Journal of Critical Care 47 (2018) 222–226

Contents lists available at ScienceDirect

Journal of Critical Care

journal homepage: www.journals.elsevier.com/journal-of-critical-care

Evaluation of the efficacy of the National Early Warning Score in predicting in-hospital mortality via the risk stratification☆

Young Seok Lee [a], Jae Woo Choi [b], Yeon Hee Park [c], Chaeuk Chung [d], Dong Il Park [d], Jeong Eun Lee [d], Hye Sun Lee [e], Jae Young Moon [d,*]

[a] Division of Respiratory and Critical Care Medicine, Department of Internal Medicine, Korea University Medical Center, Guro Hospital, Seoul, Republic of Korea
[b] Division of Pulmonary and Critical Care Medicine, Department of Internal Medicine, Cheongju St. Mary's Hospital, Cheongju, Republic of Korea
[c] Division of Pulmonary and Critical Care Medicine, Department of Internal Medicine, Daejeon St. Mary's Hospital, Daejeon, Republic of Korea
[d] Division of Pulmonology and Critical Care Medicine, Department of Internal Medicine, Chungnam National University Hospital, Chungnam National University College of Medicine, Daejeon, Republic of Korea
[e] Biostatistics Collaboration Unit, Yonsei University College of Medicine, Seoul, Republic of Korea

A R T I C L E I N F O

Keywords:
National Early Warning Score
Rapid response system
Hospital mortality
Screening
Prognosis

A B S T R A C T

Purpose: To investigate the efficacy of the National Early Warning Score (NEWS) in predicting in-hospital mortality.
Materials and methods: This was a retrospective observational study and the electronic medical records of the patients were reviewed based on NEWS at the time of admission.
Results: The performance of NEWS was effective in predicting hospital mortality (area under the curve: 0.765; 95% confidence interval: 0.659–0.846). Based on the Kaplan Meier survival curves, the survival time of patients who are at high risk according to NEWS was significantly shorter than that of patients who are at low risk ($p <$ 0.001). Results of the multivariate Cox proportional hazards regression analysis showed that the hazard ratios of patients who are at medium and high risk based on NEWS were 2.6 and 4.7, respectively ($p < 0.001$). In addition, our study showed that the combination model that used other factors, such as age and diagnosis, was more effective than NEWS alone in predicting hospital mortality (NEWS: 0.765; combination model: 0.861; $p < 0.005$).
Conclusions: NEWS is a simple and useful bedside tool for predicting in-hospital mortality. In addition, the rapid response team must consider other clinical factors as well as screening tools to improve clinical outcomes.

1. Introduction

Many types of patients can experience unexpected clinical deterioration during hospitalization, and this deterioration is associated with in-hospital mortality [1-4]. The primary aim of predicting in-hospital mortality is to improve patient prognosis. Currently, several scoring systems are used to predict in-hospital mortality [5-7]. The Acute Physiology and Chronic Health Evaluation (APACHE) and the Simplified Acute Physiology Score (SAPS) are representative prognostic models [5-7]. However, these scales are relatively complex, include several items, and cannot be used as a quick bedside tool. Recently, artificial intelligence was developed as part of a clinical decision support system to predict adverse events such as cardiac arrest several hours before its occurrence [8-11]. However, this system has not been used in critically ill patients.

Early warning systems for the early recognition of clinical deterioration in critically ill patients within 24 h can reduce the incidence of in-hospital cardiac arrest [12-14]. One such system, the standardized National Early Warning Score (NEWS) was established by the Royal College of Physicians of London and is currently used in several countries [12,15]. The NEWS has a good ability to discriminate acutely ill patients at risk of clinical deterioration within 24 h as well as events such as cardiac arrest, unexpected admission to an intensive care unit (ICU), and death. The NEWS is intended to provide reliable, timely, and effective indications of the clinical responses of acutely ill patients. By including seven simple physiological variables, the NEWS also provides a useful and rapid bedside tool [12,15-17]. For these reasons, it has been implemented in the afferent limb of the rapid response system [17,18]. However, the efficacy of the NEWS in identifying patients at risk of in-

Abbreviations: APACHE, The Acute Physiology and Chronic Health Evaluation; SAPS, The Simplified Acute Physiology Score; NEWS, National Early Warning Score; ICU, intensive care unit; RRT, rapid response team; EMR, electronic medical record; AUC, area under the curve; HR, hazard ratio; CI, confidence interval; AUC, the area under the curve; AVPU, Alert, Voice, Pain, Unresponsive.

