

Communication

The STELAR ICU: Leveraging Electronic Health Record Data to Foster Research and Optimize Patient Care

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Abstract: Electronic health records (EHR) combined with robust data collection systems can be used to simultaneously drive research and performance improvement initiatives. Our Smart, Transformative, EHR-based Approaches to Revolutionizing the Intensive Care Unit (STELAR ICU) consists of a framework of five best practices that make optimal use of objective data to guide clinicians caring for the sickest patients in our quaternary center. Our strategy has relied on an accessible data infrastructure, standardizing without protocolizing care, using technology to increase patient contact and time spent at the bedside, continuously re-evaluating performance in real-time, and acknowledging uncertainty by using electronic data to provide probabilistic weight to clinical decision-making. These strategies blur the lines between research and quality improvement, with the aim of achieving truly stellar patient outcomes.

Keywords: learning health system; electronic health records; performance improvement; standardization; guidelines; pediatric critical care

1. Introduction

In the early 2000s, technological advances accompanied by Meaningful Use mandates spurred the widespread adoption of electronic health record (EHR) systems in the United States [1]. Recognizing that EHR implementation quickly led to accumulating mountains of largely untapped data, the Institute of Medicine (now known as the US National Academy of Medicine) released its sentinel report in 2007 “The Learning Healthcare System” [2]. The report outlined the enormous potential of combining electronic data repositories generated by care with research initiatives and continuous process improvement to form health systems better able to rapidly develop and implement new evidence and innovative approaches to patient care. Like celestial navigation by early explorers, data captured by a learning health system can be used to provide objective guidance for navigating the uncertainties of clinical medicine. Modern clinicians now face the practical challenge of how best to use this information stream to improve care.

At the UPMC Children's Hospital of Pittsburgh, implementation of a Cerner EHR system (Cerner Co., Kansas City, MO, USA) in 2002 was soon followed by the establishment of a data warehouse that effectively tapped into the surging pipeline of clinical data. Within our Division of Pediatric Critical Care Medicine, we have been leveraging this trove to generate new insights into childhood disease and promote innovative processes of care. Our Smart, Transformative, EHR-based Approaches to

Revolutionizing the Intensive Care Unit (STELAR ICU) consists of a framework of five key elements and practices that make optimal use of objective data to guide clinicians caring for the sickest patients in our quaternary center. The elements and practices were designed in adherence to the Agency for Healthcare Research and Quality's definition of a learning health system (Table 1), and include (1) an accessible data infrastructure; (2) standardizing without protocolizing care; (3) using technology to increase patient contact and time spent at the bedside; (4) continuously re-evaluating performance in real-time; and (5) acknowledging uncertainty by using electronic data to provide probabilistic weight to clinical decision-making [3]. The aim of this commentary is to provide an overview of each of these five key elements.

Table 1. Characteristics of a learning health system [3].

Leadership is committed to continuous learning and improvement
Systems exist for real-time collection and application of evidence to guide care
New evidence to guide improved decision-making is made accessible with information technology
Patients are considered members of the care team
Systems exist for real-time data collection and analysis of care-related data
Outcomes, processes and training are continually assessed and improved

2. Building an Accessible Data Infrastructure

An essential element underlying our work leveraging the EHR has been a well-constructed and accessible data warehouse, which consists of an Oracle database (Oracle Co., Redwood City, CA, USA) directly fed by our Cerner Health System's Millennium database. Over time, the relevant tables extracted from the nearly 6000 harbored in the Millennium database have been whittled to the approximately 200 most salient for our purposes. Table selection was based on consensus between systems analysts, clinicians and administrators regarding the most pertinent information to promote the administrative, quality improvement and research aims of the institution. Data initially included elements of the clinical record such as details of medication administration and clinician orders, but also user clicks. Subsequently, iterative review has occurred, paring tables that have not been queried in a substantial period and preserving essentially all structured data viewable by clinicians as part of the health record. The result is a robust, highly granular database with information derived from hundreds of thousands of pediatric encounters. Data are on secure servers and primary access is restricted to a select group of database specialists and clinical superusers, with requests for administrative summary reports and research datasets requiring approval by a warehouse steering committee that meets monthly, as well as the institutional review board, as appropriate.

