A Role for the Early Warning Score in Early Identification of Critical Postoperative Complications

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Objective: We examined whether an early warning score (EWS) could predict inpatient complications in surgical patients.

Background: Abnormal vitals often precede in-hospital mortality. The EWS calculated using vital signs has been developed to identify patients at risk for mortality.

Methods: Inpatient general surgery procedures with National Surgical Quality Improvement Project data from 2013 to 2014 were matched with enterprise data on vital signs and neurologic status to calculate the EWS for each postoperative vital set measured on the ward. Outcomes of major complications, unplanned intensive care unit transfer, and medical emergency team activation were classified using the Clavien-Dindo system as grade I to V. Relationship with EWS and timing of complication was assessed using Kruskal-Wallis test and linear regression accounting for clustering with generalized estimating equation.

Results: Among 552 patients admitted to the ward postsurgery, 68 (12.3%) developed at least one grade I to III complication and 37 (6.7%) developed a grade IV/V complication. The mean maximum EWS was significantly higher preceding grade IV/V complications (10.1) compared with grade I to III complications (6.4) or across the hospital stay in patients without complications (5.4; $P < 0.01$). EWS significantly increased in the 3 days preceding grade IV/V complications ($P < 0.001$) and declined in patients without complications in the 3 days before discharge ($P < 0.001$). A threshold EWS of 8 predicted occurrence of grade IV/V complications with 81% sensitivity and 84% specificity.

Conclusions: Critical postoperative complications can be preceded by rising EWS. Interventional studies are needed to evaluate whether EWS can reduce the severity of postoperative complications and mortality for surgical patients through early identification and intervention.

Keywords: Clavien-Dindo classification, early warning score, early warning system, general surgery, patient safety, quality improvement, surgical outcomes, vital signs

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INTRODUCTION

Abnormal vitals often precede inpatient cardiac arrest providing an opportunity for early identification and intervention.[1–3] Several factors may limit medical staff ability to view and interpret abnormal vitals, including patient load, procedural attention, charting, or training level. Yet timely diagnosis of evolving complications is necessary to initiate early goal-directed therapy.[4] One reason attributed to the inability of rapid response teams to produce reductions for in-hospital mortality is untimely identification of clinical deterioration.[2,4–7] To address this need, early warning systems have been developed that use a score based on patient physiologic parameters to alert impending complications.

The development of early warning systems has largely taken place in the United Kingdom where delays in ward recognition of patient deterioration led to national reports advocating their utilization.[8–11] Of all early warning score (EWS) designs, the aggregate weighted parameter systems have the most sensitivity and specificity for predicting inpatient cardiac arrest, mortality, and intensive care unit (ICU) transfers in a broad hospital population.[12] Aggregate weighted parameter systems calculate a composite score by assigning values to abnormal variation in physiologic parameters and this score can then be used to stratify patients. Despite its potential utility, few studies have implemented the early warning system in the electronic medical record where scores can be calculated and alerts delivered simultaneously as vitals are recorded.[3,13,14]

An important aspect of EWS is the ability to segregate normal physiologic changes from pathologic vital variation. This need is heighted in postoperative patients that frequently have vital sign variation in response to the postoperative inflammatory state, volume shifts, and pain. Elevated EWS has been associated with increased morbidity and mortality in surgical patients; however, the relationship between EWS and the timing of complications is not well described.[15–18] This study sought to determine how EWS varies preceding major inpatient surgical complications occurring on a general surgery ward. We hypothesized that the EWS can reliably predict impending postoperative complications.

METHODS

Data Source

Inpatient general surgery procedures performed by surgeons in the divisions of gastrointestinal surgery and surgical oncology at a single institution were identified using American College of Surgeons National Surgical Quality Improvement Project (NSQIP) data over a 1-year period spanning 2013 to 2014. Data from these patients were merged with enterprise data on vital sign, neurologic status, ICU transfer status, and medical emergency team (MET) activation. Reliability of the NSQIP database has been previously described.[19] This project was approved by the local institutional review board committee.

