Integrating Human Factors Research and Surgery

A Review

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Objective: To provide a review of human factors research within the context of surgery.

Data Sources: We searched PubMed for relevant studies published from the earliest available date through February 29, 2012.

Study Selection: The search was performed using the following keywords: human factors, surgery, errors, teamwork, communication, stress, disruptions, interventions, checklists, briefings, and training. Additional articles were identified by a manual search of the references from the key articles. As 2 human factors specialists, a senior clinician, and a junior clinician, we carefully selected the most appropriate exemplars of research findings with specific relevance to surgical error and safety.

Data Extraction: Seventy-seven articles of relevance were selected and reviewed in detail. Opinion pieces and editorials were disregarded; the focus was solely on articles based on empirical evidence, with a particular emphasis on prospectively designed studies.

Data Synthesis: The themes that emerged related to the development of human factors theories, the application of those theories within surgery, a specific interest in the concept of flow, and the theoretical basis and value of human-related interventions for improving safety and flow in surgery.

Conclusions: Despite increased awareness of safety, errors routinely continue to occur in surgical care. Disruptions in the flow of an operation, such as teamwork and communication failures, contribute significantly to such adverse events. While it is apparent that some incidence of human error is unavoidable, there is much evidence in medicine and other fields that systems can be better designed to prevent or detect errors before a patient is harmed. The complexity of factors leading to surgical errors requires collaborations between surgeons and human factors experts to carry out the proper prospective and observational studies. Only when we are guided by this valid and real-world data can useful interventions be identified and implemented.

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WHILE THE PRECISE INcidence and epidemiology of medical mistakes still elicit debate, all can agree that human errors are inevitable in any endeavor. Errors typically have little to no consequence and often go unnoticed, but occasionally they translate into an adverse event. In the medical setting, this may be reflected in prolonged hospital stays, morbidities, or mortalities.[1-3] A growing consensus acknowledges that while errors and adverse events are often committed by individuals, they are mostly the product of faulty systems and inadequate organizational structure set forth by the institution.[4-6] Because of the critical nature of many operative interventions, surgery accounts for a large number of medical errors. In one retrospective review by Gawande et al,[7] 66% of all adverse events were found to be surgical in nature, most of which occurred in the operating room; 54% of these were judged to be preventable.[1] Beyond their cost in human lives, preventable medical errors result in financial costs projected to be between $17 billion and $29 billion per year in US hospitals.[8]

Human factors engineers seek to identify the root causes of medical and surgical errors within vulnerable systems with the intent of optimizing performance.[9] Human factors research can provide a pragmatic framework for analyzing and assessing risk and reducing error by considering where system designs could take better account of human capabilities and fallibilities. In this article, we will review (1) the systematic nature of errors and how they relate to the field of surgery, (2) human

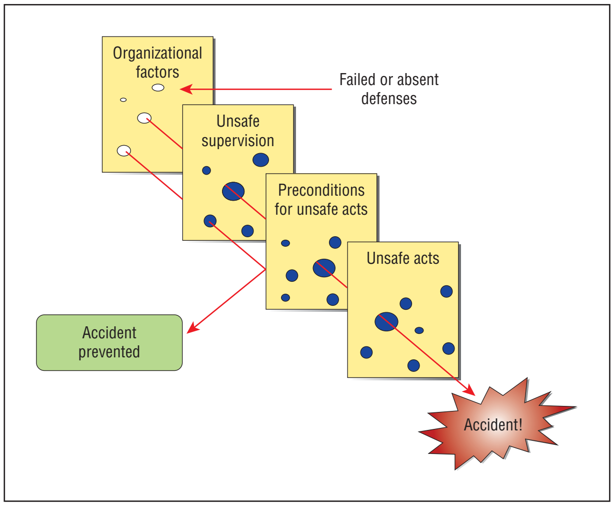

Figure 1. Swiss cheese model of accident causation. Adapted with permission from Ashgate Publishing Ltd.[17]

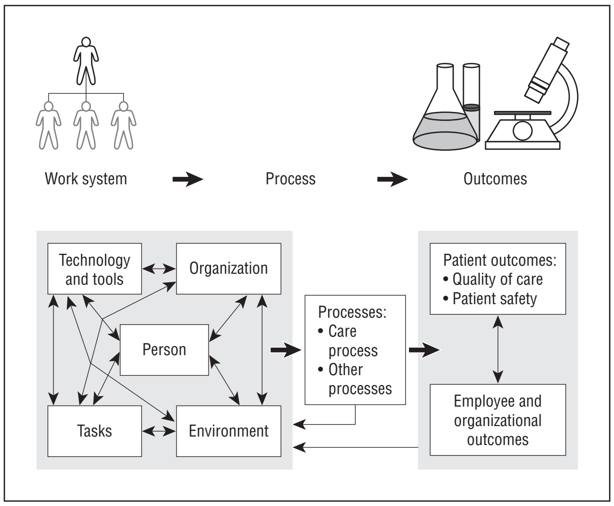

Figure 2. The Systems Engineering Initiative for Patient Safety model. Adapted with permission from BMJ Publishing Group.[21]

factors studies within the practice of surgery, and (3) the most promising interventions that have been implemented to date.

