

**REVIEW ARTICLE**

## Cardiology

# Predicting cardiac arrest in the emergency department

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**Abstract**

In-hospital cardiac arrest remains a leading cause of death: roughly 300,000 in-hospital cardiac arrests occur each year in the United States,  $\approx 10\%$  of which occur in the emergency department. ED-based cardiac arrest may represent a subset of in-hospital cardiac arrest with a higher proportion of reversible etiologies and a higher potential for neurologically intact survival. Patients presenting to the ED have become increasingly complex, have a high burden of critical illness, and face crowded departments with thinly stretched resources. As a result, patients in the ED are vulnerable to unrecognized clinical deterioration that may lead to ED-based cardiac arrest. Efforts to identify patients who may progress to ED-based cardiac arrest have traditionally been approached through identification of critically ill patients at triage and the identification of patients who unexpectedly deteriorate during their stay in the ED. Interventions to facilitate appropriate triage and resource allocation, as well as earlier identification of patients at risk of deterioration in the ED, could potentially allow for both prevention of cardiac arrest and optimization of outcomes from ED-based cardiac arrest. This review will discuss the epidemiology of ED-based cardiac arrest, as well as commonly used approaches to predict ED-based cardiac arrest and highlight areas that require further research to improve outcomes for this population.

**KEYWORDS**

cardiac arrest, deterioration, early warning scores, machine learning, prediction, quality improvement, triage

## 1 | INTRODUCTION

Despite modest improvement in survival over recent years, in-hospital cardiac arrest remains a leading cause of death, with  $\approx 300,000$  in-hospital cardiac arrest events per year in the United States.<sup>1,2</sup> Although conventional classification of cardiac arrest distinguishes between out-of-hospital cardiac arrest and in-hospital cardiac arrest, less focus has been placed on patients who develop cardiac arrest in the emergency department before admission to inpatient services.

ED-based cardiac arrest represents a unique subset of arrest patients with a potentially higher proportion of reversible etiologies

and a higher potential for neurologically intact survival than out-of-hospital cardiac arrest patients delivered to the ED.<sup>3</sup> Patients in the ED are vulnerable to unrecognized deterioration due to a combination of crowded EDs, variable frequency of vital sign observations, and long boarding times for both inpatient and critical care beds.<sup>4-7</sup> Without recognition and appropriate management, patients who deteriorate in the ED may progress to ED-based cardiac arrest. Interventions to facilitate earlier identification of patients who experience deterioration in the ED could allow for both prevention of cardiac arrest and optimization of outcomes from ED-based cardiac arrest.

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In this review, we will discuss the epidemiology of ED-based cardiac arrest, outline the commonly used methods that can be used to predict ED-based cardiac arrest, and highlight areas in need of further research.

## 2 | EPIDEMIOLOGY OF CARDIAC ARREST IN THE EMERGENCY DEPARTMENT

Despite representing almost 10% of in-hospital cardiac arrest cases, ED-based cardiac arrest has only seldom been investigated as a distinct group.<sup>3,8-10</sup> Patients who progress to ED-based cardiac arrest have a number of features associated with more favorable outcomes: they are more likely to have a ventricular arrhythmia as the initial rhythm, to have early delivery of chest compressions, and to have more prompt defibrillation when compared to patients with out-of-hospital cardiac arrest or non-ED in-hospital cardiac arrest.<sup>3,10</sup> They are also less likely to have known co-morbidities, including a number of conditions commonly associated with poor outcome from in-hospital cardiac arrest such as sepsis, liver disease, and malignancy.<sup>3,11-13</sup>

Likely related to a lower burden of co-morbidity and more favorable cardiac arrest characteristics, patients with ED-based cardiac arrest may have better outcomes than patients with either out-of-hospital cardiac arrest or non-ED in-hospital cardiac arrest. The largest study to date, a retrospective analysis of over 60,000 in-hospital cardiac arrest events from the Get With the Guidelines Resuscitation registry, found that 22.8% of patients with ED-based cardiac arrest survived to hospital discharge, compared to 10.8% of those with in-hospital cardiac arrest in the ward setting, 15.5% of in-hospital cardiac arrest in intensive care units, and 19.8% of in-hospital cardiac arrest on telemetry units. ED-based cardiac arrest was also associated with better neurological outcomes and a shorter length of hospital stay.<sup>3,14</sup>

Efforts to identify patients who may progress to ED-based cardiac arrest have traditionally been approached through identification of critically ill patients through triage on arrival to the ED and the identification of patients who unexpectedly deteriorate during their stay in the ED.<sup>15-17</sup> Each of these approaches has significant limitations.

