigger EWS may be simpler to use, this simplicity risks information loss, resulting in reduced EWS's predictive powers and a potential failure to escalate care (Fu et al., 2020). The aggregated weighted EWSs, NEWS and Compass, were the most effective in the current study, followed closely

by the combination EWSs, the Q-ADDS and MADDS series of EWSs (See Chapter 4). Several previous studies compared single trigger to aggregated weighted EWS and found the aggregated system to be superior (Churpek et al., 2013b; Churpek et al., 2014; de Pennington, Laurenson, Lebus, Sihota, & Smith, 2005; Green et al., 2018; Jarvis et al., 2015; McNeill & Bryden, 2013). In the current study, the 12 EWSs tested were most efficient at identifying patients that were not at risk of unexpected clinical deterioration (high specificity) but were less able to identify at-risk patients (relatively low sensitivity).

Implementing a method to identify deteriorating patients is mandatory in all Australian medical facilities (Anstey, Bhasale, Dunbar, & Buchan, 2019). However, there is no single National EWS recommended for implementation in Australian hospitals. The choice of EWS implemented in each facility is at the discretion of the individual medical facility/organisation (Rihari-Thomas, Digiacomo, Newton, Sibbritt, & Davidson, 2019). Many Australian medical organisations have multiple facilities, each facility utilising an EWS of their choice. In response to staff shortages, there is at times a high level of staff movement between facilities. Implementing a single standardised EWS across such organisations would help standardise patient care and increase patient safety (Nakitende, Nabiryo, Namujwiga, Wasingya-Kasereka, & Kellett, 2020).

The efficiency of any EWS is reflected in its sensitivity and specificity, that is, the number of true and false alerts generated (Roney et al., 2015; Wang, Fang, Chen, Tsai, & Kao, 2016). The incidence of true and false alerts impacts staff workload. In the current study, the EWSs with good sensitivity had poor specificity, meaning they generated many false alerts. False alerts potentially lead to alarm fatigue, loss of staff confidence in the EWS and possible compliance issues (Escobar & Dellinger, 2016; Hughes, Pain, Braithwaite, & Hillman, 2014). A high number of both true and false alerts indicates that the EWS has a poor ability to distinguish between deteriorating and non-deteriorating patients, usually reflected in a low AUROC (Area Under the Receiver Characteristic Curve). This suggests that when selecting an EWS, consideration must be given to both the sensitivity and the

specificity of the EWS. This is particularly important in the smaller regional/rural hospitals where staff may not be adequately equipped to deal with deteriorating patients. It is also of great importance that a deteriorating patient is identified early, particularly in small regional/rural hospitals that lack medical emergency or rapid response teams (Le Lagadec et al., 2020b). Early detection would afford the staff time to organise a patient transfer to a better-equipped facility. In the current study, patients that experienced an unexpected clinical deterioration event reached an emergency call threshold score approximately 20 hours preceding the deterioration event. This ultimately afforded the staff sufficient time to respond to the clinical deterioration appropriately. We have shown that it is important to choose an EWS well suited to the patient cohort and facility resources. It is also important that the EWS has good sensitivity and specificity and will alert staff to a deteriorating patient well before the clinical deterioration event occurs.

Based on the current study (See Chapter 4), it is recommended that an aggregated weighted EWS or combination EWS be considered for use in smaller, poorly resourced regional hospitals and that the EWS be tested in the target facility before its implementation. Thus, the first research question, to identify the most effective EWS or class of EWS for this patient cohort, has been achieved. Information has been added to the body of knowledge contributing to the study aim. We suggest that since the sensitivities of the existing EWSs tested were relatively low, it may be possible to develop a new EWS specifically for use in these small regional private hospitals.

Monitoring vital signs is fundamental in assessing a patient's wellness and remains the cornerstone of most EWSs (Cardona-Morrell, Prgomet, Turner, Nicholson, & Hillman, 2016). Before developing a new EWS, we thought it appropriate to study the pattern of vital sign monitoring in small regional/rural private hospitals and identify the vital signs that best predict an unexpected clinical deterioration event in the target patient cohort (See Chapter 5). Similar to other studies (Ghosh, Eshelman, Yang, Carlson, & Lord, 2018), we showed that patients who experienced clinical deterioration events (index patients) were monitored

more frequently than those that had an uneventful hospital stay (control patients). However, the completeness of vital sign monitoring was higher for the control than for the index patients. Incomplete vital sign monitoring is common in acute healthcare settings (Difonzo, 2019; Griffiths et al., 2018; Redfern et al., 2019) and has been linked to poor patient outcomes and failure to rescue (Clifton et al., 2015; Mushta et al., 2018; Smith et al., 2017). Since EWSs are based on the patient vital signs, part of our approach in developing a more efficient EWS was to emphasise the vital signs that best predict unexpected clinical deterioration events for this patient cohort (research questions 2a and 2b). We found that although none of the vital signs strongly predict patient outcomes, patients on supplementary oxygen > 3 L/min and those with heart rates > 120 beats/min were more likely to suffer an unexpected clinical deterioration event. This observation is important not only because it can be used to develop a more effective EWS but also to inform targeted staff education when implementing any EWS. It indicates that staff should be particularly vigilant around patients with these anomalies.

Utilising the new knowledge gained in Chapters 4 and 5, six new candidate EWSs were developed in Chapter 6 in response to research question 2c. The newly developed EWSs were combination EWSs, being both single trigger and aggregated weighted systems. One of the new EWS, called MOD-6, was 20% more efficient than Compass, the most efficient EWS tested in Chapter 4. Although MOD-6 was based on Compass, it differed from the latter in that it is a combination EWS, whereas Compass is an aggregated weighted EWS. Also, a graded weighted scale was introduced for supplementary oxygen. Also, the vital sign triggers thresholds were altered to suit the patient cohort better, and the medical emergency call threshold was lowered to 6. When validating the new EWS (MOD-6) using vital sign data from two independent patient cohorts, patients from well resourced and poorly resourced public hospitals (Cohorts B and C), MOD-6 did not perform significantly better than the existing EWSs. Although this result was disappointing, it confirms the finding from previous studies that EWSs are most effective when applied to the cohort for which they

were developed (Watkinson et al., 2018). Thus, in developing a new, more effective EWS for patients in small poorly-resourced private hospitals, Cohort A, research question 2 was achieved.

In conclusion, the study has achieved its aim; information has been added to the body of evidence to assist poorly resourced regional/rural hospitals make informed decisions when selecting EWSs for implementation. The most effective class of EWS, aggregated weighted or combination EWSs, has been identified and recommended for use in poorly resourced regional/rural hospitals, thus, fulfilling the requirements of research question 1. It is also suggested that changes in the vital sign trigger threshold scores be considered, as seen in MOD-6. These changes would improve the efficiency of existing EWSs without overtaxing the staff with false alarms. We anticipated that the findings from this study would contribute to and inform policy when standardising EWS for implementation in the small regional private hospitals.

General Discussion

Patient deterioration and preventable severe adverse events (SAEs) remain a significant concern for medical facilities globally (Rihari-Thomas et al., 2019). Despite more than two decades of research, little progress has been made in reducing the occurrence of in-hospital preventable patient deterioration (Credland, Dyson, & Johnson, 2018). In response, various EWSs have been introduced to the acute care setting as a means of curtailing the incidence of SAEs. To date, there is inconclusive evidence that this goal has been achieved. It has been suggested that EWSs may not be as effective as initially hoped, and reliance on these tools could jeopardise patient safety (De Bie et al., 2019; Gerry et al., 2020). Perhaps with increasing life expectancy and ever-diminishing hospital resources, the problem of unexpected patient deterioration is inevitable. As the population ages, the demand for healthcare services increases and pressure is placed on the limited medical resources available (Krütli, Rosemann, Törnblom, & Smieszek, 2016). Although medical

resource scarcity is common in developing countries, even first world countries experience scarcity due to limited medical budgets and the ever-increasing cost of healthcare (Krütli et al., 2016). Patient deterioration events and SAEs often result in poor patient outcomes and increased length of stay (Cretikos et al., 2007), adding to patient healthcare costs. Therefore, any measure that can reduce deterioration events should lessen the demand for hospital resources. In Australia, implementing a system to better recognise the deteriorating patient is mandatory (Anstey et al., 2019), and most hospitals have chosen to implement Early Warning Systems. A recent study of Australian hospitals found that since the introduction of patient deterioration detection systems, 85% of the 500 hospitals surveyed reported an improved staff awareness and management of patient deterioration (Anstey et al., 2019). Most of the existing knowledge on EWS efficacy is derived from well-resourced metropolitan hospitals. There is a conspicuous lack of information regarding the use of EWS in small, poorly resourced region/rural hospitals. We trust that the current study will contribute to the body of evidence to help poorly resourced regional/rural hospitals make informed decisions when choosing an EWS for implementation.

Using statistical methods to validate EWSs may be an oversimplification of a very complex problem. *Homo sapiens* are heterogeneous with complex physiologies that may respond differently because of their disease processes. Patients on general hospital wards are often acutely unwell, requiring complex care and are at risk of clinical deterioration (Burdeu, Lowe, Rasmussen, & Considine, 2020). Also, the staff response to patient deterioration is diverse, and their interpretations of patient's symptoms are often dependent on their years of experience, training, and the facility's culture (Lippert & Petersen, 2013; Pattison & Eastham, 2011; Shearer et al., 2012). Ultimately these factors contribute to high levels of variability of data collected. To counteract the heterogeneity of the available data, most EWS studies involve large sample sizes. This necessitates conducting these studies in tertiary or metropolitan hospitals with big patient cohorts (Ahn et al., 2020; Douw, Huisman-de Waal, van Zanten, van der Hoeven, & Schoonhoven, 2017; Smith et al., 2016).

Alternatively, many EWS efficiency studies have involved large banks of electronic vital signs data obtained from numerous metropolitan hospitals (Churpek et al., 2014; Hands et al., 2013; Pimentel et al., 2019; Shappell, Snyder, Edelson, & Churpek, 2018). Hence, there is an abundance of EWS research based on data derived from large, well-resourced metropolitan hospitals with established Rapid Response Teams. The knowledge gap resides in the smaller regional/rural hospitals without established Rapid Response Teams, where patient cohorts are small and varied, and research is generally unfunded (Barclay, Phillips, & Lyle, 2018).

Based on the statistical data generated in the current study, there is ambivalent evidence that existing EWSs developed for well-resourced metropolitan hospitals are efficacious in small, poorly resourced regional/rural hospitals. We found that the twelve existing EWSs tested (See Chapter 4) had an average sensitivity of only 50%. This means that half of the deteriorating patients in these poorly resourced regional/rural private hospitals did not reach an EWS score that would prompt an emergency medical review. Early warning charts/scores were initially designed to *help* staff recognise the deteriorating patient (Spångfors, Molt, & Samuelson, 2019). They were not intended to replace good nursing practices or the use of clinical judgement. Instead, they were designed to support clinical decision-making practices (Grant & Crimmons, 2018; Mulligan, 2010; Suokas, 2010). According to a recent study, up to 63% of nurses miss vital cues resulting in a distorted interpretation of the patients deteriorating clinical status (Al-Moteri et al., 2020). Based on the current study results, if staff focus on the EWS score to guide their patient care, instead of using the EWS to support clinical judgement, there is the potential to overlook up to half of the deteriorating patients. If the EWSs are used as intended, to augment clinical judgment, a 50% sensitivity should be viewed as a good support system for the clinical decision-making process.

Furthermore, eleven of the twelve EWSs tested in the study showed excellent specificity. This means that these EWSs would raise very few false alerts. The significance

of EWS specificity is gaining favour in medical research, with recent studies focusing on using EWSs as indicators of patients at low risk of SAEs (Mizrahi, Kott, Taub, & Goolsarran, 2020). Identifying the low-risk patients allows for redistribution of valuable hospital resources, such as adjusting patient monitoring intervals based on the patient's risk profile (Mizrahi et al., 2020). This could have practical application in the small regional/rural hospitals, which are often resource-poor. Utilising EWSs to identify the less acutely ill patients can guide nursing care and support nursing decisions. In poorly resourced hospitals, if the nurses can distinguish between patients with lower and high care requirements, it may afford them more time to respond to the deteriorating patient early and take appropriate action by either summoning specialised help or by transferring the patient to a better-resourced facility.

