Differences in Vital Signs Between Elderly and Nonelderly Patients Prior to Ward Cardiac Arrest

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Objectives: Vital signs and composite scores, such as the Modified Early Warning Score, are used to identify high-risk ward patients and trigger rapid response teams. Although age-related vital sign changes are known to occur, little is known about the differences in vital signs between elderly and nonelderly patients prior to ward cardiac arrest. We aimed to compare the accuracy of vital signs for detecting cardiac arrest between elderly and nonelderly patients.

Design: Observational cohort study.

Setting: Five hospitals in the United States.

Patients: A total of 269,956 patient admissions to the wards with documented age, including 422 index ward cardiac arrests.

Interventions: None.

Measurements and Main Results: Patient characteristics and vital signs prior to cardiac arrest were compared between elderly (age, 65 yr or older) and nonelderly (age, < 65 yr) patients. The area under the receiver operating characteristic curve for vital signs and the Modified Early Warning Score were also compared. Elderly patients had a higher cardiac arrest rate (2.2 vs 1.0 per 1,000 ward admissions; $p < 0.001$) and in-hospital mortality (2.9% vs 0.7%; $p < 0.001$) than nonelderly patients. Within 4 hours of cardiac arrest, elderly patients had significantly lower mean heart rate (88 vs 99 beats/min; $p < 0.001$), diastolic blood pressure (60 vs 66 mm Hg; $p = 0.007$), shock index (0.82 vs 0.93; $p < 0.001$), and Modified Early Warning Score (2.6 vs 3.3; $p < 0.001$) and higher pulse pressure index (0.45 vs 0.41; $p < 0.001$) and temperature (36.4°C vs 36.3°C; $p = 0.047$). The area under the receiver operating characteristic curves for all vital signs and the Modified Early Warning Score were higher for nonelderly patients than elderly patients (Modified Early Warning Score area under the receiver operating characteristic curve 0.85 [95% CI, 0.82–0.88] vs 0.71 [95% CI, 0.68–0.75]; $p < 0.001$).

Conclusions: Vital signs more accurately detect cardiac arrest in nonelderly patients compared with elderly patients, which has important implications for how they are used for identifying critically ill patients. More accurate methods for risk stratification of elderly patients are necessary to decrease the occurrence of this devastating event. (*Crit Care Med* 2015; 43:816–822)

Key Words: aged; early diagnosis; heart arrest; hospital rapid response team; physiologic monitoring; quality improvement

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Preliminary versions of these data were presented at the 2012 meeting of the American Thoracic Society, San Francisco, CA, May 20, 2012.

Dr. Churpek provided expert testimony for Rothenburg law firm, disclosed a patent pending (ARCD. P0535US.P2–for risk stratification algorithms for hospitalized patients), and received support for article research from the National Institutes of Health (NIH). His institution received grant support from the NIH-National Heart, Lung, and Blood Institute (NHLBI) (career development award from the NHLBI [K08 HL121080]). Dr. Winslow's institution received grant support from the University of Chicago Pilot and Collaborative Translations and Clinical Studies Award. Dr. Hall provided expert testimony for law firms for patients, hospitals, and health providers; received royalties from McGraw Hill and American College of Chest Physicians (textbooks); and has stock options with Vanguard (Health industry mutual funds). Dr. Edelson has disclosed a patent pending (ARCD. P0535US.P2–for risk stratification algorithms for hospitalized patients); has ownership interested in Quant HC (Chicago, IL–which is developing products for risk stratification of hospitalized patients); and received support for article research from the NIH. Her institution consulted for Early Sense and received grant support from the NHLBI (K23 HL097157); Philips Healthcare (Andover, MA); the American Heart Association (Dallas, TX); and Laerdal Medical (Stavanger, Norway). Mr. Yuen has disclosed that he does not have any potential conflicts of interest.