Early Warning Score

The EWS algorithm used was based on the previously validated VitalPAC early warning score (ViEWS).[9] Altered mental status included any of the following nursing entries: stuporous; lethargic, obtunded; unresponsive; and comatose. We restricted the analysis to EWS generated on floor locations because we were interested in predicting adverse events occurring in the lowest acuity setting. Vital sets collected in nonhospital ward locations, including procedural,

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pre-/postanesthesia, ICU, psychiatric, and rehabilitation areas were excluded from analysis. Patients with no vitals recorded from analyzed locations were excluded. Because each vital set recorded did not include all components for EWS calculation, the EWS was formulated to examine 6-hour intervals preceding each vital set and utilized the highest score for each component. Mental status was examined for the preceding 16 hours to each vital set due to less frequent recording. If a component of the EWS algorithm was not reported in the interval examined, the EWS was still calculated with the missing component contributing 0 points.

Outcomes

We examined EWS preceding the first-occurring major complication, which included postoperative deep surgical site infection, organ surgical site infection, myocardial infarction, pneumonia, wound disruption, sepsis, unplanned return to the operation room, bleeding/transfusion, acute renal failure, cerebral vascular accident, unplanned intubation, septic shock, MET activation, unplanned ICU transfer, cardiac arrest, or death. Complications were classified into 2 categories based on adaption of the Clavien-Dindo classification system to NSQIP data.[20] If an initial complication was associated with end-organ failure (acute renal failure, cerebral-vascular incident, unplanned intubation, septic shock, cardiac arrest, and death) or critical care (unplanned ICU transfer, MET call) then the initial complication was classified as a grade IV/V complication. In addition, if the initial complication was followed by end-organ failure complication or critical care event in the following 2 days, it was also considered grade IV/V. Complications not associated with end-organ failure or critical care were considered grade I to III.

Chart abstraction was performed for all wards to ICU admissions to determine unplanned ICU transfers, which were defined as an urgent or emergent transfer to an ICU from the ward and excluded patients undergoing planned procedures that required postprocedure ICU stay. Institutional criteria for MET activation include nurse-triggered recognition of single vital parameter abnormalities, decreased level of consciousness, oliguria, chest pain, or clinical concern for impending deterioration. Patients were grouped by the classification of the initial complication and only EWS preceding the initial complication were examined. Performance measures for EWS thresholds were determined by assessing for the occurrence of at least one EWS at or above threshold before grade IV/V initial complications.

Statistical Analysis

Differences between groups were compared using Wilcoxon signed-rank or Kruskal-Wallis test for continuous variables and χ^2 tests or Fisher-exact test for categorical variables. To evaluate trends in EWS by days after the operation, we used EWS data from patients with no complications in the 30-day postoperative period and EWS data from patients preceding the occurrence of their first major complication. Linear regression with generalized estimating equation to account for clustering of EWS by patient was used to estimate the slope for average maximum EWS by day preceding complication occurrence or by day preceding discharge in patients without complications. Statistical significance was set at $P < 0.05$. EWS calculation and statistical analysis was performed using SAS version 9.2 (SAS Institute, Cary, NC). Area under the receiver-operating curve (AUC) was calculated using R package pROC.[21] Plots of EWS by postoperative day were produced using R Package GGPLOT2 with smoothing employed via LOESS algorithm.[22]

RESULTS

A total of 522 patients met inclusion criteria among 621 patients undergoing inpatient general surgery procedures over a 1-year period. The algorithm for calculating EWS is shown in Table 1. Characteristics of the overall population and those with and without complications are shown in Table 2. Overall, 68 (12.3 %) patients had a grade I to III complication and 37 (6.7%) had a grade IV/V complication. Only 6 (1.1%) patients experienced a 30-day mortality. Preoperative complications were infrequent with relatively minor differences between patients with and without complications. Mean maximum EWS on floor locations was significantly higher preceding initial postoperative grade IV/V complications (10.1) compared with grade I to III complications (6.4) or across the postoperative stay in patients without complications (5.4; $P < 0.001$).