The data warehouse is refreshed approximately every 30 s, providing nearly real-time access to clinical data. While representing only a portion of the data generated by clinician and patient interactions with the EHR, these tables contain highly granular information and can be readily accessed via both SQL queries as well as via the graphical user interface SAP BusinessObjects (SAP, Paris, France). Flat files generated by either query approach can then be cleaned and curated using a variety of applications, with our preferred approach making use of a growing repository of *R* script (www.r-project.org). Data-marts are designed with an Informatica (Informatica Co., Redwood City, CA, USA) toolkit to extract, transform and load (ETL) relevant data warehouse elements, providing a priori cleanup and curation for a subset of tasks. Qlik analytics (Qlik Technologies, Radnor, PA, USA) provide readily interpretable graphical displays of these transformed data, facilitating decision-making by clinicians and administrators.

3. Standardizing without Protocolizing: Developing Institutional Guidelines Rather than "Recipes"

Calls for personalized and precision medicine have been raised in recent years concomitant with increasing efforts to standardize care, reduce variation and continue the study of relatively

heterogenous diseases such as traumatic brain injury with population-based, epidemiologic tactics. Harmonizing these often-opposing visions necessitates a strategy that guides clinicians to available resources and the present standard of care while allowing sufficient leeway for individualizing regimens when necessary. Our first foray into our institution's electronic data examined the impact of our guidelines for the management of diabetic ketoacidosis (DKA) [4]. Access to the guideline was made available on the institution's intranet and a corresponding EHR PowerPlan (orderset) was implemented to facilitate clinician adherence and optimize the efficiency of the guidelines. The guidelines were carefully constructed to invoke widely-recognized elements of management, such as the dose of an insulin infusion, while allowing clinicians the ability to individualize other components such as fluid volume and electrolyte content. We interrogated our data warehouse to examine the impact of implementing these guidelines on patient outcomes and to determine whether harbingers of patient deterioration might be elucidated using the highly detailed data.

Notably, we identified that implementation of these flexible guidelines was associated with decreased variability in length of stay amongst the sickest patients, indicating that personalization and standardization may not be mutually exclusive endeavors. Additionally, we identified that children treated for cerebral edema presented with significantly lower blood pressures compared to children who did not receive treatment for neurologic deterioration. This finding accentuated the importance of flexibility in guidelines, since children with lower blood pressure may require substantially more fluids than their normotensive counterparts and restoration of blood pressure is essential for promoting adequate cerebral perfusion. The association between blood pressure and cerebral edema also warrants additional study, particularly for its potential relevance to existing theories of ischemia-reperfusion inciting neurologic deterioration in patients with DKA.

4. Using Technology to Increase Patient Contact and Time Spent at the Bedside

Computers-on-wheels have proliferated alongside the EHR, though the gains in access and ordering efficiency may be offset by the literal barriers posed by wheeled monitors to communication and the considerable documentation time required by many modern note templates. Reducing the numbers of computers on wheels during rounds has been associated with improved participant hearing and a reduction in non-essential conversations [5]. Many medical errors and adverse events might be avoided if more time was simply spent in direct contact with patients [6,7]. Bearing this in mind, two recent improvements to our daily workflow in the pediatric intensive care unit (PICU) have utilized technology to streamline data collection, bolster communication on rounds, and reduce time spent on documentation. For years, presentations on morning rounds hinged on the pre-dawn arrival of rotating residents to the PICU, where diligent, hand-written copying of data from computer monitors to paper ensued. This routine generated a summary sheet for each patient, organized by organ-system to facilitate absorption by the attending intensivist, that was read aloud by the collecting resident during rounds. Data collection and summarization has now been automated and residents now arrive pre-dawn to quickly print their summary sheets before proceeding to examine their patients and obtain face-to-face updates from the bedside nurse. Years of preceding training are no longer wasted on tedious scribing and instead are dedicated to higher-order patient-care tasks and interactions.