## 3 | TRIAGE AS A SCREEN FOR EMERGENCY DEPARTMENT-BASED CARDIAC ARREST RISK

Although a minority of patients who present to the ED require admission in most ED environments, there is a substantial, and growing, proportion of this admitted population that is critically ill.<sup>18,19</sup> Initial triage has been the longstanding strategy to identify these patients before full evaluation. The concept of early triage was first conceived by Dominique Jean Larrey, a military surgeon in the army of Napoleon Bonaparte, who developed a three-tier rule to identify patients at most urgent need for medical care.<sup>20</sup> The concept of

triage remains largely unchanged over the past 200 years: to identify patients who require urgent medical attention to allocate resources appropriately.

Accurate triage is essential, not just to identify patients who are critically ill on arrival to the ED, but also to mobilize specialist teams for time-sensitive conditions such as acute coronary syndrome, stroke, and sepsis. An ideal triage system would also be able to identify patients at high risk of further deterioration and subsequent ED-based cardiac arrest to facilitate prompt clinical intervention. Triage systems range from simple algorithms to complex triage scores. Such systems have been designed to avoid both under-triage of patients who have time-sensitive or critical illness and over-triage of patients who could safely wait longer for clinical assessment. However, despite these intentions, evidence suggests that ED triage systems are often inadequate to achieve these goals.<sup>21-23</sup>

### 3.1 | Simple algorithmic triage

Widely used across the world, algorithmic triage scores are simple to understand and require no complex calculation. The Emergency Severity Index (ESI) and Canadian Emergency Department Triage and Acuity Scale (CTAS) are most commonly used in the United States and Canada, respectively, while the Manchester triage system (MTS) is the most commonly used triage scale in the United Kingdom (UK) and Europe.<sup>16,24,25</sup> Using a combination of the presenting complaint and an initial set of vital signs, patients are assigned a triage score to reflect the urgency of care required and expected consumption of ED resources.<sup>16,26</sup> Such scores rely heavily on subjective assessment of the urgency of presentation and are limited by variable inter-rater reliability and unreliable triage accuracy in clinical practice.<sup>22,23</sup> Additional criticisms of algorithmic triage scores include a lack of ability to discriminate between non-critically ill patients, with the majority of patients falling into a low- to mid-risk category, with both under- and over-triage of a high proportion of patients.<sup>21,27</sup>

Studies assessing and comparing the ability of such scores to predict ED-based cardiac arrest are lacking, and the few published studies are limited by a low frequency of ED-based cardiac arrest. Despite these limitations, two large retrospective studies have demonstrated associations between higher triage categories and risk of death in the ED.<sup>15,28</sup> The larger of these, a retrospective analysis of over 300,000 ED visits found that 245 out of the 284 patients who died were triaged to an MTS score of red, the highest of the five urgency categories, with a sensitivity of just over 85%.<sup>15</sup> van der Wulp and colleagues performed a retrospective analysis of almost 40,000 ED visits across four EDs in the Netherlands.<sup>28</sup> Although they also found a statistically significant association between triage category and death, they were unable to calculate the strength of the association due to low mortality rates.<sup>28</sup> The accuracy of these scores in predicting ED-based cardiac arrest and whether one score outperforms another has not been well characterized.

### 3.2 | Aggregate-weighted scores at triage

The majority of in-hospital cardiac arrest cases are preceded by worsening vital signs, changes in mentation, and other signs of physiologic instability.<sup>29–31</sup> Although many triage scores integrate grossly abnormal single vital sign abnormalities into their algorithms, such approaches struggle to identify patients who present with multiple subtle aberrancies.<sup>32</sup> The desire to identify such patients early in the course of their decompensation has led to the development and use of aggregate-weighted scores in both in-hospital settings and a limited number of ED environments, which quantify the degree of abnormality across multiple vital signs.