In patients without complications, average max EWS decreased in the first 4 postoperative days (Fig. 1). The classification, timing, and maximum EWS preceding initial major complications are shown in Table 3. Median time to the initial major complication was similar in patients with grade I to III complications (2 days; interquartile range: 0–12) and patients with grade IV/V complications (1 day; interquartile range: 1–3; $P = 0.14$). Median maximum EWS ranged from 5 to 8 preceding individual grade I to III complications and from 6 to 13 for initial grade IV/V complications.

To better understand how EWS changes in the time leading up to a complication, we examined maximum EWS by the days preceding complications or preceding discharge in patients without complications (Fig. 2). Maximum EWS for patients with grade IV/V complications increased in the 3 days before complication occurrence (slope 1.36; 95% confidence interval: 0.75–1.98; $P < 0.01$) and decreased in patients without complications (slope: –0.34; 95% confidence interval (–) 0.46 to (–) 0.22; $P < 0.01$). Mean maximum EWS was significantly different between the grade IV/V and grade I to III complication group on the day prior (7.7 vs 5.3) and on the day of complication (8.7 vs 4.8; $P < 0.01$).

To guide alert thresholds for implementation of an automated notification in the electronic medical record, we examined performance measures using different EWS thresholds for predicting grade IV/V (critical) complications at the patient level (Fig. 3). The EWS had excellent discriminatory capacity for grade IV/V complications with area under the curve = 0.90. Using EWS threshold of 8 produced a sensitivity of 81%, specificity of 84%, and positive predictive value of 27% (supplemental Table 1, http://links.lww.com/SLA/A894). Examination of EWS at discharge did not reveal a significant association with patients who did or did not require readmission (data not shown).

TABLE 1. Early Warning Score Algorithm

	3	2	1	0	1	2	3
HR		≤40	41–50	51–90	91–110	111–130	≥131
Systolic BP	≤90	91–100	101–110	111–249	≥250		
Respiratory rate	≤8		9–11	12–20		21–24	≥25
Temperature (F)	≤95		95.1–96.8	96.9–100.4	100.5–102.2	≥102.3	
Oxygen saturation	≤91	92–93	94–95	≥96			
Alertness				Alert			Altered