☆ Declarations of interest: none.

* Corresponding author at: Division of Pulmonary and Critical Care Medicine, Department of Internal Medicine, Chungnam National University Hospital, Chungnam National University College of Medicine, 282 Munhwa-ro, Jung-gu, Daejeon 301-721, Republic of Korea.
E-mail address: jymoon@cnuh.co.kr (J.Y. Moon).

https://doi.org/10.1016/j.jcrc.2018.07.011

hospital mortality at the time of admission has not been validated because the risk stratification of NEWS was developed to predict clinical deterioration within 24 h, which is a short-term outcome.

We hypothesized that the NEWS would be useful for predicting in-hospital mortality in screened patients when other factors used for predicting prognosis are considered. This study aimed to assess the efficacy of the NEWS at the time of admission for predicting in-hospital mortality and to identify clinical factors that may improve the predictive performance of the NEWS.

2. Material and methods

2.1. Study setting

This was a retrospective observational study of patients admitted between December 2013 and March 2014 at Chungnam National University Hospital, a 1200-bed tertiary academic hospital, in South Korea. In this hospital, the electronic medical record (EMR)-based NEWS system was established in November 2013 and is used for adult patients admitted to the general ward. The vital signs of admitted patients are checked regularly by registered nurses. Based on their decision-making, the nurses enter seven physiological variables into the NEWS, and the NEWS data are stored in the EMRs. After a 6-month trial, the rapid response team (RRT) introduced a track-and-trigger system in May 2014. This study included patients older than 20 years and those whose first NEWS was recorded within 48 h after admission. We included only the first serial NEWS for analysis. We excluded patients with any missing variables, patients who were discharged within 72 h of a scheduled examination or treatment (e.g., endoscopy, scheduled chemotherapy), and patients whose first NEWS was not recorded within 48 h after admission. Demographic and clinical data and survival status were obtained from the EMRs. The primary outcome among critically ill patients was in-hospital mortality.

This study was approved by the institutional review board of Chungnam National University Hospital in the Republic of Korea (No. 2015-08-040). The need for informed consent was waived because the study design was retrospective and the data were retrieved by reviewing the EMRs.

2.2. NEWS

The NEWS dataset comprises seven physiological variables: systolic blood pressure, heart rate, respiratory rate, body temperature, oxygen saturation, use of any supplemental oxygen, and level of consciousness [15]. The score for each of the seven parameters (0–3 points) is summed to calculate the NEWS. The triggering thresholds based on the NEWS were classified as low risk (1–4), medium risk (5–6 or red score), and high clinical risk (≥7). The red score was defined as an extreme variation in a single parameter (Fig. 1) [15].

2.3. Statistical analysis

Descriptive data are presented as mean ± standard deviation or as number and percentage. An independent *t*-test was used to analyze categorical data, and a chi-square test was used to analyze continuous data. Survival was calculated according to the trigger thresholds for the NEWS using Kaplan–Meier analysis and compared using the log-rank test. Cox proportional-hazards regression analysis was performed using backward elimination to identify the independent risk factors for in-hospital mortality. Statistically significant variables in the univariate analysis were subsequently included in the multivariate analysis. In the present study, we investigated the best model that included risk factors that can be used for the accurate prediction of in-hospital mortality. The discriminatory power of each model was assessed using Harrell's C-index and an analysis of the area under the curve (AUC), and results were evaluated and compared using the Bootstrap method [19]. A p value <0.05 was considered to be significant, and the results are presented as the hazard ratio (HR) and 95% confidence interval (CI). All statistical analyses were performed using the R statistical package (version 2.13.1; R Foundation, Vienna, Austria; www.R-project.org) and IBM SPSS Statistics (version 20.0; IBM Corp., Armonk, NY, USA).

