EXECUTIVE SUMMARY

- In-hospital adverse events are often preceded by observable deterioration of patient condition, suggesting that many in-hospital adverse events may be preventable.
- Timely recognition of patient deterioration followed by rapid and effective response by clinical staff is critical for optimizing patient outcomes.
- Early warning scores (EWS) can provide an effective tool for identifying patient deterioration, and have been shown to have strong predictive value for cardiac arrest and mortality.
- Unfortunately, EWS implementation can be variable and suboptimal.
- Automated clinical decision support technology can improve EWS accuracy and compliance, thus helping to identify patient deterioration sooner and allowing for proactive rather than reactive care.

Over the past two decades, the healthcare system has focused considerable attention on the concept of “failure to rescue” and the reduction of preventable harm in the hospital. Unfortunately, despite best efforts, preventable inpatient complications remain a significant problem, and there is no clear evidence that the incidence of these events has changed markedly over the last decade.

There are about 200,000 in-hospital cardiopulmonary arrests (CPAs) annually in the United States, and fewer than 20% of these arrest patients survive to discharge without anoxic brain injury. Importantly, in-hospital CPAs are often preceded by observable deterioration of patient condition, suggesting that many of these catastrophic events may be preventable. In fact, in a 2002 study of 118 in-hospital cardiac arrest cases, Hodgetts et al concluded that approximately 62% of the cases were potentially avoidable. Similarly, Akre et al found that 86% of rapid response team (RRT) activation or code blue events could have been predicted beforehand, with a median advanced warning time of 11.5 hours.

Respiratory depression and respiratory insufficiency are among the most common precipitating causes of in-hospital resuscitation or cardiac arrest events. In a 2009 analysis, Fecho et al demonstrated that respiratory depression was the precipitating cause of 61% of non-CPR resuscitation calls. Similarly, Peberdy et al showed that acute respiratory insufficiency was the precipitating cause of 38% of in-hospital cardiac arrest cases, and Wang et al found that 65% of respiratory arrest cases progressed to CPA within 10 minutes.

In addition to predicting CPA, extreme respiration rate is also a strong predictor of in-hospital mortality, and patients with respiratory compromise have up to a two-fold increase in mortality following delayed RRT activation. In a 2004 analysis of 6303 patients admitted to five hospitals, Buist et al demonstrated that a decrease in respiratory rate <6 respirations/min was the strongest evaluated predictor of mortality, with a 13.7-fold (95% CI: 2.9-64.0; p < 0.001) increase in the risk of mortality. In this patient cohort, increased respiratory rate (>30 respirations/min) was the second strongest predictor of mortality, with an associated odds ratio of 6.1 (95% CI: 3.6-10.6; p < 0.001). In an analysis of more than 6000 emergency department (ED) patients, Barford et al found that respiratory abnormalities were the strongest predictor of ICU admission, with an associated odds ratio of 9.1 (95% CI: 3.5-23.8; p < 0.0001) for a rate of >35 respirations/min. Furthermore, in their 2011 study, Bapoje et al found that respiratory failure was the most common reason for unplanned ICU transfer, accounting for 27% of cases. Unfortunately, while acute respiratory compromise is one of the most common contributors to in-hospital CPA, respiratory rate remains one of the most poorly documented physiological parameters. To compound this issue, manual counting of respiration rate is notoriously unreliable and visual signs of hypoxia such as cyanosis are slow to manifest.
The widespread adoption of RRTs, also known as medical emergency teams (METs), by hospitals over the last two decades was designed to reduce preventable harm from late recognition of physiologic instability preceding CPA.16,17 The crucial components of the RRT system were first defined by DeVita et al in 2006, who described the importance of both the “afferent” crisis detection and response triggering side of the equation (i.e., patient surveillance) and the “efferent” response and intervention by the RRT.18 Despite advances in patient monitoring technologies, there is still concern that the afferent limb remains the weak link of the system, especially in lower acuity settings with reduced patient surveillance capabilities.

