Original article

Accuracy of an expanded early warning score for patients in general and trauma surgical wards

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Background: Early warning scores may aid the prediction of major adverse events in hospitalized patients. Recently, an expanded early warning score (EWS) was introduced in the Netherlands. The aim of this study was to assess the relationship between this EWS and the occurrence of major adverse clinical events during hospitalization of patients admitted to a general and trauma surgery ward.

Methods: This was a prospective cohort study of consecutive patients admitted to the general and trauma surgery ward of a university medical centre (March–September 2009). Follow-up was limited to the time the patient was hospitalized. Logistic regression analysis was used to

assess the relationship between the EWS and the occurrence of the composite endpoint consisting of death, reanimation, unexpected intensive care unit admission, emergency surgery and severe complications. Performance of the EWS was analysed using sensitivity, specificity, predictive values and receiver–operator characteristic (ROC) curves.

Results: A total of 572 patients were included. During a median follow-up of 4 days, 46 (8 per cent) patients reached the composite endpoint (two deaths, two reanimations, 17 intensive care unit admissions, 44 severe complications, one emergency operation). An EWS ≥ 3, adjusted for baseline American Society of Anesthesiology classification, was associated with a significantly higher risk of reaching the composite endpoint (odds ratio 11·3, 95 per cent confidence interval (c.i.) 5·5 to 22·9). The area under the ROC curve was 0·87 (95 per cent c.i. 0·81 to 0·93). When considering an EWS ≥ 3 to be a positive test result, sensitivity was 74 per cent and specificity was 82 per cent.

Conclusion: An EWS ≥ 3 is an independent predictor of major adverse events in patients admitted to a general and trauma surgery ward.

Introduction

A large proportion of the in-hospital mortality is predictable and preventable if early recognition of clinical deterioration is achieved[1–3]. From observational studies it appears that in the majority of patients an adverse clinical event (e.g. death, reanimation or intensive care unit (ICU) admission) is preceded by early clinical warning signs[3–6]. However, these signs are frequently not recognized, misinterpreted or not properly treated[7]. The aim of early warning scores (EWS) is to aid early recognition of clinical deterioration in patients and consequently initiate early interventions to prevent further decline. Examples of available EWS include ‘medical emergency teams’ (MET), ‘acute life-threatening early recognition

and treatment' (ALERT), and 'critical care outreach service' (CCOS)[8–11]. However, high quality evidence on the performance of EWS is lacking[12,13].

In 2009, an expanded EWS was introduced in the Netherlands[14]. The score is composed of the clinical parameters heart rate, systolic blood pressure, respiratory rate, temperature, level of consciousness, urine production, and concern of the nursing staff about the patient. The EWS used in the present study is based on the Modified Early Warning Score, but also includes the variables urine production, neurological status and concern of nursing staff about the patient's condition[15]. In an attempt to improve patient safety, this EWS was introduced and implemented in 2009 in several Dutch hospitals, including our university medical centre. The use of the EWS is recommended by the Dutch national committee on improvement of healthcare (Centraal Begeleidings Orgaan (CBO) and safety programme VMS)[14]. However, no robust evidence on the performance of this EWS in predicting clinical deterioration was available at the time of its implementation. Moreover, this EWS had not been validated in a large population before. Therefore, the aim of the present study was to analyse the relationship between the EWS and the occurrence of major adverse events in surgical patients during hospitalization on a general and trauma surgery ward.

Methods

Study design and population

This study was designed as a single-centre prospective cohort study. The study population consisted of all consecutive patients admitted to the general and trauma surgery ward of a Level 1 trauma centre in the Netherlands between 1 March and 30 September 2009. No exclusion criteria were applied. The local medical ethics committee approved this study.

