Early detection of an impending cardiac or pulmonary arrest is an important focus for hospitals trying to improve quality of care. Unfortunately, all current early warning systems suffer from high false-alarm rates. Most systems are based on the Modified Early Warning Score (MEWS); 4 of its 5 inputs are vital signs. The purpose of this study was to compare the accuracy of MEWS against the Rothman Index (RI), a patient acuity score based upon summation of excess risk functions that utilize additional data from the electronic medical record (EMR). MEWS and RI scores were computed retrospectively for 32,472 patient visits. Nursing assessments, a category of EMR inputs only used by the RI, showed sharp differences 24 hours before death. Receiver operating characteristic curves for 24-hour mortality demonstrated superior RI performance with c-statistics, 0.82 and 0.93, respectively. At the point where MEWS triggers an alarm, we identified the RI point corresponding to equal sensitivity and found the positive likelihood ratio (LR+) for MEWS was 7.8, and for the RI was 16.9 with false alarms reduced by 53%. At the RI point corresponding to equal LR+, the sensitivity for MEWS was 49% and 77% for RI, capturing 54% more of those patients who will die within 24 hours. Journal of Hospital Medicine 2014;9:116–119. 2013 The Authors. Journal of Hospital Medicine published by Wiley Periodicals, Inc. on behalf of Society of Hospital Medicine.

Bedside calculation of early warning system (EWS) scores is standard practice in many hospitals to predict clinical deterioration. These systems were designed for periodic hand-scoring, typically using a half-dozen variables dominated by vital signs. Most derive from the Modified Early Warning Score (MEWS). Despite years of modification, EWSs have had only modest impact on outcomes. Major improvement is possible only by adding more information than is contained in vital signs. Thus, the next generation of EWSs must analyze electronic medical records (EMRs). Analysis would be performed by computer, displayed automatically, and updated whenever new data are entered into the EMR. Such systems could deliver timely, accurate, longitudinally trending acuity information that could aid in earlier detection of declining patient condition as well as improving sensitivity and specificity of EWS alarms.

Advancing this endeavor along with others, we previously published a patient acuity metric, the Rothman Index (RI), which automatically updates when asynchronous vital signs, laboratory test results, Bra-
variables employed for each system. Briefly, RI utilizes 26 variables related to clinical care and routinely available in the EMR. These include vital signs, laboratory results, cardiac rhythms, and nursing assessments. Excess risk associated with any value of a variable is defined as percent absolute increase in 1-year mortality relative to minimum 1-year mortality identified for that variable. Excess risk is summed on a linear scale to reflect cumulative risk for individual patients at any given time. RI was computed at every
new observation during a patient visit, when input values were available. Laboratory results are included when measured, but after 24 hours their weighting is reduced by 50%, and after 48 hours they are excluded. Data input intervals were a function of institutional patient care protocols and physician orders. All observations during a patient’s stay were included in the analysis, per the method of Prytherch et al. Because data did not contain the simplified alert/voice/pain/unresponsive (A/V/P/U) score, computation of MEWS used appropriate mapping of the Glasgow Coma Scale. A corresponding MEWS was calculated for each RI. The relationship between RI and MEWS is inverse. RI ranges from 0 to 14, with lower scores indicating increasing acuity. MEWS ranges from 0 to 14, with higher scores indicating increasing acuity.

**Outcome Ascertainment**

In-hospital death was determined by merging the date and time of discharge with clinical inputs from the hospital’s EMR. Data points were judged to be within 24 hours of death if the timestamp of the data point collection was within 24 hours of the discharge time with “expired” as the discharge disposition.

**Statistical Methods**

Demographics and input variables from the 2 groups of observations, those who were within 24 hours of death and those who were not, were compared using a t test with a Cochran and Cox approximation of the probability level of the approximate t statistic for unequal variances. Mean, standard deviation, and P values are reported. Discrimination of RI and MEWS to predict 24-hour mortality was estimated using area under the receiver operating characteristic (ROC) curve (AUC), and null hypothesis was tested using χ². Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), positive and negative likelihood ratios (LR+, LR−) were computed. Analyses were performed with SAS 9.3 (procedures ttest, freq, logistic, nlmixed; SAS Institute, Cary, NC). Typically MEWS = 4 triggers a protocol to increase level of assessment and/or care, often a transfer to the intensive care unit (ICU). We denoted the point on ROC curve where MEWS = 4 and identified an RI point of similar LR− and sensitivity to compare false alarm rate. Then we identified an RI point of similar LR+ for comparison of LR− and sensitivity.

