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Application Notes

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A reference guide to rapidly implementing an institutional dashboard for resource allocation and oversight during COVID-19 pandemic surge

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ABSTRACT

Objectives: We develop a dashboard that leverages electronic health record (EHR) data to monitor intensive care unit patient status and ventilator utilization in the setting of the COVID-19 pandemic.
Materials and methods: Data visualization software is used to display information from critical care data mart that extracts information from the EHR. A multidisciplinary collaborative led the development.
Results: The dashboard displays institution-level ventilator utilization details, as well as patient-level details such as ventilator settings, organ-system specific parameters, laboratory values, and infusions.
Discussion: Components of the dashboard were selected to facilitate the determination of resources and simultaneous assessment of multiple patients. Abnormal values are color coded. An overall illness assessment score is tracked daily to capture illness severity over time.
Conclusion: This reference guide shares the architecture and sample reusable code to implement a robust, flexible, and scalable dashboard for monitoring ventilator utilization and illness severity in intensive care unit ventilated patients.

Key words: informatics, medical informatics computing, health information systems, critical care

INTRODUCTION

The highly morbid nature of the COVID-19 pandemic created a rapid, unprecedented need for intensive care resources. To address this need, our tertiary care facility approximately tripled the number of intensive care unit (ICU) beds over a few weeks. Anticipating the surge in ICU admissions, the Society of Critical Care Medicine (SCCM) has suggested an augmented critical care staffing model,[1] whereby one intensivist oversees the care of up to 96 patients, di-

Lay Summary

In this article, we discuss a dashboard that was designed to meet the increased critical care needs during the COVID-19 pandemic and implemented with minimal additional resources by leveraging electronic health record data. The dashboard has two components: an overview of ventilator capability and usage to help with equipment allocation and a patient-level view of disease severity. Highlighted cells on the dashboard table are used to identify abnormal laboratory values and vital signs to shorten the time needed to triage patients, with an increasing number of highlighted cells corresponding to more severe disease. Although this system was developed for critically ill patients, its flexibility allows it to be deployed in general care wards and its scalability allows concurrent deployment across a hospital system to facilitate resource allocation. This guide provides the architecture and sample code for institutions to develop their own dashboard for large scale patient and resource monitoring needs.

vided among four teams comprised of nonintensivist physicians, advanced practice providers, and nurses.

The challenge in caring for these critically ill patients by a single intensivist is the cumbersome process of opening multiple patient charts and providing oversight to ensure adequate resource management at an ICU level and organizational level. Since ventilators have vastly different capabilities, ventilator availability and mode of ventilation of those in use are crucial information for intensivists to optimize ventilator allocation both within a patient care unit and across an organization. In addition, knowing which patients are receiving rescue therapies while waiting for a ventilator may help with staffing adjustment and ventilator allocation.

To this end, we leveraged electronic health record (EHR) data to develop a near real-time dashboard for monitoring equipment inventory and patient disease acuity. Our dashboard was built with readily available tools and minimal additional resources, with the goal of allowing the organization and intensivists to efficiently direct resources and to help nonintensivist teams care for the sickest patients. Since our dashboard can be implemented quickly and tailored to fit the monitoring, it could be an attractive model for others to adopt without investing in a commercial electronic ICU system. Therefore, we are sharing the foundations of our dashboard implementation with other institutions that also face similar monitoring needs.

METHODS

This dashboard was created on a commercially available data visualization software (Tableau, Seattle, WA, USA) that extracts data from a custom-built critical care data mart. This data mart is updated every 15 min via database-stored procedures that extract, translate, and load the required ICU metrics from Cerner Millennium Powerchart EHR (Kansas City, MO, USA). Test data were used to support the rapid prototyping of the dashboard displays, which were created in parallel with the development of the underlying database queries required to build the ICU data mart.

The design of both components (ventilator use and ventilated critical care patient view) of the dashboard was led by two critical care physicians with input from institutional leadership. The two physicians worked directly with the Information Technology analytics team using agile development methodology.[2,3] <Meetings were held twice weekly to establish the clinical requirements and the dashboard layout, as well as planning for the timeline, technology, budget, and personnel specifications. Institutional leadership especially provided feedback on the ventilator use dashboard and facilitated input from key stakeholders such as respiratory therapy. Since the project focused on producing a usable dashboard in the shortest timeframe possible, the product layout was designed around the priorities of the physicians on the project team, rather than pursuing feedback from the wider physician community. The small team translated to a short development and testing phase that took four iterations over about three months to refine the data element selections and the final layout. However, we were not able to evaluate the dashboard performance in a pandemic setting, since the pandemic staffing model at our institution had concluded prior to the end of the final testing phase; it is currently being evaluated in the nonpandemic setting.