Within the afferent limb of the RRT system, the concept of an early warning score (EWS) has been developed internationally to help identify acutely ill and deteriorating patients in acute care hospitals. As described below, the EWS provides an integrated assessment of a patient’s physiological trends in the form of a single score that can provide early recognition of the clinical signs of deterioration. Having recognized at-risk patients, the system then triggers (i.e., track and trigger) an escalation response to prevent further deterioration that may lead to CPA. This proactive response to acute deterioration optimizes patient outcomes. As such, early warning systems are clinical decision support tools used to assess basic physiological parameters to identify patients with potential or established critical illness.19

**EARLY WARNING SCORES — OVERVIEW**

As noted above, in the simplest of terms, an EWS is a derived parameter used to quickly determine the degree of illness of a patient and simplify trend tracking. Several hundred unique yet similar EWS are in use worldwide, and all rely on a combination of physiological readings such as systolic blood pressure (SBP), heart rate, respiratory rate, urine output, and body temperature, along with observations such as level of consciousness (i.e., AVPU) (Table 1). Determining an EWS value typically involves assigning a number between 0 and 3 to each of the vital signs and observations. The sum of the scores of the different parameters yields the patient’s total EWS. The higher the EWS, the more serious the patient’s condition.

Four commonly used types of EWS — the national early warning score (NEWS), the modified early warning score (MEWS), the Scottish (or standardised) early warning score (SEWS), and the Wellington early warning score (WEWS) — are compared in Table 1.

### EARLY WARNING SCORES AND CLINICAL OUTCOMES

Early warning systems, mostly using vital sign abnormalities, seem to reasonably predict the occurrence of cardiac arrest and death within 48 hours of measurement.20 Evidence also suggests that early warning systems may predict risk of ICU admission and length of hospital stay.21,22 While there may not be a sufficient body of evidence to support the argument that the use of an EWS alone is the answer, many studies have provided evidence of improvements in early detection of deterioration and/or outcome measures since the introduction of an EWS.

#### Early Warning Scores and Serious Adverse Events

A 2016 prospective study by van Galen et al examined the ability of MEWS to predict serious adverse events in a general hospital population.23 The study included 1053 patients with 3673 vital parameter measurements; 200 (19.0%) patients had a critical MEWS score. Patients with critical scores had significantly higher rates of unplanned ICU admissions [7.0% vs. 1.3%, \( p < 0.001 \)], in-hospital mortality [6.0% vs. 0.8%, \( p < 0.001 \)], 30-day readmission rates [18.6% vs. 10.8%, \( p < 0.05 \)], and a longer length of stay [15.65 (SD: 15.7 days) vs. 6.09 (SD: 6.9), \( p < 0.001 \)]. The specificity of MEWS related to composite adverse events was 83% with a negative predicting value of 98%.23 For surgical patients, Hollis et al found that critical postoperative complications can be preceded by a rising EWS. More specifically, the EWS increased significantly in the 3 days preceding grade IV/V complications and decreased in patients without complications (\( p < 0.001 \) for both). For the evaluated patients, a threshold EWS of 8 predicted the occurrence of grade IV/V complications with 81% sensitivity and 84% specificity.24

### Table 1. Comparison of selected early warning scores

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NEWS</th>
<th>MEWS</th>
<th>SEWS</th>
<th>WEWS</th>
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<tr>
<td>Respiration rate</td>
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<td>Heart rate</td>
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<td>SpO₂</td>
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<tr>
<td>Supplemental O₂</td>
<td>X</td>
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<td></td>
<td>X</td>
</tr>
<tr>
<td>Level of consciousness (AVPU)</td>
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<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Temperature</td>
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<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Urine output</td>
<td>X</td>
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<td>X</td>
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</tbody>
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AVPU = alert, verbal, painful, unresponsive; NEWS = national early warning score; MEWS = modified early warning score; SEWS = Scottish (or standardised) early warning score; WEWS = Wellington early warning score.
Early Warning Scores and Mortality

In a 2013 systematic review of EWS systems conducted by the U.S. Department of Veterans Affairs, the authors concluded the EWS appeared to have strong predictive ability for death and cardiac arrest within 48 hours. These authors noted, however, that most patients with high scores did not suffer an event and low scores did not necessarily preclude an adverse event.25