METHODS

We searched PubMed for relevant studies published from the earliest available date through February 29, 2012. The search was performed using the following keywords: human factors, surgery, errors, teamwork, communication, stress, disruptions, interventions, checklists, briefings, and training. The breadth of the topic and methodological and theoretical diversity of human factors research meant that a systematic review was neither possible nor desirable. Instead, as 2 human factors specialists, a senior clinician, and a junior clinician, we carefully selected the most appropriate exemplars of research findings with specific relevance to surgical error and safety. Opinion pieces and editorials were disregarded; we focused solely on articles based on firm evidence, with a particular emphasis on prospectively designed studies. Seventy-seven articles of relevance were selected and reviewed in detail. The themes that emerged related to the development of human factors theories, the application of those theories within surgery, a specific interest in the concept of flow, and the theoretical basis and value of human-related interventions for improving safety and flow in surgery.

HUMAN FACTORS AND SYSTEMS

Human factors can be described as the study and design of environments and processes to ensure safer, more effective, and more efficient use by humans.[10-12] The general objective of human factors engineers within the domain of health care is to maximize human performance and system efficiency while promoting health, safety, comfort, and quality of life.[13,14] Adopting a systems approach to understanding surgical errors is based on 3 principles: (1) human error is unavoidable, as it is an inherent aspect of human behavior, (2) defective systems allow human error to cause harm to the patient, and (3) systems can be designed to prevent or detect human error before a patient is harmed.[15] According to this perspective, errors are the natural consequences, not the causes, of those systemic breakdowns that affect performance.[16]

Perhaps the most familiar human factors theory is the "Swiss cheese" model of accident causation. This provides a theoretical framework for the cause of errors within the context of systems (**Figure 1**). According to this model, accidents are a result of both active and latent failures. Active failures are unsafe acts committed by the people at the human-system interface whose actions can have immediate, adverse consequences. Latent failures are the result of poor systems design or decision making by members of the organizational and management spheres. The damaging consequences of latent failures may lie dormant for a long time, only to become evident when they combine with active failures. Each slice of "cheese" is analogous to a systemic defense against error, and the holes within each slice are a combination of active and latent failures. Occasionally, the holes within each layer of defense will line up together, allowing an error to bypass the system's defenses and translate into an accident.[18-20]

Preventable adverse events are therefore not simply the result of human error but rather are due to defective systems that allow errors to occur or go unnoticed.[15] The Systems Engineering Initiative for Patient Safety model is a useful illustration of the components of a system (**Figure 2**). It places the individual at the center and carries the notion that all the elements of the system have an effect not only on the individual but also on the other elements within the system. This model suggests that surgical skill, overall performance, and outcomes are strongly affected by such factors as teamwork and communication, the physical working environment, technology, workload factors, and other organizational variables. In turn, the components of the system can influence each other.[21] For example, introduction of a new technology such as a surgical robot requires new skills to be learned, a suitable environment in which to operate and maintain it, and organizational support for the technology and people using or being treated with the new technique.

HUMAN FACTORS IN SURGERY

There is a growing body of literature relating human factors science to the practice of surgery. Operating rooms are commonly intricate, high-stress environments occupied by a broad array of technological tools and interdisciplinary staff. The operating room has a unique set of team dynamics, as professionals from multiple specialties whose goals and training differ widely are required to work in a closely coordinated fashion.[22] This complex setting provides multiple opportunities for suboptimal communication, clashing motivations, and errors arising not from technical incompetence but from cognitive biases, poor interpersonal skills, and substandard environmental factors.[22,23]

Environmental factors within the operating room such as clutter, congestion, noise, lighting, and temperature have been shown to negatively affect surgical performance.[24-26] Congestion due to the location of equipment and displays as well as the disarray of wires, tubes, and lines, known as the "spaghetti syndrome," is a common scenario in the operating room.[27] Consequently, movements by members of the surgical team are often obstructed, wiring is difficult to access and maintain, and the risks of accidental disconnection of devices and human error increase.[26] Noise can hinder the ability of a surgeon to concentrate by masking acoustic cues and interfering with internal thought processes.[13] Excessive noise may also prevent critically relevant communications from occurring among team members.[28]

