Clinical paper

The predictive power of the National Early Warning Score (NEWS) 2, as compared to NEWS, among patients assessed by a Rapid response team: A prospective multi-centre trial

Anna Thörén a,b,*, Eva Joelsson-Alm c,d, Martin Spångfors e,f, Araz Rawshani g, Thomas Kahan h, Johan Engdahl h, Martin Jonsson i, Therese Djaërv a,j

a Department of Medicine Solna, Centre for Resuscitation Science, Karolinska Institutet, SE-171 77 Stockholm, Sweden
b Department of Clinical Physiology, Danderyd University Hospital, SE-182 88 Stockholm, Sweden
c Department of Clinical Science and Education, Karolinska Institutet, SE-118 83 Stockholm, Sweden
d Department of Anaesthesia and Intensive Care, Södersjukhuset, SE-118 83 Stockholm, Sweden
e Department of Clinical Sciences, Lund University, SE-221 84 Lund, Sweden
f Department of Anaesthesia and Intensive Care, Kristianstad Hospital, SE-291 89 Kristianstad, Sweden
g Department of Molecular and Clinical Medicine, Institute of Medicine, University of Gothenburg, SE-405 30 Gothenburg, Sweden
h Division of Cardiovascular Medicine, Department of Clinical Sciences, Danderyd University Hospital, Karolinska Institutet, SE-182 88 Stockholm, Sweden
i Department of Clinical Science and Education, Centre for Resuscitation Science, Karolinska Institutet, Södersjukhuset, SE-118 83 Stockholm, Sweden
j Department of Emergency Medicine, Karolinska University Hospital, SE-171 64 Stockholm, Sweden

Abstract

Aim: Early identification of patients at risk of serious adverse events (SAEs) is of vital importance, yet it remains a challenging task. We investigated the predictive power of National Early Warning Score (NEWS) 2, as compared to NEWS, among patients assessed by a Rapid response team (RRT).

Methods: Prospective, observational cohort study on 898 consecutive patients assessed by the RRTs in 26 Swedish hospitals. For each patient, NEWS and NEWS 2 scores were uniformly calculated by the study team. The associations of NEWS and NEWS 2 scores with unanticipated admissions to Intensive care unit (ICU), mortality and in-hospital cardiac arrests (IHCA) within 24 h, and the composite of these three events were investigated using logistic regression. The predictive power of NEWS and NEWS 2 was assessed using the area under the receiver operating characteristic (AUROC) curves.

Results: The prognostic accuracy of NEWS/NEWS 2 in predicting mortality was acceptable (AUROC 0.69/0.67). In discriminating the composite outcome and unanticipated ICU admission, both NEWS and NEWS 2 were relatively weak (AUROC 0.62/0.62 and AUROC 0.59/0.60 respectively); for IHCA the performance was poor. There were no differences between NEWS and NEWS 2 as to the predictive power.

Conclusion: The prognostic accuracy of NEWS 2 to predict mortality within 24 h was acceptable. However, the prognostic accuracy of NEWS 2 to predict IHCA was poor. NEWS and NEWS 2 performed similar in predicting the risk of SAEs but their performances were not sufficient for use as a risk stratification tool in patients assessed by a RRT.

Keywords: National early warning score, National early warning score 2, Vital signs, Rapid response team, Mortality, In-hospital cardiac arrest, IHCA

Abbreviations: NEWS, National Early Warning Score, RRT, Rapid response team, IHCA, In hospital cardiac arrest, AUROC, Area under the receiver operating characteristic curves, ICU, Intensive care unit, SAE, Serious adverse event, OR, Odds ratio, CI, Confidence interval

* Corresponding author: Department of Clinical Physiology, Danderyd University Hospital, SE-182 88 Stockholm, Sweden.
E-mail address: anna.thoren@ki.se (A. Thörén).

https://doi.org/10.1016/j.resplu.2021.100191
Received 13 September 2021; Received in revised form 1 December 2021; Accepted 6 December 2021
Available online xxxxx
2666-5204/© 2021 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).
Introduction

Early identification of patients with deteriorating vital signs is of major importance in order to prevent further clinical deterioration and serious adverse events (SAEs), yet it remains a challenging task in healthcare settings worldwide. In-hospital cardiac arrest (IHCA) and unanticipated Intensive care unit (ICU) admission are SAEs associated with a high mortality, and both are typically preceded by deviating vital signs. Thus, early recognition and an adequate, timely intervention may save lives. This has prompted the development of early warning scores, which are recommended by the European Resuscitation Council (ERC) with the aim of preventing IHCA. Furthermore, Rapid response teams (RRTs) have been introduced to assess deteriorating patients, initiate interventions and, if needed, timely transfers to intensive care, with a view to improve prognosis.

