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Using markedly abnormal vital signs in the emergency department to anticipate needs for intensive care unit admission

Jason Imperato[1,2], Daniel J Henning[3,4], Patrick J McBee[1], Leon D Sanchez[2,5]

[1]Department of Emergency Medicine, Mount Auburn Hospital, Cambridge, MA, USA

[2]Harvard Medical School, Boston, MA, USA

[3]Division of Emergency Medicine, University of Washington Medicine Center, Seattle, WA, USA

[4]University of Washington Medical School, Seattle, WA, USA

[5]Department of Emergency Medicine, Beth Israel Deaconess Medical Center, Boston, MA, USA

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ABSTRACT

Objective: To assess the utility and relative strength of markedly abnormal vital signs thresholds (triggers) in prediction of the needs for intensive care unit (ICU) admission from the emergency department (ED). **Methods:** A retrospective cohort study performed in a 37 000 annual visit, urban, community teaching ED. All adult patient encounters from July 10, 2011 to July 9, 2013 were eligible for inclusion. The primary outcome was ICU admission from the ED. We collected the incidence of trigger vital signs (heart rate>130 bpm, heart rate<40 bpm, respiratory rate>30 breaths per minute, respiratory rate< breaths 8 per minute, oxygen saturation<90%, systolic blood pressure<90 mmHg) as binary variables for each patient enrolled. Univariate and multi-variable logistic regression models were created to determine the ability of the trigger vital signs to predict ICU admission. **Results:** Total of 68 554 patient encounters were included in the analysis. Of these, 2 355 [3.4%, 95% confidence intervals (CI) 3.3%-3.6%] patients exhibited trigger vital signs, and 1 135 (1.7%, 95% CI 1.6%-1.8%) patients were admitted to ICU. All trigger vital signs were strongly associated with admission to the ICU and demonstrated higher odds of ICU admission with HR<40 (odds ratio 5.2, with 95% CI 2.7-10.1) being the best predictor among the studied covariates. The likelihood of ICU admission increased in a linear fashion with the number of trigger vital signs exhibited. **Conclusions:** Trigger vital signs serve as predictors that an ED patient may need admission to the ICU and may serve as a tool to expedite disposition of these resource-intensive patients.

1. Introduction

Systems for appropriately triaging emergency department (ED) patients often employ vital signs in the early assessment to risk-stratify patients[1]. It has been reported that irregular oxygen saturation, respiratory rate and systolic blood pressure, or a combination of those vital signs are strongly associated with admission to the intensive care unit (ICU) and in-hospital mortality[2-5]. For instance, studies demonstrated that not only was the type of abnormal vital sign important, but the number of abnormalities was also predictive of increased mortality, adverse outcome and ICU admission[5]. Similarly, preventable cardiac arrests have been shown to be associated with an incorrect area of treatment, such as a patient being treated in a general ward instead of the ICU[6].

Systems using 'trigger' vital sign thresholds including

First and corresponding author: Jason Imperato, Department of Emergency Medicine, Mount Auburn Hospital, Cambridge, MA, USA.
E-mail: jimperat@mah.harvard.edu
Tel: 617-499-5617

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tachycardia [heart rate (HR) >130 bpm], bradycardia (HR<40 bpm), tachypnea [respiratory rate (RR) >30 respirations per minute], bradypnea (RR<8 respirations per minute), hypotension [systolic blood pressure (sBP) <90 mmHg] and hypoxia (oxygen saturation<90%) to prompt a rapid response have proven effective in identifying and expediting the treatment of high-risk ED patients[7,8]. Yet, it is unlikely that these vital sign thresholds are equivalent in their ability to predict patients who require a higher level of care. Evidence to assist the early prediction of ICU admission could expedite disposition and improve resource allocation in the ED.

This study seeks to: 1) determine which, if any, of the previously studied individual trigger vital sign thresholds, including abnormalities found in HR, RR, sBP and SaO2 are associated with admission to the ICU; and 2) understand relative predictive value of each individual trigger vital sign, and the presence of multiple trigger vital signs in identifying patients that will require ICU admission.