Data collection

Data collection covered demographic characteristics, the American Society of Anesthesiologists physical status classification (ASA class) and diagnosis at admission. At the time of admission, vital functions including systolic and diastolic blood pressures, heart rate, respiratory rate, temperature, level of consciousness and urine production were recorded. Concern of the nursing staff about the patient's condition was also scored. These variables were combined into the EWS (*Fig. 1*). Three times a day, the EWS values of all admitted patients were determined during the clinical round in the morning, afternoon and evening. In addition, if a patient's clinical state deteriorated, an EWS was determined and registered. Planned ICU admissions (e.g. after major surgery in high-risk patients) were not taken into account. The highest EWS observed during hospitalization, corresponding to the worst clinical situation of the patient, was used in the analysis. The EWS scores were dichotomized into EWS < 3 *versus* EWS ≥ 3. This cut-off value was prespecified, based upon the recommendations of the Dutch CBO guideline. Herein, clinical evaluation of the patient's condition by the attending physician was advised if the EWS was 3 or more. The association between the EWS and the occurrence of adverse events was studied in a pre-introduction setting. Therefore, the EWS was determined regularly but was not used to trigger the intervention team. However, the physician who decided whether the intervention team was triggered was not blinded to the EWS.

Follow-up

Follow-up was limited to the time the patient was hospitalized. A trained research nurse scored for death, reanimation, unexpected ICU admission, emergency operations and severe complications during follow-up. Planned ICU admissions (e.g. after major surgery in high-risk patients) were not taken into account. Severe complications were defined as

complications that were potentially lethal and of which the outcome could have been potentially influenced if the complication was recognized early.

Data analysis

Statistical analyses were performed using SPSS® for Windows®, version 17·0 (SPSS, Chicago, Illinois, USA) and STATA® for Windows®, version 11 (StataCorp, College Station, Texas, USA). Continuous variables are expressed as the mean(s.d.) if normally distributed or otherwise as the median (interquartile ratio). Categorical variables are expressed as frequency (percentage). Means were compared using the independent samples *t* test if normally distributed or using the Mann–Whitney *U* test if the distribution was skewed. Logistic regression models with preselected co-variables were used to obtain multivariable adjusted risk estimates. All risk estimates are reported as odds ratio (OR) with 95 per cent confidence interval (c.i.). The goodness-of-fit of the model was evaluated using the Hosmer–Lemeshow statistic. A composite endpoint consisting of death, reanimation, ICU admission, emergency operation and severe complications was used as the dependent variable. When a patient reached at least one of the above-mentioned complications the composite endpoint was considered positive. The performance of the EWS was assessed by calculating the sensitivity, specificity, positive predictive value and negative predictive value. The performance was summarized in a receiver–operator characteristic (ROC) curve. The area under the ROC curve was calculated subsequently. If the EWS was equal to or exceeded the predefined cut-off of 3 points, the test was considered positive; if the EWS was less than 3, the test was considered negative. The performance of the EWS when using other cut-off values was evaluated in terms of sensitivity, specificity, positive predictive value and negative predictive value.

Results

Study population

The study population consisted of 572 consecutive patients admitted to the general surgery and trauma surgery ward of a Dutch university medical centre. The mean age of the population was 50(20) years, and 63 per cent of the patients were men. Baseline characteristics of the study population are presented in Table 1.

[Table 1 near here]

Follow-up

During a median follow-up of 4 days, 46 patients (8 per cent) reached the composite endpoint, including two deaths (0·3 per cent), two reanimations (0·3 per cent), 17 unexpected ICU admissions (3 per cent), 44 severe complications (7·7 per cent) and one emergency operation (0·2 per cent). The aetiology of severe complications was neurological in two cases, respiratory insufficiency in eight cases, haemodynamic instability in eight cases, intestinal bleeding in two cases, sepsis in six cases, pneumothorax in four cases, pulmonary embolism in six cases, myocardial infarction in three cases, and classified as ‘other’ in five cases. No patients were lost to follow-up.

Logistic regression analysis

First, the relationship between the EWS and the composite endpoint was assessed in a logistic regression model. Patients with an EWS ≥ 3 were shown to have significantly higher risk of reaching the combined endpoint compared with patients with an EWS < 3 (OR 12·9, 95 per cent c.i. 6·4 to 25·7). Next, the variables ASA class and diagnosis at time of admission were introduced in the logistic regression model as independent variables in an attempt to exclude their potentially confounding effect on the relationship between the EWS and the composite

endpoint. Comparison of the latter model to a simple model with ASA class and EWS ≥ 3 as the only independent variables by using the likelihood-ratio test did not show a significant contribution of the variable diagnosis at time of admission to the model and was therefore left out. The logistic regression model with ASA class and EWS ≥ 3 as independent variables and the composite endpoint as the dependent variable showed that an EWS ≥ 3 was associated with significantly higher odds of reaching the composite endpoint compared with EWS < 3, when corrected for ASA class (OR 11·3, 95 per cent c.i. 5·5 to 22.9) (Table S1, supporting information). According to the Hosmer–Lemeshow statistic, there was no evidence for lack of fit of the model (1·14, $P = 0·891$).