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DOI: 10.1097/CCM.0000000000000818

In-hospital cardiac arrest causes a substantial healthcare burden, and some of these events are thought to be preventable (1–3). In particular, arrests that occur on the general hospital wards are often due to errors in triage, diagnosis, and treatment of the underlying condition (3). Vital signs are often an important component of the decision-making process regarding whether to transfer a critically ill patient to the ICU or allow them to remain in the wards. In addition, composite scores of vital sign derangement, such as the Modified Early Warning Score (MEWS) (4), are often used to trigger calls to the rapid response team (RRT) and aid with these decisions. However, the utility of these scores has been called into question given their variable accuracy and the mixed results of the

RRT literature for their effect on important outcomes, such as in-hospital mortality (5).

Increasing age is known to be an independent risk factor for adverse events in the hospital for critically ill patients (6, 7). In addition, changes in vital signs are known to occur with age (8, 9). However, the implications of these changes on vital signs prior to ward cardiac arrest are poorly characterized. If differences between elderly and nonelderly patients were discovered, it could have important implications regarding how vital signs and early warning scores are used for the identification and triage of high-risk ward patients. Therefore, we aimed to investigate the differences in vital signs between elderly and nonelderly patients in a multicenter cohort of hospitalized patients. We hypothesized that vital signs would be less deranged and therefore less accurate before cardiac arrest in elderly patients.

METHODS

Study Population and Setting

We conducted an observational cohort study at five hospitals (the University of Chicago and four NorthShore HealthSystem Hospitals—Evanston, Glenbrook, Highland Park, and Skokie) that included adult patients hospitalized in the wards from the period of November 2008 to January 2013. The University of Chicago is an urban tertiary-care university hospital, Evanston and Glenbrook are suburban teaching hospitals, and Highland Park and Skokie are community nonteaching hospitals. All hospitals had nurse-led RRTs in place during the study period. The study protocol was approved by the University of Chicago Institutional Review Board, with a waiver of consent, which was granted based on minimal harm and general impracticability (IRB #16995A).

Data Collection

Cardiac arrest, defined as the loss of a palpable pulse with attempted resuscitation, was collected via a prospective quality improvement database at the University of Chicago that has been previously described (10) and through a prospectively collected log at NorthShore University HealthSystem. All arrests underwent manual review to ensure data quality, and only a patient's index arrest in the wards was used in the analyses if they suffered more than one event. Patients who died in the wards without attempted resuscitation were not counted as cardiac arrests because these were most likely expected deaths in patients with do-not-resuscitate orders. Routinely collected vital signs (temperature, respiratory rate, heart rate, arterial blood pressure, and peripheral oxygen saturation) were collected from the electronic health record at the University of Chicago (Epic; Verona, WI) and an electronic data warehouse at NorthShore. All event and vital sign data were time and location stamped. Patient characteristics were obtained from administrative databases at all hospitals.

Statistical Analysis

Patient characteristics were compared between elderly (age, 65 yr or older) and nonelderly (age, < 65 yr) patients using *t* tests and chi-square tests for continuous and categorical data, with the exception of MEWS, oxygen saturation, and length of stay, which were presented as median (interquartile range [IQR], 25–75) and compared using the Wilcoxon rank sum due to their skewed distributions. Ward vital signs in the entire dataset were compared between elderly and nonelderly patients using a mixed-effects regression model with patient-level random effects to account for the correlation among values from the same patient. Vital signs within 4 hours of a patient's index ward cardiac arrest were then compared between these groups using the same method. The 4-hour time period was chosen because patients in this study typically had vital signs checked every 4 hours while in the wards. Vital sign trajectories in the 24 hours prior to arrest were then compared visually using restricted cubic splines with three knots. Mixed-effects models were fit to test the difference in vital sign trajectory using a model with a random intercept at the patient level and an autoregressive correlation structure. This method not only accounts for the correlation of values from the same patient but also the fact that vital signs measured closer together in time are more likely to be highly correlated than those measured farther apart (11). Each vital sign was separately modeled as the outcome variable with time and a time-age group interaction variable in the model. A statistically significant interaction term was used to define a difference in the vital sign slope between elderly and nonelderly patients.

A MEWS score was then calculated for each observation time for each patient in the entire dataset (4). If a vital sign was missing that was necessary for the calculation at a specific time point, then the previous value was carried forward. If no values were available, then a median value was imputed because these values are likely to be normal (6). The MEWS was then compared between elderly and nonelderly patients in its overall distribution in the dataset, the values 4 hours prior to cardiac arrest, and trajectory prior to the event using the same methods as for the individual vital signs.