3. Results

3.1. Baseline characteristics of the study population

During the study period, a total of 10,038 people were screened. We excluded from the analysis patients who were discharged from hospital within 72 h after admission because they underwent a simple examination or treatment (e.g., endoscopy, scheduled chemotherapy) (n = 4346), patients with missing variables such as oxygen saturation or consciousness level because these were not checked at the time of admission (n = 3897), and patients whose first NEWS was recorded after 48 h at the time of admission (n = 495). The remaining 1300 patients were included in the analysis.

The baseline characteristics of the patients are shown in Table 1. Of the 1300 patients included in this analysis, 43 (3.3%) died during hospitalization. These patients were older and more likely to be men. Most of the nonsurvivors had cancer and had been admitted for medical as opposed to surgical reasons. One-third of the nonsurvivors were at high risk based on the trigger thresholds for the NEWS. The hospital stay

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

A, Alert; V, Voice; P, Pain; U, Unresponsive

Fig. 1. National Early Warning Score (NEWS). The score for each of the seven parameters (0–3 points) is summed up to calculate the NEWS. The triggering thresholds based on the NEWS were classified as low risk (1–4), medium risk (5–6 or red score), and high clinical risk (7 or more). The red score was defined as an extreme variation in a single parameter.

Table 1
Baseline characteristics of the study population.

Characteristics	Total	Survivors	Non-survivors	*p* value
Patients, n (%)	1300	1257	43	
Age, years[a]	62 ± 15	61 ± 15	70 ± 13	<0.001
Male sex	751 (57.8)	722 (57.4)	29 (67.4)	0.212
Admission type				0.001
Medical	1006 (77.4)	964 (76.7)	42 (97.7)	
Surgical	294 (22.6)	293 (23.3)	1 (2.3)	
Diagnosis upon admission				
Cardiovascular diseases	304 (23.4)	302 (24)	2 (4.7)	0.003
Pulmonary diseases	192 (14.8)	188 (15)	4 (9.3)	0.386
Gastrointestinal diseases	159 (12.2)	155 (12.3)	4 (9.3)	0.646
Cancer	340 (26.2)	313 (24.9)	27 (62.8)	<0.001
Neurologic diseases	75 (5.8)	73 (5.8)	2 (4.7)	1.000
Renal diseases	50 (3.8)	48 (3.8)	2 (4.7)	1.000
Other diseases	180 (13.8)	178 (14.2)	2 (4.7)	0.111
Trigger thresholds for the NEWS				<0.001
Low (0–4)	1064 (81.8)	1043 (83)	21 (48.8)	
Medium (5–6 or red score)	127 (9.8)	119 (9.5)	8 (18.6)	
High (≥7)	109 (8.4)	95 (7.6)	14 (32.6)	
ICU transfer during hospital stay	145 (11.2)	137 (10.9)	8 (18.6)	0.134
Duration of hospital stay, days[a]	11 ± 19	10 ± 18	25 ± 38	0.013

NEWS, National Early Warning Score; ICU, intensive care unit.
[a] Data are presented as means ± standard deviations. Other variables are presented as numbers and percentages.

was longer in the nonsurvivors because they had more severe disease and a higher rate of transfer to the ICU.

3.2. Predictors for in-hospital mortality

Multivariate Cox proportional-hazards regression analysis using backward elimination was performed to identify the risk factors predicting in-hospital mortality. The HRs of patients at medium and high risk based on the NEWS were 2.6 and 4.7, respectively ($p < 0.001$; Table 2).

The Kaplan–Meier survival curves for the cumulative risk of in-hospital mortality according to each risk stratification revealed that the survival time was significantly shorter for patients at high than at low risk based on the NEWS (log-rank test, $p < 0.001$; Fig. 2).

