Chapter 20
Clinical Implications of Cognitive Complexity in Critical Care

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Introduction

The evolution of critical care medicine and the Intensive Care Unit (ICU) has been a major advance in the success of modern medicine. Critical care medicine is a subspecialty that provides intensive life-sustaining monitoring and therapies for patients with life-threatening conditions in a very specialized setting. Each year, more than five million patients are admitted to the 5,000 ICUs in the United States [1], and the cost to sustain this care exceeds $90 billion annually [2]. Critical care is very dynamic, fast-paced, and complex in content and delivery, and optimal critical care is provided round-the-clock by a highly specialized, multi-disciplinary team.

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The provision of critical care has improved outcomes such as mortality and has prolonged and saved countless lives since its inception.

The landmark Institute of Medicine report “To Err is Human” awoke our nation to the reality of our unsafe healthcare system [3], where deaths from medical errors are the sixth leading cause of death. This error-ridden and failure-prone system continues to grow in size and complexity, in part due to the growth of medical science and technology, information systems and capabilities, public health needs, and population growth and aging. Because the ICU exemplifies the breadth and depth of a complex healthcare system, it is a high-risk environment prone to risk, errors, and failures. In this capacity, it can significantly contribute to patient harm as indicated by the IOM report and thus remains a vital focus of efforts to improve patient safety and quality of care.

Many facets of critical care expose it to the risks of injury and harm. Clearly, the plethora of illnesses and their various manifestations and complications require a broad and deep knowledge of clinical critical care medicine, and any deficiency of this can lead to delayed or erroneous diagnoses. The need to acquire and maintain procedural skills is important to avoid injury from invasive procedures. The multi-disciplinary ICU team model mandates clear, timely, and structured communication of patient information and plan of care among team members. The availability of immediate and accurate information is paramount to avoid delays or inappropriate treatments or decisions. The multitude of interventions, consultations, and care transitions provide ample opportunity to delay or hinder workflow. The implementation of protocols and policies are vital to standardizing patient care and ensuring adherence to evidence-based practices, but their application requires understanding and engagement to be effective. Most importantly, skilled clinical decision-making is foundational to developing an effective and timely plan of care that directly affects patient outcomes in particular and healthcare delivery in general. This chapter explores some of these facets of critical care practice from the perspective of cognitive informatics and its clinical application to improve patient care delivery in the complex ICU environment.

Clinical Decision-Making

Of all the duties and challenges of today’s ICU clinician, clinical decision-making perhaps the most complex and challenging; yet it is also the most important. Clearly, knowledge of clinical science coupled with the critical thinking and procedural skills required to apply that knowledge are foundational to successful clinical practice. However, since the realm of clinical medicine lies within the larger healthcare delivery system, the determinants of good clinical practice extend beyond medical knowledge and clinical reasoning to include many other concepts. This section explores some of these concepts.

Heuristics

Clinical decision-making in high velocity environments such as the ICU has many constraints, including limited time, urgency of patients' conditions and needs, multi-tasking, high stress and high-risk situations, and nuances based on patient preferences. These conditions provide ample opportunities for the use of heuristics, or mental shortcuts in decision-making. In many circumstances, these heuristics are effective decision aids. However, they inherently have limitations and can potentially lead to bias if not used properly. Decision-making involves many different approaches and types, each of which has its own advantages and limitations. Despite the prevalent use of heuristics in clinical care, the manner in which they are used in high intensity environments such as the Emergency Center or the Intensive Care Unit has not been formally studied. To characterize physicians' use of cognitive heuristics in clinical decision-making when caring for critically ill patients, Payne et al. performed a national pilot study to ascertain critical care and emergency medicine attending physicians' perception of the frequency of use of heuristics and biases during clinical reasoning using an electronic survey instrument [4]. In this study, subjects were given a semi-structured questionnaire that contained a definition and 37 clinical examples of heuristics and biases, and they were asked to rate the prevalence of their use in clinical practice. The researchers found that physicians reported the use of several types of heuristics that differed between emergency medicine and critical care physicians. The most common ones reported by critical care physicians include: confirmation bias (tendency to look for confirming evidence to support a diagnosis, and ignore evidence to the contrary), availability (when a diagnosis is triggered by similar recent cases), planning fallacy (tendency to underestimate the time to complete a task), in-group bias (tendency to have positive views of, and give preferential treatment to, patients they perceive to be members of their own group), and deformation professional (tendency to view things according to the conventions of one's own profession).