The National Early Warning Score (NEWS), launched in 2012 in the UK, has outperformed other early warning score instruments, and has been widely adopted worldwide. NEWS has undergone extensive validation in the UK and internationally, including Sweden. An updated version, NEWS 2, was introduced in 2017 in order to improve precision and to facilitate early identification of sepsis. The main modifications were addition of a dedicated SpO₂ scoring scale (Scale 2) for use in patients with hypercapnic respiratory failure and the variable “new confusion” (including disorientation, delirium or any new onset alteration to level of consciousness) scored from 0 to 3, depending on the severity of the divergence from the normal value, added into a summary score. Patients receiving supplementary oxygen, have 2 points added to their score. A score of ≥7 is a key trigger and should prompt emergency assessment by a clinical team such as the RRT. Patients are stratified into risk categories based upon the NEWS/NEWS 2 concept also includes a clinical response scale where different interventions are linked to the summary score.

Methods

Study design and setting

This prospective, observational multicenter study was conducted between October 22, 2019 and January 13, 2020 in 26 Swedish hospitals (Supplementary Table 1). Hospitals were eligible if they had a RRT system and had implemented either NEWS or NEWS 2. The RRTs consisted of a physician and a nurse specialist from the ICU in 24 of the participating hospitals, an ICU physician only in one hospital, and a physician, a nurse specialist and an assistant nurse from the ICU in one hospital. All hospitals except one performed RRT assessments 24/7. All patients were assessed by the RRT according to clinical practice. All variables required for calculation of both NEWS and NEWS 2 scores were collected by the RRT. For each patient the scores were uniformly calculated by the study team when analysing data since miscalculation is one main cause of error when using NEWS. The decisions made after the RRT review regarding level of care and a possible revised decision of limitations of medical treatment, was also recorded. A follow-up was performed after > 24 hours, retrieving information from medical records on unanticipated ICU admission, IHCA, or in-hospital death within 24 h of the observation of vital parameters and RRT assessment.

Participants

All patients aged 18 years and older assessed by the RRTs during the inclusion period were eligible for inclusion in the study. Exclusion criteria were pregnancy and the postpartum period (i.e. 6 weeks following childbirth; n = 11), a decision of no ICU-admission prior to RRT review (n = 70) and patients being assessed as a planned follow-up after discharge from the ICU. Of a total of 1065 assessments performed during the study period, 81 met at least one exclusion criterion (Fig. 1), 19 patients were excluded due to lack of personal ID number which made it impossible to perform follow-up, and another 67 had information on at least one vital parameter missing (most frequently body temperature). Thus, 898 patients were included in the complete case analysis. Based on published results from an observational study on NEWS, we considered a study population with assessments of 1000 patients would be sufficient for the purpose of the current study.

Definitions

The NEWS scale includes seven vital signs (respiration rate, oxygen saturation, body temperature, systolic blood pressure, heart rate and level of consciousness) scored from 0 to 3, depending on the severity of the divergence from the normal value, added into a summary score. Patients receiving supplementary oxygen, have 2 points added to their score. A score of ≥7 is a key trigger and should prompt emergency assessment by a clinical team such as the RRT. Patients are stratified into risk categories based upon the total NEWS score, which can be related to the patient’s risk of critical illness. The NEWS/NEWS 2 concept also includes a clinical response scale where different interventions are linked to the summary score.

Outcomes

The outcomes were unanticipated ICU-admission, IHCA and in-hospital death within 24 h of an observation set of vital parameters and assessment by the RRT. Since IHCA and unexpected death are infrequent events all three SAEs were analysed as a composite outcome, which is in line with the Tripod guidelines. In the event of multiple outcomes, the first was used for the analysis. The study used the definition of IHCA stated by the Swedish Registry of Cardiopulmonary Resuscitation, i.e. a hospitalized patient where cardiopulmonary resuscitation and/or defibrillation have been initiated.