3.3. Prognostic capabilities of the models consisted of risk factors for in-hospital mortality

To investigate the efficacy of these factors when integrated with the NEWS versus the NEWS alone in predicting hospital mortality, Harrell's C-index was used for different combinations of risk factors and NEWS data. Model I included only the trigger thresholds for the NEWS. Model II included the trigger thresholds for the NEWS and age. Model III included the trigger thresholds for the NEWS, age, and medical reason for admission. Model IV included the trigger thresholds for the NEWS, age, medical reason for admission, and cancer. Model I (NEWS only) was effective in predicting hospital mortality at the time of admission (C-index AUC: 0.765; 95% CI: 0.659–0.846). The performance of Models II, III, and IV used for predicting in-hospital mortality were gradually improved (Model II: 0.821; Model III: 0.837; and Model IV: 0.861). The differences in the AUC for Models II, III, and IV compared with Model I were significant (Model II: $p = 0.046$; Model III: $p = 0.02$; and Model IV: $p = 0.005$) (Table 3). However, the AUCs for Models III and IV did not differ significantly from that of Model II, and the AUC for Model IV did not differ significantly from that for Model III. These findings indicate that integration of age into the NEWS was more important for predicting in-hospital mortality than the integration of other factors into the NEWS (Table 3).

Table 2
Predictive values for in-hospital mortality in patients assessed using the Cox proportional hazards models.

Risk factors	HR	95% CI	*p* value
Age, years	1.0	1.01–1.07	0.008
Medical reason for admission	7.0	0.95–51.43	0.056
Patient with cancer	4.5	2.40–8.54	<0.001
Trigger thresholds for the NEWS			<0.001
Low (0–4)	Reference		
Medium (5–6 or 'red' score)	2.6	1.12–6.00	
High (≥7)	4.7	2.35–9.47	

NEWS, National Early Warning Score.
Multivariate Cox proportional hazards regression analysis that used backward elimination was performed to predict hospital mortality after adjusting for five variables (age, medical reason for admission, cancer, trigger thresholds for the NEWS analysis, and ICU transfer during hospital stay).

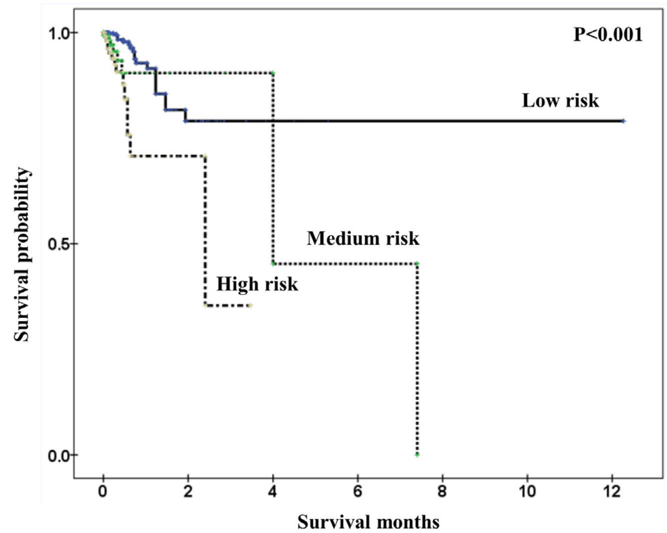

Fig. 2. Kaplan Meier survival curves for the cumulative risk of in-hospital mortality according to the trigger thresholds for the NEWS.

4. Discussion

This study aimed to assess the efficacy of the NEWS in predicting in-hospital mortality via risk stratification at the time of admission and to identify clinical factors that may improve the predictive performance of the NEWS. The use of NEWS alone was effective in predicting hospital mortality (C-index AUC: 0.765; 95% CI: 0.659–0.846). Addition of other

Table 3
Prognostic capabilities of NEWS and other factors for in-hospital mortality using the Harrell's C-index.

Models	C index	95% CI	*p* value[a]	*p* value[b]	*p* value[c]
I	0.765	0.659–0.846	Reference		
II	0.821	0.735–0.888	0.046	Reference	
III	0.837	0.756–0.9	0.02	0.182	Reference
IV	0.861	0.793–0.917	0.005	0.138	0.138

NEWS, National Early Warning Score; CI, confidence interval.
Model I included only the trigger thresholds for the NEWS. Model II included the trigger thresholds for the NEWS and age. Model III included the trigger thresholds for the NEWS, age, and medical reason for admission. Model IV included the trigger thresholds for the NEWS, age, medical reason for admission, and cancer.
[a] Comparison of AUCs between Model I and other models was tested using the Bootstrap method.
[b] Comparison of AUCs between Models II, III and IV was tested using Bootstrap method.
[c] Comparison of AUCs between Models III and IV was tested using the Bootstrap method.