Originally developed for use in detecting in-hospital deterioration in admitted patients, aggregate weighted scores such as the national and modified early warning scores are used widely in EDs in the UK.<sup>17</sup> A number of other triage scores have been specifically developed for use in the ED, with some of the best known being the rapid emergency medicine score and the Triage in Emergency Department Early Warning Score (TREWS).<sup>33,34</sup> However, many early warning scores were designed and validated for hospitalized patients, a population entirely distinct from that seen at ED triage. Only a few studies have investigated the performance of triage early warning scores in identifying or preventing ED-based cardiac arrest and most are limited by retrospective or single center design.<sup>35–38</sup> However, there is an increasing body of evidence that early warning scores may be useful in identifying patients at high risk of in-hospital mortality when used at triage.<sup>14,39–41</sup>

Of the numerous early warning scores, the Modified Early Warning Score, National Early Warning Score, and Rapid Emergency Medicine Score are the best studied in the ED.<sup>42</sup> The Modified Early Warning Score has the advantage of being the most studied early warning score in the ED.<sup>42</sup> Although most studies were retrospective, the Modified Early Warning Score has been validated across a range of countries and has been shown to predict in-hospital mortality with acceptable accuracy (area under the receiver operating characteristic curve [AUC] ranging between 0.630 and 0.891 in several studies).<sup>38,39,43</sup> Despite being widely used in the UK, the National Early Warning Score is not well studied in the ED. Alam and colleagues prospectively studied the ability of the National Early Warning Score to prognosticate patients during their ED stay and found that the National Early Warning Score at triage was strongly associated with 30-day mortality and ICU admission, but did not investigate the specific association with ED-based cardiac arrest or quantify the accuracy of the National Early Warning Score.<sup>44</sup> A prospective multicenter observational study comparing the accuracy of rapid emergency medicine score and modified early warning scores for in-hospital mortality found that rapid emergency medicine score performed better than the Modified Early Warning Score (AUC 0.707 and 0.630, respectively).<sup>43</sup> Of the early warning scores commonly used, the National Early Warning Score and the Modified Early Warning Score have the additional advantage that they have been well validated in the inpatient population as well as in the ED and could be integrated into a hospital-wide early warning score.

### 3.3 | Machine learning at triage to improve risk prediction

With the widespread adoption of the electronic medical record in EDs across the world, much excitement has been generated around the field of machine learning to improve diagnosis and treatment via electronic medical record-linked analytics. By incorporating much more granular information than conventional aggregate weighted scores, machine learning allows for the development of complex scoring systems using hundreds of variables to predict a range of adverse outcomes.

Machine learning has been applied to the field of ED triage, and several machine learning triage scores have been developed and validated for this purpose. Machine learning triage scores are able to integrate complex data and produce highly accurate triage scores that outperform conventional scoring systems such as the ESI and the National Early Warning Score.<sup>45–47</sup> Ong and colleagues developed a machine learning triage score specifically to predict cardiac arrest within 72 hours of ED triage that performed substantially better than modified early warning scores in a prospective observational study (AUC 0.781 vs 0.680).<sup>45</sup> Despite the impressive performance of these machine learning scores, studies investigating the impact of machine learning triage scores on patient outcomes are lacking.

## 4 | IDENTIFICATION OF DETERIORATION IN THE EMERGENCY DEPARTMENT

As hospitals continue to struggle with crowding, patients are spending a longer amount of time in the ED, either waiting for assessment, or as boarders awaiting admission to inpatient or critical care units.<sup>48</sup> This time represents a particularly vulnerable period, which has consistently been associated with a range of adverse patient outcomes, including increased mortality.<sup>49,50</sup> Although attention has been paid to identification of patients who are already sick on arrival to the ED or those who may require a high level of resources during their hospitalization, the characteristics of patient deterioration during their stay in the ED is less well described.