To increase the efficacy of the existing EWSs tested, a new EWS was developed, namely MOD-6. This new EWS (MOD-6), tailor-made for patients in the small regional private hospitals, was highly effective when applied to the target cohort. However, when validated using two independent cohorts from public hospitals, large metropolitan and small regional/rural hospitals, the efficiency of MOD-6 was not superior to that of other existing EWSs. This shows that even if the deteriorating patient detection and response systems are homogenous (EWS), the patient cohort and healthcare facilities are not, contributing to the discourse surrounding the efficacy of EWSs (Custo & Trapani, 2020). There is currently little agreement among health professionals regarding what constitutes a deteriorating patient and how to identify a patient at risk of an SAE (Burdeu et al., 2020; De Bie et al., 2019).
If a reduction in unplanned admission to ICU is used as the measurable outcome, then the implementation of EWSs have, in some studies, not reduced the occurrence of SAEs but has increased its incidence (Aitken et al., 2015; Massey, Aitken, & Chaboyer, 2015). However, this may be interpreted as a positive outcome if an unexpected death is prevented by transferring the patient to ICU. Therefore, if preventable death is the outcome measured, then the adoption of EWSs is considered effective in many studies (Custo & Trapani, 2020;

Mathukia et al., 2015; Mitchell et al., 2010). Clearly, this illustrates that the outcomes used will determine the efficiency of the EWS being tested. It is apparent from the literature that the same EWS applied to different cohorts in different facilities can produce vastly different results (Campbell et al., 2020; Forster et al., 2018; Rojas, Shappell, & Huber, 2017; Sutherland, Yarmis, Lemkin, Winters, & Dezman, 2020). Therefore, it is possible in the current study that MOD-6 produced different efficiencies when applied to three independent patient cohorts partly because those cohorts were selected based on different outcomes criteria.

In the current study, when comparing the efficacy of the EWSs using the independent patient cohorts, the average EWS sensitivity for the well-resourced metropolitan patients was good, approximately 70%. In contrast, the EWS sensitivity for the poorly resourced regional/rural cohort was very low, approximately 10%. The statistical interpretation of these results is that EWSs are effective in well-resourced hospitals and ineffective in small, poorly resourced hospitals. A recent study comparing the efficiency of Q-ADDS in large regional/metropolitan hospitals compared to small regional/rural hospitals produced similar results, with the EWS proving significantly more efficient in the larger, better-resourced hospitals (Dwyer et al., 201). This discrepancy could be related to facility resourcing and perhaps to how the staff in these hospitals utilises the EWSs. To respond appropriately to a deteriorating patient, staff are not only responsible for recognising the patient's declining health status but also for taking appropriate action to prevent the crisis (Wood, Chaboyer, & Carr, 2019). The actions taken by the staff is dependent on the hospital resources available, the availability of specialised critical care response teams and the hospital culture and policies. In the larger, well-resourced hospitals, the problem of patient deterioration was addressed by introducing the EWSs and the Rapid Response or Medical Emergency Teams which can be summoned quickly by the ward staff to manage any patient crises (Difonzo, 2019; Flenady et al., 2020; Nosrati et al., 2013; Rihari-Thomas et al., 2019). These teams usually comprise critical care specialists, both physicians and nurses, that can offer multi-

professional interventions to prevent SAEs from eventuating (Difonzo, 2017). It has been suggested that in well-resourced hospitals, the ward staff can activate the emergency alert, being guided by the EWS protocol when assistance is required (Petersen, Rasmussen, & Rydahl-Hansen, 2017; Rihari-Thomas et al., 2019).

Despite the elevated EWS scores, studies have shown that staff compliance with full EWS protocol is as low as 8% and for 20% to 80% of reported SAEs, staff have failed to respond to deteriorating patients (Goldhill & McNarry, 2004; Petersen et al., 2017; Trinkle & Flabouris, 2011). The high frequency of elevated EWS scores that do not eventuate in an SAE or clinical deterioration event is reported as one reason for failure to follow the EWS protocol (Petersen et al., 2017). Flenady et al. (2020) refer to this as the proactive approach to EWS response where the nurse has the confidence to adopt a 'wait-and-see' attitude when dealing with abnormal vital signs. Thus, in well-resourced metropolitan hospitals where emergency response teams are readily available to manage a crisis, it may be feasible to allow the EWS score to reach an emergency call threshold value before activating the alarm. If this is the case, the estimates of EWS efficiency at these large metropolitan hospitals will be positively biased because many of the patients for whom medical emergency alerts are raised would have achieved the EWS emergency call threshold score.

The small regional/rural hospitals, both public and private, are not well resourced, rarely have doctors on-site, and do not usually have specialist emergency response teams (Le Lagadec et al., 2020b). In most small private regional hospitals, the admitting doctor directs patient care (Nosrati, Clay-Williams, Cunningham, Hillman, & Braithwaite, 2013). However, the system fails in these small hospitals when the admitting doctor is not on-site or when the patient deteriorates outside of the doctor's skill base (Nosrati et al., 2013). In the absence of a treating doctor, the nursing response may include increasing the frequency of patient assessments, accurately measuring and interpreting the information collected, activating the medical emergency call alert, and notifying the medical officer on call

(Considine & Currey, 2015; Considine et al., 2017). If required, the nurse may conduct cardiopulmonary resuscitation or participate or take a leadership role in advance life support.

The lack of emergency response teams necessitates the development of self-reliance at the small, poorly resourced facilities, and in the absence of frequent exposure to crisis situations, staff are at risk of deskilling (Cooper et al., 2013). A loss of confidence in the nursing staffs' abilities often accompanies a lack of exposure (McDonnell et al., 2013) and, thus, a possible reluctance to deal with patient crises. In small regional/rural hospitals, a lack of resources may necessitate the early transfer of patients to better-resourced facilities before SAEs occurring (Dwyer et al., 2019; Stanley et al., 2019). However, transferring patients often require the authorisation of the treating doctor (Considine et al., 2017). Organising a patient transfer from a regional/rural hospital can be a lengthy process involving several authorisations and modes of transport (Fleet et al., 2020; Queensland Government, 2019). Given the hospitals' geographical distances from well-resourced facilities and the lack of on-site doctors, the nursing staff need to respond early to signs of patient deterioration (Cooper et al., 2013). It has been suggested that the lack of specialised resources may be compensated for by increasing the use of care protocols (Fleet et al., 2020) and by developing a standardised EWS which predicts rural inter-hospital transfers (Stanley et al., 2019). Given the time required to organise a patient transfer, arrangements would need to be made before the patients' EWS scores reach the emergency call threshold score. Therefore, the level of hospital resourcing will strongly influence the staff response to patient clinical deterioration and impact the way the staff utilise the EWSs. This, in turn, will influence the EWS's statistical efficiency with patients experiencing unexpected clinical deterioration events in poorly resourced hospitals, not attaining the high EWS scores observed in the larger metropolitan hospitals. This makes a meaningful comparison between small regional/rural and large regional/metropolitan hospitals difficult.

The sensitivity of an EWS reflects the number of true alerts generated (Burgess, Herdman, Berg, Feaster, & Hebsur, 2009), that is, the percentage of patients with a

documented clinical deterioration event that reached the emergency call threshold score on the EWS chart. From the current study, a much larger proportion of deteriorating patients achieved the medical emergency threshold in the well-resourced metropolitan hospitals compared to those in the poorly resourced regional/rural hospitals. However, in both cohorts, a portion of patients classified as experiencing an unexpected clinical deterioration event never achieved an emergency EWS threshold score. These patients were flagged as high risk, not due to a numerical EWS score, but perhaps due to the staff's concern regarding the patient's clinical status. Ede et al. (2021) refer to this as 'soft signals' of patient deterioration where the nurse recognises signs of deterioration that may or may not be captured by the EWS. Typically, staff respond by increasing patient monitoring, seeking the advice of senior, more experienced colleagues or requesting a medical review (Wood et al., 2019). A large international study has shown that experienced clinical staff, both nurses and physicians, can identify deteriorating patients based on intuition and interpretation of symptoms rather than on a numerical score (De Bie et al., 2019). The staff's ability to recognise a deteriorating patient and their willingness to trigger an emergency alert is based on numerous factors, including their clinical experience, confidence levels, risk tolerance, sense of personal responsibility and availability of facility resources (De Bie et al., 2019; McGovern, Wells, Landstrom, & Ghaferi, 2020; Shearer et al., 2012). Given the difficulty in quantifying these subjective factors, the 'worried' criterion, as an emergency call trigger, has been added to several EWSs (De Bie et al., 2019). The worried criterion is often based on subjective patient assessment unsupported by the EWS score. It empowers the nurses to request an urgent patient review based on their experience and clinical judgement (Rihari-Thomas et al., 2019). According to O'Connell, Flabouris and Thompson (2020), approximately one-third of all emergency calls are triggered by the worried criterion. The current study supports this statement because 30% of the unexpected clinical deterioration event in the well-resourced metropolitan patient cohort was flagged due to factors other than the EWS score.

In the current study, given that only 10% of the deteriorating patients in the small, poorly resourced regional/rural hospitals achieved the emergency review threshold score, there is strong, through circumstantial, evidence that the nursing staff are utilising the 'worried criterion' rather than the numerical EWS score to flag the high-risk patients. It can be argued that in these small hospitals, the EWS is being utilised correctly for early identification of deteriorating patients and thus averting a crisis situation (Burdeu et al., 2020; Spångfors, Molt, & Samuelson, 2019). Grant and Crimmons (2018) state that most EWS studies focus only on high EWS scores, thus identifying an SAE after the fact. They suggest that EWS efficiency studies should focus on predicting an SAE, therefore looking at the lower EWS scores (Grant & Crimmons, 2018). If EWSs are used in this manner, the score will be employed to support the nurses' clinical decision making. Forster et al. (2018) warn against the overreliance on a numerical score rather than integrating intuition and nursing skills in decision making. Several previous studies have stated that EWSs are useful tools in supporting clinical decision making but should not be used as substitutes for good clinical judgement (Mulligan, 2010; Petersen et al., 2017; Rihari-Thomas et al., 2019; Suokas, 2010). If the EWS is utilised as intended, then in the current study, the 10% sensitivity of the EWS, that is, the 10% of the patients that attained an EWS emergency call threshold score, could be regarded as the failures to detect clinical deterioration. These are the patients that were not transferred out early enough before their vital signs reached high levels of derangement, necessitating emergency intervention in an environment where resources are limited. For the remaining 90% of the deteriorating patients in these small hospitals, staff used the EWS to support their critical judgment, recognise the imminent crisis, and transfer the patient out to a better-resourced hospital, thus preventing an SAE. If this interpretation is correct, further research could explore if the staff at the larger regional/metropolitan hospitals utilise EWS to *identify* patient deterioration or an SAE, while staff at the smaller regional/rural hospitals use the EWS to *predict* patient deterioration.

The incidence of SAEs or clinical deterioration events is highly variable depending on the patient cohort, diagnosis, and facility resources, both in terms of equipment and staff skills (Rosero et al., 2020). In general hospital wards, the incidence of SAEs is often less than 1% of total admissions (Buist et al., 1999; Churpek et al., 2014), while in specialised high acuity areas, such as emergency departments or ICUs, the incidence increases to between 17% and 24% (Kumar et al., 2020; Viglino, L'her, Maltais, Maignan, & Lellouche, 2020). According to Romero-Brufau et al. (2015), many EWS efficiency studies do not consider the prevalence of the SAE or patient deterioration event, which will impact calculated EWS efficiency. We argue that the incidence of clinical deterioration events will undoubtedly affect the number of true and false alerts, and therefore, the staff workload. However, it should have little impact on the efficacy of the EWS as determined by statistical tests such as AUROC, sensitivity and specificity. Achieving a high EWS trigger threshold score is dependent on the level of vital sign derangement, the accuracy of patient monitoring and vital sign documentation, and the EWS trigger thresholds set (Grant & Crimmons, 2018). These factors are independent of the incidence of SAE in the patient cohort. Indirectly, the incidence of an SAE can impact the staff's ability to recognise patient deterioration. The more prevalent the incidence of clinical deterioration events, the more exposure the staff have to critically ill patients and, theoretically, the greater their proficiency at recognising deteriorating patients (Chua et al., 2019). The EWS is simply a tool to support clinical decision making. The EWSs are only as effective as the staff utilising them (Credland et al., 2018; Currey, Allen, & Jones, 2018). The prevalence of clinical deterioration events in a patient cohort should not influence the tool's effectiveness. Still, SAE prevalence may impact staff exposure to deteriorating patient situations and staff workload.