TABLE 2. Characteristics of General Surgery Population

	Overall		No Complication		Grade I–III		Grade IV		
	n	%	n	%	n	%	n	%	P
	552	(100.0)	447	(81.0)	68	(12.3)	37	(6.7)	
Demographics									
Age									
≤65	376	(68.1)	318	(84.6)	40	(10.6)	18	(4.8)	<0.01
>65	176	(31.9)	129	(73.3)	28	(15.9)	19	(10.8)	
Race/ethnicity									
Black	126	(22.8)	99	(78.6)	18	(14.3)	9	(7.1)	0.58
White	419	(75.9)	343	(81.9)	48	(11.5)	28	(6.7)	
Other	7	(1.3)	5	(71.4)	2	(28.6)	0	(0.0)	
Comorbidities									
Smoker	111	(20.1)	82	(73.9)	24	(21.6)	5	(4.5)	<0.01
DM	101	(18.3)	78	(77.2)	13	(12.9)	10	(9.9)	0.34
COPD	23	(4.2)	19	(82.6)	3	(13.0)	1	(4.3)	0.90
CHF	5	(0.9)	4	(80.0)	0	(0.0)	1	(20.0)	0.38
ESRD	2	(0.4)	2	(100.0)	0	(0.0)	0	(0.0)	0.65
Preoperative complications									
Blood transfusion	5	(0.9)	0	(0.0)	4	(80.0)	1	(20.0)	<0.01
Sepsis	12	(2.2)	7	(58.3)	3	(25.0)	2	(16.7)	0.08
Pneumonia	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	–
Acute renal failure	1	(0.2)	1	(100.0)	0	(0.0)	0	(0.0)	0.81
Ventilator >48 hours	0	(0.0)	0	(0.0)	0	(0.0)	0	(0.0)	–
SSI*	2	(0.4)	0	(0.0)	1	(50.0)	1	(50.0)	0.03
Surgery									
Elective status	448	(81.2)	372	(83.0)	52	(11.6)	24	(5.4)	0.01
Postop length of stay									
<7 days	366	(66.3)	327	(89.3)	32	(8.7)	7	(1.9)	
7 to 14 days	144	(26.1)	104	(72.2)	23	(16.0)	17	(11.8)	<0.01
14 to 30 days	31	(5.6)	14	(45.2)	9	(19.0)	8	(25.8)	
>30 days	11	(2.0)	2	(18.2)	4	(36.4)	5	(45.4)	
Procedure type									
Colorectal	218	(39.5)	166	(76.1)	33	(15.1)	19	(8.7)	
Bile duct, liver, or pancreatic	109	(19.7)	82	(75.2)	17	(15.6)	10	(9.2)	
Herniorrhaphy	48	(8.7)	43	(89.6)	3	(6.3)	2	(4.2)	
Gastric	38	(6.9)	34	(89.5)	4	(10.5)	0	(0.0)	
Breast	34	(6.2)	32	(94.1)	2	(5.9)	0	(0.0)	0.06
Small bowel	31	(5.6)	27	(87.1)	1	(3.2)	3	(9.7)	
Appendix	16	(2.9)	16	(100.0)	0	(0.0)	0	(0.0)	
Gall bladder	14	(2.5)	11	(78.6)	1	(7.1)	2	(14.3)	
Esophageal	11	(2.0)	11	(100.0)	0	(0.0)	0	(0.0)	
Spleen	5	(0.9)	3	(60.0)	2	(40.0)	0	(0.0)	
Other	28	(5.1)	22	(78.6)	5	(17.9)	1	(3.6)	

COPD indicates chronic obstructive pulmonary disease; CHF, congestive heart failure; DM, diabetes mellitus; ESRD, end-stage renal disease.
*Any surgical site infection.

DISCUSSION

This study examined the temporal association between EWS and the initial major postoperative complication occurring in general surgery patients on inpatient wards. EWS was significantly higher, preceding major complications, than across the hospital stay in patients without complications. Although EWS declined in patients with no complications as they approached discharge, patients with critical complications showed increasing EWS in the days before the event. The EWS had an excellent discriminatory capacity preceding critical complications, and use of a threshold EWS of 8 yielded alerts at acceptable rates. The EWS is a tool that may offer early identification of critical postoperative complications.

Previous findings support the association of elevated EWS and severe complications. Two studies using modified EWS algorithms on surgical ward locations have shown adequate sensitivity and specificity for either ICU transfer or a composite of life-threatening complications.[15,16] Differences in EWS threshold performance measures in these studies can largely be attributed to differences in the outcomes measured and EWS algorithm inputs. Review of vitals from 38,000 surgical patients at one institution has shown that higher EWS on presentation as well the direction in EWS change is associated with increased mortality.[17] Adding to this evidence, our

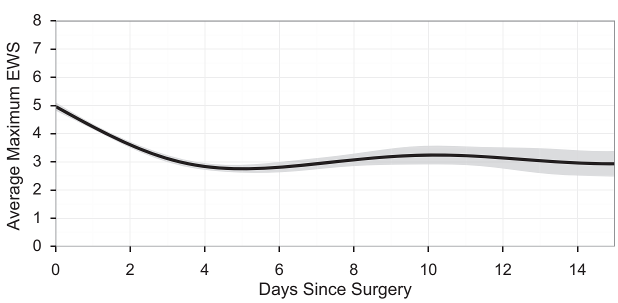

FIGURE 1. Early warning score by time after surgery in patients without complications.