risk factors for predicting in-hospital mortality to the NEWS had a significantly higher predictive power than the NEWS alone (C-index AUC: 0.861 vs. 0.765; $p = 0.005$). From the perspective of the RRT, evaluation of the risk for in-hospital mortality at the time of admission is important. When considering other factors (e.g., age and comorbidities) as well as the NEWS, the RRT alarm pathway is more effective as a clinical decision-making tool for reducing in-hospital mortality.

The NEWS has a good ability to discriminate acutely ill patients at risk of clinical deterioration within 24 h, as well as at events such as cardiac arrest, unexpected admission to an ICU, and death [12,15-17]. This tool is more effective than 33 other systems for predicting the individual outcomes of unexpected ICU admission or death but not cardiac arrest alone [12,15,20,21]. However, the efficacy of the NEWS as a predictor of in-hospital mortality has not been validated because the tool was developed to predict short-term outcomes occurring within 24 h. This study showed that the NEWS was effective in predicting in-hospital mortality (C-index AUC: 0.765). Several studies have reported on the efficacy of the NEWS in predicting 30-day mortality as a secondary outcome, but these studies were conducted in limited clinical settings, such as the emergency room [22-24]. Our study focused on patients admitted to the general ward. Until now, several scales used to predict mortality and under development were not applicable to all patients at the time of admission because of their complexity (i.e., inclusion of numerous items) [5,6]. By contrast, the NEWS is a simple, useful, and rapid bedside tool comprising seven physiological variables: systolic blood pressure, heart rate, respiratory rate, body temperature, oxygen saturation, use of supplemental oxygen, and level of consciousness [15]. These data are easily obtained compared with other factors such as laboratory tests or imaging results. Therefore, the NEWS as a simple and useful bedside tool can be used for predicting in-hospital mortality on all patients admitted to the general ward.

The NEWS was recently updated to the NEWS2 based on more recent studies [25]. The new recommendations of the NEWS2 are as follows. 1) A NEWS ≥5 is a key threshold for the activation of the RRT, meaning that a patient with a NEWS ≥5 should receive more attention and treatment by the RRT to prevent a poor prognosis. 2) To overcome the imprecision of recording the use of oxygen in patients with hypercapnic respiratory failure, the NEWS2 suggests recording the recommended oxygen saturation in patients with hypercapnic respiratory failure, especially in those with chronic obstructive pulmonary disease. 3) New-onset confusion was added to the AVPU scoring scale in the NEWS because new-onset confusion (including disorientation, delirium, or any acute reduction in the Glasgow Coma Scale score) is an important sign of potentially serious clinical deterioration. 4) The NEWS2 can be used for detecting sepsis or clinical deterioration in patients with prior infection. For example, in patients with known or suspected infection, a NEWS ≥5 should prompt suspicion of sepsis. These updates of the NEWS system should improve the assessment of the severity of acute illness, detection of clinical deterioration, and initiation of a timely and competent clinical response. Considering the results of our study, use of the NEWS2 at the time of admission for adult patients may provide a more accurate prediction of both clinical deterioration within 24 h and in-hospital mortality compared with the original NEWS.

In this study, the death of some of the nonsurvivors was not predicted by the NEWS, whose AUC was 0.765 when used alone for predicting in-hospital mortality. Therefore, the NEWS alone cannot perfectly predict long-term prognosis in patients with a complex situation, such as old age, underlying disease, or comorbidities, each of which can affect in-hospital mortality. We therefore decided to assess whether adding other factors that can affect in-hospital mortality could increase the ability to predict in-hospital mortality in acutely ill patients. In this study, the integration of other factors, such as old age, medical reason for admission, and cancer, to the NEWS allowed more accurate predictions of in-hospital mortality compared with the NEWS alone. Among the added factors, the inclusion of age was important in predicting in-hospital mortality (Table 3). Advanced age is an independent risk factor for adverse events in hospital and is associated with several comorbidities [26-29]. Our findings suggest that the addition of age to the NEWS may result in more accurate predictions of in-hospital mortality compared with the NEWS alone.