The researchers then performed a proof-of-concept study, where data were collected during morning rounds in an adult medical ICU at a large teaching hospital [4]. Clinical team interactions were recorded and "single purpose phrases" – phrases deemed to represent a single decision, thought or action – were identified and coded based on information utilized, decision quality, outcome, and the use of heuristics. Many types of heuristics, in addition to those mentioned above, were identified and were part of one of the three main steps in the critical care process: immediate need assessment, addressing problem, and patient management. In each of these steps, the authors identified potential reasoning errors that may lead to erroneous decisions which included neglecting or not considering pertinent data, considering data not associated with the correct diagnosis, inaccurate mapping of the patient's situation, not considering all possible diagnoses, not noticing a change in the patient's status, not fully investigating all diagnostic possibilities, and not recognizing a pre-existing condition that may impact the current clinical state.

This work demonstrated that heuristics are prevalent throughout the spectrum of critical care practice. The ICU environment is ideal for the use of heuristics when applied appropriately, and their use can have a powerful salutary effect on decision-making and efficiency of care. On the other hand, their misuse can result in flawed reasoning and ultimately incorrect decisions that lead to poor, delayed, or even dangerous patient care. In fact, this study's results are impressive but not surprising in the extent and scope of biases prevalent among critical care physicians, and one can only hypothesize the effect of this cognitive "habit" on diagnostic accuracy. Because of the great positive and negative potential of the use of heuristics, it is imperative that knowledge gained from this and other studies on heuristics be extended and integrated into clinical training, where it can nicely complement the reasoning and thinking patterns taught through the use of the scientific method and deductive reasoning. This incorporation of heuristics in daily clinical decision-making is particularly important not only because of growing workloads reducing thinking time, but also from the increased transitions of care (shift work), increasing complexity of patients' illnesses, and increasing sub-specialization of all branches of clinical science and care delivery. The fast pace of the ICU and the need to immediately address urgent patient care issues can easily lead to a "cookbook" approach to medicine, which may be appropriate most of the time but detrimental for the more unique cases. On the other hand, the contentious nature of clinical practice and diagnostics would benefit from a more standardized approach to decision-making. The incorporation of heuristics – and the knowledge and increased awareness of its potential biases – can facilitate physicians' reasoning and decision-making while at the same time caution them from its pitfalls. In fact, Croskerry et al. suggested that cognitive de-biasing strategies, where clinicians are educated about biases and how to avoid them, can reduce diagnostic errors, a major component of medical errors [5].

Error Management by Individuals

Risk and error are pervasive components of complex systems. In healthcare, the Institute of Medicine estimated that between 44,000 and 98,000 patients die every year from preventable medical error [3], a projection that many today believe is underestimated. Furthermore, since this report's publication in 1999, there has been little improvement in patient safety as a result of risk mitigation and error reduction, and medical errors cause more deaths in the United States than AIDS, breast cancer, or motor vehicle accidents [6]. The traditional approach to error mitigation has been to focus on the individual through blame, education, re-training, or punishment. This approach fails to incorporate the concept of systems improvement in complex settings, where the interaction of multiple factors in the system is more likely to contribute to risk and error than individual limitations or bad intentions. The scientist Hutchins pioneered work on cognition in complex systems and shifted the focus from individuals functioning in their environment to groups of individuals interacting with all the components in their real-world system [7]. Furthermore, the traditional approach has been predicated on the belief that increased knowledge and expertise reduce error and poor outcomes, a concept that is increasingly refuted and replaced by a systems improvement and human factors interaction approach. It is currently believed that error and risk are inevitable components of complex systems, and the main focus therefore should be on risk and error detection and recovery in addition to error mitigation to control adverse outcomes [8]. Prior studies have reported that both experts and non-experts commit errors in complex clinical environments, but the nature and management of these errors rather than their number differ significantly. In addition, experts detect more errors and correct them more efficiently than non-experts, particularly more complex ones [9, 10]. Cognitive complexity work has become increasingly focused on these aspects of risk and error mitigation [11, 12].

Building on prior work, Patel et al. conducted an in vitro study of error detection and recovery on 25 attending (expert) and resident (non-expert) physicians in makeshift laboratory settings at 2 sites [13]. Participants were presented with two clinical problem cases in paper form that contained a range of knowledge-based and procedural management errors embedded within them, such as inappropriate antibiotics, contraindications for procedures, and missed diagnoses. Subjects were not informed beforehand (primed) that errors were present in the cases and were asked to evaluate their management. Analysis of natural language responses were analyzed in areas such as error detection, error corrections, and justification of clinical decisions. Results demonstrated that experts were somewhat better able to detect errors, particularly the most complex types, and did so as they were working through the problem. However, error detection by experts fell short of expectations, with no participant detecting more than half of the embedded errors, regardless of expertise. Error detection by non-experts was more likely related to adverse events, and more often detected after reading through the entire case. Experts more frequently provided justifications for their detection of errors than non-experts, perhaps reflecting their teaching role and skills. Non-experts demonstrated a more cautious detection of errors and had a slower recovery time. This study implies that error detection and recovery are dependent on expertise and that although all clinicians at all levels make errors, the type, effect, and recovery from these errors differ by expertise.