Finally, the area under the receiver operating characteristic curve (AUC) was calculated for each individual vital sign for elderly and nonelderly ward patients for cardiac arrest by using the highest and lowest values during the ward admission for those who suffered an arrest compared to those discharged alive without suffering an arrest or ward to ICU transfer during their admission (12). A similar analysis was performed for the MEWS using the highest value for each patient during their ward admission. Patients were then separated into deciles of age, and the MEWS AUC analysis was repeated and compared to the prevalence of cardiac arrest in each age group. Finally, a sensitivity analysis was performed where age greater than or equal to 75 was considered elderly instead of age greater than or equal to 65 for the MEWS comparisons. All analyses were performed using Stata version 12.1 (Stata, College Station, TX), with a two-tailed *p*-value less than 0.05 denoting statistical significance.

RESULTS

A total of 269,999 patient admissions occurred during the study period, of which 43 patients did not have age documented during their stay. This resulted in a total of 269,956 patient admissions and 422 index ward cardiac arrests for study inclusion. All vital signs had less than 5% missing except for oxygen saturation (12%) and Alert, responds to Voice, responds to Pain, Unresponsive (AVPU) scale (28%). Variable missingness was similar between elderly and nonelderly patients except that elderly patients were more likely to be missing blood pressure (4% vs 3%) and less likely to be missing AVPU (23% vs 32%) than nonelderly patients. Elderly patients accounted for 46% of the study population (n = 123,671) and 65% of the ward cardiac arrests (n = 273). Elderly patients were less likely to be female (56% vs 64%; $p < 0.001$), less likely to be black (13% vs 23%; $p < 0.001$), and had a higher cardiac arrest rate (2.2 vs 1.0 per 1,000 ward admissions; $p < 0.001$) and in-hospital mortality (2.9% vs 0.7%; $p < 0.001$) compared with nonelderly patients (**Table 1**). In addition, elderly patients presented more often with asystole than nonelderly patients (23% vs 14%), but these differences in initial rhythm were not statistically significant between the two groups ($p = 0.06$). Comparisons between the vital signs of elderly and nonelderly patients in the entire dataset are shown in **Table 2**, which were all significantly different ($p < 0.001$). Of note, although statistically significant, the MEWS and its distribution were similar in both patient groups using the entire dataset (median MEWS of 1 [IQR, 1–2]). In addition, the MEWS was similar at the time of ICU transfer for nonelderly (median MEWS of 2 [IQR, 1–4]) and elderly (median MEWS of 2 [IQR, 1–3]) patients.

In the 4 hours before cardiac arrest, elderly patients had lower mean heart rate (88 vs 99 beats/min; $p < 0.001$), diastolic blood pressure (60 vs 66 mm Hg; $p = 0.007$), shock index (0.82 vs 0.93; $p < 0.001$), respiratory rate (22 vs 23 breaths/min; $p = 0.05$), and MEWS (median 2 vs 3; $p < 0.001$) and higher pulse pressure index (0.45 vs 0.41; $p < 0.001$) and temperature (36.4°C vs 36.3°C; $p = 0.047$) (**Table 3**). In addition, respiratory rate and pulse pressure index trajectories were steeper in the 24 hours prior to cardiac arrest for nonelderly compared with elderly patients ($p = 0.001$ and $p = 0.05$). The MEWS trajectory was similar between the two groups prior to the event (**Fig. 1**). The AUCs for the highest and lowest vital signs during the ward stay were greater for nonelderly compared with elderly patients with the exception of the minimum respiratory rate (**Table 4**). The most accurate vital signs for nonelderly patients were the maximum respiratory rate (AUC, 0.82; 95% CI, 0.79–0.86) and heart rate (AUC, 0.77; 95% CI, 0.73–0.81). For elderly patients, the maximum respiratory rate (AUC, 0.67; 95% CI, 0.64–0.71) and the shock index (AUC, 0.67; 95% CI, 0.63–0.70) were the most accurate. The MEWS was significantly more accurate for detecting ward cardiac arrest in nonelderly patients compared with elderly patients (AUC, 0.85; 95% CI, 0.82–0.88 vs AUC, 0.71; 95% CI, 0.68–0.75; $p < 0.001$). A sensitivity analysis performed by changing the definition of elderly to age 75 or greater resulted in similar findings (AUC, 0.81; 95% CI, 0.78–0.83 vs AUC, 0.71; 95% CI, 0.66–0.75; $p < 0.001$). Separating the patients into deciles by age demonstrated an increasing prevalence of cardiac arrest and a decreasing accuracy of the MEWS with increasing age (**Fig. 2**).