TABLE 3. Classification, Timing, and Preceding EWS for Individual Complications

	Overall		Days to Complication		Max EWS Prior	
	N	%	Median	(IQR)	Median	(IQR)
Grade I–III Initial Outcomes						
Bleeding/transfusion	30	(25.6)	0.0	(0.0–2.0)	6.0	(5.0–8.0)
Organ space SSI	15	(12.8)	15.0	(9.0–20.0)	6.0	(4.0–7.0)
Sepsis	10	(8.5)	0.5	(0.0–9.0)	6.5	(5.0–8.0)
Deep SSI	7	(6.0)	12.0	(10.0–18.0)	7.0	(5.0–10.0)
Reoperation	7	(6.0)	9.0	(5.0–21.0)	6.0	(4.0–8.0)
Pneumonia	2	(1.7)	3.5	(3.0–4.0)	7.0	(7.0–7.0)
Pulmonary embolism	1	(0.9)	14.0	(14.0–14.0)	8.0	(8.0–8.0)
Wound disruption	1	(0.9)	15.0	(15.0–15.0)	5.0	(5.0–5.0)
Grade IV/V Initial Outcomes						
Unplanned ICU transfer	12	(10.3)	2.5	(1.0–3.5)	10.0	(8.0–12.5)
Medical emergency team call	7	(6.0)	1.0	(0.0–1.0)	12.0	(9.0–13.0)
Bleeding/transfusion	6	(5.1)	0.0	(0.0–1.0)	11.0	(9.0–12.0)
Myocardial infarction	4	(3.4)	4.0	(1.0–2.5)	10.0	(7.5–12.5)
Unplanned intubation	3	(2.6)	2.0	(1.0–4.0)	12.0	(10.0–13.0)
Septic shock	3	(2.6)	0.0	(0.0–1.0)	11.0	(10.0–11.0)
Death	3	(2.6)	15.0	(8–27)	6.0	(5.0–11.0)
Pneumonia	2	(1.7)	2.0	(1.0–3.0)	12.0	(12.0–12.0)
Reoperation	2	(1.7)	6.0	(3.0–9.0)	10.0	(9.0–11.0)
Cerebrovascular accident	1	(0.9)	2.0	(2.0–2.0)	13.0	(13.0–13.0)
Organ space SSI	1	(0.9)	0.0	(0.0–0.0)	7.0	(7.0–7.0)

EWS indicates early warning score; IQR, interquartile range; SSI, surgical site infection.