In a follow-up study, Razzouk et al. studied error recovery in vivo through the use of virtual world technology to simulate the verbal presentation of cases in a clinical setting [14]. The objective was to determine whether failed error detection was due to lack of knowledge or other reasons. The experiment involved 17 physicians-in-training at various levels of their post-graduate programs (interns, residents, and fellows) who were presented with two verbal case scenarios on OpenSim (an open source project that provides a host server for virtual worlds; http://opensimulator.org) representing common ICU cases that contained embedded errors with varying degrees of complexity. Subjects observed a case presentation in the context of a virtual ICU environment, then summarized their impressions of the case. Subsequently, they answered a set of knowledge-based questions designed to test for the knowledge prerequisite to the detection of each embedded error. For the second case, they repeated this procedure after being primed to focus on error detection. Results demonstrated that priming had a significant effect on error detection. The authors concluded that while detection of embedded errors by non-expert physician learners was limited, it improved significantly with priming.

This implies that performance can be substantially improved with specific training and may ultimately have a salutary effect on patient outcomes and safety.

These studies and others focusing on error and risk detection, prevention, and recovery have direct implications on how critical care medicine is practiced. Critical care physicians will increasingly encounter complex patients, utilize complex technologies and data, interact with complex specialties and policies, and function in an accountable public and professional climate. Cognitive demands such as decision-making, team-leading, multi-tasking, information analysis, and communication require continuous attention and effort and may interfere with clinical duties needed more urgently in critically ill situations. In addition, these studies build on prior knowledge regarding teams' response to error. Error detection and recovery by teams is better compared to individuals working alone (see below), although new errors may be generated by team discussions [15]. A solid understanding of how clinicians at all levels of expertise function effectively and safely is vital to improving the quality of our patients' care and outcomes, and these studies on risk and error management provide a foundational perspective to improve our clinical practice.

Expertise in knowledge and skills is vital to good clinical practice but has a limited effect on error occurrence. As clinicians and human beings managing patients in complex and risky environments, we must acknowledge that we will always make errors – albeit different types – and that most may not even be recognized by us or others. Attention should therefore focus on improved error detection and recovery rather than error elimination, as evidenced by an increased body of literature reporting that error elimination is an impractical and unobtainable goal. Fortunately, while error management is a skill that can be acquired with expertise, it may also be learned by non-experts earlier in their careers through specific training. Clearly, experience can increase vigilance about potential specific dangers and lead to rapid intervention to prevent or control them. But as Razzouk et al. demonstrated in their study, perhaps "priming" physicians at the start of their careers during their training using interactive formats may accelerate this knowledge and incorporate it into their practice earlier. Priming may have a major effect on adverse outcome reduction in academic institutions in particular, which are often the most complex and error-prone healthcare facilities due to the presence of trainees managing the sickest patients. Furthermore, contrary to popular belief, other studies have reported that the greatest number of errors may occur at low workloads and the least at high workloads [16]. However, error detection at high workloads is decreased, leading to a higher level of adverse outcomes. In addition, with training the total number of errors remains the same, but error detection improves. Earlier error detection can have important clinical consequences in patients with high acuity illnesses such as in the ICU environment.

Error Management by Teams

From exploring error management by individuals [12], Patel et al. extended their work to decision-making within clinical teams. Using a semi-naturalistic approach, two cases with embedded errors were presented to 5 ICU teams (including a total of 32 clinician subjects) during rounds, and the teams were instructed to discuss and comment on the cases' management. Error generation, detection, and recovery were evaluated and compared between individuals and teams. Teams detected a mean of 4.8 ± 1.3 of a total of 8 errors in both cases, accounting for 60 % of all errors and performing better than individuals, none of whom identified more than half of the embedded errors in any experiment (these results are not strictly comparable, as different case scenarios were used in each experiment, but the suggestion of better performance by teams is nonetheless encouraging and intuitively appealing). Teams performed better at detecting complex and knowledge-based errors than simple and procedure-based ones. Interestingly, longer team discussions resulted in generation of new errors. However, the likelihood of recovery from errors also increased with the number of interactive dialogue episodes. At the same time, errors were being generated as the length of the dialogue increased, suggesting that at some point in time, dialogue about patient care moves away to discussion of more general issues related to developing broader understanding of the problem.