Summarization constitutes a majority of the effort of physician documentation, yet as with the residents' role as scribe, seldom adds significant value to patient care. By automating summarization, we have crafted daily progress notes that are nearly entirely self-generating, contingent only on physicians for subjective interpretations, updates and plans. Accordingly, we have replaced the traditional computer-on-wheels with nimble, 2-in-1 tablet-laptops that allow attending physicians in our PICU to complete nearly the entirety of their progress notes while on rounds in the morning. This change has freed entire middays and evenings; physicians, once consumed by documentation into the late hours of the night, are compelled to provide a quick update to morning documentation at the end of the afternoon to ensure appropriate billing compliance for the day. Early analysis indicates an average reduction in time to note completion of 7 h with this new system ($p < 0.001$). As with

the rounding summary sheet, this system also reduces opportunities for error by eliminating the bleary-eyed scribes from data capture.

5. Driving Change with Real-Time, Acuity-Adjusted Dashboards

Acuity-adjusted mortality is a standard metric in the field of intensive care for peer benchmarking and can be used to track process improvement. Acuity scores allow institutions to account for a mixture of illness-severities when describing cohort data and aggregate outcomes, ensuring that centers won't be cast unfavorably simply for providing care to sicker patients. Such scores commonly consist of multivariable regression equations which incorporate relevant characteristics such as age, diagnosis, vital signs and laboratory values. Data collection and score construction can be tedious and time-consuming, with many institutions hiring dedicated staff for the task. Given the associated labor requirements, data review is then limited to a quarterly or biannual basis. Our PICU has historically demonstrated favorable acuity-adjusted outcomes when subject to multi-center data review. However, the onerous process of data collection and analysis generated wariness that we might one day be caught-off-guard at an annual review by deteriorating outcomes.

While acuity scores are generally designed to incorporate prospectively collected elements, we turned to our data mart to construct validated metrics of pediatric acuity using strictly structured data elements. By mapping each element to a structured surrogate, our electronic pediatric risk of mortality IV (e-PRISM IV) and electronic pediatric logistic organ dysfunction score 2 (e-PELOD2) demonstrated excellent discrimination for in-hospital mortality, identical or superior to previously published c-statistics by each scores' designer [8,9]. Rules for score construction have been incorporated into Informatica ETL and provide nearly real-time depictions of acuity-adjusted outcomes via a Qlik dashboard for a running 3.5 years of PICU and cardiac ICU encounters at our institution. More than 13,000 distinct ICU encounters are represented on the dashboard. Users can drill down into specific time epochs or diagnosis cohorts and a calibration plot reflects the changing prediction characteristics of the relevant acuity score as the cohort is modified.

6. Electronic Data and Probabilistic Decision-Making

Clinical intuition relies on an adept clinician's brain rapidly assigning probabilistic weight to myriad simultaneously assessed variables to generate a care decision. More meaningful or risk-laden decisions are generally considered more carefully and account for as much pertinent information as is available. Readily accessible repositories of electronic data can be used to supplement clinical intuition by providing additional, objective weight to facilitate probabilistic decision-making. We recently explored the utility of two low-cost, widely available inflammation biomarkers, c-reactive protein and ferritin, for stratifying pediatric patients at risk for mortality and demonstrated that patients with elevated levels of both markers were significantly more likely to develop multi-organ dysfunction and die compared to patients with low levels of both markers [10]. This type of approach, which translates clinical observation and experience into discrete risk categories than can be examined and considered by less experienced clinicians, represents a significant step towards using electronic data to codify intuition.

7. Conclusions

The use of EHR data to drive performance improvement and research agendas marks a new evolutionary stage of healthcare. Large-scale endeavors, such as multi-center harmonization of EHR data for predicting patient outcomes and accelerating clinical research have already demonstrated some significant successes [11,12]. Less clear is what influence these new technologies will have on the front lines of care. Ubiquitous EHR systems have placed modern clinicians in the fortunate position of being surrounded by information. Our STELAR ICU has effectively leveraged electronic data and technology through five best practices to improve the efficiency of care, rigorously analyze clinical processes, shed new light on characteristics of childhood disease, and initiate new strategies

for probabilistic decision-making. These strategies combine disease inquisition with performance improvement projects, blurring the lines between research and quality improvement, with the aim of achieving truly stellar patient outcomes.

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