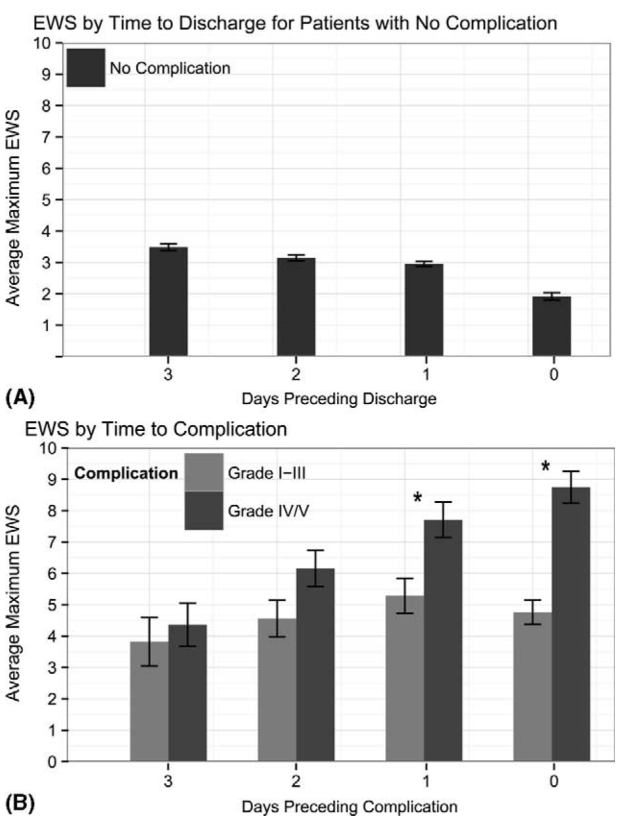

FIGURE 2. A, Average maximum early warning score by day before discharge in patients without complications. B, Average maximum early warning score by day before complication. *$p < 0.05$ comparing grade I–III to grade IV/V.

study is the first to assess EWS in relation to the initial major postoperative complication and shows distinct difference of EWS in the days before critical complications. Further, the findings illustrate a clear decrease of EWS in the immediate postoperative period in patients without complications, which can pose a problem when using low EWS threshold alerts.

The EWS components and algorithm used in this study were selected for their simplicity and ease of future implementation. Key to the application of the EWS is its integration into the electronic medical record to offer real-time monitoring, calculation accuracy, and trend tracking for clinical decision support.[14] There are numerous physiologic composite measures with a variety of inputs that

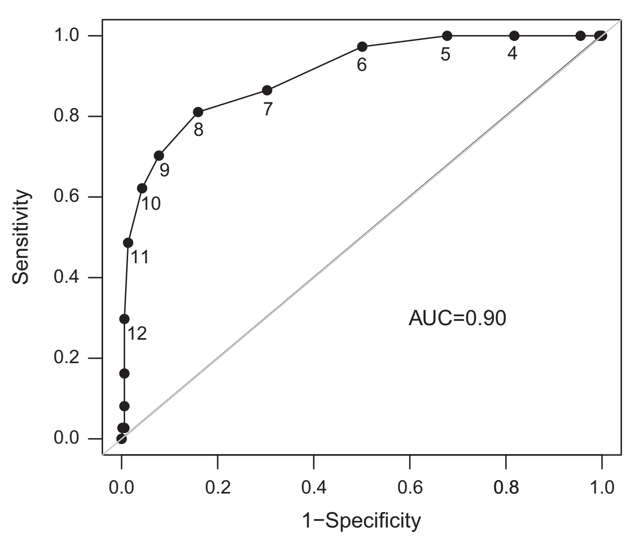

FIGURE 3. Receive operating curve for early warning score thresholds preceding grade IV/V initial complications. Numbers along curve represent early warning score thresholds.

have been previously described, and at least one is now commercially available for the electronic medical record.[12,23] Though few studies have compared the accuracy of different composite measures in surgical populations, our results illustrate that even simple composite physiologic measures have the capacity to forewarn critical complications. However, prospective studies measuring the impact of composite measures on outcomes have been limited to before and after studies and only shown a modest improvement in mortality.[24–26]

As traditionally used, the EWS can trigger alerts at different thresholds with protocols ranging from increasing vital frequency, primary physician notification, or MET activation, depending on the EWS level. The thresholds chosen can have significant impact on their acceptance among clinical providers and must be selected to minimize alarm fatigue from false positive alerts.[27] Other trigger mechanisms could include alerts produced after a threshold is met repetitively or alerts produced by a rate of increase in EWS. Although there are scenarios where the EWS would only reinforce a patient's condition to clinical staff, there are also likely circumstances that it could act as a safeguard for timely communication of patient condition. Future prospective research is needed to understand what alert threshold and mechanism is best suited to provide new timely information to clinical staff and have an impact on surgical outcomes. Beyond an alert system, the EWS can also be viewed as a summary measure of patient status for triage of clinical resources, such as criteria for transfer to a different level of care, nursing assignments, and ward acuity.[28] We did not find an association with EWS at discharge and readmission, but this should be further examined in larger cohorts.