Statistical analysis

Descriptive data are presented as medians or proportions, with the appropriate dispersion measure. Logistic regression was used to predict ICU admission, IHCA and mortality as well as the combined outcome of these SAEs. The results were presented as odds ratio (OR) with 95% confidence interval (CI), adjusted for age and gender. The Hosmer & Lemeshow test was conducted to determine the goodness-of-fit. The ability of NEWS and NEWS 2 to discriminate patients at risk of IHCA and in-hospital death was evaluated by use of the area under the receiver operator characteristic curves (AUROC). Differences in AUROC between NEWS and NEWS 2 were compared by the DeLong test. The effect of the commonly used thresholds for triggering specific actions (e.g. aggregated NEWS or
Descriptive data of the 898 patients included and the RRT assessment are presented in Table 1. Median age was 72 years, 42.9% were women and the most common causes for admission to hospital were infections, followed by surgical and orthopedic conditions (Table 1 and Supplementary Table 2). Only a few patients (13.2%) had a decision on limitations of medical treatment (Table 1).

The majority of RRT assessments were performed during office hours, and most patients assessed by the RRT were hospitalized in wards belonging to internal medicine and surgery (Table 1). The reasons for RRT activation were the NEWS or NEWS 2 score in 59.9%, staff concern in 24.6% and other causes in 15.5% (Table 1 and Supplementary Table 3). The median NEWS or NEWS 2 score during RRT assessment for patients remaining at ward, transferred to the High dependency unit or the ICU, respectively, are listed in Table 2. A NEWS score ≥ 7 was present among 71.2% and a NEWS 2 score ≥ 7 was present among 72.8% of the patients.

During the study period, 26.8% of the patients were immediately transferred to the ICU and 10.6% to a higher level of care other than ICU (Table 2). Their NEWS and NEWS 2 scores are presented in Table 2. In some cases (7.5%), a new decision regarding limitations of medical treatment was made by the RRT.

A total of 333 patients (37.1%) were admitted to the ICU within 24 h, 10 patients (1.1%) suffered from cardiac arrest within 24 h and 51 patients (5.7%) died within 24 h of the RRT assessment (Table 2). In all, 394 patients (43.9%) were affected by the composite outcome.

A NEWS or NEWS 2 score ≥ 7 was associated with the composite endpoint and also with mortality and ICU admission (Table 3). The OR for IHCA was not computed due to low number of cases.

The prognostic accuracy of NEWS and NEWS 2 according to low risk and medium/high risk by NEWS (according to NEWS or NEWS 2 scores ≥ 5 and ≥ 7 respectively) is presented in Table 4. There was no difference in the number needed to evaluate between NEWS and NEWS 2 using a threshold of ≥ 7 (number needed to evaluate 7 for both scales). Using a threshold of ≥ 5 the number needed to evaluate was 15 (NEWS) and 13 (NEWS 2) respectively. The relative true positive ratios of NEWS 2 compared to NEWS were 0.98 (threshold ≥ 5) and 1.01 (threshold ≥ 7), respectively, whereas the relative false positive ratios were 0.97 (threshold ≥ 5) and 1.03 (threshold ≥ 7) respectively.

The ability for NEWS and NEWS 2 to discriminate the composite outcome was 0.62 for both scales (Fig. 2). In discriminating mortality, the AUROC for NEWS was 0.69 and for NEWS 2 0.67 (Fig. 2). For the outcome unanticipated ICU admission, the AUROC for NEWS and NEWS 2 was 0.59 and 0.60 respectively. The AUROC for discriminating IHCA was 0.51 for NEWS and 0.47 for NEWS 2. The AUROC curves for unanticipated ICU admittance and IHCA are presented in Supplementary Fig. 1.

Discussion

The major finding in this prospective multicentre cohort study among hospitalized deteriorating patients assessed by a RRT is the acceptable prognostic accuracy of NEWS 2 to predict mortality within 24 h. However, the predictive power to identify patients at risk of unanticipated ICU admission was rather weak and regarding IHCA the prediction was poor. Furthermore, the predictive power for the composite endpoint (i.e. unanticipated ICU admission, mortality or IHCA within 24 h) was rather weak. We found that NEWS and NEWS 2 performed similar in predicting the risk of unanticipated ICU admission, mortality or IHCA within 24 h.