One of the core design goals of the data mart was to assure compliance with data governance standards and to promote the reuse of certified data sets used for self-service reporting across the health system. Usage of the certified data sets assured that a single source of truth is used throughout the project and across the health system for all ICU and COVID-related metrics. Derived metrics such as scores, averages, tolerances, and percentages were calculated, validated, and certified at the data mart level. The certified data sets were made available to the visualization layer of the dashboard for reporting. This approach allowed the dashboard architecture to focus on providing feature-rich displays with maximum end-user flexibility while removing the need to calculate complex clinical metrics within the visualization layer.

Information security policies governing the dashboard deployment are dependent on where the dashboard is rendered. The primary method to access the dashboard is on a hospital desktop computer browser, via a link from the hospital intranet to the Tableau server. User credentials are managed through the hospital's Active Directory service, with a session idle timer of 30 min. This method grants full information access to all licensed and credentialed users. The secondary method will display the dashboard on a wall-mounted screen in a secure location with limited access, where time-outs will not occur. This display will not allow end-user interaction, and patient privacy can be protected by displaying only room and bed numbers. In addition, the large display can only be controlled by the information technology service.

RESULTS

The dashboard has two components. The first component indicates ventilator resources and utilization, as follows: (1) number of ventilators in use; (2) number of ventilators available; (3) invasive or noninvasive mechanical ventilation; (4) model of the ventilator; and (5) mode of mechanical ventilation (Figure 1). The second view provides detailed information on multiple ICU patients simultaneously

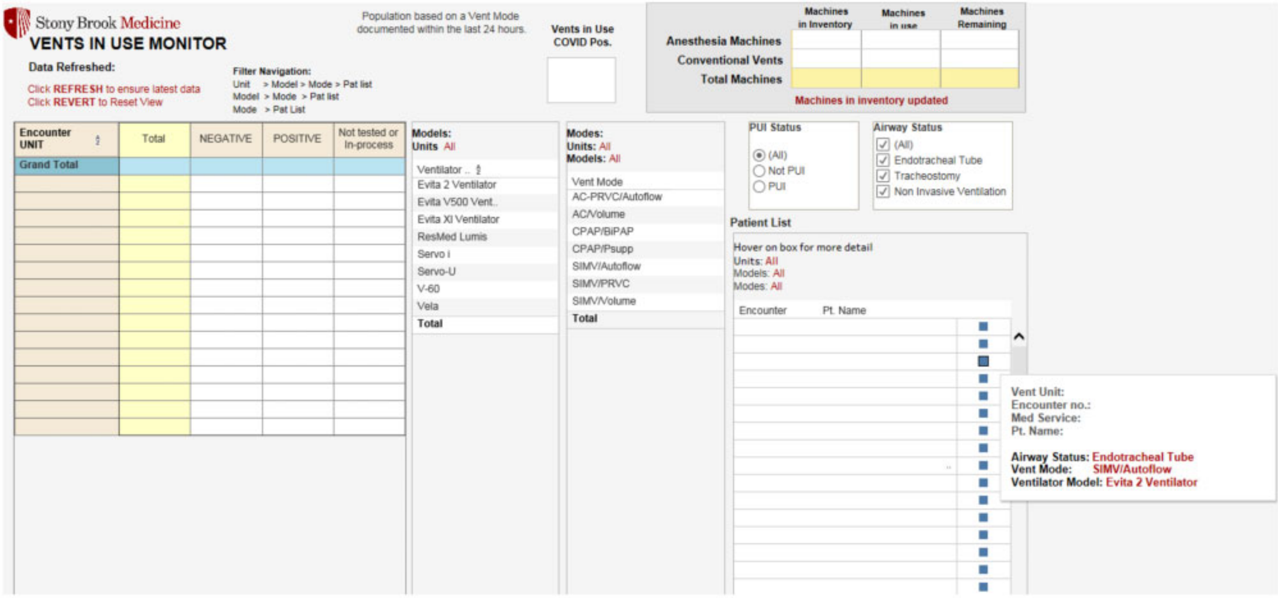

Figure 1 Ventilator utilization dashboard. Institutional ventilator utilization view that provide counts of ventilator machine types and operating modes, and number of COVID-19 patients on ventilators. The unit-based view (left columns) counts the number of COVID-19 positive and negative patients on ventilators in each unit. The view can be filtered by PUI status and airway status. A patient list (bottom right) that meets the filtered criteria is also displayed. PUI: person under investigation.