Diagnostic performance

The sensitivity of an EWS ≥ 3 was 74 (95 per cent c.i. 59 to 85) per cent and the positive predictive value was 26 (95 per cent c.i. 19 to 35) per cent. The specificity was 82 (95 per cent c.i. 78 to 85) per cent and the negative predictive value 97 (95 per cent c.i. 95 to 99) per cent. The area under the ROC curve was 87 (95 per cent c.i. 81 to 93) per cent. A two-by-two table is presented in Table 2. The diagnostic performance of the EWS when using different cut-off values is shown in Table 3.

[Tables 2 and 3 near here]

Discussion

The EWS, when used in clinical practice at a Dutch university hospital, was shown to be an independent predictor of death, reanimation, unexpected ICU admission, emergency operations and severe complications in general surgery and trauma surgery patients. EWS scores of 3 or more were associated with 13 times higher odds of the occurrence of the composite endpoint, and 11 times higher odds of the occurrence of the composite endpoint

corrected for ASA class. The negative predictive value of EWS scores of 3 or more is 97 per cent, indicating that this score is a highly reliable screening tool.

Previous studies showed that the scientific background of studies investigating the performance of EWS is diverse and of poor methodological quality[12,13]. The strength of the present study, in which a real-world sample of 572 consecutive patients was analysed, is the completeness of the data; no patients were lost to follow-up. Also, since no patients were excluded, the results may have a wider applicability to other hospitals.

The cumulative incidence of adverse events during hospitalization was 8 per cent. This shows that patients in this study cohort had a substantial risk of encountering adverse events, especially if one takes into account that the average age of our study population was 50 years and the vast majority of the patients had a baseline ASA class of 1 point, indicating a low perioperative risk. Moreover, the percentage of patients admitted with a potentially high-risk diagnosis (i.e. thoracic trauma, polytrauma, pelvic injury) was low. In the present study all events were stringently scored and were included in the analysis. The reported high risk in our study underlines the importance of awareness of adverse events during hospitalization, especially in patients with a favourable risk profile at first sight.

The analyses of the performance of the EWS showed that an EWS score of 3 or more yielded a negative predictive value of 97 per cent (i.e. for EWS < 3, the chance of not reaching the composite endpoint is 97 per cent), making the EWS particularly useful as a screening tool. The ideal diagnostic tool has a 100 per cent positive and negative predictive value. However, when designing a screening tool, it is more important to be able to identify all patients that are potentially at risk (i.e. high negative predictive value) than to be able to selectively identify only those patients that will indeed develop the event, certainly if the event is harmful. Analysing the diagnostic performance of the EWS at different cut-off levels, the cut-off of 3 points seems to be optimal. If the cut-off level is increased, the

specificity of the EWS is also increased, but sensitivity is lacking (54 per cent at a cut-off of 4 points).

At this time, the EWS is being used in our university medical centre in different surgical wards. If a patient scores above the predetermined cut-off value of EWS ≥ 3 at a certain time, the attending physician is warned by the nursing staff in order to evaluate the patient's condition and to establish a treatment plan if needed. When the patient does not respond on this implemented treatment the ICU physician is asked to evaluate the patient's condition at an early stage. Whether this strategy will lower the percentage of adverse events will be the subject of a later study. A previous randomized clinical trial did not show a significant reduction in cardiac arrest rates after the introduction of a medical emergency team, but this was possibly because of its underpowered sample size[8]. A recent study analysing the effectiveness of implementation of a medical emergency team showed a decreased cardiac arrest rate and in-hospital death rate after implementation but did not report on other outcome parameters such as ICU admission or emergency surgery[16].