The predictive power of NEWS has varied in previously published studies depending on the study settings and cohorts. As to prediction of mortality, our results are in line with Tirkkonen et al and Fernando et al who also studied RRT cohorts in contrast to the general hospitalized population; notably both studies had a longer time horizon than our study.

The ability of NEWS and NEWS 2 in this study to predict ICU admissions amongst patients assessed by the RRT was rather weak, both in absolute terms and compared to previous studies. Deranged
### Table 1 – Study cohort characteristics and data on RRT assessments (n = 898). Data are presented as numbers (percentages).

| Age (years), median (Q1, Q3) | 72 (64, 79) |
|------------------------------|-------------|
| Female                       | 385 (43)    |
| Clinical affiliation         |             |
| Medicine                     | 359 (40)    |
| Surgery                      | 263 (29)    |
| Orthopedic                   | 83 (9.2)    |
| Infection                    | 76 (8.5)    |
| Emergency Department         | 39 (4.3)    |
| Geriatric                    | 16 (1.8)    |
| Psychiatry                   | 6 (0.7)     |
| Other                        | 56 (6.2)    |
| Diagnosis upon admission     |             |
| Surgical diseases            | 199 (22.7)  |
| Infections                   | 163 (18.1)  |
| Orthopedic diseases          | 76 (8.5)    |
| Sepsis                       | 73 (8.1)    |
| Dyspnoe                      | 46 (5.1)    |
| Malignancy                   | 28 (3.1)    |
| Cardiovascular diseases      | 25 (2.8)    |
| Respiratory diseases         | 24 (2.7)    |
| Altered level of consciousness | 22 (2.4)  |
| Catastrophic conditions      | 21 (2.3)    |
| Neurological diseases        | 17 (1.9)    |
| Other cause of admission     | 204 (23)    |
| Primary reason for RRT call  |             |
| NEWS/NEWS 2 score           | 538 (60)    |
| Concern for the patient      | 221 (25)    |
| Other                        | 139 (16)    |
| Time of day RRT assessment   |             |
| 08:00 to 17:00               | 673 (75)    |
| On-call hours (17:00 to 08:00)| 225 (25)   |
| LOMT prior to RRT assessment |             |
| Full care                    | 780 (87)    |
| DNACPR                       | 111 (12)    |
| Other                        | 7 (0.8)     |

NEWS, National Early Warning Score; RRT, Rapid response team; LOMT, limitations of medical treatment; DNACPR, do not attempt cardiopulmonary resuscitation.

### Table 2 – Decisions on continued care after RRT assessment, outcomes and median scores for NEWS and NEWS 2 respectively (n = 898).

| Decision on continued care after assessment, n (%) |  |
|---------------------------------------------------|---|
| Immediate admission to ICU                        | 241 (27) |
| Patients remaining at ward after RRT assessment   | 562 (63) |
| Patients transferred to HDU                       | 95 (11)  |
| Patients receiving a new LOMT                     | 67 (7.5) |

| Outcomes, n (%)                                   |  |
|---------------------------------------------------|---|
| Admission to ICU within 24 h after RRT assessment | 333 (37) |
| Cardiac arrest within 24 h of RRT assessment      | 10 (1.1) |
| Mortality within 24 h of RRT assessment           | 51 (5.7) |

| NEWS score median, (Q1, Q3)                        |  |
|---------------------------------------------------|---|
| Immediate admission to ICU                        | 9 (7.11) |
| Patients remaining at ward after RRT assessment   | 8 (6.10) |
| Patients transferred to HDU                       | 8 (6.10) |

| NEWS 2 score median, (Q1, Q3)                      |  |
|---------------------------------------------------|---|
| Immediate admission to ICU                        | 9 (7.11) |
| Patients remaining at ward after RRT assessment   | 8 (6.10) |
| Patients transferred to HDU                       | 8 (6.10) |

NEWS, National Early Warning Score; RRT, Rapid response team; ICU, Intensive care unit; HDU, High dependency unit; LOMT, limitation of medical treatment.
SAEs. One explanatory model is that the cardiac arrests are harder to predict than other SAEs due to a component of sudden cardiac death. This is in line with previous studies, showing a modulated NEWS concept.