The inclusion of age as a component of track-and-trigger systems used for identifying sick adult patients remains controversial [27,30-32]. Some authors have stated that the integration of age into the early warning score allows more accurate identification of adverse outcomes. However, others have argued that younger patients who previously would have been salvaged by an early warning system might not be monitored effectively if the cutoffs are determined using age as an additional factor [27]. The inclusion of age in track-and-trigger systems can cause complex problems, and this concern is reasonable; however, the inclusion of age in the assessment of risk is feasible. Age-related changes in vital signs might cause confusion even if an appropriate intervention is provided by the RRT [27,32-34].

Disregarding the physiological characteristics of critically ill elderly patients might leave other potential victims out of the hospital's risk-control strategy, which might also complicate the coordination of responses. Our results suggest that the RRT must recognize the need for age-specific track-and-trigger systems. For example, the simple NEWS cutoffs cannot distinguish the risk between an 80-year-old patient with a low alertness score based on the NEWS and a 40-year-old patient with a medium or high alertness score. These findings have important implications for risk stratification when using vital signs to detect acutely deteriorating patients in the ward. Considering a goal of RRT system is to achieve better outcomes, different workflows that trigger specific interventions or efferent limbs should be considered in elderly patients and in those with a serious disease such as cancer.

Finally, this study included 1300 patients admitted for medical and surgical reasons in South Korea. In addition, our results reflected the patient's natural course accurately and objectively because our dataset was developed before we applied RRT approaches. Therefore, our dataset was good enough to prove the NEWS upon admission to the general ward may help predict a patient's prognosis accurately and objectively.

This study had several limitations. First, this was a retrospective study performed in a single medical center. Second, the proportion of aging patients in our study was high. However, it was similar to that in other regional referral hospitals and the general increase in the elderly population is a problem worldwide. Third, we cannot rule out the possibility of selection bias because many patients with missing variables were excluded. However, most of the missing variables were oxygen saturation or level of consciousness. This means that nurses did not use these variables according to their decision-making because the patients appeared to be mentality alert or did not require oxygen. Therefore, these patients may mean that they had a less severe disease state and a low risk of in-hospital mortality. Considering that the aim of this study was to investigate the NEWS as a predictor of in-hospital mortality, the effect of missing data on our results may be negligible. In addition, our results reflected the patient's natural course accurately and objectively because our dataset was developed before we applied RRT approaches.

Despite these limitations, our study has clinical relevance because it shows that the NEWS is a predictor of in-hospital mortality and that integration of other factors into the NEWS after activation of the RRT is important to improve clinical outcomes.

5. Conclusions

The NEWS is a simple, useful, and rapid bedside tool for predicting in-hospital mortality in the clinical setting. Activation of the RRT should consider the use of additional clinical factors as well as screening tools for improving clinical outcomes. Further studies with a larger sample size are needed.

Acknowledgement

We are grateful to the Chungnam National University Hospital Rapid Response Team for their key role in this work. We are indebted to Jusang Lee, RN, Na Eun Min, RN, and Jeong Eun Park, RN, for the data collection of this article. We also express our appreciation to the emergency and acute care team, J.W Lee, MD., H.J Ahn, MD., and S Ryu, MD., for their dedication to improving patient care.

Funding

This research did not receive any specific grant from funding agencies in the public, Commercial, or no-for profit sectors.

Author contribution

(1) **Contributed substantially to the conception and design of the study**: Young Seok Lee, Jae Young Moon.
(2) **The acquisition of data, or the analysis and interpretation of the data**: Young Seok Lee, Jae Woo Choi, Yeon Hee Park, Chaeuk Chung, Dong Il Park, Jeong Eun Lee, Hye Sun Lee, Jae Young Moon.
(3) **Drafted or provided critical revision of the article**: Young Seok Lee, Jae Woo Choi, Yeon Hee Park, Chaeuk Chung, Dong Il Park, Jeong Eun Lee, Hye Sun Lee, Jae Young Moon.
(4) **Provided final approval of the version submitted for publication**: Young Seok Lee, Jae Woo Choi, Yeon Hee Park, Chaeuk Chung, Dong Il Park, Jeong Eun Lee, Hye Sun Lee, Jae Young Moon.