The notion that teams almost always perform better than individuals is again reaffirmed by this study. Indeed, team-based learning is rapidly replacing traditional formats as a core model for education in medical schools, where the focus is on team-centered decision-making and cognition [17]. Many factors of teamwork may contribute to improved decision-making and error management: sharing of individual knowledge, social interactions stimulating generation of ideas, correction of mistakes and slips, aligning and focusing on common objectives, lack of social or organizational hierarchy hindering discussions, safety culture, and shared responsibility and accountability. While involving several perspectives adds to the collective knowledge, a more important concept demonstrated by this study is the fact that increased discussion time increased the likelihood of error detection and recovery despite generating more errors! This underscores the power and value of distributed cognition through open discussion among professionals in high-risk, time-limited, and dynamic situations such as the ICU. It would be of interest to re-evaluate this concept during varying levels of workload, work complexity, and team interpersonal relationships. The growing complexity of patient illnesses and needs demand a more team-focused approach to clinical management to optimize safety and efficiency of the delivery of care.

Hand-offs

Communication failures in healthcare remain a leading cause of medical errors and adverse events, and almost half of them occur during the handoff process [18, 19]. A handoff in clinical care refers to the transfer of information, responsibility, and authority between two or more providers to ensure the continuity of patient care [20, 21]. The dynamic complexity and needs of round-the-clock ICU environment, coupled with changing demands on healthcare providers such as limited residents' duty hours and growing shortages of nurses and physicians, emphasize the increasing reliance on information exchange among providers and hospitals during shift changes and patient transfers. Several tools have been utilized to facilitate handoffs, including structured notes, electronic programs, and checklists [22–24]. However, handoffs remain misunderstood, error-prone [25], and underutilized [26], contributing to a lack of consistency in their use [27]. A better understanding of the handoff process is vital to improving the design of handoff tools and their effective use in clinical practice. Several recent studies have shed light on this vital communication event.

One approach to studying handoffs is to study the tools or materials used by clinicians. Collins et al. analyzed nurses', physicians', and physician assistants' (PA) handoff artifacts at change-of-shift in a specialty surgical ICU at a large urban medical center [28]. The 22 document types were typically semi-structured handwritten forms and observation of their use in practice revealed that nurses and physicians/PAs' handoff process was largely similar, consisting of a conversation between providers of the outgoing and incoming shifts supported by these artifacts and the occasional use of the electronic medical records. There was also significant overlap of the specific content of the artifacts between nurses and physicians. This may suggest that the development of an interdisciplinary handoff tool is a reasonable approach to standardizing communication among disciplines, contrary to the current segregated approach.

The study of handoff tools in isolation cannot capture the interplay between use of these tools and the state of the clinical unit, hence the need for a more holistic approach. In their pursuit to study handoffs in a dynamic ICU environment, Abraham et al. developed a clinician-centered approach where the effectiveness of handoff tools was evaluated in the context of their use and the current patient workload [29]. This approach utilized multiple methods including direct observation and shadowing, interviews, artifact evaluation, surveys, and audio recordings. Their subsequent studies discussed below were also largely based on this methodology.

To evaluate the current handoff process in a clinical environment, Abraham et al. conducted a qualitative study on group handoffs in the ICU setting in a large academic center. The main handoff in the ICU occurred during morning rounds where residents formally presented the patient cases to the oncoming team. The study researchers evaluated the handoff process through the clinician-centered approach described above, using a combination of direct observation, shadowing providers during their work, interviews of the providers, and audio-recordings of handoff communication. The handoff process was divided into three phases: pre-turnover phase, where the provider collected and prepared the information for the handoff; the handoff phase, comprised of the communication activity during the rounds; and the post-turn-over phase, comprised of the patient care activities as a result of the handoff. Outcomes of the handoffs included acceptance of the information, rejection of the information, or requests for further information. Results indicated that there were two critical sources of information breakdown. One was the inconsistent use of the available SOAP note (*S*ubjective, *O*bjective, *A*ssessment, and *P*lan) for handoff, which demonstrated the suboptimal use of a structured tool consistent with the information needs at handoff time. The other critical source of information breakdown was the lack of completion of the pre-turnover activities that are required for effective handoff. Based on these findings, the authors suggested a more structured handoff tool that can direct information exchange better: one that is based on a body-systems format, and an information-push approach to handoffs that emphasize information being sent to users without their explicit request.