2. Materials and methods

2.1. Study design and setting

Study population consisted of all patient encounters aged 18 and older presenting to the ED. Patients who left without being seen and patients who were transferred to another hospital were excluded.

A retrospective observational study of patients was conducted presenting to a 37 000 annual visit, urban, community teaching hospital. The study enrolled from July 10, 2011 to July 9, 2013. The hospital institutional review board approved the study design with waiver of informed consents.

During the study time period, there were a total of 74 084 patient encounters. Amount of 1 069 (1.4%) patients who left without being seen, 3 215 (4.3%) patients who were aged < 18 years, and 1 246 (1.7%) patients transferred to another hospital were excluded. Of the transferred patients, 793 (63.6%) were for primarily psychiatric reasons. After exclusions, 68 554 patient encounters met the eligibility criteria during the study timeframe. The mean age for the population was 69 years, of which 54.6% were female. During the study timeframe 20 794 (30.3%) patients were admitted to the hospital, of which 1 742 (2.5%) patients were admitted to the SDU and 1 134 (1.7%) were admitted to the ICU.

2.2. Methods and measurements

Patients who met one or more trigger criteria on initial vital signs were identified by screening all patient encounters at the end of the specified study period using the ED proprietary electronic documentation and tracking system utilized by physicians and nurses that was ChartMed v0.5 based off FileMaker Inc. Platform (Santa Clara, CA). Trigger vital signs that occurred in the pre-hospital setting or later in the ED stay were not included in this analysis.

Admission data for those patient encounters were analyzed in which patients had one or more of the predefined ‘trigger’ vital signs: tachycardia (HR>130 bpm), bradycardia (HR<40 bpm), tachypnea (RR>30 respirations per minute), bradypnea (RR<8 respirations per minute), hypotension (sBP<90 mmHg) and hypoxia (oxygen saturation<90%). Additional data were extracted from the ED documentation and tracking system included patient age, gender, disposition (admitted, transferred, discharged, left without complete evaluation) and admission location. Patients who required admission to the hospital could be admitted to one of several locations. These included ICU, step-down unit (SDU), telemetry ward with and without continuous oxygen saturation monitoring, and unmonitored ward. The decision to admit to the ICU was made after a discussion between the Emergency Medicine attending physician and the in-house Critical Care attending physician. The SDU was an intermediate care area between the ICU and ward with enhanced nursing capabilities not available on the regular floors.

2.3. Outcomes

Primary outcome of study was initial hospital disposition from the ED: ICU or non-ICU (SDU, admission or discharge). Each trigger vital sign was used as a binary covariate, either present or absent on the initial vital signs. Likewise, the absolute number of triggers present for each patient was used as an ordinal variable: 1, 2, or >2.

2.4. Analysis

In order to demonstrate the odds of ICU admission versus non-ICU admission based on the type and absolute number of trigger vital signs, we used logistic regression for each covariate to determine odds ratios and 95% confidence intervals (CI). To determine the relative predictive value of the type and absolute number of trigger vital signs, a multivariate logistic regression was created using a sub-group of patients who exhibited at least one trigger vital sign. All individual trigger vital signs were included a priori, and the absolute number of triggers and multiple interactions between individual covariates were tested to determine if they added predictive value, guided by changes in the model C-statistic. The Hosmer-Lemeshow test was used to assess model calibration. Lastly, for each individual trigger, the test characteristics for ICU admission were calculated. Statistical analysis was performed using SAS 9.3 (Cary, NC).

3. Results

3.1. Characteristics of study subjects

Among the eligible patient population, there were 2 355 (3.4%) patients identified with at least one trigger vital sign. Among those patients with at least one trigger vital sign, there were 430 patients (18.3%) admitted to the ICU representing 37.9% of all admissions to the ICU. Table 1 showed the frequency of abnormal vital signs and ICU admissions present in the patient population.