Kellett and colleagues conducted a prospective cohort study of a consecutive sample of adult patients (n = 75 419) using an abbreviated version of a previously derived EWS, VitalPac Early Warning Score (ViEWS) (temperature, SBP, oxygen saturation, use of supplemental oxygen, heart rate, respiratory rate). Vital signs were recorded using VitalPac software. Among medical patients, the abbreviated ViEWS had an area under the receiver operator characteristic curve (AUROC) of 0.89 (95% CI: 0.85-0.92) as a predictor of death within 48 hours of the observed score (from admission).26 Similarly, Prytherch and colleagues conducted a prospective cohort study to derive the EWS ViEWS (plus mental status) among patients on a general medical service with vital sign data recorded using VitalPac software (n = 35 585). The ViEWS score had an AUROC of 0.888 (95% CI: 0.880-0.895) as a predictor of death within 24 hours of the observed score. The sensitivity of the ViEWS was about 67% at a specificity of 90%.27

Burch et al reported that the proportion of patients who died in hospital increased significantly as the MEWS increased. The authors also reported that in-hospital mortality increased significantly with an increased number of abnormal parameters recorded in the ED. Interestingly, the authors also report that a comparison of in-hospital deaths with alive discharges showed that the mean MEWS was significantly higher among those who died (4.5 vs. 3.8, p = 0.001), but there was no significant difference between the two groups in terms of mean age, SBP, pulse rate, respiratory rate, or temperature.28 In a 2016 study by Jo et al, the authors found that a composite NEWS-Lactate (NEWS-L) score using a patient’s initial serum lactate level demonstrated excellent predictive value for 2-day mortality, with an AUROC of 0.96 (95% CI: 0.94–0.98).29

Several studies have also reported a reduction in deaths following implementation of an early warning system. In 2010, Mitchell et al reported the results of a prospective controlled trial of the effect of a multifaceted intervention, including MEWS, on early recognition and intervention in deteriorating hospital patients in two Australian hospitals. In this study, the authors noted a statistically significant reduction in deaths (0.2% vs. 1.0%, p = 0.03), along with improved vital sign documentation and increased medical reviews.30 Similarly, Moon et al implemented an EWS at two hospitals, and at both institutions deaths per hospital admission decreased significantly from 1.4% to 1.2% (p < 0.0001). In addition, both the mortality per cardiac arrest call and the in-hospital mortality of patients admitted to the ICU having undergone CPR fell significantly (26% to 21%, p < 0.0001, and 70% to 40%, p < 0.0001, respectively).31 Paterson et al found a reduction of in-hospital mortality of 2.8% (p = 0.046), from 5.8% before implementation of EWS to 3.0% after implementation.32 These authors also found that mortality rose more than 8-fold for a score of ≥ 4, compared with a score of 0 to 3 (difference in proportions, 15.3%; 95%CI: 3.7-26.9).

Early Warning Scores and Cardiac Arrest

In a 2013 systematic review conducted by the U.S. Department of Veterans Affairs, EWS appeared to have strong predictive ability for cardiac arrest within 48 hours.25 Several studies have also found a reduced incidence of cardiac arrests following the implementation of an early warning system. Moon et al found that the proportion of cardiac arrest calls per adult admission decreased in both hospitals involved in a study after the introduction of EWS (0.4% to 0.2%, p < 0.0001, and 0.34% to 0.28%, p < 0.0001).31 In a study by Maupin et al, the authors reported a decrease in the number of code blue events outside the ICU from 0.77 per 1000 patient days to 0.39 per 1000 patient days, but the statistical significance was not reported.33 Similarly, Nishijima et al found that the introduction of a MEWS system reduced the rate of in-hospital cardiac arrest (IHCA) by enabling earlier intervention. More specifically, the rate of IHCA per 1000 admissions decreased from 5.21 to 2.05 (p < 0.01).34 In a 2016 study of 99 patients with in-hospital cardiac arrest by Wang et al, the authors found that periarrest MEWS was lower in the survival-to-discharge group (4.41 ± 2.28 vs. 5.82 ± 2.84, p = 0.053). In multivariate logistic regression analysis, periarrest MEWS was an independent predictor for survival to discharge, such that a rise in periarrest MEWS reduced the chance of survival to discharge by 0.77-fold (95% CI: 0.60-0.97, p = 0.028). The authors concluded that periarrest MEWS could be considered as an independent predictor of mortality after in-hospital cardiac arrest.35