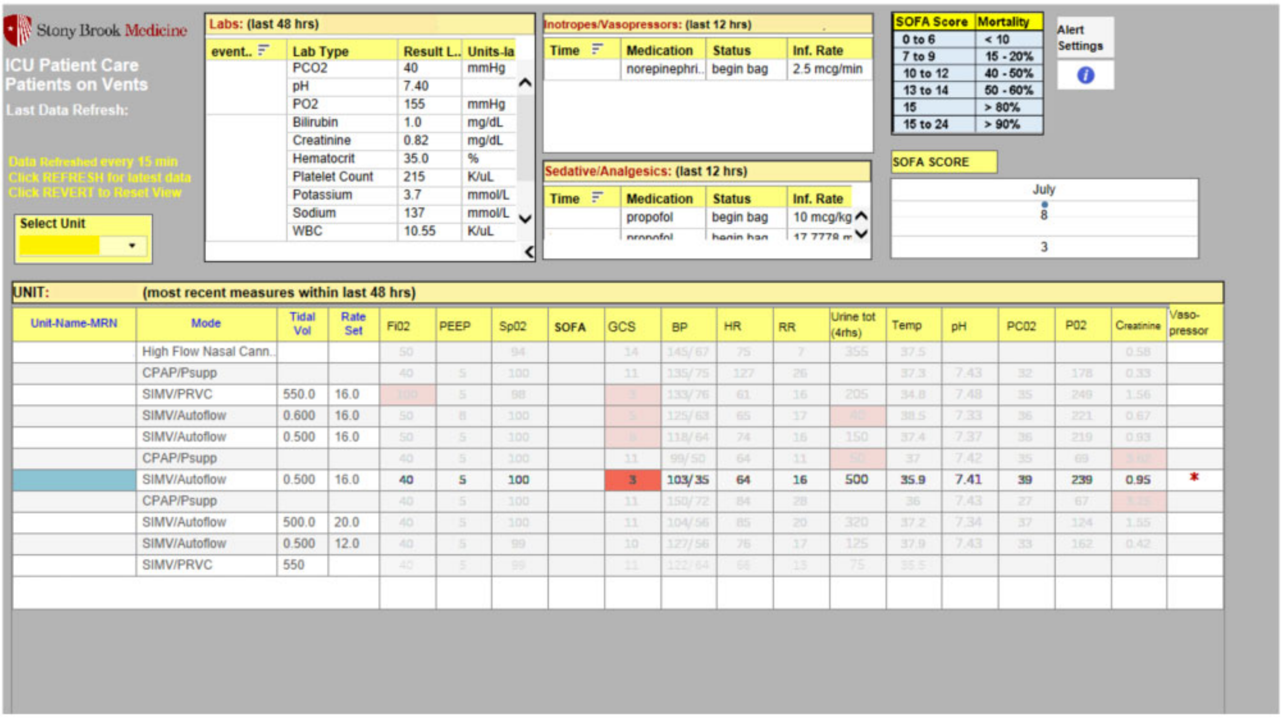

Figure 2 Ventilated ICU patient care dashboard. The central console displays all patients and their ventilator settings, arterial blood gas results, GCS scores, SOFA scores, vital signs, urine output, creatinine, and vasopressor usage. Abnormal values are highlighted in pink. The list of patients can be filtered by selecting a patient care unit. Upon selecting a patient, the dashboard displays additional lab results, vasopressors, and sedatives/analgesics specifics, as well as SOFA score trend. Information for other patients becomes greyed out to help draw clinician attention. GCS: Glasgow Coma Scale. SOFA: Sequential Organ Failure Assessment score. PEEP: positive end-expiration pressure. FiO_2: fraction of inspired oxygen. SpO_2: peripheral oxygen saturation. BP: blood pressure. HR: heart rate. RR: respirator rate; PCO_2: partial pressure of carbon dioxide. PO_2: partial pressure of oxygen.

as a complement to the EHR. The central console displays the latest ventilator settings, blood gas results, vital signs, vasopressor/inotrope usage, Glasgow Coma Scale (GCS) score, Sequential Organ Failure Assessment (SOFA) score, urine output, and serum creatinine (Figure 2). If the value in a cell falls outside of a predetermined threshold, the cell color changes to pink; an increasing number of pink cells for a patient indicates more severe illness. The intensivist can thereby rapidly assess multiple patients without opening individual patient charts.

Selecting a patient from the console displays additional data in the top patient-specific panels, including additional hematology and chemistry results, as well as a detailed vasopressor, sedative, and analgesic infusion information. It also includes daily SOFA scores, with a trend line capturing values from previous days, thereby providing a discreet, measurable index of illness severity over time. When rendered on an end-user desktop, the dashboard data refresh every 15 min with user interaction. When deployed on large wall-mounted screens however, the dashboard is automatically refreshed via a Tableau-based application program interface script.

DISCUSSION

During the height of the pandemic in our region, an early version of the dashboard's ventilator component was used by institutional leadership to understand in near real-time how many ventilators and anesthesia machines were in use. Based on feedback, the final version of the dashboard has been updated to display details about the ventilator model, settings, and location. This is because ventilator capabilities vary substantially by machine, and only select models can provide high levels of ventilatory support, for example, Airway Pressure Release Ventilation. With such finite resources, ventilator allocation strategies can be optimized based on the level of ventilatory support needed.