Implementation of EWS in hospitals represents a potential structural and process measure for improvement of clinical outcomes. Timeliness of diagnosis and treatment for postoperative complications may partially explain variation in hospital mortality rates after surgical complications or failure-to-rescue rates.[29] A small portion of high-risk individuals account for the majority of failure-to-rescue events, and prevention or resolution of the first-occurring postoperative complication has greatest potential to improve this measure.[30] The impact of the first complication is highlighted in elderly patients, where initial postoperative pulmonary and infectious complications are associated with significant mortality.[31] Though we could not assess EWS differences in patients with failure to rescue due to a low mortality rate, the EWS tool could potentially address this need by identifying early signs of developing life-threatening complications to reduce subsequent mortality.

Our analysis has several limitations. This study was performed retrospectively and there were relatively few grade IV/V complications. The accuracy of complication timing is limited to 24-hours intervals as identified in NSQIP chart abstraction. Because the location of complication occurrence could not be restricted and calculation of EWS was limited to ward locations, the true extent of EWS variation before specific complications may be underestimated. Though the EWS algorithm used is based on a previously validated algorithm, it was modified by removal of urine output and oxygen delivery as inputs and may have decreased discriminatory capacity for complications compared with other composite measures. The generalizability may be limited by the surgical population principally comprising colorectal and hepatobiliary procedures. Due to high complication rates associated with these procedure types, use of the EWS in a ward with less complication prone patients would lead to less positive predictive value. Lastly, this analysis examined EWS ability to predict the occurrence of the first postoperative complication and may not represent changes in EWS that occur for subsequent complications.

CONCLUSIONS

Rising EWS in postoperative surgical patients can be a sign of impending life-threatening complications. The EWS is a tool that may provide early identification and treatment of postoperative complications to reduce subsequent morbidity and mortality.

Future studies should prospectively measure the risk reduction produced by implementation of an EWS into the electronic medical record.