Mortality
NEWS ≥ 7, unadjusted 3.2 (1.3–7.6) 0.008
NEWS ≥ 7, adjusted 3.0 (1.3–7.2) 0.012
NEWS 2 ≥ 7, unadjusted 2.4 (1.0–5.5) 0.031
NEWS 2 ≥ 7, adjusted 2.3 (1.0–5.2) 0.047

Composite outcome
NEWS ≥ 7, unadjusted 2.1 (1.6–2.9) <0.001
NEWS ≥ 7, adjusted 2.2 (1.6–3.0) <0.001
NEWS 2 ≥ 7, unadjusted 2.1 (1.5–2.9) <0.001
NEWS 2 ≥ 7, adjusted 2.2 (1.6–3.0) <0.001

TABLE 3 – Logistic regression of the NEWS and NEWS 2 associations with the outcomes unanticipated ICU admission, mortality or IHCA all within 24 h of RRT assessment (n = 898).

| Outcome | NEWS ≥ 7, unadjusted | NEWS ≥ 7, adjusted | NEWS 2 ≥ 7, unadjusted | NEWS 2 ≥ 7, adjusted |
|---------|----------------------|--------------------|------------------------|----------------------|
| ICU Admission | 1.8 (1.3–2.5) <0.001 | 1.9 (1.4–2.6) <0.001 | 1.8 (1.3–2.5) <0.001 | 1.9 (1.4–2.6) <0.001 |
| Mortality | 3.2 (1.3–7.6) 0.008 | 3.0 (1.3–7.2) 0.012 | 2.4 (1.0–5.5) 0.031 | 2.3 (1.0–5.2) 0.047 |
| Composite outcome | 2.1 (1.6–2.9) <0.001 | 2.2 (1.6–3.0) <0.001 | 2.1 (1.5–2.9) <0.001 | 2.2 (1.6–3.0) <0.001 |

We found that both NEWS and NEWS 2 performed poorly in predicting cardiac arrest. This is in line with previous studies, showing that the discriminative ability of all early warning scores (including NEWS) is weaker in predicting cardiac arrest compared to other SAEs. One explanatory model is that the cardiac arrests are harder to predict than other SAEs due to a component of sudden cardiac arrhythmias or coronary occlusions without prior deviating vital signs in IHCA.

Table 4 – Prognostic accuracy for NEWS and NEWS 2 for the composite outcome unanticipated ICU admission, mortality or IHCA all within 24 h of RRT assessment (n = 898).

| Outcome | NEWS ≥ 5 (n = 801, 89.2%) | NEWS ≥ 5 (n = 784, 87.3%) | NEWS ≥ 7 (n = 639, 71.2%) | NEWS ≥ 7 (n = 654, 72.8%) |
|---------|---------------------------|---------------------------|---------------------------|---------------------------|
| Sensitivity percent (95% CI) | 93.2 (90.1–95.5) | 91.8 (88.5–94.4) | 80.0 (75.5–84.0) | 81.1 (76.7–85.0) |
| Specificity percent (95% CI) | 13.5 (10.7–16.7) | 15.8 (12.8–19.1) | 34.9 (30.8–39.1) | 32.8 (28.9–37.0) |
| Diagnostic accuracy percent (95% CI) | 45.9 (42.6–49.2) | 46.7 (43.4–50.0) | 53.2 (49.9–56.5) | 52.4 (49.1–55.8) |
| Positive predictive value % (95% CI) | 42.4 (39.0–46.0) | 42.7 (39.2–46.3) | 45.7 (41.8–49.6) | 45.3 (41.4–49.2) |
| Negative predictive value % (95% CI) | 74.2 (64.3–82.6) | 73.7 (64.6–81.5) | 71.8 (65.9–77.2) | 71.7 (65.6–77.3) |
| Positive likelihood ratio | 1.08 (1.03–1.13) | 1.09 (1.04–1.14) | 1.23 (1.13–1.33) | 1.21 (1.12–1.30) |
| Negative likelihood ratio | 0.51 (0.33–0.78) | 0.52 (0.35–0.77) | 0.57 (0.45–0.72) | 0.58 (0.45–0.74) |
| Percentage of subjects with outcome ruled out (95% CI) | 10.8 (8.8–13.0) | 12.7 (10.6–15.1) | 28.8 (25.9–31.9) | 27.2 (24.3–30.2) |
| Percentage of subjects with outcome ruled in (95% CI) | 89.2 (87.0–91.2) | 87.3 (84.9–89.4) | 71.2 (68.1–74.1) | 72.8 (69.8–75.7) |
| Diagnostic OR (95% CI) | 2.1 (1.3–3.4) | 2.1 (1.3–3.2) | 2.1 (1.6–2.9) | 2.1 (1.5–2.9) |
| NNE (95% CI) | 15 | 13 | 7 | 7 |
| rTPR | 0.98 | 0.97 | 1.01 | 1.03 |
| rFPR | 0.97 | 0.97 | 1.01 | 1.03 |