We have shown that by modifying the EWS trigger threshold, the EWS sensitivity can be increased, resulting in more true alerts. However, the specificity will decrease, increasing the number of false alarms. These false alarms increase operational costs by wasting clinical staff's time, and according to Kolic, Crane, McCartney, Perkins, and Taylor (2015), false

alerts should be a critical consideration in EWS efficiency. To illustrate this concept, NEWS has an emergency call trigger threshold score of ≥ 7, and in a recent study, an additional response tier was added involving a single trigger component with an EWS threshold score of three. This resulted in an improved sensitivity but a 30% increase in the number of alerts generated and no improvement in the EWS accuracy (Campbell et al., 2020). The current study has shown that the number of false alarms can be disproportionally greater when compared to true alarms and will increase as the incidence of clinical deterioration events decrease. For example, assuming an EWS sensitivity of 50% and a specificity is 98%, at a clinical deterioration event incidence of 10%, there will be 50 true alerts and 18 false alerts per 1000 patients (50% x 100 deterioration events per 1000 patients and 2% x 900 uneventful stays per 1000 patients). At a 1% incidence of clinical deterioration event, there will be five true alerts and 19.8 false alerts per 1000 patients (50% x 10 clinical deterioration events per 1000 patients and 2% x 990 uneventful stays per 1000 patients). The ratio of false to true alerts increases as the incidence of clinical deterioration events decrease. There is a risk that to widen the safety net, the EWS trigger scores are injudiciously lowered, thus increasing the sensitivity but reducing the specificity of the EWS. This would raise the number of true and false alarms, increasing the workload, risking alarm fatigue, and losing staff confidence in the EWS (Escobar & Dellinger, 2016; Grant & Crimmons, 2018; Roney et al., 2015). This would potentially increase the risk of failure to rescue, impacting patient safety (Johnston et al., 2015). There is also the added risk of developing a culture of complacency if the number of false alarms is high (Grant & Crimmons, 2018). False alarms can also frighten the patients and their families, resulting in heightened stress and patient dissatisfaction (Escobar & Dellinger, 2016). If the current research has added to the body of knowledge to help nurses recognise the benefits of using EWS for their intended purpose, and if it helps achieve assent, then this research has had a good outcome.

We envisage that this research can encourage staff to use EWS to support and not replace clinical judgement. As a precautionary note, it is particularly important that students

and novice nurses understand the purpose of EWSs. Novice nurses rely heavily on EWSs in their decision making (Spångfors et al., 2019). Therefore educators should emphasise the importance of utilising the EWS score as a decision-making support tool and not as a replacement for good clinical judgement. The EWS should be seen as one component of the clinical environment used to enhance, not dictate, clinical decision making (Forster et al., 2018; McGovern et al., 2020). Sound clinical judgement is acquired through clinical exposure and experience (Dresser, 2019). There is often a disconnect between physical assessment skills taught in the undergraduate curriculum and what is practised in the clinical setting (Chua et al., 2019). Novice nurses must be encouraged to not rely on an EWS score to guide their patient care but to monitor the patients carefully and learn to recognise the signs of deterioration. This requires active, direct involvement in ongoing patient care so that the nurse can recognise subtle changes in the patient's clinical condition (Chua et al., 2019). Exposure to acute clinical situations will help novice nurses develop the essential nursing intuition, which is the fundament on which the EWS 'worried' criterion is based (Odell, Victor, & Oliver, 2009).

In response to patient safety events, there is a tendency for health care organisations to eliminate contributing factors, introduce more policies and protocols, and add additional layers of control (Cunningham, 2018). Instead of enhancing patient safety, such additional controls can become counter-intuitive, restrict staff action and discourage flexibility (Cunningham, 2018). If EWSs are viewed as a patient safety measure to control staff response and behaviour rather than support clinical decision making, patients may inadvertently be put at risk. The implementation of protocols or systems will not protect patients but risks the loss of staff self-determination and situational awareness and the ability of staff to respond to changing environments (Cunningham, 2018). It is estimated that by 2025, Australia's demand for clinical nurses will greatly exceed supply (Health Workforce Australia, 2014). Since more than 80% of failures to respond to patient deterioration incidences are due to human factors (Australian Commission on Safety and Quality in Health

Care, 2012), there is a move towards automating patient monitoring and escalating patient care (Gerry et al., 2020; Paulson, Dummett, Scruth, & Reyes, 2020; Rihari-Thomas et al., 2019). There have been suggestions to develop complex automated algorithms that consider the rate of EWS score change and calculates the probable effect of a given treatment response (Escobar & Dellinger, 2016). The system would identify the deteriorating patient and define a suitable care escalation treatment (Escobar & Dellinger, 2016). Such systems would be feasible if appropriately abnormal vital signs precede deterioration events. Vital signs, while helpful, are still imperfect indicators of health status (Greenwood, Stirling, & Bull, 2018). The current study has shown that severely abnormal vital signs did not precede a reasonably large number of clinical deterioration events. These patients would remain undetected by an automated system, thus compromising their safety.

Electronic medical records and remote monitoring of patients have become increasingly popular, allowing clinical staff to simultaneously monitor numerous patients (Rosero et al., 2020). Automated predictive analysis can further increase the monitoring capacity and automate decision making by alerting staff to patient deterioration (Churpek et al., 2014; Rosero et al., 2020). Automation can compensate for poor staff compliance and inadequate decision making (Bonnici, Gerry, Wong, Knight, & Watkinson, 2016). A comparative study of electronically versus manually activated MET alerts showed that the patient outcomes were significantly better when electronically generated alerts was used (Huh et al., 2014). However, patient deterioration is often multifactorial, with only 85% of SAEs preceded by abnormal vital signs that an automated EWS system will detect (Rosero et al., 2020). The remaining 15% of the deteriorating patients are at risk of remaining undetected if staff rely on automated systems. This would include those patients whose care is escalated due to nursing intuition that something is amiss (De Bie et al., 2019). The adoption of automation introduces the risk that staff become tempted to watch the monitors rather than the patients, especially when workloads increase. If this occurs, patients may be put at risk, and there is the potential for staff deskilling as they develop a reliance on

automation for decision making (Grant, 2019; Rihari-Thomas et al., 2019). Nurse-driven bedside patient monitoring is critical in reducing SAEs (Rosero et al., 2020). Even in a non-automated situation, if EWSs are used to replace clinical decision making, there is a possibility that the EWS score will replace nursing vigilance and sound clinical judgement to the detriment of the patient. This reinforces the need for ongoing staff support and education. Unfortunately, education alone cannot ensure understanding, compliance, changes in clinical practice or improve critical thinking (Rihari-Thomas et al., 2019). If the staff view the EWS as just another task to be completed without appreciating the tool's objective, then the EWS has failed to achieve its intended purpose. Monitoring patient's vital signs is often viewed as a low priority task and delegated to the less skilled staff (Kellett & Sebat, 2017). It is essential that the significance of vital sign monitoring in identifying deteriorating patients be reinforced through ongoing education tailored to the clinical setting and facility resources. Simulation training is an effective means of providing staff exposure to these infrequent events (Chung et al., 2018; Cooper et al., 2013). The appropriate use of EWSs must be encouraged at all staffing levels if patient safety is to be addressed.

Although the current study devotes much time to the validation of EWSs, its principal aim is not to debate the merits of EWSs or their effect on patient outcomes. This study merely compares various EWSs to help poorly resourced facilities make informed decisions when selecting EWSs for implementation. The study also suggests judicious changes in the EWS trigger thresholds to improve the efficiency of the EWSs emphasising heart rate and supplementary oxygen supply since these are relatively good predictors of patient deterioration for the target patient cohort. The information generated in the current study will help to bridge the gap in knowledge between the well-resourced metropolitan and more poorly resourced regional/rural facilities. The study objectives were achieved; a recommendation was made regarding the EWS class best suited for poorly resourced private regional hospitals and how such EWS trigger thresholds could be judiciously altered to maximise their patient deterioration detection potential.

Conclusion

The class of EWSs best suited for use in small regional private hospitals was identified as an aggregated weighted EWS, Compass. Through judicious changes to the vital sign threshold ranges, introducing a graded weighted scale for supplementary oxygen, and converting the now modified Compass to a combination EWS, a new EWS called MOD-6 was developed. MOD-6 was 20% more effective than Compass when applied to patients from the small regional private hospitals. When MOD-6 was validated using independent patient cohorts, its efficacy remained good but not markedly superior to Compass, NEWS or Q-ADDS. This confirms the importance of testing the EWS for the intended target patient cohort before implementation.

This study has shown that vital signs are appropriate indicators of patient deterioration. Patients who suffer deterioration events have more severely abnormal vital signs than patients who have an uneventful hospital stay. The evidence suggests that the nursing staff are aware of the importance of vital sign monitoring as indicators of patient deterioration since these patients were monitored more frequently than those not at risk of deterioration. Also, patients from small regional rural contexts that require more than 3L/min of supplementary oxygen and/or experience tachycardiac events are particularly at risk of unexpected clinical deterioration. This information can serve to inform future practice, enhance patient safety and guide nursing education.

The various EWSs tested in the current study were found to have relatively low sensitivities but excellent specificities, enabling them to effectively identify patients not at risk of deterioration. This is valuable information in guiding decision making regarding the distribution of facility resources. Furthermore, the study has shown that the various EWSs appear more effective, having higher sensitivities in well-resourced regional/metropolitan hospitals than in poorly resourced regional/rural hospitals. Although low sensitivity is usually interpreted as EWS inefficiency, we have offered an alternative interpretation. Staff at small,

poorly resourced regional/rural hospitals appear to be utilising the EWS as intended, to support clinical decision making and prevent an SAE eventuating. While in the well resourced regional/metropolitan hospitals, the staff appear to use the EWS to guide their nursing care. Thus, the differences in EWS efficiency at the well-resourced versus the poorly resourced hospitals appear to be related to how the EWSs are utilised in these facilities. Based on the results of this study, staff in smaller regional rural facilities potentially use EWSs to help staff identity clinical deterioration and prevent SAE. We believe that the results of this study will serve to inform poorly resourced regional/rural medical facilities when selecting an EWS for implementation.

Theoretical Contributions of this Study

This study has demonstrated how Gearing's nine steps framework can successfully be applied when developing a retrospective chart audit to study the efficiency of EWSs. Each of Gearing's nine steps was followed to ensure the rigour and validity of this retrospective study (Gearing, Mian, Barber, & Ickowicz, 2006). The current study is one of the first quantitative studies comparing and validating EWS efficiencies for small, poorly resourced regional private hospitals in Australia. Most EWS studies are conducted in large tertiary hospitals for logistical reasons, leaving a distinct gap in knowledge in the small regional/rural hospitals. We expect that the current research will contribute to filling this knowledge gap. This study has shown the feasibility of conducting data collection in small, poorly resourced facilities. Despite the logistical difficulties and time-intensive activities of accessing patient charts, retrieving and manually entering data, such research can be a fruitful and rewarding experience. In facilitating this research, a digital tool was developed using Microsoft Excel, which enabled the simultaneous comparison of numerous EWSs from three different classes of EWSs. This tool was later used in a similar independent study involving data collected from 13 study sites (Dwyer et al., 2019) and, with minor adaptions, can be applied to any analogous studies.

Many of the EWSs included in this study have not previously been validated, either in rural or well-resourced urban hospitals. Significantly, this is one of the only studies that compare all three classes of EWSs. Several previous studies have compared two classes of EWSs, single trigger and aggregated weighted systems (Churpek, Yuen, & Edelson, 2013b; Gao et al., 2007; Jarvis et al., 2015; McNeill & Bryden, 2013), but to our knowledge, none have included all three classes of EWSs for an Australian cohort. It is hoped that by including all three classes of EWSs and applying them to a little-researched patient cohort, small regional/rural Australian hospitals will be better informed when choosing an EWS for implementation. Since EWSs were not in use for much of the data collecting period, the tool's efficacy is being evaluated in the absence of response bias resulting from the EWS escalation protocol.

Most EWS efficiency studies emphasise AUROC and sensitivity as efficiency measures (Gerry et al., 2020). The current study has followed this approach but has also utilised specificity to calculate the number of false alerts generated by the EWSs.
Few previous studies have considered the number of alerts generated by the EWSs. We have shown how specificity and sensitivity can be used to calculate the ratio of false to true alerts for a given patient cohort and how this directly impacts the EWS efficiency and the staff workload. We have also shown how the ratio of false to true alerts increases as the incidence of clinical deterioration events decrease for a given EWS sensitivity and specificity. Currently, EWSs are generally regarded as successful if they trigger many true alerts (Rihari-Thomas et al., 2019). A few recent EWS studies have considered the number of true and false alerts (Sutherland et al., 2020), or have focused on reducing the number of unnecessary alerts (Williams, Cardona-Morrell, Stevens, Bey, & Smith Glasgow, 2017). Basing EWS efficiency on the number of alerts or the specificity of the tool is a relatively novel approach. The current study has also offered an alternative interpretation of the EWS sensitivity. If viewed purely from a statistical perspective, a low sensitivity indicates an ineffective EWS. However, if consideration is given to the facility resourcing and

geographical location, low sensitivity may be interpreted as an effective EWS. If EWSs are used to predict patient deterioration, corrective action is taken, and an SAE is avoided, the sensitivity would be low, but the EWS would be highly effective. To the best of our knowledge, that interpretation of EWS sensitivity has not previously been suggested.