DISCUSSION

In this multicenter observational study, we found dramatic differences in the accuracy of vital signs and the MEWS between elderly and nonelderly patients. Importantly, the prevalence of cardiac

TABLE 1. Comparisons of Patient Characteristics Between Elderly and Nonelderly Patients

Characteristic	Elderly Patients (n = 123,671)	Nonelderly Patients (n = 146,285)	Total (n = 269,956)
Age, mean (SD), yr	79 (8)[a]	45 (13)	60 (20)
Female sex, n (%)	69,276 (56)[a]	93,005 (64)	162,281 (60)
Race n (%)			
Black	16,049 (13)[a]	33,621 (23)	49,670 (18)
White	75,142 (61)[a]	65,288 (45)	140,430 (52)
Other/unknown	32,480 (26)[a]	47,376 (32)	79,899 (30)
Cardiac arrests, n (per 1,000 ward admissions)	273 (2.2)[a]	149 (1.0)	422 (1.6)
Initial rhythm of cardiac arrest, n (% out of 422 index arrests)			
Pulseless electrical activity	136 (50)	93 (62)	229 (54)
Ventricular fibrillation or ventricular tachycardia	61 (22)	30 (20)	91 (21)
Asystole	63 (23)	21 (14)	84 (20)
Unknown	14 (5)	6 (4)	20 (5)
Length of ward stay prior to arrest, median (interquartile range), hr (n = 422)	58 (28–152)	57 (23–112)	57 (24–120)
In-hospital mortality, %	2.9[a]	0.7	1.7

[a]p value < 0.05 for comparison between elderly and nonelderly patients.

TABLE 2. Comparisons of Mean Vital Signs and Modified Early Warning Score Between Elderly and Nonelderly Patients in Entire Dataset

Variable	Elderly Patients (n = 123,671)	Nonelderly Patients (n = 146,285)	All Patients (n = 269,956)
Temperature, °C	36.6 (0.6)[a]	36.6 (0.6)	36.6 (0.6)
Respiratory rate, breaths/min	19 (3)[a]	18 (2)	19 (3)
Heart rate, beats/min	80 (16)[a]	84 (16)	82 (16)
Systolic blood pressure, mm Hg[b]	129 (24)[a]	123 (21)	126 (22)
Diastolic blood pressure, mm Hg[b]	66 (13)[a]	71 (13)	69 (13)
Pulse pressure index	0.48 (0.09)[a]	0.42 (0.08)	0.45 (0.09)
Shock index	0.64 (0.18)[a]	0.70 (0.18)	0.67 (0.18)
Oxygen saturation, median (IQR), %	97 (95–98)[a]	98 (96–99)	97 (95–99)
Modified Early Warning Score, median (IQR)	1 (1–2)[a]	1 (1–2)	1 (1–2)

IQR = interquartile range.

[a]p value < 0.001 for comparison between elderly and nonelderly patients.

[b]Blood pressure was noninvasively measured arterial blood pressure.

Pulse pressure index = (systolic blood pressure – diastolic blood pressure)/(systolic blood pressure); Shock index = systolic blood pressure/heart rate.

TABLE 3. Differences in Vital Signs Within 4 Hours of Cardiac Arrest Between Elderly and Nonelderly Patients

Variable	Elderly Patients (n = 273)	Nonelderly Patients (n = 149)	p
Temperature, °C	36.4 (0.7)	36.3 (0.9)	0.047
Respiratory rate, breaths/min	22 (5)	23 (7)	0.050
Heart rate, beats/min	88 (23)	99 (25)	< 0.001
Systolic blood pressure, mm Hg[a]	112 (30)	113 (28)	0.08
Diastolic blood pressure, mm Hg[a]	60 (16)	66 (17)	0.007
Pulse pressure index	0.45 (0.1)	0.41 (0.12)	< 0.001
Shock index	0.82 (0.31)	0.93 (0.32)	< 0.001
Oxygen saturation, median (IQR), %	97 (94–99)	96 (93–99)	0.696
Modified Early Warning Score, median (IQR)	2 (1–3)	3 (2–5)	< 0.001

IQR = interquartile range.