**RESULTS**

A total of 1,794,910 observations during 32,472 patient visits were included; 617 patients died (1.9%). Physiological characteristics for all input variables used by RI or MEWS are shown in Table 2, comparing observations taken within 24 hours of death to all other observations.

RI versus MEWS demonstrated superior discrimination of 24-hour mortality (AUC was 0.93 [95% confidence interval [CI]: 0.92-0.93] vs 0.82 [95% CI: 0.82-0.83]; difference, 0.11 [95% CI: 0.10-0.11]; P = 0.0001). ROC curves for RI and MEWS are shown in Figure 1; the MEWS is subsumed by RI across the entire range. Further, paired comparisons at points of clinical importance are presented in Table 3 for LR+, LR−, sensitivity, specificity, PPV, and NPV. In the first pair of columns, MEWS = 4 (typical trigger point for alarms) is matched to RI using sensitivity or LR−; the corresponding point is RI = 16,
which generates twice the LR+ and reduces false alarms by 53%. In the second pair of columns, MEWS = 4 is matched to RI using PPV or LR+; the corresponding point is RI = 30, which captures 54% more of those patients who will die within 24 hours.

**DISCUSSION**

We have shown that a general acuity metric (RI) computed using data routinely entered into an EMR outperforms MEWS in identifying hospitalized patients likely to die within 24 hours. At similar sensitivity, RI yields an LR+ more than 2-fold greater, at a value often considered conclusive. MEWS is derived using 4 vital signs and a neurologic assessment. Such a focus on vital signs may limit responsiveness to changes in acuity, especially during early clinical deterioration. Indeed, threshold breach tools may inadvertently induce a false sense of an individual patient’s condition and safety.12 The present findings suggest the performance of RI over MEWS may be due to inclusion of nursing assessments, laboratory test results, and heart rhythm. Relative contributions of each category are: vital signs (35%), nursing assessments (34%), and laboratory test results (31%). We found in previous work that failed nursing assessments strongly correlate with mortality,13 as illustrated in Table 2 by sharp differences between patients dying within 24 hours and those who did not.

Sensitivity to detect early deterioration, especially when not evidenced by compromised vital signs, is crucial for acuity vigilance and preemptive interventions. Others14 have demonstrated that our approach to longitudinal modeling of the acuity continuum is well positioned to investigate clinical pathophysiology preceding adverse events and to identify actionable trends in patients at high risk of complications and sepsis after colectoral operations. Future research may reveal both clinical and administrative advantages to having this real-time acuity measure available for all patients during the entire hospital visit, with efficacy in applications beyond use as a trigger for EWS alarms.

Study limitations include retrospective design, single-center cohort, no exclusion of “expected” hospital deaths, and EMR requirement. For MEWS, the Glasgow Coma Scale was mapped to A/V/P/U, which does not appear to affect results, as our c-statistic is identical to the literature.15 Any hospital with an EMR collects the data necessary for computation of RI values. The RI algorithms are available in software compatible with systems from numerous EMR manufacturers (eg, Epic, Cerner, McKesson, Siemens, AllScripts, Phillips).

The advent of the EMR in hospitals marries well with an EWS that leverages from additional data more information than is contained in vital signs, permitting complex numeric computations of acuity scores, a process simply not possible with paper systems. Further, the automatic recalculation of the score reduces the burden on clinicians, and broadens potential use over a wide range, from minute-by-minute recalculation when attached to sensors in the ICU, to comparative metrics of hospital performance, to non-clinical financial resource applications. This new information technology is guiding methods to achieve a significant performance increment over current EWS and may assist earlier detection of deterioration, providing a chance to avoid medical crises.15

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