By utilising patient data from three independent cohorts, this study has provided evidence that the EWSs are utilised differently in the large regional/metropolitan, compared to the small regional/rural hospitals. We suggest that the EWS appears to be used to predict deterioration events in the smaller regional/rural hospitals, with staff responding early and preventing SAEs, thus a proactive response. Staff actions appear to be mainly guided by the EWS protocol in the larger well-resourced hospitals, thus following a more reactive response to patient deterioration. This study has shown that a low EWS sensitivity may be interpreted as a proactive response to patient deterioration under these circumstances. This could potentially have a profound influence on how EWS sensitivity is interpreted in future research.

This study has confirmed that vital signs are good but fallible indicators of patient deterioration. Also, that tachycardiac patients and those on supplementary oxygen are particularly vulnerable and should be monitored closely. This contributes to the growing body of evidence suggesting that the need for supplementary oxygen is a good indicator of clinical decline (Luís & Nunes, 2018; Watkinson et al., 2018). The inclusion of supplementary oxygen flowrate is gaining prominence as an indicator of patient deterioration (Royal College of Physicians, 2017; Skov et al., 2020). We have also shown the feasibility of utilising various methods of developing new EWSs and have added a graduated weighted score for supplementary oxygen flowrate as an EWS contributing variable. As a result, we have produced a new EWS, MOD-6, which is 20% more effective at identifying high-risk patients than the existing EWS, Compass, for the target cohort. As suggested in previous studies, this study has also demonstrated that any new EWS must be tested for the target cohort before implementation.

Practical Applications and Recommendations

This study has shown that, given the success of the newly developed EWS, MOD-6, a combination EWS should be considered for implementation in small regional private facilities. If the vital sign trigger ranges are altered, it should be done judiciously to prevent high numbers of false alerts. It is recommended that MOD-6 be tested in other smaller regional/rural facilities. Testing of the new EWS should be executed with the active participation of the front-line clinical staff. Active participation helps to achieve assent, with staff proactively recognising the need for change and the researchers working with the staff in the staffs' environment to achieve this change (Tourgeman-Bashkin et al., 2013). If the nursing staff are actively involved in testing the new EWS, it will promote staff ownership of the project and encourage participation in finding a feasible solution (Harrington et al., 2013). During the testing phase, the number of alerts should be recorded and compared to the incidence of deterioration events. The definition of clinical deterioration events or SAEs, the measurable outcomes, should be carefully considered. Since the EWS is intended to help staff identify patient deterioration early and prevent SAEs (Spångfors et al., 2019), it is suggested that emphasis should be placed on unplanned transferrals to a higher level of care and unexpected mortality. Unexpected mortality would indicate EWS failure, that is, failure to rescue (Rosero et al., 2020). Obtaining statistics on the incidence of failure to rescue would provide insight into patient safety issues requiring addressing (Rosero et al., 2020). Capturing both the number of alerts and SAEs or clinical deterioration events will indicate the number of true and false alerts generated by the EWS, which will have direct implications for staff workload and possibly staff confidence in the EWS. It is most important to involve the organisation’s management in the testing of any new EWS. The management support will help facilitate change in the wards/hospital involved in the research project and possibly in all hospitals within the organisation. We believe that the current study and the proposed future testing of new EWSs will contribute towards achieving a standardised EWS for all small private regional hospitals within the target organisation.

Although this study focused on the efficiency of the EWS, the afferent limb, EWSs cannot be successfully employed without due consideration to the staff response, the efferent limb of the system. In these small, poorly resourced regional/rural hospitals, given the geographical distance from specialised care, the EWSs must be used for their intended purpose, that is, to identify clinical deterioration early and prevent SAEs (Fleet et al., 2020; Spångfors et al., 2019). The staff must make good use of clinical judgement by requesting urgent medical assistance before an EWS emergency call threshold score is reached. Activating an emergency alert or requesting urgent medical review without the support of a high EWS score requires courage and confidence. This can be achieved with the support of peers, clinician leaders and management (Rihari-Thomas et al., 2019). We have shown that the number of false alerts can increase as the incidence of clinical deterioration events decreases. If false alerts are common and clinical deterioration events infrequent, staff risk losing confidence in the EWS and potentially deskilling in the absence of exposure to critical situations (Chua & Liaw, 2015; Rihari-Thomas et al., 2019). Therefore, it is recommended that ongoing education be offered to the clinical staff concerning deteriorating patients and the appropriate use of the EWS as a clinical judgement support tool. It is particularly important that the novice nurses who may lack the experience in recognising a deteriorating patient be reminded of the intended purpose of the EWS. If EWSs are to be successfully employed as an SAE prevention strategy, they must be supported at all levels of the organisation. Executive assent is necessary if the implementation and correct application of any system is to be successful (Rihari-Thomas et al., 2019). The drivers must come from the top down, and if management views the EWS as an auditing tool to enforce compliance, it is likely to meet with staff resistance. It is essential that all staffing levels are provided with adequate evidence of the EWS efficiency to ensure staff acceptance and compliance.

The study has shown that the vital signs are good indicators of the patient's clinical state. Most deteriorating patients show multiple sets of abnormal vital signs before the SAE. In our cohort of patients from regional private facilities, we found that patients with

tachycardia and those requiring supplementary oxygen of more than 3 L/min are at high risk of deterioration events. It is recommended that nursing staff be made aware of the importance of vital sign monitoring and that the correlation between clinical deterioration events and tachycardia and/or the need for supplementary oxygen be emphasised. Should the small regional/rural hospitals consider altering an existing EWS, it is recommended that a higher weighting be given to heart rates greater than 100 beats/min and to the need for supplementary oxygen at a flow rate greater than 3 L/min. Since the current research was conducted in the local context, it is hoping that the evidence produced can be used at all levels of the organisation to encourage compliance.

This study has provided good supporting evidence of the efficacy of EWSs in identifying patients at risk of deterioration. The implementation of either an aggregated weighted or, preferably, a combination EWS is recommended. If the vital sign trigger thresholds are to be altered, it should be done judiciously to prevent high numbers of false alerts. We have recommended that any new EWS be tested at the target facility before implementation. The nursing staff be active participants in the testing phase to claim ownership of the research. Also, nursing staff should be aware that EWSs are intended to support clinical decision-making and not substitute clinical judgement. Where appropriate, nurses should be encouraged to request urgent medical assistance in the absence of high EWS scores and know that in doing so, they will be supported by management. Furthermore, it is believed that this study will encourage regional/rural nursing research and serve to highlight the impact that such research can have on patient safety in these small, poorly resourced facilities.

Study Limitations

Although the small sample size and the cohort of subcritical patients were regarded as limiting factors, the data utilised in the study is representative of the regional/rural population, and the findings are relevant to this patient context. This is the nature of the

research data available at these small regional medical facilities (Fleet et al., 2020). The study cohort consisted mainly of geriatric patients, potentially prone to inevitable deterioration events. Although this leads to some problems in generalisation to a broader patient population, it is representative of the hospital admission demographics in regional/rural Australia. Ideally, it would have been appropriate to increase the number of study sites to obtain more patient diversity and a more extensive study cohort. For logistical reasons, Cohort A, the dominant patient cohort in the study, was derived from only two private hospitals as all data had to be manually extracted and entered by the researcher.

The commonly adopted statistical test to determine the EWS efficacy is the AUROC. Using the AUROC is appropriate if the intrinsic prognostic information (data used to calculate the AUROC) is robust and the outcomes measured are well defined (Altman & Royston, 2000; Fang, Lim, & Balakrishnan, 2020). With EWSs, the prognostic information equates to the patient vital sign data, which is not always complete or reliably documented, and the outcomes measured are often fluid (Al-Moteri, Cooper, Symmons, & Plummer, 2020; Tarassenko et al., 2011). These limitations applied to the current study. Although all efforts were made to ensure the quality of the data used, poor documentation limited the robustness of the findings. Incomplete data is a recognised limitation of retrospective chart audit studies (Dworkin, 1987; Gearing et al., 2006; Nakitende et al., 2020; Pan, Fergusson, Schweitzer, & Hebert, 2005). In the current study, to compensate for this limitation, all sets of documented vital signs for the cohort of patients from the small private regional hospitals were collected over 72 hours and were included in the quantitative analyses. The large volume of data collected minimised the risk of missing variables in the data set. We recognise that this is a limitation of the study.

Furthermore, several different vital sign observation charts were used over the data collection period for the cohort of patients from the small regional private hospitals. In the latter part of the data collection period, various EWSs were introduced. This variation in observation charts could have impacted vital sign data documentation and the nursing

response, thus augmenting the heterogeneity of the data collected. The limited number of index patients and the fluidity of the unexpected clinical deterioration event categories necessitated the grouping of the various deterioration events for this cohort. When the EWSs were tested using only the unexpected clinical deterioration event category of unexpected deaths, an irrefutable category, the resulting pattern of EWS efficiencies remained mostly unchanged. This helps to justify the rationale underlying the decision to combine the unexpected clinical deterioration event categories. Using different patient outcomes to define unexpected clinical deterioration events in the three patient cohorts is a limitation of the study. This could have impacted the outcomes of the study (Altman & Royston, 2000).
For Cohort A, patients from the regional private hospitals, the patient notes and records were carefully scrutinised to ensure the correct interpretation of the nature of the clinical deterioration event. For Cohorts B and C, patients from the public hospitals, all patient transfers and Medical Emergency Team activations are clearly documented.

Being a quantitative study design lends itself to exploring the *what/which* question but not the *why*. The current study has, amongst others, ascertained which class of EWS best identifies patient deterioration in poorly resourced facilities but has failed to explore the human aspect of EWS efficiency, the staff response to the deteriorating patient. Staff assent, compliance, and interpretation of the EWSs scores are significant contributing factors in EWS efficiency (Rosero et al., 2020; Tourgeman-Bashkin et al., 2013). Although it is beyond the scope of this study to explore how the EWSs are utilised on the wards, it warrants further study and is a limitation of this thesis. Much of this study was undertaken using data from two hospitals belonging to one regional private medical organisation. While it is hoped that the findings will be beneficial to other similar facilities, the local context may render them not directly applicable.

Future Research

In the quest to identify the EWS best suited for use in small, poorly resourced regional/rural facilities, this study has perhaps produced more questions than answers. The new candidate EWS, MOD-6, should be tested in the target medical facilities to determine its practical application and validity. If the pilot trial is successful, the adoption of MOD-6 should be considered as a standardised EWS for all the small regional hospitals within the organisation. A before-and-after study should be considered to determine whether the new EWS can reduce the incidence of SAEs or unexpected clinical deterioration events. This study could also investigate whether the implementation of EWSs has improved the frequency and completeness of vital signs monitoring. Given the relatively small cohort of patients in these private regional facilities and the time limitations, it may be prudent to expand the study to include multiple facilities. Logistically, this may prove to be both time-intensive and expensive.

A quantitative study only tells half of the story. The efficiency of any EWS is dependent on staff compliance and attitudes. Although several metropolitan and a few regional studies have focused on staff attitudes and compliance to EWSs, none have been conducted for the regional private hospital sector. Given the differences in management styles, resourcing, staff mix and staff training models between the private and public hospital sectors, it would be of great interest to conduct a qualitative study investigating staff attitudes, understanding and use of the scoring system in the private regional/rural hospitals.

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Appendix A—CQU Confirmation of Candidature

Research Division
Bldg. 32 Level 2
CQUniversity
North Rockhampton QLD 4702
☎ (07) 4923 2228
rhd-admin@cqu.edu.au

26 September 2016

Dr Marie D. Le Lagadec
11 Bargara Lakes Drive
Bargara QLD 4670

Dear Dr Le Lagadec,

Your application for Confirmation of Candidature, and the recommendation of the Confirmation Panel have been received in the Research Division.

This recommendation has been approved by the Research Higher Degrees Committee of CQUniversity.

Please find attached a copy of your Candidature Budget, as approved by this Committee. As noted in the budget, expenditure in excess of the maximum funding approved by CQUniversity is the responsibility of the Candidate. Guidelines to access Candidate Support Funds and Candidate Travel Support are provided on the Research Division Moodle site.