Poor communication has been increasingly regarded as a causal factor in a large percentage of sentinel events within the health care system.[28-31] The Joint Commission reports communication as the number one root cause of sentinel events from 1995 through 2004. In one study, incomplete or erroneous communication was a causal factor in 43% of errors made during surgery.[32] Yet another study found that 36% of communication errors in the operating room resulted in inefficiency, team tension, resource waste, patient inconvenience, and procedural error.[31] Surgeons who are capable of adapting their communication style when operating with new or inexperienced team members have been able to foster team coordination in a manner that reduces errors and improves patient outcomes.[33]

Similarly, technical surgical errors cannot be understood in isolation from the actions of other members of the team. In one study, teamwork factors alone accounted for 45% of the variance in the errors committed by surgeons during cardiac cases.[30] In a study comparing the effectiveness of primary (familiar) and secondary (unfamiliar) surgical teams, primary teams revealed significantly fewer surgical errors and miscommunication events per case.[16] The stability of a cohesive team fosters the development of trust among team members, which allows for adaptation to nonverbal communication styles and facilitates the anticipation of others' actions.

Although effective teamwork and communication are fundamental to patient safety in the operating room, acute stress increasingly is recognized as a key component of surgical performance.[34,35] Surgeons encounter frequent stressors in the operating room, including technical complications, time pressure, distractions, interruptions, and increased workload.[36] Excessive levels of intraoperative stress can compromise both technical and nontechnical skills.[37,38] Indeed, being able to operate effectively under such stress-inducing conditions is a hallmark of expertise.[36] A marker of surgical excellence is not error-free performance but rather the ability to manage errors and problematic events during an operation.[29] In essence, because patient anatomy and physiological response to surgery may not always be predictable, it makes sense to control for as many other uncertainties as possible and thus allow a more appropriate individualized response for each patient. This may ultimately illustrate the need for surgery-specific human factors theoretical development, as aviation models, for example, become increasingly outdated.

PROSPECTIVE ANALYSIS OF FLOW DISRUPTIONS

Methods of capturing systemic errors include both retrospective reviews and prospective observational studies. Retrospective studies are prone to hindsight bias.[39] For example, it is difficult to determine how sleeplessness, distractions, poor communication, and technical factors may have contributed to the occurrence of a retained sponge in the abdomen weeks after the event transpired. Additionally, retrospective studies cannot detect near harm or potential adverse events, which occur far more frequently and offer as much information as the catastrophic but rare adverse event.[40-42] In contrast, prospective observational research offers objective analysis of events and allows for the study of near misses, errors, adverse events, team performance, and organizational culture.[43,44] However, the rarity of capturing an uncommon death or adverse event makes it difficult to justify endless hours of observation. This dilemma has prompted researchers to monitor the quality of performance through the measurement of outcome events other than death.[45] Surrogate measures, such as errors and disruptions, can often be used to predict the occurrence of a catastrophic adverse event or death if the proposed measure correlates with a clinically meaningful outcome and fully captures the effect of a particular treatment.[46]

The concept of flow was first promulgated in the 1960s by Mihaly Csikszentmihalyi when he observed artists who would get lost in their work, disregarding their need for food, water, and even sleep. Flow is a mental state in which a person is fully immersed in a complex activity that is intrinsically motivated by his or her own talents and interests; flow imparts a distorted sense of time and a loss of any feeling of self-consciousness. According to Csikszentmihalyi, flow can be attained only if an individual possesses the proper skill set necessary to carry out a task worthy of the challenge. While flow shares some surface characteristics with other urgent tasks, it is elevated by the matching of hard-won skills and innate talents with a meaningful and noble purpose.[47,48] When this concept is applied to the field of surgery, flow could refer to the ease and fluidity with which an operation progresses.

Surgical flow disruptions are deviations from the natural progression of a procedure that potentially compromise the safety of the operation.[30] The significance of flow disruptions lies in their ability to provide a window to the quality and safety of the system before a serious accident occurs.[39] Indeed, flow disruptions can be viewed as a surrogate measure for errors occurring in the operating room. Although a single flow disruption will likely result in little to no consequence on the outcome of an operation, the accumulation of flow disruptions has empirically been linked to a higher prevalence of surgical errors.[30] Observational studies focusing on flow disruptions allow for a systematic, quantitative, and replicable assessment of the relationships between the surgical environment, processes, and outcomes.[49]

Through the observation of 31 cardiac surgery operations, Wiegmann et al[30] showed that surgical errors increase significantly with increases in flow disruptions such as impaired teamwork, communication failures, equipment and technology problems, extraneous interruptions, and issues in resource accessibility. Catchpole et al[22,50] confirmed that complications during operations can arise from an escalation of smaller problems and that these problems can be mitigated by effective teamwork and communication. de Leval et al[29] prospectively observed 243 arterial switch operations among pediatric patients in 16 British institutions and analyzed the effects of major and minor events. They found that both major events (those errors that are likely to have direct and serious consequences to the patient) and the accumulation of minor events (those that disrupt the smooth flow of the procedure) had significant effects on death and/or near misses. They also found that as the number of minor events increased, the ability of a surgical team to cope with major problems significantly decreased.[51] They concluded that the accumulation of minor events appeared to diminish the compensatory resources of the surgical team, increasing their susceptibility to committing errors.[33]

