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Guest Editorial

Computer-based decision support for critical and emergency care

This special issue of the journal contains a collection of papers on the topic of computer-based decision support for critical care and emergency medicine. Critical and emergency care environments are complex, fast-paced, and information intensive. Often highly collaborative and resource-limited, the challenges in decision making span social, organizational, and technical dimensions. Computer-based decision-support tools and systems are considered to be crucial in meeting the fundamental objectives of ensuring safety and providing efficient, cost-effective delivery of high quality patient care [1–3].

Those among us who have been involved in clinical intensive and emergency care for several decades will recall the growing excitement that accompanied the rapid development of the fast and powerful microprocessor, sophisticated, high-speed networking and communication infrastructure, and inexpensive, highly miniaturized supporting equipment. The early pioneers in computer-based critical care used million dollar, stand-alone mainframe computers or high-end mini-computers that were beyond the reach of most intensive care units (ICUs), emergency departments (EDs) and informaticist clinicians. The microprocessor and communication technologies offered real hope for improved patient care [4,5].

In some ways, the new technologies did bring change to ICUs and EDs. Physiologic monitors gained more intelligent functions like arrhythmia analysis [6], new bedside sensor/computational devices like pulse oximeters were developed, and IV pumps got "smarter" and gained electronic displays. Commercial Electronic Medical Record (EMR) systems were developed for ICUs and later for EDs. However, the grand challenges of critical and emergency care went unanswered, and the reason for that is very important. Bedside computers did not become devices that could reliably diagnose a patient's disease, prevent a preventable death or even control the infusion of a vasoactive drug based on blood pressure or other physiologic parameters. This is not to undercut the role that a bedside monitor can possibly play in alarming "Asystole" to save a patient's life. But the reality is that the grand challenges of critical and emergency care were no more solvable on the latest grid computers or multi-core microprocessors with wireless broadband communication than they had been on mainframe computers. The missing ingredient was *new methods* to meet the challenges. That is the fundamental importance of the papers in this special issue, because they address critical deficiencies in the way computers can be applied to improve the care of patients.

Even as we contemplate the ways that we see bedside and networked computers (and their applications) helping our patients today, it is clear there is much more work to be done. Intensivists know that most "asystole" alarms from physiologic monitors are false, regardless of the device's make, model or brand. The ratio of false to true critical alarms is as high as 100 to 1, even with the most current devices. The bedside nurse can confirm a false alarm in a split-second glance at the display screen, but this escapes the grasp of the monitor's many microprocessors. Essentially none of JBI's readers uses computers to diagnose critical and emergency illness, but shouldn't we be able to do so after all this time? Even the smartest IV pumps have not figured out how to prevent all drug errors, especially those that occur at the sharp edge of care, at the bedside. We desperately need new methods—technical solutions and developmental approaches that will allow us to implement them successfully in practice.

The authors of the articles herein have dedicated themselves to help solve some of these fundamental problems. In this special issue you will find articles on cognitive models of critical care decision support, automated triage assistance for EDs, reduction of false alarm rates for critical arrhythmias, adaptive physiologic monitoring, computer-based ventilator weaning, early diagnosis of traumatic anemia, use of informational technology in surgical ICUs, and usage analysis of computer-based insulin management. The insights in these articles can help us to build safer and more effective ICUs and EDs. Beyond simply reading these articles, we all need to play a role in making sure that these ideas are tested clinically and adopted wherever possible.

The first two articles in this issue review cognitive models and conceptual frameworks for understanding and evaluating problem complexities and solution approaches in the critical and emergency care settings. These methodological reviews, in keeping with JBI's routine approach to such papers, cover a wide spectrum of issues, including decision support in general and triage assistance in particular.