Please note that use of Candidate Support Funds and Candidate Travel Support is subject to CQUniversity policies and procedures, which may require approval of individual expenditure from the Deputy Vice-Chancellor Research and/or the Deputy Vice Chancellor Finance. You are encouraged to liaise with Natasha Toon in the Research Division with regards to individual purchases and bookings, well in advance of the requirements for the expenditure to be incurred.

ORCID ID
Now that you have been admitted to full candidature you are encouraged to register for an ORCID ID. The process is very fast, and will take just a few minutes of your time! To register for an ORCID ID please complete the form at https://orcid.org/register

ORCID is a unique identifier code for authors. The ORCID ID overcomes issues with current author identifiers such as name changes (due to marriage), cultural differences in name order, and inconsistent use of full names and initials. An ORCID ID will assist you and the University to efficiently trace and distinguish **your academic publications** from those of others. An increasing number of Australian and international journals and funding agencies are accepting ORCID IDs as a preferred identifier for authors and researchers. Once you have registered for an ID please email rhd-admin@cqu.edu.au advising your ID number, so that it can be added to your Student File.

It is with pleasure that I advise you of your admission to full PhD Candidature. Best wishes for your ongoing program of research and study.

Yours sincerely

Associate Professor Susan Kinnear
Dean of Graduate Studies
Chair of Research Higher Degrees Committee

Appendix B—Between-the-Flags (BTF) EWS

NSW Health

FAMILY NAME | MRN
GIVEN NAME | ☐ MALE ☐ FEMALE
D.O.B. ____/____/____ | M.O.
ADDRESS

STANDARD ADULT GENERAL OBSERVATION CHART

☐ Altered Calling Criteria | LOCATION

ALL OBSERVATIONS MUST BE GRAPHED | COMPLETE ALL DETAILS OR AFFIX PATIENT LABEL HERE

Date / Time

AIRWAY/BREATHING
- Respiratory Rate: 35, 30, 25, 20, 15, 10, 5
- SpO2%: 100, 95, 90, 85
- Oxygen: O2 Lpm / Device

Key: RA = Room Air, NP = Nasal Prongs, FM = Simple facemask, NRB = non Re-breather, VM = Venturi Mask

CIRCULATION
- Blood Pressure (mmHg) SBP ≥ trigger: 230, 220, 210, 200, 190, 180, 170, 160, 150, 140, 130, 120, 110, 100, 90, 80, 70, 60, 50, 40
- Heart Rate *: Rhythm; 160, 150, 140, 130, 120, 110, 100, 90, 80, 70, 60, 50, 40

DISABILITY
- Neurological: A, V, P, U

Enter appropriate letter. A = Alert, V = Rousable by voice (conduct GCS), P = Rousable only by pain (conduct GCS), U = Unresponsive

Initials

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NSW Health

FAMILY NAME | MRN
GIVEN NAME | ☐ MALE ☐ FEMALE
D.O.B. ____/____/____ | M.O.
ADDRESS

STANDARD ADULT GENERAL OBSERVATION CHART

☐ Altered Calling Criteria | LOCATION

ALL OBSERVATIONS MUST BE GRAPHED | COMPLETE ALL DETAILS OR AFFIX PATIENT LABEL HERE

Date / Time

EXPOSURE
- Temperature (°C) *: 41, 40.5, 40, 39.5, 39, 38.5, 38, 37.5, 37, 36.5, 36, 35.5, 35, 34.5, 34

Pain
Assess pain level at rest and with movement. Enter R for at rest, M for movement
- Severe (7-10)
- Moderate (4-6)
- Mild (1-3)
- Nil

Initials

Blood Glucose: Date, Time, BGL

Bowels: Date

Weight: Date, ☐ Daily

Urinalysis: Date, Time, SG, pH, Leuk, Blood, Nitrite, Ketones, Bilirubin, U/BM, Protein, Glucose

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Appendix C—Adult Observation and Response Chart v9 (ARC)

Date																				
Time																				
Respiratory Rate (breaths / min)	Write > 35																			Write > 35
	30-34																			30-34
	25-29																			25-29
	20-24																			20-24
	15-19																			15-19
	10-14																			10-14
If respiratory rate > 35 or < 4, write value in box	5-9																			5-9
	Write < 4																			Write < 4
O_2 Saturation (%)	98-100																			98-100
	95-97																			95-97
	93-94																			93-94
	90-92																			90-92
	87-89																			87-89
If O_2 saturation < 84, write value in box	85-86																			85-86
	Write < 84																			Write < 84
O_2 Flow Rate (L / min)	> 13																			> 13
	10-12																			10-12
	7-9																			7-9
	4-6																			4-6
	< 3																			< 3
Blood Pressure (mmHg)	Write > 200																			Write > 200
	190s																			190s
	180s																			180s
	170s																			170s
	160s																			160s
	150s																			150s
	140s																			140s
	130s																			130s
Score systolic BP	120s																			120s
	110s																			110s
	100s																			100s
If systolic BP > 200, write value in box	90s																			90s
	80s																			80s
	70s																			70s
	60s																			60s
	50s																			50s
	40s																			40s
Heart Rate (beats / min)	Write > 140																			Write > 140
	130s																			130s
	120s																			120s
	110s																			110s
	100s																			100s
	90s																			90s
	80s																			80s
	70s																			70s
	60s																			60s
	50s																			50s
If heart rate > 140 or < 30, write value in box	40s																			40s
	Write < 30s																			Write < 30s
Temperature (°C)	Write > 39.1																			Write > 39.1
	38.5-39.0																			38.5-39.0
	38.0-38.4																			38.0-38.4
	37.5-37.9																			37.5-37.9
	37.0-37.4																			37.0-37.4
	36.5-36.9																			36.5-36.9
	36.0-36.4																			36.0-36.4
If temperature > 39.1 or < 35.4, write value in box	35.5-35.9																			35.5-35.9
	Write < 35.4																			Write < 35.4
Consciousness If clinically necessary, wake patient to assess and score	Alert																			Alert
	To voice																			To voice
	To pain																			To pain
	Unresp.																			Unresp.
Pain Score None (0) - Worst (10)	Write																			Write
Intervention	E.g. 'a'																			E.g. 'a'

Surname: _____

Given Names: _____

DOB: _____ / _____ / _____ Sex: M / F

UR No.: _____

(Affix Patient ID Label Here)

EMERGENCY CALL

Response criteria:	Action required:
• **Any observation in the purple area** • **Cardiac or respiratory arrest** • **Seizure / sudden loss of consciousness** • You are worried about the patient but they do not fit the above criteria	• **Activate Emergency Response (call button or phone 400 / 409 as required)** • **Commence emergency procedures** • **Notify Admitting Medical Officer as soon as possible (must be within 15 minutes of event)**

MEDICAL OFFICER REVIEW

Response criteria:	Action required:
• **Any observation in the red area** • You are worried about the patient but they do not fit the above criteria	• Check Modifications section • Notify Team Leader on duty • Contact Admitting Medical Officer as soon as possible (utilising SHARED format) • Medical Officer to review patient within 30 minutes • Document all actions

TEAM LEADER REVIEW

Response criteria:	Action required:
• **Any observation in the orange area** • You are worried about the patient but they do not fit the above criteria	• Check Modifications section • Team Leader to review patient within 30 minutes • Contact Admitting Medical Officer if concerns (utilising SHARED format) • Document all actions

INCREASED SURVEILLANCE

Response criteria:	Action required:
• **Any observation in the yellow area** • You are worried about the patient but they do not fit the above criteria • The patient or relative expresses concern	• Check Modifications section • Inform Senior Nurse • Consider IV access • Increase frequency of observations to hourly until resolved / escalated

Appendix D—Adult Observation and Response Chart 2 v2 (ARC_2)

Date																			
Time																			
Respiratory Rate (breaths / min)	Write ≥ 35																		Write ≥ 35
	30–34																		30–34
	25–29																		25–29
	20–24																		20–24
	15–19																		15–19
	10–14																		10–14
	5–9																		5–9
	≤ 4																		≤ 4
O_2 Saturation (%)	98–100																		98–100
	95–97																		95–97
	93–94																		93–94
	90–92																		90–92
	87–89																		87–89
	85–86																		85–86
	Write ≤ 84																		Write ≤ 84
O_2 Flow Rate (L / min)	≥ 13																		≥ 13
	10–12																		10–12
	7–9																		7–9
	4–6																		4–6
	≤ 3																		≤ 3
Blood Pressure (mmHg) ↑↓ Score systolic BP. If systolic BP ≥ 200, write value in box	Write ≥ 200																		Write ≥ 200
	190s																		190s
	180s																		180s
	170s																		170s
	160s																		160s
	150s																		150s
	140s																		140s
	130s																		130s
	120s																		120s
	110s																		110s
	100s																		100s
	90s																		90s
	80s																		80s
	70s																		70s
	60s																		60s
	50s																		50s
	40s																		40s
	30s																		30s
Heart Rate (beats / min). If heart rate ≥ 140, write value in box	Write ≥ 140																		Write ≥ 140
	130s																		130s
	120s																		120s
	110s																		110s
	100s																		100s
	90s																		90s
	80s																		80s
	70s																		70s
	60s																		60s
	50s																		50s
	40s																		40s
	30s																		30s
Temperature (°C)	Write ≥ 39.1																		Write ≥ 39.1
	38.5-39.0																		38.5-39.0
	38.0–38.4																		38.0–38.4
	37.5–37.9																		37.5–37.9
	37.0–37.4																		37.0–37.4
	36.5–36.9																		36.5–36.9
	36.0–36.4																		36.0–36.4
	35.5–35.9																		35.5–35.9
	Write ≤ 35.4																		Write ≤ 35.4
Consciousness If clinically necessary, wake patient to assess and score	Alert																		Alert
	To Voice																		To Voice
	To Pain																		To Pain
	Unresp.																		Unresp.
Pain Score None (0) – Worst (10)	Write																		Write
Intervention	E.g. 'a'																		E.g. 'a'

UR Number: _____

Family name: _____

Given names: _____

Date of birth: __/__/__ Sex: ☐M ☐F

(Affix patient identification label here)

DRAFT - NOT FOR USE

Emergency Call

Response Criteria	Actions Required
• **Any observation is in a purple area** • You are worried about the patient but they do not fit the above criteria	• Place Emergency call • Begin initial life support interventions • Advanced life support provider to attend patient immediately

Clinical Review

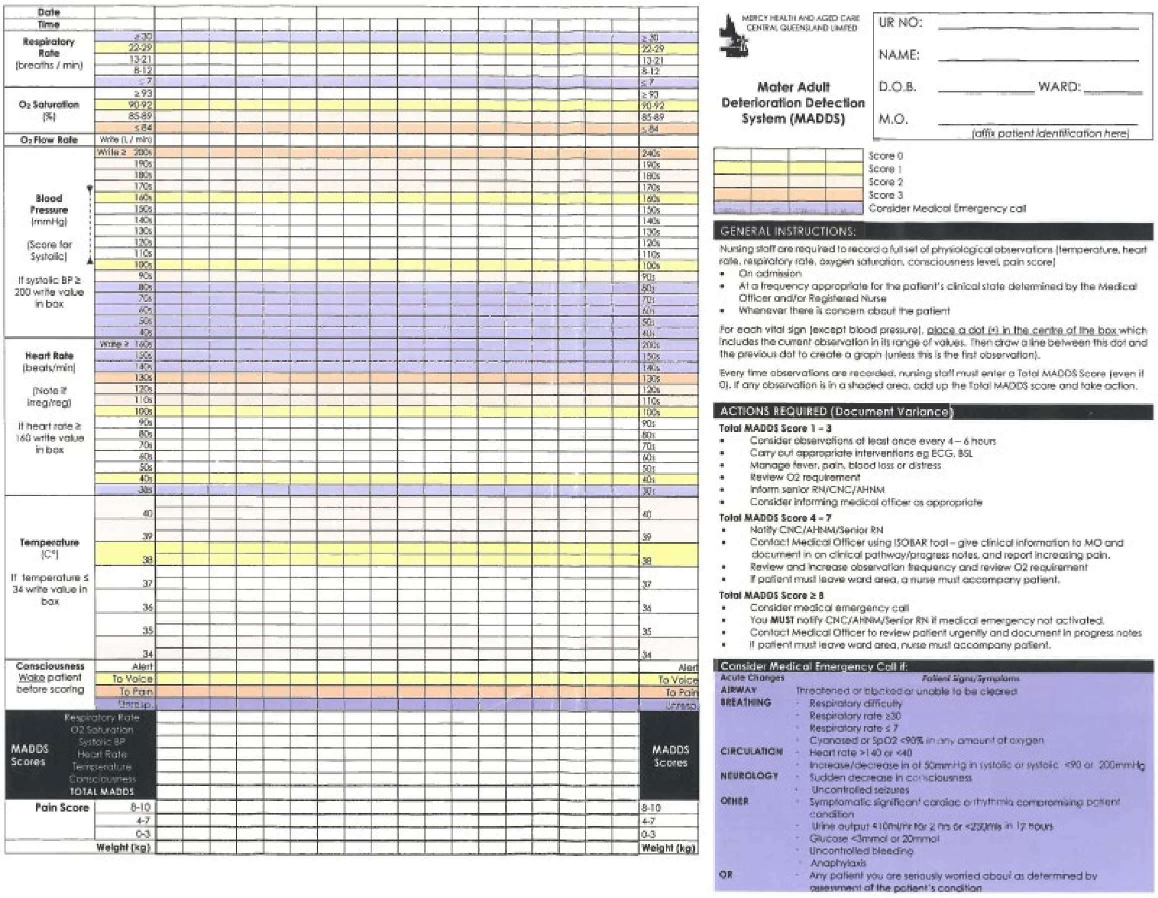
Response Criteria	Actions Required
• **Any observation is in an orange area** • You are worried about the patient but they do not fit the above criteria	• Senior medical officer review (registrar or above) within 30 minutes • Request review, and note on the back of this form • Increase frequency of observations *[specify frequency]*