Based on this information, Abraham et al. conducted a follow-up study to determine the effectiveness of a structured handoff tool compared to the commonly used SOAP handoff note in the same ICU setting [30]. The new *H*andoff *I*ntervention *T*ool (HAND-IT) is based on a body system-oriented format with two design requirements: content standardization and content summarization (problem-case narrative format). Handoffs on morning multidisciplinary rounds were evaluated by the research team and the use of the tools was evaluated for missed or incorrect information and missed problem list items (information breakdown), changes to plan of care (decision-making breakdowns), and expertise of the clinicians. The study team found that significantly more information was missed or incorrect, more changes to the plan of care were made, and more missed problem list items occurred using the SOAP tool compared to the HAND-IT tool. Furthermore, interns' performance (first year residents with less experience and expertise) was significantly improved by the better information organization in the HAND-IT tool. The authors concluded that the HAND-IT tool improved handoffs and was more resilient, requiring more breakdowns before it resulted in missed information. These findings suggest improved information transfer tools of this nature may enhance clinical efficiency and potentially patient safety.

Poor handoffs remain a threat to safety and quality of patient care [18]. Poor handoffs may result in information loss, compromised decision-making, reduced communication and teamwork, errors and adverse outcomes, and increased costs. The quality of handoffs can be affected by a plethora of factors: stress, fatigue, memory overload, multitasking, interruptions, training and education, team dynamics and relationships, levels of expertise, and professional hierarchies [31]. An effective handoff tool should therefore be structured and focused, and should integrate information technology. Standardization of handoffs is associated with improved communication and information flow [32], and Abraham et al. confirmed this concept by demonstrating that a standardized tool facilitates information flow and decision-making. Furthermore, a good handoff tool encourages discussion among clinicians that not only supports patient care but promotes shared learning and cultivates professional relationships. Finally, a structured tool reduces the risk of information loss or errors by non-experts and would be particularly helpful in academic settings or for physicians starting out their careers, mitigating the risk inherent in clinicians-in-training.

The growing need to improve this aspect of clinical care is reflected by the Joint Commission mandate to standardize communication activities between clinicians during transitions of care [23]. Since handoffs occur in all transitions of care settings, they are vital to the safety and continuity of care of any patient but particularly the critically ill or complex patient. However, the development of a structured tool to facilitate handoffs is an important yet insufficient step towards this goal. Like the use of any tool, training, monitoring, and adaptation of the use of the handoff tool is necessary, with feedback to the users and customization of the tool as needed.

Tools may need to be modified according to the setting of their use: emergency center to ward, or operating room to ICU, or inpatient to outpatient. Additional studies on the handoff process are needed to optimize this foundational aspect of communication, teamwork, decision-making, and ultimately good clinical practice.

Workflow

Workflow is a sequence of activities or operations performed in a system by variously involved agents and resources. It provides an overview of the conditions or context in which processes within a system occur and all the factors that can contribute to those processes. Workflow analysis is vital to improving any system and its outcomes; in healthcare, workflow has a direct correlation to patient outcomes, as it can influence timing of care, decision-making, and compliance with protocols and policies. However, since workflow is a multidimensional concept, it is inherently difficult to study in its entirety. Typical methods of workflow analysis include ethnographic observations, interviews and surveys. However, these approaches are limited by the inability to capture information from various perspectives simultaneously, an important perspective since workflow entails interactions among various systems, needs, and resources. Nevertheless, the need to understand it better is vital to improving healthcare delivery.

Vankipuram et al. have offered a new model to augment the traditional approaches to studying workflow in complex clinical environments [33]. In their paper, they describe the use of radio identification technology (RID) for quantitative continuous monitoring to supplement the traditional qualitative methodology, analogous to the use of the "black box" in aviation. RID-enabled tags are worn by clinicians and communicate with base units that measure distances, locations, and time at particular locations within a selected environment, providing information on the interactions of agents and artifacts in the said environment. The Hidden Markov Modeling technique (HMM) was then used to develop a prediction model of 15 simulated trauma activities in a laboratory based on observations in a trauma unit, and the model predicted 87.5 % of the clinician activities. While clinical trials are still pending, this appealing model has great potential to provide information on the efficiency and structure of workflow in a clinical environment during various levels of demand and resource needs. In addition, it can be used to generate information on teamwork coordination, real-time conditions during which errors or failures develop, and changing needs based on changing demands, personnel, and resources. This may help in improving outcomes, such as reducing waiting times in the ICU, as reported by Chen et al. [34].