In another prospective ethnographic study, communication breakdown, information loss, increased workload, and competing tasks were found to pose the greatest threats to patient safety in the operating room.[12] Healey et al[25] found that distractions and interruptions related to communication, equipment, procedures, and the operative environment occurred most frequently and were most visibly disruptive. They also found the most distracting communications to be related to operating room equipment, responses to queries about other patients, and ongoing management of the operating list with the members of the operating room team.[52] Similar patterns have been obtained in urological surgery as well as specialties outside surgery, including intensive care units and emergency departments.[53-56]

INTERVENTIONS

The analysis of errors and adverse events in health care has prompted the implementation of several types of interventions to help reduce the frequency of such events. Checklists, most notably the World Health Organization Surgical Safety Checklist, have been proposed to improve safety and process reliability. Checklists ensure against errors of omission, promote explicit consistency of repetitive tasks, and improve procedural learning as well as process reliability.[19] However, a checklist is effective only if it is well designed and used appropriately; as a consequence, not all checklist studies show efficacy.[57,58] In the wrong situation, a poorly implemented checklist could itself lead to flow disruptions during the case. Thus, where such interventions do not complement existing systems of work, they may be met with cultural resistance, particularly when they are viewed as just another task to complete.[59,60] Despite the adoption of a surgical site marking checklist mandated by the Joint Commission on Accreditation of Healthcare Organization in 2004, wrong-site operations and near misses continue at an unchanged pace.[61]

Another potential solution to improving safety and efficiency in the operating room is the preoperative briefing. Briefings improve team awareness or knowledge through shared information, explicit confirmation, reminders, and education. They also help identify problems, encourage prompt decision making, and initiate follow-up actions.[31] Briefings have been found to significantly reduce the perceived risk for wrong-site surgery and improve perceived collaboration among the operating room staff.[62,63] They have also been found to reduce communication failures, reduce disruptions in surgical flow, reduce delays, and allow better identification of problems and knowledge gaps.[31,64,65] Despite the benefits that they provide, briefings may be viewed negatively by some because of associated delays and the need to simultaneously assemble all members of the operating team.

A third solution that has become increasingly popular is the implementation of teamwork-based training courses. These courses aim to improve interpersonal relationships through the improvement of nontechnical skills such as communication and leadership. They have been shown to deliver better observed team skills, better satisfaction with care, improved compliance with briefings, and reduced error rates.[66-71] They can also lead to better organizational perceptions that help sustain institutional change.[68,72,73] Improved teamwork ultimately leads to intersecting goals among team members, thereby improving the flow with which an operation progresses. However, such training largely derives from aviation principles that may not always apply to the specific needs of the teams, and in most cases, the requirements for refresher training are poorly considered. The complexity of patient physiology requires that a physician approach the human body as an interrelated system composed of multiple organs constantly communicating and interacting with one another. Pathologic conditions are rarely corrected by a “silver bullet” approach but rather require multimodal treatments. The systemic failures within health care, which lead to errors and adverse events, may also need to be remediated in a similar manner. Checklists, briefings, and teamwork training can all be effective in reducing systemic failures; however, there are many more opportunities to improve flow. In fact, the Systems Engineering Initiative for Patient Safety and other human factors models suggest that training and behavioral change should be seen as a last resort. Improving the design of equipment, the order, allocation, and definition of surgical tasks, the design of the surgical environment, and the organization of services and support around the maintenance and improvement of surgical flow could all yield improvements in surgical performance and eventually outcomes. Therefore, the best approach to improving safety is likely to be a combination of approaches.

CONCLUSIONS

Although most recommendations for surgical improvement would be to carefully implement checklists, briefings, and training, organizational leaders must consider the effects that such changes will have on the system as a whole. To improve working environments for the entire team and sustain positive systemic changes, one must fully understand the violations and why individuals and organizations drift away from safety. The continuation of prospectively designed studies through direct observation of flow disruptions coupled with incident reporting systems and the use of morbidity and mortality conferences will help us to understand why errors occur and thus allow us to develop the best solutions for change.

While it is apparent that some incidence of human error is unavoidable, there is much evidence in medicine and other fields that systems can be better designed to prevent or detect errors before a patient is harmed. The complexity of factors leading to surgical errors requires collaborations between surgeons and human factors experts to carry out the proper prospective and observational studies. Only when we are guided by valid and real-world data can useful interventions be identified and implemented.

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