These actions are generic and must be adapted to reflect local circumstances
Stakeholders only

General Instructions

- You must record appropriate observations:
  - On admission
  - At a frequency appropriate for the patient's clinical state.
- You must record a full set of observations:
  - If the patient is deteriorating or an observation is in a shaded area
  - Whenever you are concerned about the patient.
- When graphing observations, place a dot (•) in the centre of the box which includes the current observation in its range of values and connect it to the previous dot with a straight line. For blood pressure, use the symbol indicated on the chart.
- Whenever an observation falls within a shaded area, you must initiate the actions required for that colour, unless a modification has been made (see overleaf).
- If observations fall within both purple and orange coloured areas for the same time period, the actions required for the purple area apply.

Appendix E—Mater Adult Deterioration Detection System (MADDS)



Observation	Range
Date	
Time	
Respiratory Rate (breaths / min)	≥30
	22-29
	13-21
	8-12
	≤7
O2 Saturation (%)	≥93
	90-92
	85-89
	≤84
O2 Flow Rate	Write (L / min)
Blood Pressure (mmHg) (Score for Systolic) If systolic BP ≥ 200 write value in box	Write ≥ 200s
	190s
	180s
	170s
	160s
	150s
	140s
	130s
	120s
	110s
	100s
	90s
	80s
	70s
	60s
	50s
	40s
Heart Rate (beats/min) (Note if irreg/reg) If heart rate ≥ 160 write value in box	Write ≥ 160s
	150s
	140s
	130s
	120s
	110s
	100s
	90s
	80s
	70s
	60s
	50s
	40s
	30s
Temperature (C°) If temperature ≤ 34 write value in box	40
	39
	38
	37
	36
	35
	34
Consciousness Wake patient before scoring	Alert
	To Voice
	To Pain
	Unresp.
MADDS Scores	Respiratory Rate
	O2 Saturation
	Systolic BP
	Heart Rate
	Temperature
	Consciousness
	TOTAL MADDS
Pain Score	8-10
	4-7
	0-3
Weight (kg)	

MERCY HEALTH AND AGED CARE CENTRAL QUEENSLAND LIMITED

Mater Adult Deterioration Detection System (MADDS)

UR NO: ____________

NAME: ____________

D.O.B. ____________ WARD: ________

M.O. ____________

(affix patient identification here)

Score 0
Score 1
Score 2
Score 3
Consider Medical Emergency call

GENERAL INSTRUCTIONS:

Nursing staff are required to record a full set of physiological observations (temperature, heart rate, respiratory rate, oxygen saturation, consciousness level, pain score)

- On admission
- At a frequency appropriate for the patient's clinical state determined by the Medical Officer and/or Registered Nurse
- Whenever there is concern about the patient

For each vital sign (except blood pressure), place a dot (•) in the centre of the box which includes the current observation in its range of values. Then draw a line between this dot and the previous dot to create a graph (unless this is the first observation).

Every time observations are recorded, nursing staff must enter a Total MADDS Score (even if 0). If any observation is in a shaded area, add up the Total MADDS score and take action.

ACTIONS REQUIRED (Document Variance)

Total MADDS Score 1 – 3

- Consider observations at least once every 4 – 6 hours
- Carry out appropriate interventions eg ECG, BSL
- Manage fever, pain, blood loss or distress
- Review O2 requirement
- Inform senior RN/CNC/AHNM
- Consider informing medical officer as appropriate

Total MADDS Score 4 – 7

- Notify CNC/AHNM/Senior RN
- Contact Medical Officer using ISOBAR tool – give clinical information to MO and document in on clinical pathway/progress notes, and report increasing pain.
- Review and increase observation frequency and review O2 requirement
- If patient must leave ward area, a nurse must accompany patient.

Total MADDS Score ≥ 8

- Consider medical emergency call
- You **MUST** notify CNC/AHNM/Senior RN if medical emergency not activated.
- Contact Medical Officer to review patient urgently and document in progress notes
- If patient must leave ward area, nurse must accompany patient.

Consider Medical Emergency Call if:

Acute Changes	*Patient Signs/Symptoms*
AIRWAY	Threatened or blocked or unable to be cleared
BREATHING	- Respiratory difficulty
	- Respiratory rate ≥30
	- Respiratory rate ≤ 7
	- Cyanosed or SpO2 <90% in any amount of oxygen
CIRCULATION	- Heart rate >140 or <40
	- Increase/decrease in of 50mmHg in systolic or systolic <90 or 200mmHg
NEUROLOGY	- Sudden decrease in consciousness
	- Uncontrolled seizures
OTHER	- Symptomatic significant cardiac arrhythmia compromising patient condition
	- Urine output <10ml/hr for 2 hrs or <250mls in 12 hours
	- Glucose <3mmol or 20mmol
	- Uncontrolled bleeding
	- Anaphylaxis
OR	- Any patient you are seriously worried about as determined by assessment of the patient's condition

Appendix F—Mater Adult Deterioration Detection System v2 (MADDS$_2$)

Date Time														
Respiratory Rate (breaths / min)	Write ≥ 35													Write ≥ 35
	26–34													26–34
	25													25
	13–24													13–24
	8–12													8–12
If respiratory rate ≥ 35 or ≤ 7, write value in box	Write ≤ 7													Write ≤ 7
O_2 Saturation (%)	98–100													≥ 98
	94–97													95–97
	91–93													93–94
	87–90													90–92
	85–86													85–86
If O_2 saturation ≤ 84, write value in box	Write ≤ 84													Write ≤ 84
O_2 Flow Rate (L / min)	Write L / min													Write L / min
Blood Pressure (mmHg)	Write ≥ 200													Write ≥ 200
	190s													190s
	180s													180s
	170s													170s
	160s													160s
	150s													150s
	140s													140s
	130s													130s
	120s													120s
	110s													110s
	100s													100s
Score systolic BP	90s													90s
	80s													80s
	70s													70s
	60s													60s
	50s													50s
If systolic BP ≥ 200, write value in box	Write ≤ 40s													Write ≤ 40s
Heart Rate (beats / min)	Write ≥ 140													Write ≥ 140
	130s													130s
	120s													120s
	110s													110s
	100s													100s
	90s													90s
	80s													80s
	70s													70s
	60s													60s
	50s													50s
	40s													40s
If heart rate ≥ 140 or ≤ 30, write value in box	Write ≤ 30s													Write ≤ 30s
Temperature (°C)	Write ≥ 39.1													Write ≥ 39.1
	38.5–39.0													38.5–39.0
	38.0–38.4													38.0–38.4
	37.5–37.9													37.5–37.9
	37.0–37.4													37.0–37.4
	36.5–36.9													36.5–36.9
	36.0–36.4													36.0–36.4
	35.5–35.9													35.5–35.9
If temperature ≥ 39.1 or ≤ 35.4, write value in box	Write ≤ 35.4													Write ≤ 35.4
Consciousness If clinically necessary, wake patient to assess and score	Alert													Alert
	To Voice													To Voice
	To Pain													To Pain
	Unresp.													Unresp.
MADDS Scores	Respiratory Rate O_2 Saturation Systolic BP Heart Rate Temperature Consciousness TOTAL MADDS													MADDS Scores
Intervention	'V'													E.g. 'a'
Pain Score	8-10													8-10
	4-7													4-7
	0-3													0-3
	Weight (kg)													Weight (kg)

MERCY HEALTH AND AGED CARE CENTRAL QUEENSLAND LIMITED

UR Number: _____

Family name: _____

Given names: _____

Date of birth: ____/____/____ Sex: ☐ M ☐ F

(Affix patient identification label here)

Mater Adult Deterioration Detection System (MADDS)

If any observation is in a shaded area, add up the Total MADDS Score and take the action required for that score.

- Score 0
- Score 1
- Score 2
- Score 3
- **Emergency call**

Total MADDS Score 1–3
- Inform senior nurse and/or Team Leader
- Increase frequency of observations to 4 Hourly

Total MADDS Score 4–5
- NUM or AHNM review within 30 minutes
- Increase frequency of observations to a minimum of hourly
- NUM or AHMN to escalate to VMO

Total MADDS Score 6–7
- NUM or AHMN review within 15 minutes
- Contact VMO to review patient within 30 minutes
- Increase frequency of observations to a minimum of 5-15 minutes as required
- Remain with patient until review

Total MADDS Score ≥ 8
- Place Code Blue Call
- Begin initial life support interventions (support airway, breathing, circulation)
- Advanced life support provider to attend patient immediately

Emergency call if:

Any observation is in a purple area
Airway threat
Respiratory or cardiac arrest
New drop in O_2 saturation < 90%
Sudden fall in level of consciousness
Seizure
You are seriously worried about the patient but they do not fit the above criteria

Appendix G—Mater Adult Deterioration Detection System v5 ($MADDS_5$)

Date	
Time	
Respiratory Rate (breaths / min) If respiration rate >35 or ≤4, write value in box	Write ≥ 35
	30 - 34
	25-29
	20-24
	15-19
	10-14
	5-9
	≤ 4
O_2 Saturation (%) If O_2 saturations ≤84, write value in box	98 - 100
	95 - 97
	93 - 94
	90 - 92
	85 - 89
	Write ≤ 85
O_2 Flow Rate (L/min)	≥13
	10 - 12
	7 - 9
	4 - 6
	≤ 3
	Note on RA
Blood Pressure (mmHg) (Score for Systolic) If systolic BP ≥200, write value in box	Write ≥ 200s
	190s
	180s
	170s
	160s
	150s
	140s
	130s
	120s
	110s
	100s
	90s
	80s
	70s
	60s
	50s
	40s
Heart Rate (beats/min) (Note if irreg/reg) If heart rate ≥ 140 or ≤30, write value in box	Write ≥140s
	130s
	120s
	110s
	100s
	90s
	80s
	70s
	60s
	50s
	40s
	Write ≤ 30s
Temperature (°C) If temperature ≥ 39.1 or ≤35.4, write value in box	Write ≥ 39.1
	38.5 - 39.0
	38.0 - 38.4
	37.5 - 37.9
	37.0 - 37.4
	36.5 - 36.9
	36.0 - 36.4
	35.5 - 35.9
	Write ≤ 35.4
Consciousness	Alert
	To Voice
	To Pain
	Unresp
MADDS SCORE	Respiratory Rate
	O2 Saturation
	O_2 Flow Rate
	Systolic BP
	Heart Rate
	Temperature
	Consciousness
	TOTAL MADDS
Interventions	e.g. 'A'
	Bowels
Pain Score	8 - 10
	4 - 7
	0 - 3
	Weight

Mater Adult Deterioration Detection System (MADDS)

SURNAME_____

GIVEN NAME:_____

DATE OF BIRTH: _____ SEX M / F

UR NO: _____

(Affix Patient label here)

	Score 0
	Score 1
	Score 2
	Score 3
	Medical Emergency call

ACTIONS REQUIRED (Document Variance)

Total MADDS Score 1 - 3

- Consider observations at least once every 4 hours
- Carry out appropriate interventions eg ECG, BSL
- Manage fever, pain, blood loss or distress
- Review O2 requirement
- Inform senior RN/NUM/AHNM
- Consider informing medical officer as appropriate
- Document Interventions

Total MADDS Score 4 - 7

- Notify NUM/AHNM/Senior RN
- Contact Medical Officer using SHARED tool - give clinical information to MO and document in on clinical pathway/progress notes, and report increasing pain.
- Review and increase observation frequency e.g. every 2 hours and review O2 requirement
- If patient must leave ward area, a nurse must accompany patient.
- Document Interventions

Total MADDS Score ≥ 8

- Medical emergency call
- You **MUST** notify NUM/AHNM/Senior RN /MET Nurse if medical emergency not activated.
- Contact Medical Officer to review patient urgently and document in progress notes
- If the patient must leave ward area a registered nurse must accompany patient.