To further understand the nature and impact of interruptions on clinical workflow, Mamykina et al. performed an observational study of 34 nurses and physicians in a pediatric ICU [35]. The researchers shadowed individual subjects for an hour during their shifts and recorded information on number, types, sources, timing, and resumption lag (time to return to original task) of interruptions. A total of 547 interruptions were recorded, averaging 9.85 times/h for residents and 9.52 times/h for nurses. The most common source of interruptions was by clinicians on the same team or the same unit for both professionals (more than 60 % of interruptions). Other types of interruptions included clinicians outside of the unit, phone and pagers, patients and visitors, and patient monitoring equipment. Nurses were more likely to get interrupted by patients and visitors and monitoring equipment, while physicians were more likely to get interrupted by pagers and clinicians from outside the unit. Some types of interruptions such as those from clinicians outside of the unit peaked in the morning hours, while interruptions between team members steadily increased during the day. Interruptions among team members were uncommon when the team was together performing patient rounds but increased after rounds. The root causes of interruptions were categorized as follows: coordinating work (provide directives and instructions, request for help, obtain or share information, and determine responsibilities), situation awareness (updates and current activities, events, state of resources), mutual understanding (clarifying expectations), shared decision-making, mentoring, patient/family requests, emotional affiliation (seeking or offering emotional support to colleagues), social (work unrelated), and device alarm. The most common groups were coordinating work, situation awareness, and mutual understanding, accounting for about 60 % of all interruptions. Although not common, patient/family requests and shared decision-making resulted in the longest resumption lag (average 20 min).

This study confirms what almost all clinicians will acknowledge: interruptions in daily clinical workflow are common and varied and occur throughout the shift. Interruptions not only disrupt the work routines but can affect the decision-making process that occurs almost continually in high intensity environments such as the ICU. This may have a detrimental impact on patient safety and efficiency of clinical work. While the types of interruptions are many, they overlap among specialties, such as nurses and physicians, and may characterize a particular unit or department depending on their unique characteristics. Finally, interruptions may be an indicator for potentially improved workflow, highlighting areas where increased efficiency was needed such as communication, information flow, and determination of roles and responsibilities. Better tools such as information displays or handoff processes may attenuate interruptions and facilitate improved flow and patient care. Better rules or policies such as the “sterile cockpit” – where the person performing a task is protected from interruptions due to the serious and important nature of the task – can not only reduce interruptions but improve safety and reduce the likelihood of errors. Of course, one must always consider the emotional and psychological toll interruptions have on the busy professional, contributing to stress, team dynamics, and burnout.

Information Seeking Behavior

A major determinant of effective and safe clinical decision-making is the availability of accurate, specific, and timely data at the bedside. Technology and electronic medical records form a growing facilitative role on data collection and ultimately on healthcare decisions and outcomes. Our healthcare system finds itself in the midst of a major transition from the traditional paper-based medical record and order entry to an electronic, nationally compatible information system. How clinicians utilize and access their information sources, and how hospitals and healthcare systems collect information on their clinicians' activities and needs, will significantly affect workflow, decision-making, resource use, and ultimately patient care. Two studies have investigated information seeking methods, each providing a unique perspective on clinician activities.

Kannampallil et al. combined human observation with sensor-based technology to investigate clinician activities in a complex clinical environment [36]. Sensor-based technologies have been used to study mobility and interactions of clinicians [37]. This study was conducted in the Emergency Center (EC) of a Level I Trauma center teaching hospital and utilized *tags* attached to clinicians (attending physicians, residents, nurses) and stationary *base stations* placed at key locations to capture the tracking of the tags. The information captured described the movements and interactions of the clinicians within the ED that can be used to study and even predict models of clinician activities. These data included: location and time spent at that location, transitions among locations, and aggregation with other clinicians. Human observers followed the tagged subjects and collected specific information to confirm the accuracy of the information made by the tags as well as obtain additional information. Results demonstrated good correlation between locations of the clinicians from tag (sensors) and observers' data. Residents and nurses spent more time in the trauma rooms at the bedside, while attending physicians spent more time with other physicians than with nurses. There were few consistent patterns of location, particularly among nurses.

Sensor data technology is a potentially valuable tool to improve clinical care by measuring the complexity of a clinical environment. Data collected on movement and interactions among clinicians can measure and provide valuable insight into clinician effort and activities, teamwork and collaboration, resource and time utilization, workflow patterns and efficiency measurements (see prior "Workflow" section), and retrospective review of environmental conditions when an error or bad outcome is investigated. This information can be used by clinicians and hospital leadership in several ways. First, it can help plan resource needs and allocation of specific units, time periods, and workloads that more precisely control costs, inventory, and waste and reflect real-time changing needs that characterize busy clinical settings. Second, it can monitor changes in processes or structures within a clinical environment and adjust that change accordingly. Third, sensor data technology can offer real-world education and training opportunities to identify and mitigate disruptions, risks, errors, inefficiencies, and process failures, but also to promote teamwork, efficiency, and prioritization. Finally, by complementing clinical forums such as the Morbidity and Mortality Conference or Multi-disciplinary Rounds, it can provide a valuable framework to study origin and progression of errors and unexpected patient outcomes. Information such as clinician activities, demands, and needs can be assessed around the time an adverse outcome occurred, improving our ability to learn about these situations and prevent them in the future.