Early Warning Scores and Sepsis

A 2016 study of 245 patients with sepsis by Albur et al found that the EWS on day 0, 1, and 2, and the average 14-day EWS, were significantly higher in patients who died by 28 days from the onset of bacteremia (95% CI: 0.4-0.6; p < 0.001). A stepwise rise in EWS and failure of improvement in EWS by 2 points 48 hours after the onset of bacteremia were associated with poor outcome. These authors concluded that EWS was a simple and cost-effective bedside tool for the assessment of severity and prognosis of sepsis caused by Gram-negative bacteremia.36
Early Warning Scores and ICU Admissions

Overall, the evidence to date is mixed with respect to the impact of early warning system implementation on rates of unplanned ICU transfers. Two studies found a significant increase in the number of ICU admissions after implementing an EWS, accounting for differences in overall hospital admission rates.17 Moon et al, in an 8-year audit across two institutions, found a decrease in the number of unplanned admissions to the ICU after implementing EWS (3% vs. 2% and 6.65% vs. 2.63%).22 Peris et al looked at high dependency unit (HDU) and ICU admission rates after implementation of the EWS in emergency surgical patients. HDU admission significantly increased from 14% to 21% (p = 0.0008), while a significant decrease of ICU admission was reported from 11% to 5% (p = 0.0010).23 In the study by Mitchell et al, the introduction of a multifaceted intervention to detect clinical deterioration, including MEWS, led to a reduction in unplanned ICU admissions (0.5% vs. 1.8%, p = 0.0006).19

In a 6-year prospective study of 925 ED patients with community-acquired pneumonia, Sbiti-Rohr et al found that there was a stepwise increase in mortality with higher NEWS categories and that NEWS provided moderate discrimination (AUC, 0.73) for predicting ICU admission.39

Early Warning Scores and Length of Hospital Stay

As with ICU transfers, the evidence regarding the impact of EWS implementation on hospital length of stay (LOS) is inconsistent. Green et al studied ward patients with abnormal vital signs referred to the ICU liaison team or patients with an unplanned ICU admission or medical emergency and compared data from 12 months before EWS implementation to 24 months after implementation. They found no difference in the total LOS: 19 (9–39) days vs. 18 (8–33.7) days. In addition, the length of time an unstable patient was on the ward before ICU admission was found to be less after implementing EWS (percentage of patients with clinical markers of instability for ≥6 hours, 41.2% vs. 24.5%).40 In a study including all patients admitted to the ward before ICU admission was found to be less after implementing EWS (percentage of patients with clinical markers of instability for ≥6 hours, 41.2% vs. 24.5%).40 Jones et al reported on a study including all patients admitted to the ward and had a shorter pre–post design (47 days pre and 338 days post). They found a significant decrease in LOS: 9.7 vs. 6.9 days, p < 0.001.41 Paterson et al compared 4 months before and 4 months after implementation and showed an increase in LOS from 4.0 (1.8–8.3) days to 4.8 (2.2–9.8) days. LOS was significantly correlated with a higher EWS (p = 0.001).42 Bokhari et al found that the median LOS for all patients admitted to the ICU or HDU increased from 3 to 4 days, but they did not perform a statistical test to compare the distribution of the LOS in the before and after group.42 Peris et al did not find a significant change in LOS (mean before, 8 days; mean after, 7 days); however there was a trend toward shorter LOS.38

Early Warning Scores and Rapid Response Team Activation

Four studies evaluated the impact of EWS on RRTs and code teams and found at least a 50% increase in the number of RRT or ICU liaison team calls; three of the studies found a 6% to 33% decrease in the number of code blue calls.11,31,40,43 Green et al found that the number of code blue calls for a patient still breathing and with a pulse increased from 47.9% to 64.4%.40 Maupin et al demonstrated in the first 2 months of the pilot on the medical/oncology unit, only one code blue occurred on the unit, representing a decrease of 70%. The number of RRT calls increased by 246%. From the start of house-wide spread on August 5, 2008, through August 2009, code blues outside the ICU decreased from 0.77 to 0.39 per 1000 patient days, representing a house-wide 50% decrease in code blues when compared with the same period in 2007. RRT calls increased by 110%.31 In 2010, Robb and Seddon reported a 2.5-fold increase in RRT calls, from 27.5 per month to 70 per month after initiation of an EWS system in a New Zealand hospital.44

ECONOMIC IMPACT OF EARLY WARNING SCORE IMPLEMENTATION

The evidence to date regarding the economic impact of EWS implementation is largely indirect, focusing on cost avoidance through improved patient outcomes and efficiency improvements.