NEWS and NEWS 2 were similar in predicting the composite outcome (e.g. unanticipated ICU-admission, IHCA and mortality within 24 h of RRT assessment). This extends results by Piementel et al., who compared the ability of NEWS and NEWS 2 to identify hospitalized patients in general wards at risk of SAEs. These authors found no benefit of NEWS 2 in any diagnostic group compared to NEWS. However, due to their retrospective study design the documentation of the parameter “new confusion” added in NEWS 2 could not be taken into account.

The study was conducted in a cohort of RRT patients, while NEWS was originally aimed to enable early identification of patients deteriorating on a general ward. The pre-selection of patients in this study, who have already been found eligible for RRT alerting, clearly alters the conditions and most likely introduces a limitation to the validated NEWS concept.

NEWS has previously shown good to excellent discriminative ability in identifying patients in generalized hospital wards at risk of SAEs. However, in our study on patients receiving RRT assessment, NEWS and NEWS 2 performed less well. Our findings are in
line with previous findings by Shappell et al., notably the outcome measure in that study was in-hospital mortality. On the other hand, Tirkkonen et al found that NEWS had a moderate predictive power as to hospital outcome in a cohort of patients attended by a RRT.25 There were very few patients scoring low in NEWS/NEWS 2 in the study cohort, which most likely have had an impact on the predictive power of NEWS and NEWS 2. Furthermore, the adjacent RRT assessment in our study most likely also inflicted the predictive power of NEWS and NEWS 2, since published studies implicate that the majority of RRT assessments results in treatment or intervention.28 Nevertheless, given the limited knowledge on how to safely and effectively triage patients being assessed by RRTs, our findings add valuable insights on this group of high-risk patients.

The trade-off between the sensitivity and the specificity of an early warning score used for activation of the RRT is a delicate matter as a poor sensitivity risks to miss deteriorating patients whilst a poor specificity risks generating frequent activations resulting in alarm fatigue. This is of importance in relation to resource allocation and staff workload, considering the large number of RRT assessments performed in clinical practice.

We found a marginally higher sensitivity of NEWS 2 compared to NEWS (threshold ≥ 7), as expected at the expense of a lower specificity. Using a threshold of ≥5, the sensitivity of NEWS 2 was marginally lower compared to NEWS with a slightly higher specificity. However, a relative false positive ratio of 1.03 (NEWS 2/NEWS, threshold ≥ 7) and 0.97 (NEWS 2/NEWS, threshold ≥ 5) respectively may suggest a similar risk of “false alarms” when comparing NEWS and NEWS 2.

Future research should focus on improving the identification of high-risk patients among those being assessed by RRTs without increasing the workload for the medical staff. In pursuit of a decision support in the form of a new prediction model one may consider adding biochemical markers, age, comorbidity and information extracted from electronic health records. Also, the rapid development of artificial intelligence will likely facilitate real-time analyses when creating accurate and simple future prediction models for risk assessment.

**Strengths and limitations**

This is a large, prospective cohort study, covering 26 hospitals in Sweden, with a rigorous study protocol and a low rate of missing variables. The uniform calculation of both NEWS and NEWS 2 scores by the study team constitutes another strength. However, there are several limitations. We did not retrieve any information about comorbidities, functional status, or frailty. There may also have been variations across hospitals with regards to measurements of vital parameters. Furthermore, some participating hospitals have High dependency units, whereas patients in other hospitals would have been admitted directly to the ICU. This may have contributed to a slight underestimation of the number of unanticipated ICU admissions.