3.2. Main results

Among all patients, each trigger vital sign was strongly associated with ICU admission in the univariate analysis (Table 2), although the strength of association between the trigger threshold and ICU admission was not equivalent across trigger thresholds. For instance, patients with a HR over 130 bpm have an odds ratio (OR) of 10.8 (95% CI 8.9-13.2) for ICU admission compared to those with a RR over 30 bpm who have an OR of 49.7 (95% CI 15.2-163.0), or those with a HR under 40 bpm who have an OR of 47.8 (95% CI 26.1-87.5) for ICU admission. Likewise, having multiple abnormal vital signs was associated with an increased likelihood of admittance to the ICU, and the more trigger vital signs that were present, the higher the OR of ICU admission.

The multivariate logistic regression model predicting ICU admission among patients with at least one trigger vital sign, using HR>130 as the reference group was included in Table 2. This model demonstrated the relative strength of association between each trigger vital sign and ICU admission after controlling for the presence or absence of the other trigger vital signs and the number of trigger thresholds met. With a C-statistic for the model of 0.675 and a Hosmer-Lemeshow test result of 0.46, the model had a modest ability to discriminate patients who would be admitted to the ICU and was well calibrated. All trigger vital signs demonstrated significantly higher odds of ICU admission compared to HR>130, with HR<40 (OR 5.2, with 95% CI 2.7-10.1) being the best predictor among the covariates used. Further,

Table 1

Proportion of patients and frequency of ICU admission by vital sign abnormality and trigger frequency.

Parameters	Criteria fulfilled *n* (%)	ICU admission *n* (%)	Sensitivity (%) (95% CI)	Specificity (%) (95% CI)	Positive predictive value (95% CI)	Negative predictive value (95% CI)
Trigger vital sign						
HR > 130 bpm	888 (1.30)	125 (14.1)	11.0 (9.3-13.0)	98.9 (98.8-99.0)	14.1 (12.0-16.4)	98.5 (98.5-98.5)
HR < 40 bpm	43 (0.10)	19 (44.2)	1.7 (1.0-2.6)	100.0 (100.0-100.0)	44.2 (30.3-59.0)	98.4 (98.4-98.4)
RR > 30 breaths per minute	498 (0.70)	113 (22.7)	10.0 (8.3-11.9)	99.4 (99.4-99.5)	22.7 (19.4-26.4)	98.5 (98.5-98.5)
RR < 8 breaths per minute	11 (0.02)	5 (45.5)	0.4 (0.1-1.0)	100.0 (100.0-100.0)	44.5 (20.3-73.2)	98.4 (98.4-98.4)
Oxygen saturation < 90%	666 (1.00)	148 (22.2)	13.1 (11.1-15.2)	99.2 (99.2-99.3)	22.2 (19.4-25.4)	98.5 (98.5-98.6)
sBP < 90 mmHg	547 (0.80)	147 (26.9)	13.0 (11.1-15.1)	99.4 (99.4-99.5)	27.0 (23.5-30.6)	98.6 (98.5-98.6)
Triggers						
1	2355 (3.40)	430 (18.3)	37.9 (35.1-40.8)	97.1 (97.0-97.3)	18.3 (17.0-19.6)	98.9 (98.9-99.0)
2	276 (0.40)	113 (40.9)	10.0 (8.3-11.9)	99.8 (99.7-99.9)	40.9 (35.5-46.7)	98.5 (98.5-98.5)
3 or more	20 (0.03)	13 (65.0)	1.2 (0.6-2.0)	100.0 (100.0-100.0)	65.0 (42.6-82.3)	98.4 (98.4-98.4)

Table 2

Univariate and multivariable logistic regression analyses showing the OR for ICU admission in the presence of each trigger vital sign and the number of trigger vital sign thresholds. The multivariable model includes all displayed covariates.