Initiate Emergency/MET call if any of the following apply: As this may indicate a seriously ill or at risk patient.
(If the patient has a NFR order and for terminal care these triggers may not apply)

Acute Changes	Patient Signs/Symptoms
	Any observation is in a purple area
AIRWAY	Threatened or blocked or unable to be cleared
BREATHING	• Respiratory difficulty • Respiratory Arrest • Cyanosed or a New drop in SpO2 <90% in any amount of oxygen • Increased O2 requirements
CIRCULATION	• Cardiac Arrest • Increase/decrease in of 30 mmHg - 50mmHg in systolic or systolic <90 or 200mmHg
NEUROLOGY	• Sudden decrease in consciousness • Seizures
OTHER	• Symptomatic significant cardiac arrhythmia compromising patient condition • Urine output <10ml/hr for 2 hours or <250mls in 12hours • Glucose <3mmol or ≥ 20mmol • Uncontrolled bleeding • Anaphylaxis
Or	Any patient you are seriously worried about as determined by assessment of the patient's condition

Appendix H—Queensland Maternity Early Warning Tool v3 (Q-MEWT)

Post-natal		Date / Time		Date / Time	
Respiratory Rate (breaths / min)	E	≥36		≥36	E
	3	35		35	3
	2	31–34		31–34	2
	1	21–30		21–30	1
	0	13–20		13–20	0
	1	10–12		10–12	1
	E	≤9		≤9	E
O_2 Saturation (%)	0	≥95		≥95	0
	1	93–94		93–94	1
	2	91–92		91–92	2
	E	≤90		≤90	E
O_2 Flow Rate (L / min)	3	>11		>11	3
	2	>5–11		>5–11	2
	1	2–5		2–5	1
	0	<2		<2	0
RA Room Air / RM Face Mask / NP Nasal Prongs / NR Non Re-breather		Mode		Mode	
Systolic Blood Pressure (mmHg) e.g.	E	≥160		≥160	E
	3	150s		150s	3
	2	140s		140s	2
	0	130s		130s	0
		120s		120s	
		110s		110s	
	1	100s		100s	1
		90s		90s	
	2	80s		80s	2
	E	70s		70s	E
Diastolic Blood Pressure (mmHg) e.g.	E	110s		110s	E
	2	100s		100s	2
	1	90s		90s	1
	0	80s		80s	0
		70s		70s	
		60s		60s	
	1	50s		50s	1
	2	40s		40s	2
	E	30s		30s	E
Blood Pressure (mmHg)					
Heart Rate (beats / min)	E	≥140		≥140	E
	3	130s		130s	3
	2	120s		120s	2
		110s		110s	
	1	100s		100s	1
	0	90s		90s	0
		80s		80s	
		70s		70s	
		60s		60s	
		50s		50s	
	3	40s		40s	3
	E	30s		30s	E
Temperature (°C)	E	≥40.0		≥40.0	E
	3	39.0–39.9		39.0–39.9	3
		38.0–38.9		38.0–38.9	
	1	37.5–37.9		37.5–37.9	1
	0	36.0–37.4		36.0–37.4	0
	1	35.1–35.9		35.1–35.9	1
	2	34.1–35.0		34.1–35.0	2
	3	≤34.0		≤34.0	3
Consciousness If necessary, wake patient before scoring	0	Alert		Alert	0
	2	To Voice		To Voice	2
	E	To Pain		To Pain	E
		Unresponsive		Unresponsive	
Total Q-MEWT Score				☐ Tick box if modifications in use	
Intervention		(e.g. 'A')			

Score Legend

0	Score 0
1	Score 1
2	Score 2
3	Score 3
E	Emergency Call

(Affix identification label here)

URN:
Family name:
Given name(s):
Address:
Date of birth:
Sex: ☐ M ☐ F ☐ I

Post-natal

Modifications

- Use modifications IF the woman's usual observations are abnormal by Q-MEWT parameters AND are to be tolerated.
- Modifications must be authorised by a SMO / Registrar / PHO (or equivalent) or HHS approved Senior Midwife.
- Modifications must be assessed and rewritten with each new Q-MEWT chart.

Reason for modification:

Authorised by (SMO / Registrar / PHO or HHS approved Senior Midwife):

Full name (please print):

Designation: Signature:

Date: / / Time: :

Write the acceptable range (will score zero) below:

Respiratory Rate	to		breaths/min
O_2 Saturation	to		%
O_2 Flow Rate	to		L/min
Systolic BP	to		mmHg
Diastolic BP	to		mmHg
Heart Rate	to		beats/min

Scoring Note: For observations outside the modified range, revert to the original score on Q-MEWT.

For example: If an O_2 saturation of 93-94% is tolerated (ie. it has been modified to score zero), and the O_2 saturation falls to 92%, it would still score 2.

Actions Required for Rural and Remote Facilities

Q-MEWT Score	Observations (minimum frequency) 2 hrs immediately post delivery	Observations (minimum frequency) >2 hrs post delivery	Notify	Escalate (if no review)	Intra-hospital Escort
0	½ hourly	8 hourly			
1–3	½ hourly	4 hourly	• Team Leader		
4–5	½ hourly	1 hourly	• Team Leader • Medical Officer (MO) review within 30 minutes	• If no review within 30 minutes, follow local escalation plan for medical support or advice	Midwife / Nurse
6–7	½ hourly	½ hourly	• Team Leader • Notify local on-call Maternity MO to review patient within 10 minutes • If patient likely to require transfer, contact QCC* (1300 799 127) or RFDS† (if normal referral pathway)	• If review delayed or concern at bedside, midwife / nurse to directly notify QCC* (1300 799 127) or RFDS† (if normal referral pathway)	Midwife / Nurse and Medical Officer
≥8	10 minutes	10 minutes	• Initiate emergency call as per local facility protocol • Local on-call Maternity MO to attend as soon as possible • Midwife / Nurse to directly notify QCC* (1300 799 127) or RFDS† (if normal referral pathway)	• Midwife / nurse to directly notify QCC* (1300 799 127) or RFDS† (if normal referral pathway)	

*QCC = Queensland Emergency Medical System (QEMS) Coordination Centre
†RFDS = Royal Flying Doctors Service (Cairns Base: 4040 0500; Charleville Base: 4654 1443; Mt Isa Base: 4743 2802)

Emergency call if:

- **Any observation is in a purple area**
- Airway threat
- Respiratory or cardiac arrest
- Sudden fall in level of consciousness
- Seizure
- Sudden heavy blood loss
- Sedation level of 3 (severe)
- You are concerned about the patient but they do not fit the above criteria

Appendix I—Queensland Adult Deterioration Detection System v5 (Q-ADDS)

Adult		Date		
		Time		
Respiratory Rate (breaths / min) Measure for a full minute	E	≥ 36	≥ 36	E
	3	35	35	3
	2	31–34	31–34	2
	1	21–30	21–30	1
	0	13–20	13–20	0
	1	9–12	9–12	1
	E	≤ 8	≤ 8	E
O_2 Saturation (%)	0	≥ 98	≥ 98	0
		95–97	95–97	
	1	90–94	90–94	1
	2	85–89	85–89	2
	3	≤ 84	≤ 84	3
O_2 Flow Rate (L / min)	3	> 11	> 11	3
	2	> 5–11	> 5–11	2
	1	2–5	2–5	1
	0	< 2	< 2	0
RA Room air NP Nasal prongs FM Face mask NR Non-re-breather		Mode		
Blood Pressure (mmHg) Score systolic BP	3	≥ 200	≥ 200	3
	2	190s	190s	2
		180s	180s	
		170s	170s	
	1	160s	160s	1
	0	150s	150s	0
		140s	140s	
		130s	130s	
		120s	120s	
		110s	110s	
	1	100s	100s	1
	2	90s	90s	2
	E	80s	80s	E
		70s	70s	
		60s	60s	
Heart Rate (beats / min)	E	≥ 140	≥ 140	E
	3	130s	130s	3
	2	120s	120s	2
		110s	110s	
	1	100s	100s	1
	0	90s	90s	0
		80s	80s	
		70s	70s	
		60s	60s	
		50s	50s	
	1	40s	40s	1
	E	30s	30s	E
Temperature (C)	2	≥ 39.5	≥ 39.5	2
		38.5–39.4	38.5–39.4	
	1	38–38.4	38–38.4	1
	0	37.5–37.9	37.5–37.9	0
		37–37.4	37–37.4	
		36.1–36.9	36.1–36.9	
	1	35.1–36	35.1–36	1
	2	34.1–35	34.1–35	2
	3	≤ 34	≤ 34	3
Consciousness If necessary, wake patient before scoring	0	Alert	Alert	0
	1	Voice	Voice	1
	E	Pain	Pain	E
		Unresp.	Unresp.	
TOTAL Q-ADDS SCORE				☐ Tick box if modifications in use
Intervention		(e.g. 'A')		

Score Legend

0	Score 0
1	Score 1
2	Score 2
3	Score 3
E	Emergency Call

(Affix identification label here)

URN:

Family name:

Given name(s):

Address:

Date of birth: Sex: ☐ M ☐ F ☐ I

Actions Required for Tertiary and Secondary Facilities

Total Q-ADDS Score 0
- Minimum 8th hourly *Total Q-ADDS Score*

Total Q-ADDS Score 1–3
- Carry out and document appropriate interventions as prescribed
- Consider increasing frequency of observations (minimum 4th hourly)
- Manage fever, pain or distress
- Review oxygen requirement
- Consider notifying team leader

Total Q-ADDS Score 4–5
- Notify team leader
- Request ward doctor to review patient within 30 minutes
- Carry out and document appropriate interventions as prescribed
- Hourly observations (or more frequently if indicated)
- Obtain a *Total Q-ADDS Score* after interventions
- If no review within 30 minutes, escalate to registrar review
- If patient must leave ward area, nurse must accompany patient

Total Q-ADDS Score 6–7
- Notify team leader
- Request registrar to review patient within 30 minutes, ward doctor to attend
- Carry out and document appropriate interventions as prescribed
- Registrar to ensure consultant is notified
- Half hourly observations (or more frequently if indicated)
- Obtain a *Total Q-ADDS Score* after interventions
- If no review within 30 minutes, or if concerned, initiate emergency call
- If patient must leave ward area, doctor and nurse must accompany patient

Total Q-ADDS Score ≥ 8
- Initiate emergency call
- Registrar to ensure consultant is notified
- If patient must leave ward area, registrar and nurse must accompany patient

Emergency call if:
- **Any observation is in a purple area**
- Airway threat
- Respiratory or cardiac arrest
- New drop in O_2 saturation < 90%
- O_2 saturation < 85% without response to O_2
- Sudden fall in level of consciousness
- Seizure
- Sedation score of 3 (severe)
- You are concerned about the patient but they do not fit the above criteria

Appendix J—Queensland Adult Deterioration Detection System with Systolic blood pressure scale v6 (Q-ADDS + BP)