Delayed assessment and management of deteriorating patients has long been associated with worse outcomes in hospitalized inpatients.<sup>51</sup> This has led to the establishment of rapid response systems (RRS), which are hospital-wide efforts to identify and respond to such patients. The RRS is a multi-tiered approach to patient safety, composed of an identification and notification system which recognizes deterioration and triggers the time-sensitive response of a rapid response team or other specialist team to respond to specific emergencies such as marked clinical deterioration, cardiac arrest or pulmonary embolism.<sup>52,53</sup> Some scholars have called for a similar approach to ED patients in an attempt to identify deteriorating patients prior to clinical decompensation.<sup>54</sup>

Deterioration is common in the ED, even in patients admitted with “normal” vital signs, and is unsurprisingly associated with worse patient outcomes.<sup>55–57</sup> Without regular reassessment and close monitoring,

patients in the ED are at high risk of unrecognized deterioration.<sup>58</sup> Although not all cardiac arrest is predictable, the majority of in-hospital cardiac arrest is preceded by deterioration of patient vital signs. Quantifying the impact of delayed assessment and intervention in this vulnerable population remains challenging; however, analyses of adverse events within hours of hospital admission from the ED have suggested that abnormal vital signs are frequently present on hospital admission, raising the possibility of identifying some of these patients earlier.<sup>59,60</sup>

#### 4.1 | Early warning scores

The use of serial early warning scores has not been robustly studied in the ED, although the predictive ability of these scores is well-established in inpatient units.<sup>44,61,62</sup> A prospective observational study of the performance of early warning score in a European ED demonstrated that National Early Warning Score was able to predict hospitalization, length of stay, ICU admission, and mortality.<sup>44</sup> Another prospective observational study demonstrated the use of serial early warning scores to characterize a patient's clinical trajectory, with decreasing early warning scores correlating with better outcomes.<sup>41</sup> However, to the best of our knowledge, there are no studies that have examined the impact of actually implementing an early warning score system in an ED setting on patient outcomes. A survey of over 250 UK EDs demonstrated that early warning scores were used in the vast majority, despite the lack of robust evidence in this population.<sup>17</sup>

### 5 | RESEARCH GAPS AND AREAS OF UNCERTAINTY

ED-based cardiac arrest remains a relatively understudied population in contrast to other subsets of in-hospital cardiac arrest. A more comprehensive understanding of the epidemiology and etiology of this subset of cardiac arrest could help to identify factors that could further improve outcomes for this population. A focus on identification and management of patients who are at high risk of deterioration may help to reduce the rates of ED-based cardiac arrest, but this approach has not been robustly studied in the ED.

The performance of individual triage approaches has been well-characterized; however, there are many fundamental gaps in our understanding of how best to predict ED-based cardiac arrest at the point of triage. The paucity of data comparing the ability of triage methods to identify ED-based cardiac arrest leaves EDs with a choice between using newer, increasingly complex, triage scores without a strong base of evidence, and simpler triage methods that were neither designed for, nor well validated for this purpose.

The widespread availability of the electronic medical record might allow for the opportunity to integrate more complex and automated scoring systems: optimizing accuracy at triage and in detecting patient deterioration, while simultaneously obviating the need for subjective assessment, manual calculations, and human error. However, this area

is in need of well-designed, prospective studies of scores that have been designed for, and validated in, ED patient cohorts.

As patients continue to spend increasing amounts of time in the ED, it is imperative that clinical deterioration is identified prior to ED-based cardiac arrest. The question of whether or not scores can identify patients at risk of ED-based cardiac arrest has now been answered: it is clear that highly accurate scores can be developed for the ED population, either by using aggregate weighted scores or by developing complex automated machine learning early warning scores. However, such scores represent only one limb of the RRS and must be built into a system that can identify, assess, and intervene on deteriorating patients in order to change outcomes.

### 6 | CONCLUSIONS

Patients admitted to the ED are at a high risk of unrecognized clinical deterioration. Focusing efforts on the prediction and prevention of ED-based cardiac arrest could further improve outcomes for this vulnerable population.

#### AUTHOR CONTRIBUTIONS

OJLM, DPE, and BSA, all contributed substantially to the conception, drafting, literature review, and writing of the manuscript. All authors have reviewed the current version of the manuscript, give their approval for its publication, and agree to be accountable for all aspects of this work.

#### CONFLICT OF INTEREST

OJLM has no relevant conflicts of interest to declare. DPE is a co-developer of eCART, an early warning tool, which is currently patent pending (ARCD.P0535US.P2). She has an equity interest in AgileMD which commercially deploys eCART and other clinical decision support tools on its own platform and in conjunction with Philips Healthcare and EarlySense. She has received research support and/or speaking honoraria from both Philips and Early Sense. BSA has no relevant conflicts of interest to declare.

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