REFERENCES

1. Hodgetts TJ, Kenward G, Vlachonikolis IG, et al. The identification of risk factors for cardiac arrest and formulation of activation criteria to alert a medical emergency team. *Resuscitation*. 2002;54:125–131.
2. Churpek MM, Yuen TC, Huber MT, et al. Predicting cardiac arrest on the wards: a nested case-control study. *Chest*. 2012;141:1170–1176.
3. Hravnak M, Edwards L, Clontz A, et al. Defining the incidence of cardiorespiratory instability in patients in step-down units using an electronic integrated monitoring system. *Arch Intern Med*. 2008;168:1300–1308.
4. Edelson DP. A weak link in the rapid response system. *Arch Intern Med*. 2010;170:12–13.
5. Chan PS, Khalid A, Longmore LS, et al. Hospital-wide code rates and mortality before and after implementation of a rapid response team. *J Am Med Assoc*. 2008;300:2506–2513.
6. Chan PS, Jain R, Nallmothu BK, et al. Rapid response teams: a systematic review and meta-analysis. *Arch Intern Med*. 2010;170:18–26.
7. Hillman K, Chen J, Cretikos M, et al. Introduction of the medical emergency team (MET) system: a cluster-randomised controlled trial. *Lancet*. 2005;365: 2091–2097.
8. Gao H, McDonnell A, Harrison DA, et al. Systematic review and evaluation of physiological track and trigger warning systems for identifying at-risk patients on the ward. *Intensive Care Med*. 2007;33:667–679.
9. Prytherch DR, Smith GB, Schmidt PE, et al. ViEWS—towards a national early warning score for detecting adult inpatient deterioration. *Resuscitation*. 2010;81:932–937.
10. Royal College of Physicians. *National Early Warning Score (NEWS): Standardising the Assessment of Acute-Illness Severity in the NHS. Report of a Working Party*. London, UK: Royal College of Physicians; 2012.
11. McQuillan P, Pilkington S, Allan A, et al. Confidential inquiry into quality of care before admission to intensive care. *Br Med J*. 1998;316: 1853–1858.
12. Churpek MM, Yuen TC, Edelson DP. Risk stratification of hospitalized patients on the wards. *Chest*. 2013;143:1758–1765.
13. Kho A, Rotz D, Alrahi K, et al. Utility of commonly captured data from an EHR to identify hospitalized patients at risk for clinical deterioration. *AMIA Annu Symp Proc*. 2007;404–408.
14. Jones S, Mullally M, Ingleby S, et al. Bedside electronic capture of clinical observations and automated clinical alerts to improve compliance with an early warning score protocol. *Crit Care Resusc*. 2011;13:83–88.
15. Gardner-Thorpe J, Love N, Wrightson J, et al. The value of modified early warning score (MEWS) in surgical in-patients: a prospective observational study. *Ann R Coll Surg Engl*. 2006;88:571–575.
16. Smith T, Den Hartog D, Moerman T, et al. Accuracy of an expanded early warning score for patients in general and trauma surgery wards. *Br J Surg*. 2012;99:192–197.
17. Kellett J, Wang F, Woodworth S, et al. Changes and their prognostic implications in the abbreviated VitalPAC early warning score (ViEWS) after admission to hospital of 18,827 surgical patients. *Resuscitation*. 2013;84:471–476.
18. Moore LJ, Jones SL, Kreiner LA, et al. Validation of a screening tool for the early identification of sepsis. *J Trauma*. 2009;66:1539–1546.
19. Shiloach M, Frencher SK Jr, Steeger JE, et al. Toward robust information: data quality and inter-rater reliability in the American College of Surgeons National Surgical Quality Improvement Program. *J Am Coll Surg*. 2010;210: 6–16.
20. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg*. 2004;240:205–213.
21. Robin X, Turck N, Hainard A, et al. pROC: an open-source package for R and S+ to analyze and compare ROC curves. *BMC Bioinformatics*. 2011;12:77.

22. Wickham H. *GGPLOT2: Elegant Graphic for Data Analysis.* New York: Springer; 2009.
23. Rothman MJ, Rothman SI, Beals J4th. Development and validation of a continuous measure of patient condition using the electronic medical record. *J Biomed Inform*. 2013;46:837–848.
24. Bellomo R, Ackerman M, Bailey M, et al. A controlled trial of electronic automated advisory vital signs monitoring in general hospital wards. *Crit Care Med*. 2012;40:2349–2361.
25. Moon A, Cosgrove JF, Lea D, et al. An eight year audit before and after the introduction of modified early warning score (MEWS) charts, of patients admitted to a tertiary referral intensive care unit after CPR. *Resuscitation*. 2011;82:150–154.
26. Patel MS, Jones MA, Jiggins M, et al. Does the use of a "track and trigger" warning system reduce mortality in trauma patients? *Injury*. 2011;42:1455–1459.
27. Weingart SN, Toth M, Sands DZ, et al. Physicians' decisions to override computerized drug alerts in primary care. *Arch Intern Med*. 2003;163:2625–2631.
28. Piper GL, Kaplan LJ, Maung AA, et al. Using the Rothman index to predict early unplanned surgical intensive care unit readmissions. *J Trauma Acute Care Surg*. 2014;77:78–82.
29. Ghaferi AA, Birkmeyer JD, Dimick JB. Variation in hospital mortality associated with inpatient surgery. *N Engl J Med*. 2009;361:1368–1375.
30. Ferraris VA, Bolanos M, Martin JT, et al. Identification of patients with postoperative complications who are at risk for failure to rescue. *J Am Med Assoc Surg*. 2014;149:1103–1108.
31. Sheetz KH, Krell RW, Englesbe MJ, et al. The importance of the first complication: understanding failure to rescue after emergent surgery in the elderly. *J Am Coll Surg*. 2014;219:365–370.