The present study has some limitations. First, the physician making the decision about what intervention to use was not blinded to the EWS score. Second, the nurse making decisions about the outcome was also not blinded to the EWS score. This could have caused a bias, since both the decision to intervene and the decision of whether the composite endpoint was reached could have been influenced by the EWS score value. On the other hand, we do not believe that this would have introduced major bias; the interventions that were registered were not likely to be triggered by the EWS score alone, and the endpoints used were rather hard and not open for interpretation. Further research should focus on more precise risk stratification of patients and on cost-effectiveness analyses of this strategy. Furthermore, research on potential survival benefit due to early recognition of clinical deterioration and

subsequent early intervention should be performed. The extended EWS is now used in routine clinical care in our hospital.

Disclosure

The authors declare no conflict of interest, and no funding was obtained for the study.

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Table 1 Baseline characteristics of the study population

Baseline characteristic	All (*N* = 572)
Age, year	50(20)
Male gender	359 (63%)
ASA classification	
ASA 1	329 (58%)
ASA 2	134 (23%)
ASA 3	102 (18%)
ASA 4	7 (1%)
Glasgow Coma Scale	
GCS 15	560 (98%)
GCS 14	10 (2%)
GCS <14	1 (0.2%)
Hospitalization, days	4 (1–4)
Admission indication	
Thoracic trauma	32 (6%)
Abdominal trauma	17 (3%)
Extremity trauma	208 (36%)
Polytrauma	47 (8%)
Elective abdominal surgery	147 (26%)
Spine or pelvic injury	7 (1%)
Other*	112 (20%)
Temperature, °C	37·4(0·82)
Transcutaneous oxygen saturation, %	97(5)
Systolic blood pressure, mmHg	128(23)
Diastolic blood pressure, mmHg	72(13)
Heart rate, beats per min	84(18)
Respiration rate, breaths per min	17(5)
Urine output, ml/24 h	1688(965)
Haemoglobin, mmol/l	7·6(1·5)
White blood cell count, cells × 10^9/l	10·3 (8·0–13·1)
C-reactive protein, mg/l	24·5 (2–103)

Data are presented as mean(s.d.), median (interquartile range) or total number (%).*Consisted mainly of acute abdominal surgery (e.g. cholecystectomy, appendectomy), abdominal wall hernias and cicatricial hernias. ASA, American Society of Anesthesiologists; bpm, beats per minute.

Table 2 Two-by-two table for patients reaching the endpoint and for patients not reaching the composite endpoint, dichotomized for EWS < 3 *versus* EWS ≥ 3

	Endpoint	No endpoint	Total
EWS ≥ 3	34	95	129
EWS < 3	12	431	443
Total	46	526	572

EWS, early warning score.