References

[1] Merchant RM, Yang L, Becker LB, Berg RA, Nadkarni V, Nichol G, et al. Incidence of treated cardiac arrest in hospitalized patients in the United States. Crit Care Med 2011;39(11):2401–6.
[2] Brennan TA, Leape LL, Laird NM, Hebert L, Localio AR, Lawthers AG, et al. Incidence of adverse events and negligence in hospitalized patients. Results of the Harvard Medical Practice Study I. N Engl J Med 1991;324(6):370–6.
[3] Sandroni C, Nolan J, Cavallaro F, Antonelli M. In-hospital cardiac arrest: incidence, prognosis and possible measures to improve survival. Intensive Care Med 2007;33(2):237–45.
[4] Le Guen M, Tobin A. Epidemiology of in-hospital mortality in acute patients admitted to a tertiary-level hospital. Intern Med J 2016;46(4):457–64.
[5] Salluh JI, Soares M. ICU severity of illness scores: APACHE, SAPS and MPM. Curr Opin Crit Care 2014;20(5):557–65.
[6] Zimmerman JE, Kramer AA, McNair DS, Malila FM. Acute Physiology and Chronic Health Evaluation (APACHE) IV: hospital mortality assessment for today's critically ill patients. Crit Care Med 2006;34(5):1297–310.
[7] Moreno RP, Metnitz PG, Almeida E, Jordan B, Bauer P, Campos RA, et al. SAPS 3—from evaluation of the patient to evaluation of the intensive care unit. Part 2: development of a prognostic model for hospital mortality at ICU admission. Intensive Care Med 2005;31(10):1345–55.
[8] Liu N, Koh ZX, Goh J, Lin Z, Haaland B, Ting BP, et al. Prediction of adverse cardiac events in emergency department patients with chest pain using machine learning for variable selection. BMC Med Inform Decis Mak 2014;14:75.
[9] Shashikumar SP, Stanley MD, Sadiq I, Li Q, Holder A, Clifford GD, et al. Early sepsis detection in critical care patients using multiscale blood pressure and heart rate dynamics. J Electrocardiol 2017;50(6):739–43.
[10] Nemati S, Holder A, Razmi F, Stanley MD, Clifford GD, Buchman TG. An interpretable machine learning model for accurate prediction of sepsis in the ICU. Crit Care Med 2018;46(4):547–53.
[11] Hanson 3rd CW, Marshall BE. Artificial intelligence applications in the intensive care unit. Crit Care Med 2001;29(2):427–35.
[12] Smith GB, Prytherch DR, Meredith P, Schmidt PE, Featherstone PI. The ability of the National Early Warning Score (NEWS) to discriminate patients at risk of early cardiac arrest, unanticipated intensive care unit admission, and death. Resuscitation 2013;84(4):465–70.
[13] Jo S, Lee JB, Jin YH, Jeong TO, Yoon JC, Jun YK, et al. Modified early warning score with rapid lactate level in critically ill medical patients: the ViEWS-L score. Emerg Med J 2013;30(2):123–9.
[14] Alam N, Hobbelink EL, van Tienhoven AJ, van de Ven PM, Jansma EP, Nanayakkara PW. The impact of the use of the Early Warning Score (EWS) on patient outcomes: a systematic review. Resuscitation 2014;85(5):587–94.
[15] Williams B, Alberti G, Ball C, Bell D, Binks R, Durham L. National Early Warning Score (NEWS): standardising the assessment of acute-illness severity in the NHS. London: The Royal College of Physicians; 2012.
[16] Uppanisakorn S, Bhurayanontachai R, Boonyarat J, Kaewpradit J. National Early Warning Score (NEWS) at ICU discharge can predict early clinical deterioration after ICU transfer. J Crit Care 2018;43:225–9.
[17] Churpek MM, Snyder A, Han X, Sokol S, Pettit N, Howell MD, et al. Quick sepsis-related organ failure assessment, systemic inflammatory response syndrome, and early warning scores for detecting clinical deterioration in infected patients outside the intensive care unit. Am J Respir Crit Care Med 2017;195(7):906–11.