From a different perspective, another report by Kannampallil et al. studied the information-seeking behaviors of physicians in a complex environment. Under direct observation of the study team, seven expert physicians reviewed the entire medical record of a single patient case in the ICU. The type of data retrieved (subdivided into categories), the time and source for data retrieval, and the *information gain* (number of information units in a sub-source divided by the time spent on that source, with greater gain for newly-encountered information than redundant information) were collected and analyzed. Results indicated that information was distributed among various sources; these sources were utilized for different types of data collection and the information gain differed among sources. Structured organization of information facilitated accelerated retrieval by the physicians. Physicians toggled between the paper and electronic records, but the total time spent on each did not differ. Information gain was greater for electronic medical records, mostly because of the uniqueness of the data. The total amount of information obtained, however, was greater for the paper records.

This study underscores several important clinical concepts. First, it highlights the efficiency of data collection by physicians. This study demonstrates the extensive time and cognitive energy spent by physicians seeking, filtering, and organizing data from a myriad of sources. This lost time and energy distract from clinical care provided by the physician. In addition, searching for information from multiple sources may disrupt the logical flow of reasoning during clinical decision-making. Second, information seeking challenges may contribute to data loss and misinterpretation. In the context of a busy clinical situation, difficulties in data acquisition may not be tolerated for a prolonged period of time, tempting the discouraged physician to obviate further data pursuit and potentially affecting the clinical decision and plan of care. Third, the distributive nature of clinical data may contribute to missing or conflicting information, requiring additional time and effort to confirm or even rectify the void or discordance. This is not only inefficient but can be directly harmful to patient safety. Finally, there is a "learning curve" inherent in navigating data sources, which may continue to escalate as sources of data change. This further burdens the physician with the need to relearn processes and needlessly expend further time and energy.

The efforts demonstrated by these studies to characterize information-seeking behaviors are vital to promoting efficient, timely, and safe clinical care. The use of sensor-data technology to study clinicians' activities can inform hospital and physician leadership about resource needs and workloads, monitor and adapt new programs or policies based on real-time data, and facilitate teamwork and collaboration. Similarly, understanding how physicians seek information can facilitate and redesign decision-making, workflow, and other value-added activities. In addition, the development of standardized data platforms may attenuate the challenges of cognitive barriers such as knowledge deficits, memory-capacity limitations, and information overload that impede decision-making.

Protocol-Based Practice

Protocols and guidelines are important tools in complex environments and have demonstrated beneficial effects on patients' safety and outcomes in the ICU [38, 39]. Protocol-based practice improves care by reducing reliance on memory, decreases variation and non-value added work by clinicians, guides care based on scientific evidence, adds structure and predictability to complex tasks, and promotes standardization of practice [40–42]. More importantly, in the clinical arena where unexpected events and patient deterioration are common, protocols cannot be followed for all patients all of the time. Deviations from protocols are often regarded as "errors," but in the complex and constantly changing arena of healthcare, some deviations may be necessary and indeed beneficial to care. How and when to apply, modify, or deviate from them is an important area for further study to improve the development and application of this important tool and to promote the development of the "shared mental model" characteristic of high reliability teams.

To understand the socio-technical factors that affect the use of a protocol in a complex clinical setting, Myneni et al. evaluated a common computerized weaning protocol (CWP) in a medical intensive care unit (MICU) [43]. The initial step was to create a FRAM-based model (Functional Resonance Accident Method) of the CWP to categorize the specific components of the protocol and to learn how they interact to produce desired or unexpected outcomes. This indicated that there were many factors in the CWP that were inadequate and unpredictable, which may ultimately affect how the protocol is used and the outcomes it produces. Most of these factors could be rectified through education, improved communication among users, and impact demonstration. The next step in this study involved the observation of 65 weaning sessions using the CWP, and each session was categorized as favorable (45, 69 %), unfavorable (4, 6 %), and near-miss (16, 25 %). Major problems identified with the CWP and potentially leading to the unfavorable or near-miss outcomes related to misinterpretation of specific steps, on-time delivery support, inadequate communication and collaboration among clinicians, and insufficient feedback of the protocol's impact on quality of care delivery. While several implications arise from this study, the most important is that it demonstrates that the introduction of a clinical practice protocol does not ensure its consistent or even accurate application.