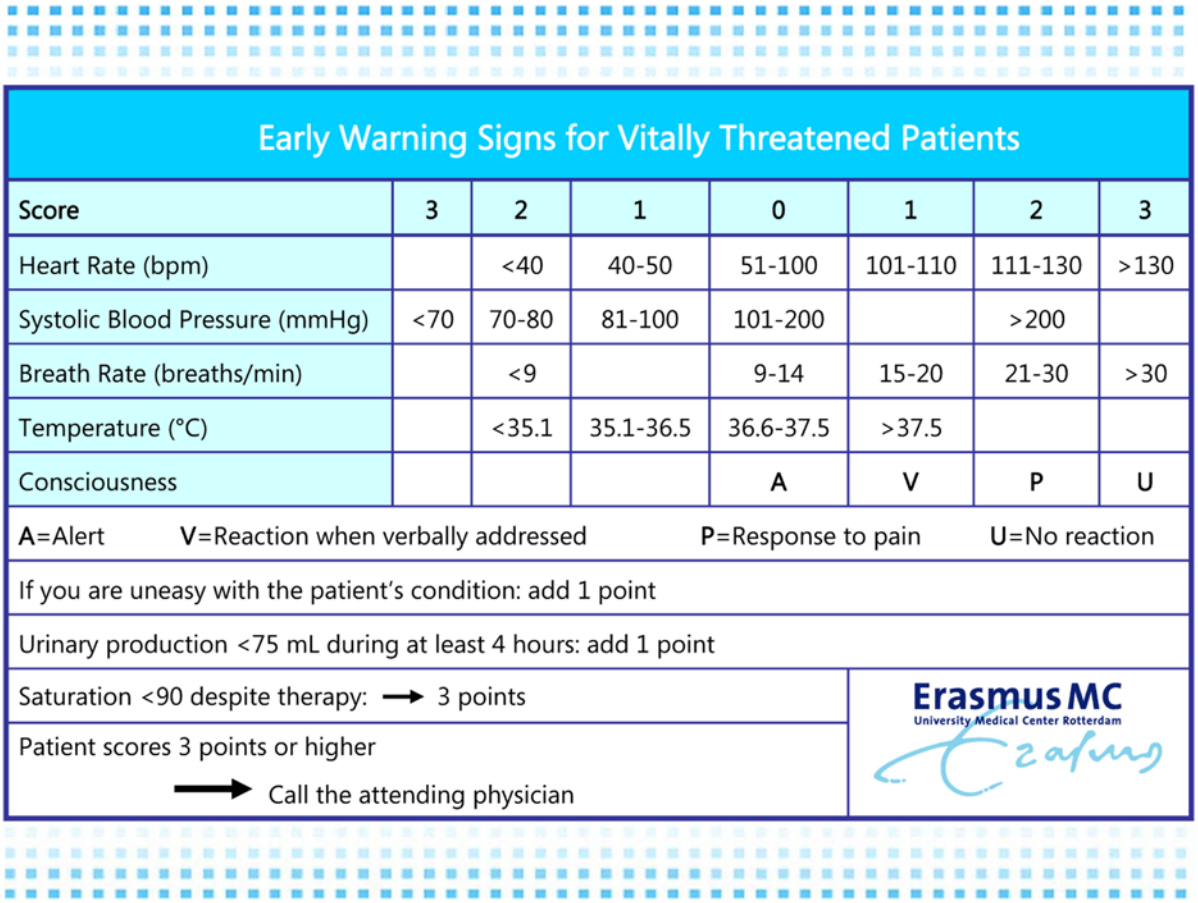
Table 3 Sensitivity, specificity, positive predictive value and negative predictive value at different cut-off points of the EWS

Cut-off value	Sensitivity (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)
EWS ≥ 1	96 (84, 99)	24 (21, 28)	10 (7, 13)	98 (94, 99)
EWS ≥ 2	91 (78, 97)	57 (53, 62)	16 (12, 21)	99 (96, 99)
EWS ≥ 3	74 (59, 85)	82 (78, 85)	26 (19, 35)	97 (95, 99)
EWS ≥ 4	54 (39, 69)	94 (91, 95)	42 (30, 56)	96 (94, 97)
EWS ≥ 5	50 (35, 65)	99 (97, 99)	77 (57, 89)	96 (94, 97)

Data are presented as point estimate (corresponding 95% confidence interval). EWS, early warning score.

FIGURE LEGENDS

Fig. 1. The expanded early warning score flowchart.



Early Warning Signs for Vitally Threatened Patients							
Score	**3**	**2**	**1**	**0**	**1**	**2**	**3**
Heart Rate (bpm)		<40	40-50	51-100	101-110	111-130	>130
Systolic Blood Pressure (mmHg)	<70	70-80	81-100	101-200		>200	
Breath Rate (breaths/min)		<9		9-14	15-20	21-30	>30
Temperature (°C)		<35.1	35.1-36.5	36.6-37.5	>37.5		
Consciousness				A	V	P	U
A=Alert **V**=Reaction when verbally addressed **P**=Response to pain **U**=No reaction							
If you are uneasy with the patient's condition: add 1 point							
Urinary production <75 mL during at least 4 hours: add 1 point							
Saturation <90 despite therapy: → 3 points							
Patient scores 3 points or higher → Call the attending physician							

Table S1 Variables in the logistic regression equation with independent variables EWS ≥ 3 and ASA class (categorical), and the combined endpoint as dependent variable

Variable	β	s.e. (β)	Odds ratio
EWS ≥ 3	2·421	0·363	11·3 (5·5, 22·9)
ASA 1 (reference)			
ASA 2 *versus* ASA 1	0·575	0·437	
ASA 3 *versus* ASA 1	1·437	0·413	
ASA 4 *versus* ASA 1	2·301	0·934	

Values in parentheses are 95 per cent confidence intervals. EWS, early warning score; ASA, American Society of Anesthesiologists.