[18] Tirkkonen J, Huhtala H, Hoppu S. In-hospital cardiac arrest after a rapid response team review: a matched case-control study. Resuscitation 2018;126:98–103.
[19] Harrell Jr FE, Lee KL, Matchar DB, Reichert TA. Regression models for prognostic prediction: advantages, problems, and suggested solutions. Cancer Treat Rep 1985;69(10):1071–7.
[20] Yu S, Leung S, Heo M, Soto GJ, Shah RT, Gunda S, et al. Comparison of risk prediction scoring systems for ward patients: a retrospective nested case-control study. Crit Care 2014;18(3):R132.
[21] Jarvis SW, Kovacs C, Briggs J, Meredith P, Schmidt PE, Featherstone PI, et al. Are observation selection methods important when comparing early warning score performance? Resuscitation 2015;90:1–6.
[22] Alam N, Vegting IL, Houben E, van Berkel B, Vaughan L, Kramer MH, et al. Exploring the performance of the National Early Warning Score (NEWS) in a European emergency department. Resuscitation 2015;90:111–5.
[23] Nannan Panday RS, Minderhoud TC, Alam N, Nanayakkara PWB. Prognostic value of early warning scores in the emergency department (ED) and acute medical unit (AMU): a narrative review. Eur J Intern Med 2017;45:20–31.
[24] Nickel CH, Kellett J, Cooksley T, Bingisser R, Henriksen DP, Brabrand M. Combined use of the National Early Warning Score and D-dimer levels to predict 30-day and 365-day mortality in medical patients. Resuscitation 2016;106:49–52.
[25] Williams B, Alberti G, Ball C, Bell D, Binks R, Durham L. National Early Warning Score (NEWS) 2: standardising the assessment of acute-illness severity in the NHS. London: The Royal College of Physicians; 2017.
[26] Vetrano DL, Foebel AD, Marengoni A, Brandi V, Collamati A, Heckman GA, et al. Chronic diseases and geriatric syndromes: the different weight of comorbidity. Eur J Intern Med 2016;27:62–7.
[27] Smith GB, Prytherch DR, Schmidt PE, Featherstone PI, Kellett J, Deane B, et al. Should age be included as a component of track and trigger systems used to identify sick adult patients? Resuscitation 2008;78(2):109–15.
[28] Formiga F, Ferrer A, Sanz H, Marengoni A, Alburquerque J, Pujol R. Patterns of comorbidity and multimorbidity in the oldest old: the Octabaix study. Eur J Intern Med 2013;24(1):40–4.
[29] Cigolle CT, Langa KM, Kabeto MU, Tian Z, Blaum CS. Geriatric conditions and disability: the health and retirement study. Ann Intern Med 2007;147(3):156–64.
[30] Duckitt RW, Buxton-Thomas R, Walker J, Cheek E, Bewick V, Venn R, et al. Worthing physiological scoring system: derivation and validation of a physiological early-warning system for medical admissions. An observational, population-based single-centre study. Br J Anaesth 2007;98(6):769–74.
[31] Churpek MM, Yuen TC, Park SY, Meltzer DO, Hall JB, Edelson DP. Derivation of a cardiac arrest prediction model using ward vital signs. Crit Care Med 2012;40(7):2102–8.
[32] Churpek MM, Yuen TC, Winslow C, Hall J, Edelson DP. Differences in vital signs between elderly and nonelderly patients prior to ward cardiac arrest. Crit Care Med 2015;43(4):816–22.
[33] Tirkkonen J, Setala P, Hoppu S. Characteristics and outcome of rapid response team patients ≥75 years old: a prospective observational cohort study. Scand J Trauma Resusc Emerg Med 2017;25(1):77.
[34] Shappell C, Snyder A, Edelson DP, Churpek MM. Predictors of in-hospital mortality after rapid response team calls in a 274 hospital Nationwide sample. Crit Care Med 2018;46(7):1041–8.