Deviations from standardized polices or protocols are a common component of complex clinical care and occur for various reasons. Building on a prior study by Kahol et al. [44], Vankipuram et al. investigated the adaptive behavior of clinicians in following the standardized Advanced Trauma Life Support (ATLS) guideline [45] in a busy Level I Trauma center [46]. Field observations of junior (non-expert) and senior (expert) residents occurred for 30 trauma cases to identify if deviations from the management protocol occurred, their types, and reasons. Deviations were categorized into errors (violated standards), innovations (provided potentially beneficial novel perspective), proactive (potentially beneficial activity performed in anticipation of future need) and reactive (activity performed in reaction to an unanticipated event). A total of 153 deviations occurred whose types were related to the clinician's experience level. Proactive deviations were similar among groups, but innovations were greater among experts and reactive deviations and errors were greater among non-experts. More deviations occurred later in the management process. Errors occurred throughout the patient care period, but innovations occurred after the initial patient evaluation (primary patient survey) where more flexibility in the protocol is permitted.

In healthcare, more often than not, a policy or protocol is developed and implemented without any follow-up monitoring or analysis on its use or effect. The assumptions underlying this practice are that the protocol is self-explanatory;

it will demonstrate benefit based on the literature or others' experience; it will be easily integrated into the current workflow, and it does not add further time or effort on the user. A weaning protocol is a strong evidence-based and well-accepted intervention in the critical care community that has been in use at the study institution for a while. Yet the study indicated that 31 % of cases resulted in an unfavorable or near-miss outcome. This suggests that even the application of a common and well-established protocol is fraught with difficulties and variation. Clinicians and nurses in particular can attest to the myriad of instances when leadership implements a policy that is ineffective, unclear, and unmonitored and only contributes to the added workload without any clear indication of benefit such as safety or efficiency. Therefore, the application of a protocol should include regular re-evaluation to provide amendments when necessary to optimize its effectiveness. Protocols need to evolve to accommodate changing patient needs, new technology and medical science, and personnel turnover. The use of a tool like FRAM should be a routine practice at healthcare facilities to ensure that protocol-based practice is updated, efficient, and effective with minimal disruption to current workflow. In fact, routine revisions of protocols may even indicate that their utility and role have expired, prompting their retraction from the practice setting. Furthermore, optimum use of a protocol will encourage its use and support the standardization of practice.

Ineffective use of protocols can also affect deviations by increasing errors and reduce innovations and proactive interventions. Since deviations from protocols are a common and often expected component of protocol-based practice, it is vital to minimize unwanted deviations by ensuring the protocol is used optimally and appropriately. Protocol implementation should be supplemented by robust training in its use, not only to increase effectiveness and promote engagement as explained above, but to guide the user to incorporate positive deviations as needed and minimize error or reactive deviations. More effective understanding of the protocol may mitigate other reasons for non-beneficial deviations, such as individual preferences, habits, or outside influences. Of note, the rigid implementation of protocol, particularly those based on extrapolations of evidence from the study population to a broader unstudied population, may not demonstrate the intended benefit and may in fact be harmful. Tight glucose control is a classic example of how a single study resulted in a rapid development and implementation of hyperglycemia protocols nationally that required strict control parameters and resulted in increased mortality due to hypoglycemic events [47]. Again, this demonstrates that protocols are tools for to be used and adapted to the clinical situation.

Conclusion

The increasing complexity of the ICU milieu, coupled with the growing demands on critical care, the integration of multiple informational systems and sources, and the accelerating growth in medical science and technology all mandate a greater need to integrate, coordinate, and facilitate ICU workflow, handoffs, information collection and analysis, and decision-making. The studies discussed in this chapter have reported on different models used to evaluate these multidimensional aspects of critical care and have shed considerable light on how clinicians practice from a practical and applied perspective. They have also demonstrated the potential for new models and tools to improve safety, efficiency, and the effective application of evidence-based medicine. This increased understanding of cognitive systems in clinical care can lead to the development of new models to deliver care, more effective training approaches to teach aspiring clinicians, and better use of technology to facilitate safe and efficient medical care. Critical care medicine – in fact, all medical specialties – must incorporate this dimension to their practices to elevate their quality of care to the level of a highly reliable organization such as the aviation industry or the military. The twentieth century has focused on increasing and applying knowledge gained from medical science to improve diagnostics and therapeutics to treat disease and prolong lives. As our healthcare system grows in size and complexity, we must complement this exponential growth in medical science with the equal understanding and application of cognitive science to improve healthcare delivery and ultimately offer the level of care the twenty-first century will demand.

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