[a]Blood pressure was noninvasively measured arterial blood pressure.

Pulse pressure index = (systolic blood pressure – diastolic blood pressure)/(systolic blood pressure); Shock index = systolic blood pressure/heart rate.

arrest increases with age, whereas the accuracy of the MEWS decreases. Consistent with this finding was the fact that almost all vital signs more accurately detected cardiac arrest in the nonelderly patients compared with elderly patients. In addition, there were differences in which vital signs were most accurate between these groups. These findings have important implications for the risk stratification of hospitalized patients and suggest that those at highest risk of cardiac arrest are the most challenging to detect using routine physiologic measurements. Our work also suggests that, similar to pediatric patients (13–17), the age of the patient should be considered when interpreting vital sign derangements in order to make appropriate triage decisions.

These results add to the literature regarding the association between age, vital signs, and adverse outcomes for adult patients in the wards. For example, Smith et al (18) investigated the relationship between age, vital signs, early warning scores, and in-hospital mortality in a cohort of 9,987 patient admissions. They found that in-hospital mortality was higher for older patients at a given vital sign and MEWS value. In addition, Bleyer et al (19) also showed that in-hospital mortality increased with age for a given number of vital sign derangements. Several studies, including those by Subbe et al (4), Duckitt et al (20), and our group, have shown that adding age to early warning scores can increase their accuracy for detecting adverse outcomes. This is consistent with the inclusion of age in other well-validated risk scores such as the Acute Physiology and Chronic Health Evaluation algorithms (6). Finally, developers of pediatric early warning scores have recognized the

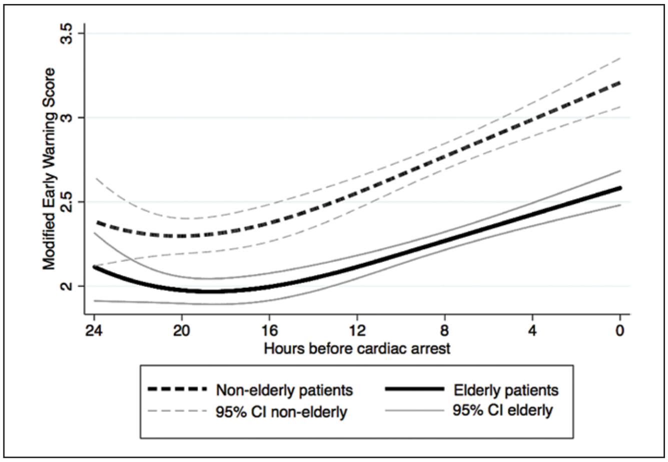

Figure 1. Trajectory of the Modified Early Warning Score in the 24 hours prior to cardiac arrest for elderly and nonelderly patients.

need for age-specific scoring systems given the fact that normal values change with the age of the patient (14–17).

Vital signs are routinely and intermittently collected in ward patients and are often used to make ICU triage decisions and to trigger RRT calls. Age-related changes in vital signs are known to occur, particularly decreases in maximum heart rate and the arterial partial pressure of oxygen (8, 9, 21). In addition, the decrease in vascular compliance and capacitance associated with ageing would be expected to increase systolic blood pressure and decrease diastolic blood pressure for any given stroke volume and hence have an impact on the pulse pressure index dependent on the relative changes in systolic and diastolic pressures (8). In addition, medications taken for medical conditions, such as β-blockers, can blunt the physiologic response to stress and are more commonly used by older patients (22). Another contributing factor to our findings may be that elderly patients have a more limited physiologic reserve compared with nonelderly patients and thus cannot tolerate the same level of derangement in vital signs. For example, cardiac output, vital capacity, creatinine clearance, and the ability to maintain glucose homeostasis are all known to decrease with age (9). Finally, elderly patients were more likely to have a cardiac arrest with asystole as the presenting rhythm in our dataset than nonelderly patients (23% vs 14%). These events are likely less predictable, on average, than cardiac arrests due to other causes, such as the progression of sepsis or respiratory failure. Regardless of the net effects of these wide ranging physiologic explanations, it would not be surprising if different predictive tools based on vital signs would need to be age-adjusted.

