CLINICAL RESEARCH STUDY

THE AMERICAN JOURNAL of MEDICINE®

Real-Time Automated Sampling of Electronic Medical Records Predicts Hospital Mortality

Hargobind S. Khurana, MD,[a,b,c] Robert H. Groves, Jr., MD,[a,b,c] Michael P. Simons, MD,[d,e] Mary Martin, PharmD,[f] Brenda Stoffer, RN,[g] Sherri Kou, MS,[h] Richard Gerkin, MD,[i] Eric Reiman, MD,[j,k] Sairam Parthasarathy, MD[l]

[a]*Banner TeleHealth, Mesa, Ariz;* [b]*Care Management, Banner Health, Phoenix, Ariz;* [c]*Health Management, Banner Health, Phoenix, Ariz;* [d]*Banner Medical Group, Phoenix, Ariz;* [e]*Banner Estrella Medical Center, Phoenix, Ariz;* [f]*Banner Corporate Center, Phoenix, Ariz;* [g]*Information Technology Clinical Systems, Banner Health, Phoenix, Ariz;* [h]*Clinical Performance Analytics, Banner Health, Phoenix, Ariz;* [i]*University of Arizona College of Medicine-Phoenix;* [j]*Banner Research, Banner Health, Phoenix, Ariz;* [k]*Banner Alzheimer's Institute, Phoenix, Ariz;* [l]*University of Arizona and Banner University Medical Center, Tucson.*

ABSTRACT

BACKGROUND: Real-time automated continuous sampling of electronic medical record data may expeditiously identify patients at risk for death and enable prompt life-saving interventions. We hypothesized that a real-time electronic medical record-based alert could identify hospitalized patients at risk for mortality.

METHODS: An automated alert was developed and implemented to continuously sample electronic medical record data and trigger when at least 2 of 4 systemic inflammatory response syndrome criteria plus at least one of 14 acute organ dysfunction parameters was detected. The systemic inflammatory response syndrome and organ dysfunction alert was applied in real time to 312,214 patients in 24 hospitals and analyzed in 2 phases: training and validation datasets.

RESULTS: In the training phase, 29,317 (18.8%) triggered the alert and 5.2% of such patients died, whereas only 0.2% without the alert died (unadjusted odds ratio 30.1; 95% confidence interval, 26.1-34.5; $P < .0001$). In the validation phase, the sensitivity, specificity, area under the curve, and positive and negative likelihood ratios for predicting mortality were 0.86, 0.82, 0.84, 4.9, and 0.16, respectively. Multivariate Cox-proportional hazard regression model revealed greater hospital mortality when the alert was triggered (adjusted hazards ratio 4.0; 95% confidence interval, 3.3-4.9; $P < .0001$). Triggering the alert was associated with additional hospitalization days (+3.0 days) and ventilator days (+1.6 days; $P < .0001$).

CONCLUSION: An automated alert system that continuously samples electronic medical record data can be implemented, has excellent test characteristics, and can assist in the real-time identification of hospitalized patients at risk for death.

 • *The American Journal of Medicine (2016) 129, 688-698*

KEYWORDS: Critical illness; Electronic health records; Forecasting; Mortality; Sepsis

Sepsis is a major cause of mortality in hospitalized patients and requires prompt identification and treatment.[1] Prompt intervention is crucial considering that studies have shown that mortality from septic shock is increased by 7.6% for every hour of delayed treatment initiation following the onset of hypotension.[2] Conventionally, providers perform risk evaluations at the bedside and make interventions based on their subjective understanding, which then informs multiple subsequent aspects of clinical decision-making.[1,3] A variety of risk-assessment tools are currently in use to detect mortality in hospitalized patients.[4-9] Continuous monitoring for early warning scores (EWS) and other acuity scores such as modified EWS and Rothman index are utilized to identify adverse trends and physiological deterioration.[10] Health systems also utilize risk-adjustment models, but mostly retrospectively for quality-of-care assessments.[11] Acute Physiology and Chronic Health Evaluation (APACHE) scores are widely

Funding: See last page of article.

Conflict of Interest: See last page of article.

Authorship: See last page of article.

Requests for reprints should be addressed to Hargobind S. Khurana, MD, Banner TeleHealth, 2145, W. Southern Ave., 3rd Floor, Mesa, AZ 85202.