Parameters	Univariate logistic regression					Multivariable logistic regression				
	Beta coefficient	Standard error	Unadjusted OR	95% CI	*P* value	Beta coefficient	Standard error	Adjusted OR	95% CI (%)	*P* value
Vital signs										
HR > 130 bpm	2.38	0.97	10.8	8.9 - 13.2	<0.01	Vital sign reference				
HR < 40 bpm	3.87	11.07	47.8	26.1 - 87.5	<0.01	1.70	1.28	5.2	2.7 - 10.1	<0.01
RR > 30 breaths per minute	3.90	17.60	49.7	15.2 - 163.0	<0.01	0.37	0.20	1.4	1.0 - 2.0	0.03
RR < 8 breaths per minute	2.96	1.94	19.3	15.5 - 24.0	<0.01	1.39	1.48	4.0	1.1 - 14.5	0.03
Oxygen saturation < 90%	3.21	2.30	24.9	20.4 - 30.4	<0.01	0.46	0.20	1.6	1.2 - 2.1	<0.01
sBP < 90 mm Hg	2.96	1.73	19.4	16.0 - 23.5	<0.01	0.90	0.36	2.5	1.8 - 3.3	<0.01
Triggers										
1	2.67	0.92	14.4	12.6 - 16.6	<0.01	Trigger number reference				
2	3.73	4.85	41.7	32.2 - 54.0	<0.01	0.90	0.41	2.5	1.7 - 3.5	<0.02
3 or more	4.71	34.23	111.5	44.4 - 280.1	<0.01	1.49	1.43	4.4	1.6 - 12.4	<0.03

Values are significant at P<0.01.

the OR of ICU admission increased in a linear fashion with the number of trigger vital signs exhibited.

4. Discussion

This study shows that the presence of any of the specified trigger vital signs, although representing only a small proportion of the total ED population, was strongly associated with admission to the ICU. The univariate strength of relationship between trigger thresholds was highest for patients with a HR<40 bpm and RR>30 bpm. Similarly, the study shows that all trigger vital signs demonstrate significantly higher odds of being admitted to the ICU, with HR<40 bpm being most predictive. For each additional trigger vital sign present at ED triage, the likelihood of being admitted to the ICU greatly increases. Patients with two and three or more abnormal vital signs were 2.5 fold and 4.4 fold more likely to be admitted to the ICU compared to patients with only one trigger vital sign.

The association between each abnormal vital sign threshold and the need for ICU admission is in agreement with other prior risk-stratification rules, which demonstrates that abnormal vital sign thresholds provide predictive value when predicting the need for ICU admission[9]. Furthermore, this study goes one step further to identify which of these vital sign thresholds are most predictive of patients who will require a higher level of care. While creating a prediction rule for ICU admission was not the goal of this study, the multivariate model area under the curve (0.675) showed comparable accuracy to other previously published prediction rules[2,10], affirming that these vital sign thresholds are strong predictors for ICU admission without any added clinical data. This analysis allows us to anticipate patients who will require ICU admission upon arrival to the ED, and mobilize appropriate resources to expedite the admission process.

This study was subject to all limitations of a retrospective design, including the possibility of incomplete or incorrectly entered data and limited sample size. The study was conducted at a single site so was subjected to standard practice at one facility. As a result, differences in patient population and frequency of patients with trigger vital signs may vary from hospital to hospital. Moreover, the thresholds to admit to the ICU may vary depending on the facility. Furthermore, we were not able to collect other covariates that may have relationship with ICU admission, including but were not limited to pre-existing medical conditions, type of medical presentation, physician discretion in regards to admission location or other ICU influencing patient characteristics. Patients who were transferred were not included in the data analysis. The vast majority of the transfers were for psychiatric complaints and less likely to have had vital signs that met trigger criteria. Only initial and not subsequent vital sign abnormalities were included in the study analysis. As a result, patients who developed abnormal vital signs during their ED course were not factored into the study. Lastly, factors that prompt ICU admission certainly include more than vital sign abnormalities alone, and this study cannot account for all reasons that a patient requires ICU admission nor does it account for variability for critical care admission threshold for each individual physician.

In summary, because the presence of any trigger vital sign is a strong predictor of admission to an ICU, early notification and clinical consideration is warranted when caring for patients with one or more of these specified trigger vital signs.

Conflict of interest statement

The authors declare that they have no conflict of interest.

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