Our findings have important implications for how vital signs are used for detecting high-risk ward patients and suggest that a “one-size fits all” approach to early warning scores may not be optimal. This is consistent with findings from the pediatric literature, where the different normal ranges for vital signs are known to vary by age (13). First, the differences in relative accuracy of vital signs within each patient group suggest that having separate early warning scores for elderly and nonelderly patients would be more accurate than a unified risk score for all patients. Second, the fact that the prevalence of cardiac arrest increases with age while vital sign accuracy decreases suggests that the addition of age to risk scores might help mitigate this disparity. In fact, we have previously shown that age is an independent risk factor for ward cardiac arrest in two single-center studies (23, 24), similar to other groups (18–20). Finally, the poor accuracy of the MEWS for elderly patients demonstrates the need to find other predictors of cardiac arrest that could supplement early warning scores for

TABLE 4. Comparisons of Areas Under the Receiver Operating Characteristic Curves Between Elderly and Nonelderly Patients for Whether a Cardiac Arrest Occurred Using the Highest and Lowest Values for Individual Vital Signs and the Modified Early Warning Score[a]

	Highest Value		Lowest Value	
Variable	Elderly	Nonelderly	Elderly	Nonelderly
Temperature	–	0.53 (0.47–0.58)	0.56 (0.52–0.60)	0.65 (0.60–0.70)
Respiratory rate	0.67 (0.64–0.71)	0.82 (0.79–0.86)	0.57 (0.53–0.61)	0.54 (0.49–0.59)
Heart rate	0.63 (0.60–0.67)	0.77 (0.73–0.81)	–	–
Systolic blood pressure[b]	–	0.57 (0.52–0.62)	0.65 (0.61–0.69)	0.67 (0.62–0.73)
Diastolic blood pressure[b]	–	0.59 (0.54–0.64)	0.60 (0.56–0.63)	0.65 (0.60–0.70)
Pulse pressure index	0.48 (0.44–0.52)	0.60 (0.54–0.66)	0.57 (0.54–0.61)	0.68 (0.63–0.73)
Shock index	0.67 (0.63–0.70)	0.76 (0.72–0.81)	–	–
Oxygen saturation	–	–	0.55 (0.51–0.59)	0.69 (0.64–0.74)
Modified Early Warning Score	0.71 (0.68–0.75)	0.85 (0.82–0.88)	–	–

[a]Data presented as area under the receiver operating characteristic curve (95% CI).

[b]Blood pressure was noninvasively measured arterial blood pressure.

Dashes denote that the variable’s area under the receiver operating characteristic curve was statistically worse than 0.50 and thus not predictive in the noted direction.

Pulse pressure index = (systolic blood pressure – diastolic blood pressure)/(systolic blood pressure); Shock index = systolic blood pressure/heart rate.