E-mail address: Hargobind.Khurana@bannerhealth.com

0002-9343/$ -see front matter
http://dx.doi.org/10.1016/j.amjmed.2016.02.037

used to identify individual risk after the first 24 hours of admission to the intensive care unit (ICU), but are limited in their application to critical care patients and dependent on information from the first 24 hours only.[12,13] Alternatively, diagnosis-specific triage has been adopted for early identification and treatment for high-risk conditions such as sepsis or delirium.[14,15]

Despite such available tools, there have not been any reports of tools applied in real time that continuously sample physiological and laboratory information from electronic medical records and synthesize a composite alerting signal that alerts the clinician at the bedside of possible clinical deterioration. In the era of big data and predictive analytics, however, the performance of real-time automated continuous sampling and analysis of electronic medical record data may allow early identification of patients at risk for sepsis and death and provide opportunity for expeditious interventions aimed at reducing sepsis-related mortality. A recent retrospective analysis that involved development of a new prediction score (TREWscore) analyzed historical physiological and laboratory data collected in the ICU and demonstrated the ability to predict severe sepsis better than EWS.[16] Despite such available tools, to our knowledge, there is an implementation gap in that there are no automated tools that can *continuously sample* and screen data derived from electronic medical record systems of hospitalized patients and warn providers of impending mortality.

We wish to report the successful implementation of a real-time automated continuous sampling and analysis of electronic medical record data over 24 hospital facilities that allowed early identification of patients with high risk for hospital mortality. We developed this real-time alert to detect the presence of both systemic inflammatory response syndrome and acute organ dysfunction, with the rationale that the need for $\geq$2 systemic inflammatory response syndrome criteria alone excludes 1 in 8 otherwise similar patients with substantial mortality.[17] We hypothesized that a real-time electronic medical record-based alert that automatically and continuously samples electronic medical record data and utilizes systemic inflammatory response syndrome and acute organ dysfunction-derived criteria could enhance the identification of hospitalized patients at high risk for mortality. Such an alert could facilitate real-time risk stratification and appropriate resource allocation strategies and aggressive management aimed at reducing mortality.

CLINICAL SIGNIFICANCE

- An alert based upon "real-time" electronic medical record data can identify hospitalized patients at risk for death.
- Patients who triggered the alert had 4 times the chance of dying the next hospital day when compared with patients who did not trigger the alert.
- Such predictive analytics was implemented in a "real-world" setting involving 24 hospitals and enabled early and targeted medical intervention.
- Triggering the alert was associated with additional hospitalization days and ventilator days.

METHODS

The systemic inflammatory response syndrome and organ dysfunction (SIRS/OD) alert logic was developed at Banner Health using Cerner Discern Expert (Cerner Corporation, North Kansas City, Mo). The SIRS/OD alert logic would trigger an alert in the electronic medical record whenever the nurse or providing physician accessed the patient's chart (**Figures 1** and **2**). This study is a retrospective assessment of the data that were collected and was approved by the Banner Health Institutional Review Board, including a waiver for informed consent (IRB #05-14-0014). The data from 312,214 consecutive hospitalized patients from 24 hospitals that were subjected to the SIRS/OD alert logic from April 29, 2011 until June 30, 2013, were analyzed. We divided the data into 2 equal halves—a training and validation data set—of 156,107 patients each.

The SIRS/OD alert logic and system are outlined in **Figures 1** and **2**, respectively. More detailed information on the SIRS/OD logic is provided in the **Appendix** (available online). This screening system was based upon the identification of 3 events, 2 independent and one correlating, from data entered into the electronic medical record. The 2 independent elements are: the "systemic inflammatory response syndrome event"—detection of 2 traditional systemic inflammatory response syndrome criteria occurring within 6 hours of each other (with the exception of those white blood cell-related values for which a 30-hour timeframe was permitted), and the "acute organ dysfunction event," which involved detection of any acute organ dysfunction as defined by strict criteria (**Figure 1B**). The final event ("correlating") is an evaluation for the temporal association of the 2 prior elements, requiring that systemic inflammatory response syndrome and acute organ dysfunction events occur within 8 hours of each other. If all of these conditions were met, then the SIRS/OD alert was triggered (**Figures 1A** and **B**). We undertook steps to mitigate the occurrence of false alert firings described in the **Appendix** (available online).

The alert may fire in patients while in the emergency department, or in those admitted to the hospital inpatient or ICU setting. Once the alert was triggered, providers were expected to respond to confirm or refute the presence of severe sepsis. If the providers confirmed, or failed to respond to the alert, the alert would not trigger again during that hospital stay. If the providers refuted the presence of severe sepsis, the alert could trigger after a 48-hour latency period if the trigger criteria were met again. We evaluated