**Conclusion**

The prognostic accuracy of NEWS 2 to predict mortality within 24 h was acceptable in patients being assessed by a RRT. The predictive power to identify patients at risk of unanticipated ICU admission or the composite endpoint was rather weak, and the predictive power to identify patients at risk for IHCA was poor.

Whereas NEWS and NEWS 2 performed similar in predicting the risk of SEAs, their performances were not sufficient to enable use as a risk stratification tool among patients being assessed by a RRT.
Acknowledgements

The authors acknowledge Löf, the Swedish patient insurance, and Region Stockholm for financial support. The study sponsors have not been involved in the study design, conduction, analysis and interpretation of data, in the writing of the manuscript or in the decision to submit the manuscript for publication.

We are indebted to our contacts at the hospitals and their colleagues who manned the RRTs for their hard and dedicated work collecting and reporting study data. We would also like to thank all head of departments of Anaesthesia and Intensive Care at the hospitals for their support and resource allocation. All participating hospitals and their respective contacts are listed below.

Uppsala University Hospital: Lucian Covaciuc, MD, and Magnus von Seth, MD, PhD.

Ainggaagås Hospital: Annette Nyberg, MD.

Hospital of Blekinge, Karlskrona: Carina Andersson, CCRN.

Capio St. Göran: Michael Wanecek, MD.

Danderyd University Hospital: Katharina Kieneker, MD, PhD, Anna Aronsson, CCRN, and Liselotte Wall, CCRN.

Gävle Hospital: Christina Claesson, CCRN.

Halland Hospital, Halmstad: Andrees O’Neill, MD.

Halland Hospital, Varberg: Magnus Ringmark, MD.

Helsingborg Hospital: Niklas Nielsen, MD, PhD and Sara Ander- tyn, CCRN.

Kalix Hospital: Sofia Söderholm, MD.

Kristianstad Hospital: Martin Spånngors, PhD, CCRN.

Kungälv Hospital: Gita Norén, CCRN, and Johanna Kloo, CCRN.

Karolinska University Hospital, Solna: Gabriella Jäderling, MD, PhD, Olia Friman, PhD, CCRN, and Sverre Kulberg, CCRN.

University Hospital of Umeå: Camilla Brorsson, MD.

Northern Ålvsborg County Hospital: Erika Axelsson, CCRN, and Jimmy Bjelkengren, CCRN.

Piteå Hospital: Anna Aström, CCRN.

Sahlgrenska University Hospital, Sahlgrenska: Vitus Krumbholz, MD.

Sahlgrenska University Hospital, Mölndal: Anne Jensen, CCRN.

Sahlgrenska University Hospital, Östra: Bertil Andersson, MD, and Sebastian Sporrong, CCRN.

Skåne University Hospital, Lund: Björn Bark, MD, and Lottie Lagerstedt, CCRN.

Skåne University Hospital, Malmö: David Westin, MD, and Jas- mina Huskanovic, CCRN.

Sunderby Hospital: Martina Wikström, CCRN.

Södersjukhuset: Eva Joelsson-Alm, PhD, CCRN, and Fredrik Häggström, CCRN.

Värnamo Hospital: Mathias Lindblad, MD, and Terje Blomstrand, MD.

Växjö Hospital: Gunilla Karlsson, CCRN.

Östersund Hospital: Line Samuelsson, MD, PhD.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2021.100191.