For the critical care patient component of the dashboard, we focused on displaying data elements fundamental to ICU patient care. We designed this dashboard based on the appearance of various early warning systems (EWS) and included key components of ICU care, that is, vital signs, ventilator settings, blood gases, and vasopressor support. Vital signs are the first component of our dashboard. In combination with neurologic assessment, that is, GCS and urine output, they provide continually updated global patient evaluation. Hence, the dashboard shares features with the Modified Early Warning Score and National Early Warning Score, which aim to detect alterations to any of the components that generally precede noticeable clinical deterioration.[4–9] Our approach also mitigates the limitation of most EWS relating to the accuracy of frequent vital sign recordings by utilizing invasive monitoring techniques.[10,11] Although EWS were primarily designed for general wards, the shared elements indicated above provide intensivists staffing the command center and the provider teams outside the ICU with readily actionable intelligence to facilitate care escalation or de-escalation in severely ill patients regardless of their physical location. Further, these continually updated data elements are also utilized by the SOFA, which is calculated daily.

The second element is a focused systems-based assessment. Ventilator settings, arterial blood gas values, pulse oximetry values, and vasopressor/inotrope usage are provided for the pulmonary and cardiac systems. We selected epinephrine, norepinephrine, dopamine, and dobutamine as the most frequently used infusions based on our pharmacy review of current hospital formulary, as well as an internal review of critical care guidelines, but others can be added to fit institutional needs. The selection of a patient provides details on the medications and doses. Serum creatinine values and 4-h urine output are provided for the genitourinary system. For the neurological system, GCS is provided in the central console and details on continuous analgesic and/or sedative intravenous infusions are provided upon individual patient selection. The Richmond Agitation-Sedation Scale can be substituted for GCS, if desired.

The third element provides an overall assessment of illness severity via the SOFA score. A separate view of the daily SOFA score trend is also displayed upon patient selection, so clinicians can monitor for improvement versus deterioration. SOFA is a composite score that tracks organ failure from six systems for predicting outcomes in critically ill patients.[12,13] Indeed, the 2015 New York State ventilator allocation guidelines utilize the SOFA score to guide ventilator allocation.[14]

The final element is the lab view; upon selecting a patient, it displays basic chemistry, hematologic, and arterial blood gas values. As the myriad of data elements essential to patient care become more rapidly and easily accessible, this dashboard can theoretically prevent and/or mitigate adverse events and the deaths that may follow, thereby improving Failure to Rescue metrics.[15]

Color coding was added to the central console to improve visualization, decrease response times, and decrease error rates.[5,6] Once a value exceeds the set threshold, the color of the cell changes. We used thresholds for abnormal values in the central console rather than weighted values, because the weighted values would require further validation which would not allow us to rapidly deploy our prototype. While color changes do not carry equal significance between different cells, for example, an elevated temperature is considered differently than a decreased pulse oximetry value, a quick glance at the central console can identify sicker patients as those with more color changes.

The dashboard's critical care patient component has completed the quality assurance process and now is being used by a small group of critical care physicians before wider deployment. Preliminary feedback indicated that the dashboard provides a rapid assessment of multiple patients and a recommendation was made for future iterations to include prone/supine patient positioning, renal replacement therapy, and inclusion of nonventilated ICU patients.

While lacking the depth of the monitoring and interactive functionality of a commercially developed electronic ICU suite, the dashboard has the advantage of low cost and quick deployment since it was implemented using software and technical resources on-hand. Unlike commercial products however, the dashboard lacks 24/7 technical support and is dependent on the validity of EHR data.

This dashboard offers scalability for deploying across a healthcare system for simultaneous management of multiple critical care units. Besides ventilators, other items such as renal replacement therapy and ECMO can be added. Although originally intended for the ICU, it can be altered to fit the needs of general wards. Finally, the data tables populating the dashboard can be used for research and quality improvement activities as the critical care data mart is already being used for institutional review board approved studies at our institution.

We are sharing our experience to help other institutions adopt their own dashboard for resource allocation and optimize patient outcomes. To this end, we supply build instructions in the supplement, including an architecture schematic and sample Structured Query Language code used to extract and visualize the data. Although the sample code is provided on GitHub, (https://github.com/ctsaiwa/eICU) without any guarantees about its results, our team welcomes communication for additional support. While we used one specific data visualization software and one EHR, this guide can serve as a platform-agnostic reference.

AUTHOR CONTRIBUTIONS

All authors made substantial contributions to this work.

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CONFLICT OF INTEREST STATEMENT

None declared.

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