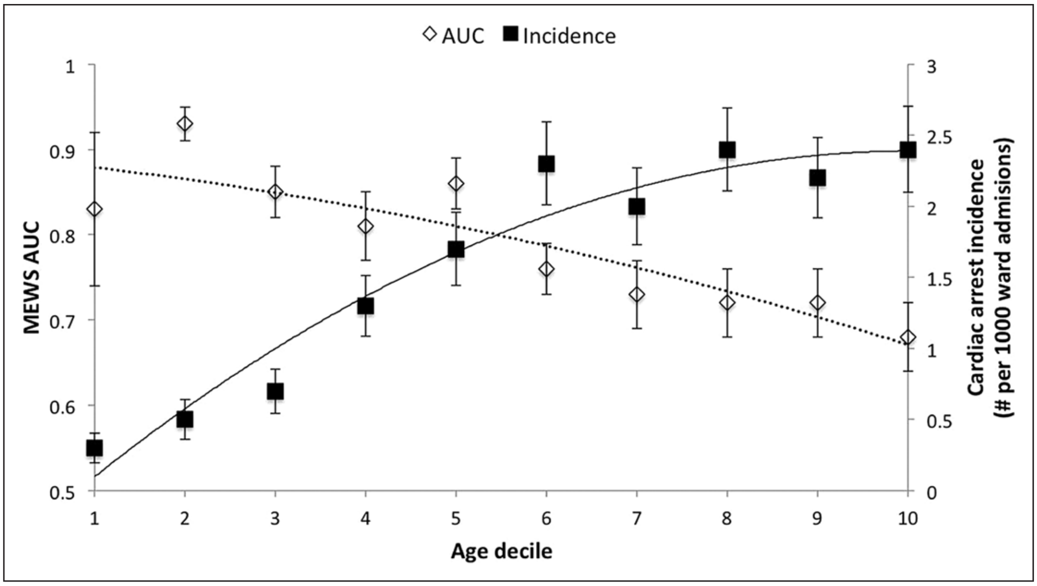

Figure 2. Area under the receiver operating characteristic curve (AUC) of the Modified Early Warning Score (MEWS) and the prevalence of cardiac arrest by deciles of increasing age. *Lines* represent best-fit curves for the trend in AUCs (*dotted*) and cardiac arrest prevalence (*solid*) across age deciles.

these patients. For example, comorbidities, use of medications, such as β-blockers, and admitting diagnosis are all potential variables that could improve the accuracy of these systems.

Our study has several strengths compared with previous investigations. First, our patient population comes from a diverse set of hospitals, including an urban tertiary-care center, two suburban teaching hospitals, and two community nonteaching hospitals. Second, we focused on ward cardiac arrest patients. In our hospital system, these are the patients who would benefit most from an accurate early warning score given the fact that they remained in the wards instead of being transferred to the ICU. Patients who die in the wards would include both these patients and patients who were under comfort care and who would not have benefitted from early detection for life-saving interventions, thereby making mortality a less favorable outcome to investigate. Finally, we not only demonstrated that the risk of arrest increases with age but also investigated the accuracy of vital signs and the MEWS within each age group. This allowed us to highlight the poor accuracy of vital signs for the patients with the highest risk of the event.

Our study also has several limitations. First, we did not have access to patient medication use and comorbidities, which may impact both physiology and a patient's risk of cardiac arrest. However, the vast majority of early warning scores in use today do not account for these variables, so our study provides insight into how vital signs and the MEWS perform in "real-world" use. Second, the cutoff of age 65 is a somewhat arbitrary one for investigating physiological changes. However, this distinction is commonly used in the medical literature, and it has particular relevance in the United States because patients who acquire Medicare coverage are more likely to have access to medications for chronic diseases. In addition, we showed that the accuracy of the MEWS decreased overall across deciles of age and that our findings did not change when altering the definition of elderly to only include patients at least 75 years old. Third, our study involved five hospitals in Illinois, and the results may not be generalizable to other settings or countries. Finally, the exact values of the AUC for different vital signs and the MEWS for cardiac arrest will likely vary across hospitals and countries with varying resources and ICU bed availability. However, our findings have greater generalizability than previous studies given the diverse nature of our multicenter dataset.

CONCLUSIONS

In conclusion, there are significant differences in vital signs and their accuracy prior to cardiac arrest in the wards, which has important implications for how they are used for ICU triage decisions and triggering RRTs. Importantly, the poor accuracy for the MEWS in elderly patients suggests that additional predictors of cardiac arrest, such as comorbidities, are needed to accurately identify these patients. In addition, the fact that the most accurate vital signs were different for elderly compared with nonelderly patients suggests that age-specific early warning scores may improve accuracy over current systems.

ACKNOWLEDGMENTS

We thank Donald Saner, MS, Justin Lakeman, and Contessa Hsu for assistance with data extraction and technical support; Poome Chamnankit, MS, CNP, Kelly Bhatia, MSN, ACNP, and Audrey Seitman, MSN, ACNP, for performing manual chart review of cardiac arrest patients; and Nicole Twu, MS, for administrative support.

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