REFERENCES

1. Andersen LW, Holmberg MJ, Berg KM, Donnino MW, Granfeldt A. In-Hospital Cardiac Arrest: A Review. Jama 2019;321:1200–10.
2. Nolan JP, Soar J, Smith GB, et al. Incidence and outcome of in-hospital cardiac arrest in the United Kingdom National Cardiac Arrest Audit. Resuscitation 2014:85:987–92.
3. Kolte D, Khera S, Aronow WS, et al. Regional variation in the incidence and outcomes of in-hospital cardiac arrest in the United States. Circulation 2015;131:1415–25.
4. Rawshani A, Herlitz J. Yearly Report 2019 Swedish National Quality Registry for Cardiopulmonary Resuscitation. Swedish National Quality Registry for Cardiopulmonary. Resuscitation 2019.
5. Schein RM, Hazdai N, Pena M, Ruben BH, Sprung CL. Clinical antecedents to in-hospital cardiopulmonary arrest. Chest 1990;98:1388–92.
6. Kause J, Smith G, Prytherch D, Parr M, Flabouris A, Hillman K. A comparison of antecedents to cardiac arrests, deaths and emergency intensive care admissions in Australia and New Zealand, and the United Kingdom—the ACADEMIA study. Resuscitation 2004;62:275–82.
7. Harrison GA, Jacobs TC, Kilborn G, McLaws ML. The prevalence of recordings of the signs of critical conditions and emergency responses in hospital wards—the SOCCER study. Resuscitation 2005;65:149–57.
8. Hillman KM, Bristow PJ, Chey T, et al. Duration of life-threatening antecedents prior to intensive care admission. Intensive Care Med 2002;28:1629–34.
9. Perkins GD, Graesner JT, Semeraro F, et al. European Resuscitation Council Guidelines 2021: Executive summary. Resuscitation 2021;161:1–60.
10. Smith ME, Chiavarro JC, O’Neill M, et al. Early warning system scores for clinical deterioration in hospitalized patients: a systematic review. Am Thorac Soc 2014;11:1454–65.
11. Devita MA, Bellomo R, Hillman K, et al. Findings of the first consensus conference on medical emergency teams. Crit Care Med 2006;34:2463–78.
12. (London) RCoP. National early warning score (NEWS); 2012 (2019-06-10).
13. 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;84:465–70.
14. Spånfrors M, Anvidsson L, Karlsson V, Samuelson K. The National Early Warning Score: Translation, testing and prediction in a Swedish setting. Intensive Crit Care Nurs 2016:37:62–7.
15. Gerry S, Bonnici T, Birks J, et al. Early warning scores for detecting deterioration in adult hospital patients: systematic review and critical appraisal of methodology. BMJ (Clin Res ed) 2020;369:m1501.
16. The Royal College of Physicians. National Early Warning Score (NEWS) 2: Standardising the assessment of acute-illness severity in the NHS. 2017, p. 1–77.
17. Friman O, Bell M, Djørve T, Hvarfner A, Jaderling G. National Early Warning Score vs Rapid Response Team criteria-Prevalence, misclassification, and outcome. Acta anaesthesiol Scand 2019;63:215–21.
18. Prytherch DR, Smith GB, Schmidt PE, Featherstone PI. VIEWs—Towards a national early warning score for detecting adult inpatient deterioration. Resuscitation 2010;81:932–7.
19. Pimentel MAF, Redfern OC, Gerry S, et al. A comparison of the ability of the National Early Warning Score and the National Early Warning Score 2 to identify patients at risk of in-hospital mortality: A multi-centre database study. Resuscitation 2019;134:147–56.
20. Collins GS, Reitsma JB, Altman DG, Moons KG. Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis (TRIPOD): the TRIPOD Statement. Br J Surg 2015;102:148–58.

21. Hanley JMB. A method of comparing areas under receiver operating characteristic curves derived from the same cases. Radiology 1983;148:839–43.

22. Fernando SM, Fox-Robichaud AE, Rochwerg B, et al. Prognostic accuracy of the Hamilton Early Warning Score (HEWS) and the National Early Warning Score 2 (NEWS2) among hospitalized patients assessed by a rapid response team. Crit Care 2019;23:60.

23. Filleron T. Comparing sensitivity and specificity of medical imaging tests when verification bias is present: The concept of relative diagnostic accuracy. Eur J Radiol 2018;98:32–5.

24. Romero-Brufau S, Huddleston JM, Escobar GJ, Liebow M. Why the C-statistic is not informative to evaluate early warning scores and what metrics to use. Crit Care 2015;19:285.

25. Tirkkonen J, Karlsson S, Skrifvars MB. National early warning score (NEWS) and the new alternative SpO2(2) scale during rapid response team reviews: a prospective observational study. Scand J Trauma Resusc Emerg Med 2019;27:111.

26. Tirkkonen J, Kontula T, Hoppu S. Rapid response team patients triaged to remain on ward despite deranged vital signs: missed opportunities? Acta anaesthesiol Scand 2017;61:1278–85.

27. 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;46:1041–6.

28. Flabouris A, Chen J, Hillman K, Bellomo R, Finfer S. Timing and interventions of emergency teams during the MERIT study. Resuscitation 2010;81:25–30.