Cardiac arrests are extremely costly and impact resources, staff time, and general expenses related to the care of these patients. A cardiac arrest leads to emergency transfer to a higher level of care, increased patient monitoring, and increased nursing supervision. An in-hospital cardiac arrest patient has an average LOS of approximately 2 weeks, thus leading to increased short- and long-term hospital costs. In a recent analysis, Chan et al found that in-hospital cardiac arrest patients had mean inpatient costs of around $7741 at 30 days and $18 629 in the first year, with cumulative incident rates of 35 readmissions per 100 patients during the first 30 days and 185 readmissions per 100 patients at 1 year.45 It is anticipated that introducing an EWS will improve patient outcomes by reducing the number of unplanned admissions to the ICU and reducing the number of cardiac respiratory arrests. Patients who experience a cardiac respiratory arrest could spend a number of days in the ICU, thus savings would be expected because of the reduction in use of ICU beds, as well as potential savings on follow-up treatments for disability that the patient may suffer.
Evidence of Clinical Decision Support Solutions

As noted above, vital signs, and in particular respiratory rate, are often not reliably measured and EWS are therefore often not correctly calculated. Technology can help facilitate the measurement of vital signs, derive an EWS automatically, and provide caregivers a prompt on what to do next. Evidence suggests that relying on manual charting (i.e., “spot checking” every 4 hours) of vital signs can often result in infrequent measurements, incomplete datasets, and errors in EWS calculations. Thus, improving these processes through the incorporation of new technologies can have wide-ranging benefits.

Schmidt et al described the impact of introducing an electronic physiological surveillance system (EPSS) on hospital mortality. The study used software that prompted nurses to record complete vital signs at the patient’s bedside at appropriate intervals on handheld devices; researchers then used the physiological value along with the locally embedded aggregate weighted EWS to assign a weighting for each patient, based on the difference between the physiological value and the predetermined normal range. The EPSS then automatically calculated the patient’s EWS and provided instantaneous bedside decision support to the clinical staff. The authors concluded that these data provided evidence that increasing the reliability of the collection, documentation, and display of vital signs in the hospital was associated with a significant reduction in patient mortality.

Bellomo et al reported on a study involving close to 20,000 patients and 10 hospitals on 3 different continents. They found that the use of an automated clinical decision support system — when compared with hospitals’ previous practices for measuring vital signs and calculating EWS to activate an RRT — is associated with increased survival immediately after RRT treatment, shorter median hospital LOS in patients in the U.S. hospitals included in the study, and shorter time to complete and record a set of vital signs.

Kang et al studied the eCART algorithm, which uses HL7 feeds from laboratory information systems and bedside vital signs monitors, integrated into a scoring database where scores were calculated in real time and stored without visualization for clinical providers. Timing and sensitivity of EWS-based RRT activation were compared with standard-of-care RRT activation for patients who experienced a ward cardiac arrest or ICU transfer. Real-time EWS calculation detected four times as many cardiac arrests and 50% more ICU transfers than the standard, nurse-led RRT activation system. In addition, patient EWS values met the high-risk criteria about 8 hours before standard RRT activation and the intermediate-risk criteria about 1 day before RRT activation.

In a study conducted by Jones et al, spot-check vital signs data and observations were taken manually and recorded into a personal digital assistant (PDA) at the bedside, connected to a wireless network. Automated electronic alerts were then issued directly to doctors based on EWS values. Results demonstrated a reduction in hospital LOS by 2.8 days after implementation. EWS accuracy improved 81% to 100% with electronic calculation. EWS protocol compliance, as measured by documentation of clinical responses dictated by institutional procedures, increased from 29% to 78% for patients with an EWS of 3 to 5 and from 67% to 96% for patients with an EWS of >5.