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Patel and colleagues [7] provide an extensive methodological review of translational cognition for decision support in both inpatient critical care and outpatient emergency environments. The authors highlight the complexity of medical decision making, especially in data rich, emergency environments, i.e., typical ICU and ED situations. This article provides an extensive review of methodologies for medical cognition and their application to clinically intensive and critical settings. The purpose of the review is to delineate fully the complexities of critical decision making and the application of these complexities in the development of computer-based decision support. Distributed cognition is a factor in these environments, because physicians, nurses, pharmacists and therapists often work closely together in direct patient care and joint decision making. Real world examples are used to illustrate how and why clinicians make decisions under pressure with constraints like incomplete information, inadequate time, interruptions and fragmented workflow. A cognitive taxonomy for medical errors is also provided as a basis for decision support. The framework of cognition is reviewed in detail to provide the basis for effective computer-based decision support in critical environments.

Abad-Grau and colleagues [8] review the important performance criteria of computer-based triage assistance systems in the ED setting. Effective triage classification allows prioritization of care according to severity, which could lead to more effective resource allocation and better outcomes. This article examines and summarizes the system features that determine how well a triage assistance system supports triage classification, diagnosis, and training. The features include classification accuracy and robustness, model clarity and adaptability, decision speed and specificity, ability to integrate data from different sources, representation of temporal variations, and support for expert knowledge specification and learning from data. The purpose of the review is to help adopt or develop suitable classification frameworks to provide triage assistance effectively. Two common classification frameworks—decision trees and Bayesian networks—are compared in detail. A comprehensive survey on current systems is also conducted to identify additional features that may lead to more accurate and practical triage assistance systems.

The next four articles introduce new methods to solve general and specific problems for various critical and emergency tasks. These methods include new technologies and novel applications on alarm filtering, alarm generation, and protocol implementation in the ICU, and on risk prediction in trauma management.

Providing intensive care for acutely ill patients includes continuous monitoring of the patient's status using invasive and non-invasive methods. During the continuous monitoring period, multiple devices collect large amounts of raw data. Based on relatively simple rules, the data streams can generate myriads of alarms that require the clinician's attention and may lead to alert fatigue. For a long time, separating insignificant events or false positive alarms from potentially life-threatening events that require clinicians to take immediate action has challenged the minds of researchers. Various post-processing methodologies have been developed and applied to improve the signal-to-noise ratio [4–6]. Many challenges remain, however, in effectively validating and implementing these algorithms in practice.

Correlating patient data from ECG and arterial blood pressure waveforms, Aboukhalil and colleagues [9] describe the development and evaluation of algorithms that suppress false alarm rates for five categories of critical, potentially life-threatening arrhythmias. The authors evaluated the algorithm to detect asystole, extreme tachycardia, extreme bradycardia, ventricular tachycardia and ventricular fibrillation against a reference standard that included the annotation of two independent reviewers. The analyzed dataset included more than 5000 alarms during approximately 41,000 h of simultaneous ECG and blood pressure recordings from 447 patients. The algorithms considerably reduced the false alarm rates while true alarms were not missed for four of the five critical arrhythmia categories. These efforts demonstrate the potential and the challenges of combining data from multiple sources. The large, annotated database is publicly available and provides a valuable resource and opportunity for other researchers who wish to develop and examine novel methods for reducing false alarm rates.

Zhang and Szolovits [10] approach the challenge of reducing false alarm rates from a different perspective. The authors hypothesized that thresholds for false alarm rates are not static criteria but could benefit from individual adjustments that account for the variability of individual patients and their clinical conditions. The intriguing approach assumes that machine learning techniques can be applied to bedside monitoring data to create patient-specific alarm thresholds. To examine the feasibility and potential of creating a real-time adaptive system, the authors applied classification trees and artificial neural networks to about 200 h of continuous monitoring data. During the data collection periods, bedside observers annotated events, which provided the information to define the reference standard for the study. Not surprisingly longer training periods using individual patient data resulted in more accurate classification.

While both studies above present new and exciting approaches for analyzing data from continuous monitoring of intensive care patients, they also provide insight to existing challenges. Creating reliable reference standards for clinically meaningful alarms, accounting for the temporal correlation among the collected data, selecting optimal sampling frequencies, and implementing zero-tolerance for missing critical, life-threatening alarms are only a few of these critical challenges.