Adult																								
		Date																						
		Time																						
Respiratory Rate (breaths / min) Measure for a full minute	E	≥35																						E
	3	30–34																						3
	2	25–29																						2
	1	21–24																						1
	0	17–20																						0
		13–16																						
	1	9–12																						1
O_2 Saturation (%)	E	≤8																						E
	0	≥98																						0
		95–97																						
	1	90–94																						1
	2	85–89																						2
	3	≤84																						3
Oxygen* (L / min or % delivered) *If on HF / NIV use % delivered	E	NRM																						E
	3	>11 / >50%																						3
	2	>5–11 / >40–50%																						2
	1	2–5 / 28–40%																						1
	0	<2 / <28%																						0
FM Face mask; HF High flow; NIV Non invasive; NP Nasal prongs; NRM Non re-breather; RA Room air; HFNP High flow nasal prongs		Mode																						
		High flow rate in L/min																						
Blood Pressure (mmHg) Score systolic BP		≥200																						≥200
		190s																						190s
		180s																						180s
		170s																						170s
		160s																						160s
		150s																						150s
		140s																						140s
		130s																						130s
		120s																						120s
		110s																						110s
		100s																						100s
		90s																						90s
		80s																						80s
		70s																						70s
		60s																						60s
Systolic BP score																								
Heart Rate (beats / min)	E	≥140																						E
	3	130s																						3
	2	120s																						2
		110s																						
	1	100s																						1
	0	90s																						0
		80s																						
		70s																						
		60s																						
		50s																						
	2	40s																						2
	E	30s																						E
Temperature (°C)	2	≥39.5																						2
		38.5–39.4																						
	1	38–38.4																						1
	0	37.5–37.9																						0
		37–37.4																						
		36.1–36.9																						
	1	35.1–36																						1
	2	34.1–35																						2
	3	≤34																						3
Consciousness If necessary, wake patient before scoring	0	Alert																						0
	1	Voice																						1
	4	New confusion / agitation	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
	E	Pain																						E
		Unresponsive																						
Modifications in use		M																						
TOTAL Q-ADDS SCORE																								
Interventions		(e.g. 'A')																						
Initials																								

Score Legend

0	Score 0
1	Score 1
2	Score 2
3	Score 3
4	Score 4
5	Score 5
E	Emergency call

(Affix identification label here)

URN:

Family name:

Given name(s):

Address:

Date of birth: Sex: ☐ M ☐ F ☐ I

Indicate which systolic BP scoring preference is in use (Usual or Default). If the Usual systolic BP is selected, write the Usual systolic BP in the space provided:

☐ Usual systolic BP: ..... mmHg

☐ Default systolic BP: 120mmHg

Target Systolic BP (SMO / Registrar ONLY): mmHg

Name: | Name:

Signature: | Signature:

Designation: | Date: | Designation: | Date:

Circle the column showing the patient's Usual / Default / Target systolic BP

Actual BP	180s	170s	160s	150s	140s	130s	120s	110s	100s	90s	80s
≥200	EMERGENCY CALL										
190s	0	0	1	1	1	2	2	3	3	4	4
180s	0	0	0	0	1	1	2	2	3	3	4
170s	0	0	0	0	1	1	2	2	3	3	3
160s	1	0	0	0	0	0	1	1	2	2	2
150s	1	1	0	0	0	0	0	1	1	2	2
140s	1	1	1	0	0	0	0	0	1	1	1
130s	2	1	1	0	0	0	0	0	0	0	1
120s	2	2	1	1	0	0	0	0	0	0	0
110s	2	2	2	1	1	0	0	0	0	0	0
100s	3	3	2	2	2	1	1	0	0	0	0
90s	3	3	3	2	2	2	2	1	1	0	0
80s										1	0
70s	EMERGENCY CALL										
60s											

Emergency call if:

- Airway Threat
- Respiratory or cardiac arrest
- Q-ADDS Score ≥8
- Any observation in a purple area (**E**)
- O_2 saturation <90% without response to oxygen
- Seizure >2 minutes
- Sedation score of 3 (severe)
- You are concerned about the patient but they do not fit the above criteria

Actions Required for Rural and Remote Facilities *RSQ Retrieval Services Queensland

Q-ADDS Score	Observations (min. frequency)	Notify	Escalate (if review delayed / concern)	Intra-hospital Escort
0	8 hourly			
1–3	4 hourly	• Team Leader		
4–5	1 hourly	• Team Leader • Medical Officer within 60 minutes	• If no review after 60 minutes, or if concerned, follow local escalation plan	Nurse
6–7	½ hourly	• Team Leader • Local doctor to review within 30 minutes • Local doctor to discuss with relevant medical officer at regional / tertiary facility	• If no review after 30 mins, or if concerned, inform Team Leader and Team Leader must notify RSQ* on 1300 799 127	Nurse
≥8 or E	10 minutely	• Initiate Emergency Call • Local doctor to attend immediately • Inform Team Leader and Team Leader must notify RSQ* on 1300 799 127	• Inform Team Leader and Team Leader must notify RSQ* on 1300 799 127	Nurse and Medical Officer

Interventions Relating to observations from page 2 or the Pain at Rest Table on page 4

If an intervention is administered, record here and note letter in *Intervention* row on page 2 in appropriate time column

A
B
C
D
E
F
G

Appendix J—Adult Deterioration Detection System v2 (ADDS)

Date Time																					
Respiratory Rate (breaths / min) If respiratory rate ≥ 35 or ≤4, write value in box	Write ≥ 35																				Write ≥ 35
	30–34																				30–34
	25–29																				25–29
	20–24																				20–24
	15–19																				15–19
	10–14																				10–14
	5–9																				5–9
	Write ≤ 4																				Write ≤ 4
O_2 Saturation (%) If O_2 saturation ≤ 84, write value in box	98–100																				≥ 98
	95–97																				95–97
	93–94																				93–94
	90–92																				90–92
	87–89																				87–89
	85–86																				85–86
	Write ≤ 84																				Write ≤ 84
O_2 Flow Rate (L / min)	≥ 13																				≥ 13
	10–12																				10–12
	7–9																				7–9
	4–6																				4–6
	≤ 3																				≤ 3
Blood Pressure (mmHg) Score systolic BP If systolic BP ≥ 200, write value in box	Write ≥ 200																				Write ≥ 200
	190s																				190s
	180s																				180s
	170s																				170s
	160s																				160s
	150s																				150s
	140s																				140s
	130s																				130s
	120s																				120s
	110s																				110s
	100s																				100s
	90s																				90s
	80s																				80s
	70s																				70s
	60s																				60s
	50s																				50s
	40s																				40s
Heart Rate (beats / min) If heart rate ≥ 140 or ≤ 30, write value in box	Write ≥ 140																				Write ≥ 140
	130s																				130s
	120s																				120s
	110s																				110s
	100s																				100s
	90s																				90s
	80s																				80s
	70s																				70s
	60s																				60s
	50s																				50s
	40s																				40s
	Write ≤ 30s																				Write ≤ 30s
Temperature (°C) If temperature ≥ 39.1 or ≤ 35.4, write value in box	Write ≥ 39.1																				Write ≥ 39.1
	38.5–39.0																				38.5–39.0
	38.0–38.4																				38.0–38.4
	37.5–37.9																				37.5–37.9
	37.0–37.4																				37.0–37.4
	36.5–36.9																				36.5–36.9
	36.0–36.4																				36.0–36.4
	35.5–35.9																				35.5–35.9
	Write ≤ 35.4																				Write ≤ 35.4
Consciousness If clinically necessary, wake patient to assess and score	Alert																				Alert
	To Voice																				To Voice
	To Pain																				To Pain
	Unresp.																				Unresp.
ADDS Scores Respiratory Rate O_2 Saturation O_2 Flow Rate Systolic BP Heart Rate Temperature Consciousness TOTAL ADDS																					ADDS Scores
Intervention	E.g. 'a'																				E.g. 'a'

UR Number: _____

Family name: _____

Given names: _____

Date of birth: ___/___/___ Sex: ☐ M ☐ F

DRAFT - NOT FOR USE

(Affix patient identification label here)

Adult Deterioration Detection System (ADDS)

If any observation is in a shaded area, add up the Total ADDS Score and take the action required for that score.

- Score 0
- Score 1
- Score 2
- Score 3
- **Emergency call**

Actions Required

Total ADDS Score 1–3

- Inform senior nurse and/or Team Leader
- Increase frequency of observations *[specify frequency]*

Total ADDS Score 4–5

- Senior nurse and/or junior medical officer review within 30 minutes
- Increase frequency of observations *[specify frequency]*

Total ADDS Score 6–7

- Senior medical officer review (registrar or above) within 30 minutes
- Request review, and note on the back of this form
- Increase frequency of observations *[specify frequency]*

Total ADDS Score ≥ 8

- Place Emergency call
- Begin initial life support interventions (support airway, breathing, circulation)
- Advanced life support provider to attend patient immediately

These actions are generic placeholders only and must be altered to reflect local circumstances

Emergency call if:

- Any observation is in a purple area
- Airway threat
- Respiratory or cardiac arrest
- New drop in O_2 saturation < 90%
- Sudden fall in level of consciousness
- Seizure
- You are seriously worried about the patient but they do not fit the above criteria

Appendix K—Compass EWS (ViEWS)

Early Warning Score - ViEWS - Key							
SCORE	3	2	1	0	1	2	3
Respiratory Rate (bpm)	≤ 8		9 - 11	12 - 20		21 - 24	≥ 25
SpO_2 (%)	≤ 91	92 - 93	94 - 95	≥ 96			
Inspired O_2 (F_iO_2)				Air			Any O_2
Systolic BP (mmHg)	≤ 90	91 - 100	101 - 110	111 - 249	≥ 250		
Heart Rate (BPM)		≤ 40	41 - 50	51 - 90	91 - 110	111 - 130	≥ 131
AVPU/CNS Response				Alert (A)			Voice (V), Pain (P), Unresponsive (U)
Temp (°C)	≤ 35.0		35.1 - 36.0	36.1 - 38.0	38.1 - 39.0	≥ 39.1	

Total Score	Minimum Observation Frequency	ALERT	RESPONSE
1	12 Hourly	Nurse in charge	Nurse in charge to review if new score1
2	6 Hourly	Nurse in charge	Nurse in charge to review
3	4 Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review within 1 hour
4-6	1 Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review within ½ hour 2. If no response to treatment within 1 hour contact Registrar 3. Consider continuous patient monitoring 4. Consider transfer to higher level of care
≥ 7	½ Hourly	Nurse in charge & Team/On-Call Registrar Inform Team/On-Call Consultant	1. Registrar to review immediately 2. Continuous patient monitoring recommended 3. Plan to transfer to higher level of care 4. Activate Emergency Response System (ERS) *(as appropriate to hospital model)*
Note: Single Score triggers			
Score of 2 HR ≤ 40 (Bradycardia)	½ Hourly	Nurse in charge & Team/On-call SHO	1. SHO to review immediately
*Score of 3 in any single parameter	½ Hourly or as indicated by patient's condition	Nurse in charge & Team/On-call SHO	1. SHO to review immediately 2. If no response to treatment or still concerned contact Registrar 3. Consider activating ERS

*In certain circumstances a score of 3 in a single parameter may not require ½ hourly observations i.e. some patients on O_2.

- When communicating patients score inform relevant personnel if patient is charted for supplemental oxygen e.g. post-op.
- Document all communication and management plans at each escalation point in medical and nursing notes.
- Escalation protocol may be stepped down as appropriate and documented in management plan.

IMPORTANT:

1. If response is not carried out as above CNM/Nurse in charge must contact the Registrar or Consultant.
2. If you are concerned about a patient escalate care regardless of score.

Taken from the Compass training manual

Avard, B., McKay, H., Slater, N., Lamberth, P., Daveson, K., & Michell, I. (2011). *Compass. Pointing you in the right direction. ACT Health.* Retrieved from http://www.rcsi.ie/files/facultyofnursingmidwifery/20160811103824_5.2%20NEWS%20Training.pdf

Appendix L—National Early Warning Score v2012 (NEWS)

NEWS KEY 0 1 2 3	NAME:	D.O.B.	ADMISSION DATE:
DATE			DATE
TIME			TIME
RESP. RATE ≥25		3	≥25
21-24		2	21-24
12-20			12-20
9-11		1	9-11
≤8		3	≤8
SpO_2 ≥96			≥96
94-95		1	94-95
92-93		2	92-93
≤91		3	≤91
Inspired O_2% %		2	%
TEMP ≥39°		2	≥39°
38°		1	38°
37°			37°
36°		1	36°
≤35°		3	≤35°
NEW SCORE uses Systolic BP BLOOD PRESSURE 230		3	230
220			220
210			210
200			200
190			190
180			180
170			170
160			160
150			150
140			140
130			130
120			120
110		1	110
100		2	100
90		3	90
80			80
70			70
60			60
50			50
HEART RATE >140		3	140
130			130
120		2	120
110			110
100		1	100
90			90
80			80
70			70
60			60
50		1	50
40			40
30		3	30
Level of Consciousness Alert			Alert
V / P / U		3	V / P / U
BLOOD SUGAR			Bl'd Sugar
TOTAL NEW SCORE			TOTAL SCORE
Additional Parameters			
Pain Score			Pain Score
Urine Output			Urine Output
Monitoring Frequency			Monitor Freq
Escalation Plan Y/N n/a			Escal Plan
Initials			Initials

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NHS Training for Innovation