Churpek et al conducted a study using HL7 feeds from laboratory information systems, and bedside vital sign monitors were integrated into a scoring database where scores were calculated in real time and stored without visualization for clinical providers. Results demonstrated the median time to ICU transfer from first critical EWS value was 5.4 hours. Delayed transfer (>6 hours) occurred in 46% of patients and was associated with increased mortality compared with patients transferred early (33% vs. 25%). Each 1-hour increase in delay was associated with an adjusted 3% increase in odds of mortality. In patients who survived to discharge, delayed transfer was associated with longer hospital LOS (median, 13 vs. 11 days).

In a 2016 study of more than 6500 patients by Pullinger et al, the authors implemented an automated, electronic observation chart system with automated EWS calculation using bedside vital sign entry on networked mobile devices. The authors found that, after implementation, 93% of patients had an accurate EWS compared with 53% of patients before implementation.

Consistency of Evidence to Date

Evidence to date supporting the clinical benefit of EWS implementation is inconsistent, likely due to a number of factors. With several hundred unique yet similar EWS systems in use worldwide, there can be substantial institution-to-institution variability in EWS implementation. Along these lines, slight differences in EWS calculation and RRT calling criteria can have significant impact on clinical outcomes. In addition to errors in calculation, evidence suggests that EWS implementation can be suboptimal.

Along these lines, the accuracy and predictive value of any EWS calculation is only as good as the accuracy of its individual components. As noted above, respiratory compromise is a strong predictor of impending cardiac arrest, but respiratory rate remains one of the most poorly documented physiological parameters. Thus any errors (or omissions) in respiratory rate will be carried over into the EWS and reduce the ability of the EWS to accurately describe the patient’s condition.
In a 2009 study, Robb et al showed that although RRT calls increased from 27.5 per month to 70.5 per month, only 30% of activation findings resulted in a call, suggesting that the true increase in activation should have been nearly ten-fold to >200 per month. The study found no clinical benefit after their EWS implementation, despite a steep escalation in RRT calls. However, the authors reported that the RRT was only activated in 30% of indicated situations, per the EWS. For this study, failure to truly implement the EWS RRT activation loop may have been responsible for the lack of clinical benefit in this study.44 Along these lines, Subbe et al showed significant, high inter-rater variability on whether a given MEWS profile warranted a trigger action. The study also showed that MEWS was correctly calculated less than 80% of the time by nurses in a live setting.52

In addition to inconsistent implementation of RRT-calling criteria, several studies have highlighted the inconsistency of vital sign monitoring, especially at night. In a 2013 study, Hands et al compared the pattern of vital signs and VitalPAC Early Warning Score (ViEWS) data collected from admissions to all adult inpatient areas to the hospital's clinical escalation protocol; 950,043 vital sign datasets were recorded. The daily pattern of observation documentation was not uniform; there were large morning and evening peaks, and lower nighttime documentation. Approximately 24% of vital sign datasets with ViEWS ≥9 were measured at night as compared with 10% to 20% for other ViEWS values. Half of patients with ViEWS values of 7 to 8 and approximately one-third of those with ViEWS ≥9 in the period 20:00 to 23:59 did not have vital signs recorded in the following 6 hours. These authors concluded there was only partial adherence to the vital sign monitoring protocol. Sicker patients appeared more likely to have vital signs measured overnight, but even their observations were often not followed by timely repeat assessments.46 Similarly, Gordon and Beckett found that only 21% of night-shift charts had complete and correct SEWS documentation, with no calculation in 55% of charts and incorrect calculation in 21% of charts. One or more observation was missing in 84% of charts.53 In the 2016 study by van Galen et al, while early warning protocol adherence was 89%, MEWS values were calculated incorrectly 18% of the time.55

**SUMMARY**

Early warning scores provide an integrated parameter for tracking changes in patient physiology. While the evidence to date is somewhat inconsistent, early warning systems, mostly using vital sign abnormalities, seem to reasonably predict the occurrence of cardiac arrest and death within 48 hours of measurement. Evidence also suggests that they may predict risk of intensive care admission and length of hospital stay. While there may not be a sufficient body of evidence to support the argument that the use of an EWS alone is the answer, many studies have provided evidence of improvements in early detection of deterioration and/or outcome measures since the introduction of an EWS. The continued integration and optimization of clinical decision support technology into early warning systems has the potential to improve the overall implementation of the system, thus increasing the ability of the system to accurately identify patients in need of increased care while potentially reducing clinical staff workloads and improving work flow.