Computer-driven protocols for ventilator management have long held the promise of safer, more effective care and quicker liberation of patients to spontaneous ventilation. Sorenson and colleagues [11] describe a new approach to the development and implementation of computer-based ventilator protocols. They employed a frame-based methodology to develop and implement protocols. The framework contains a knowledge base, a patient data base, an inference engine and a way to communicate advice or actions to users. Frames can be used to advantage in this situation because they can be created and expressed in familiar medical terms and concepts. At the Latter-day Saints (LDS) Hospital, frames were used to encapsulate and express the National Institutes of Health (NIH)/National Heart Lung and Blood Institute (NHLBI) Acute Respiratory Distress Syndrome (ARDS) Network weaning protocol. This protocol is generally accepted as valid, but experience has shown that physicians cannot easily follow it in a manual fashion. The frame-based protocol was tested for incorporation into routine clinical care and generated advice for ventilator changes that were accepted by LDS physicians 80% of the time. In summary, frame-based representation for real-time decision making was found to be useful and productive for evidence-based ventilator weaning in ARDS patients.

Many classical and traditional data analysis techniques in statistics, control theory, mathematics, artificial intelligence, and machine learning have been successfully deployed in limited critical and emergency care settings. Rapid advancement in the care procedures and increasing complexity of the care settings, however, have made effective applications of such techniques very challenging. Chen and colleagues [12] present a novel application of classical data analysis techniques in distributed, mobile patient monitoring in emergency medicine. They demonstrate how a robust, real-time classifier can be used to identify whether a trauma patient is hemorrhaging during aeromedical transport to a hospital. In this application, basic vital-sign variables are input into linear classifiers, which are then combined into an ensemble classifier. The ensemble classifier is fast, reasonably accurate and consistent, even with inconsistent or incomplete data. It can tolerate missing values in the input data, and be improved by more and better-quality data With simple computational requirements and remarkable performance, the ensemble classifier was shown to be a promising step toward incorporating advanced technologies in small, reliable, fast devices for real-time, continuous monitoring of trauma patients.

The last two articles evaluate the effectiveness of computer-based decision-support systems in critical and emergency care settings. The interrelationships among the technical features of the computer-based technologies, the organizational conditions of the care settings, and the social functions of the workflow processes are examined in a broad spectrum of activities—from supporting general collaborative work in the surgical ICU to assessing user acceptance of specific automated recommendations from an insulin-titration protocol.

Complex, expensive information systems are increasingly being deployed in the information-rich, resource-limited, and highly collaborative critical and emergency care settings. Systematic analyses on the roles that they play in collaborative care support and the potential strengths and limitations are important for their effective deployment. Reddy and colleagues [13] examine the effectiveness of an electronic patient record system in supporting general collaborative work in the surgical ICU. Based on a socio-technical perspective, they report the results and summarize the insights from studies over a 7-month evaluation period in an urban teaching hospital in the United States. Using qualitative data-collection and analysis methods based on grounded theory [4], they identify the main tasks that a critical care information system supports in the collaborative workflow, illustrate the common patterns in user habits and clinical tasks, and suggest how better to evaluate the collaborative decision-support features in such a system. The study highlights the nature and significance of the awareness about one another's activities that a critical-care information system brings to the clinicians; it also argues that the capability to support shared awareness is an essential evaluation (and possibly design) criterion for such a system.

Understanding the various facets of user adoption remains an important prerequisite for designing, implementing and refining effective information technology applications. Sward and colleagues [14] examine their reported rationale when intensive care unit nurses decline recommendations from a computer-based insulin-titration decision-support system. The study adapted a previously established and validated information technology evaluation framework that assesses the implementation efforts along five socio-technical dimensions. While nurses declined only five percent of the recommendations, the evaluation instrument provided the research team with actionable information for further improving the decision-support system. While many implementations emphasize the importance of organizational factors, this study occurred in a setting that has a long tradition of implementing and using computer-based protocols for patient care. Thus, factors that were directly associated with content and clinical use of the computer-based protocol dominated the evaluation. Finally, the study emphasizes the value of applying an existing framework, even if the instrument is required to be custom tailored for the specific application, clinical environment, and user group.

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