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Human Factors in Surgery: From Three Mile Island to the Operating Room

Key Words

Risk management • Adverse events • Human factors

Abstract

Human factors is a definition that includes the science of understanding the properties of human capability, the application of this understanding to the design and development of systems and services, the art of ensuring their successful applications to a program. The field of human factors traces its origins to the Second World War, but Three Mile Island has been the best example of how groups of people react and make decisions under stress: this nuclear accident was exacerbated by wrong decisions made because the operators were overwhelmed with irrelevant, misleading or incorrect information. Errors and their nature are the same in all human activities. The predisposition for error is so intrinsic to human nature that scientifically it is best considered as inherently biologic. The causes of error in medical care may not be easily generalized. Surgery differs in important ways: most errors occur in the operating room and are technical in nature. Commonly, surgical error has been thought of as the consequence of lack of skill or ability, and is the result of thoughtless actions. Moreover the 'operating theatre' has a unique set of team dynamics: professionals from multiple disciplines are required to work in a closely coordinated fashion. This complex environment provides multiple op-

portunities for unclear communication, clashing motivations, errors arising not from technical incompetence but from poor interpersonal skills. Surgeons have to work closely with human factors specialists in future studies. By improving processes already in place in many operating rooms, safety will be enhanced and quality increased.

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Introduction

Human factors is a definition that includes:

- The science of understanding the properties of human capability (*human factors science*).
- The application of this understanding to the design and development of systems and services (*human factors engineering*).
- The art of ensuring successful applications of human factors engineering to a program (*human factors integration*).

The expression 'human factors science/research/technologies' is mostly synonymous with the term '*ergonomics*', having separate origins but covering the same technical areas.

Human factors are sets of human-specific physical, mental and behavioural properties which are specific to humans and either may interact in a critical or dangerous

manner with technological systems, human natural environment and human organizations.

The choice/identification of human factors usually depends on their possible negative or positive impact on the functioning of human organizations and human-machine systems.

The identification and study of human factors is important for safety because they can be the cause of severe human errors on the levels of physical behaviour and socio-cognitive decision-making.

Areas of interest for human factors practitioners includes: training, staffing evaluation, communication, task analyses, functional requirements analyses and allocation, job descriptions and functions, procedures and procedure use, knowledge, skills, and abilities; organizational culture, human-machine interaction, workload on the human, fatigue, situational awareness, usability, user interface, learn ability, attention, vigilance, human performance, human reliability, human-computer interaction, control and display design, stress, visualization of data, individual differences, aging, accessibility, safety, shift work, work in extreme environments including virtual environments, human error, and decision-making.

Many areas cited above characterize the medical practice and particularly the surgical practice. Nowadays, the medical field has become increasingly aware of the need to understand human factors in adverse events (near misses, critical incidents, and deaths). Of particular importance is research that takes a systems approach to identify the organizational, team, and human causes that lead to adverse events [1].

Research on human factors in the operating room (OR) is particularly relevant to surgeons. It includes attitudes of the OR team, surgeons' leadership styles, the impact of new technology on performance, surgical decision-making in laparoscopic procedures, and the development of team-training simulators [1–6].

In this paper we review the main topics about human factors in surgical practice, also tracing their origins and their recent applications in OR.

Human Factors: The Lesson of Three Mile Island

The field of human factors traces its origins to the Second World War, during which time aircraft technology crossed the critical threshold of complexity exceeding the capacity of the human mind to comprehend simultaneously all aspects of the entire system. It was recognized

then that the machine (environment) itself must be designed with the '*human in mind*' so that correct behaviours were facilitated.

These lessons were applied to humans in complex industrial settings after the disaster at Three Mile Island. Three Mile Island Nuclear Generating Station was a civilian nuclear power plant located on an island in the Susquehanna River near Harrisburg, Pa., USA. The plant is most well known for being the site of the worst civilian nuclear accident in US history (there were no deaths) when in 1979 TMI-2 reactor suffered a partial meltdown.

The event was largely publicized, but the accident was not as terrible as the media made it out to be. The radiation leak was contained and killed no people.

Three Mile Island has been of interest to human factors engineers as an example of how groups of people react and make decisions under stress. There is consensus that the accident was exacerbated by wrong decisions made because the operators were overwhelmed with information, much of it irrelevant, misleading or incorrect. As a result of the TMI-2 incident, nuclear reactor operator training has been improved.

Before the incident it focused on diagnosing the underlying problem; afterwards, it focused on reacting to the emergency by going through a standardized checklist to ensure that the core is receiving enough coolant under sufficient pressure.

In addition to the improved operating training, improvements in quality assurance, engineering, operational surveillance and emergency planning have been instituted. Improvements in control room habitability, 'sight lines' to instruments, ambiguous indications and even the placement of 'trouble' tags were made; some trouble tags were covering important instrument indications during the accident. Improved surveillance of critical systems, structures and components required for cooling the plant and mitigating the escape of radionuclides during an emergency were also implemented. In addition, each nuclear site must now have an approved emergency plan to direct the evacuation of the public within a 10-mile emergency planning zone and to facilitate rapid notification and evacuation.

The Many Faces of Error

'*To err is human*' is the title of the Institute of Medicine's Report [7] and it was a famous statement attributed to the famous English writer Alexander Pope (1688–1774)

in his first major poem 'An Essay on Criticism'. 'To forgive divine' is the other half of statement which has been persistently overlooked by all stakeholders of healthcare. Concerning all the implications, we prefer the Latin version of the statement by Lucio Anneo Seneca (4 BC–65 AC) 'Errare humanum est, perseverare autem diabolicum'. But how and why we must 'to not forgive' and 'to not persevere'?

Errors and their nature are the same in all human activities and professions. The predisposition for error is so intrinsic to human behaviour and activity (i.e. human nature) that scientifically it is best considered as inherently biologic, since correct performance and error result from the same mental process [8]. All the available evidence clearly indicates that human errors are random unintended events. Indeed, although we can predict the probability of specific errors by well-established human reliability assessment techniques [9], the actual moment in which an error occurs cannot be predicted.

The behaviourist defines the error as 'the flip side of correct human performance', itself the product of cognitive ability and the level of psychomotor skill, which in professions requiring dexterity and eye-hand coordination (as surgery), determines safe and optimal execution (proficiency). In this context, we can differentiate between 'innate ability or aptitude', which an individual is born with and brings to particular tasks, and 'skill', in execution, which is acquired by training and reinforcement [8].

Errors by humans can come in many forms. They can be *slips*, because an action conducted is not what is intended, or they may be *lapses*, such as memory failures or omissions [10]. *Mistakes* can involve errors in planning, although action may proceed as intended. The situation could have been inadequately assessed, and/or could have involved a lack of knowledge [7].

Errors may or may not have a consequence (when the error translates into an accident or adverse event). The nature of the error is the same irrespective of outcome, no consequence, or consequence (adverse event). It is dependent on chance and on the prevailing circumstances, which are external to the actor and which Reason [10, 11] attributes to latent defects within the system in which one operates [8].

Reason's model of accident causation provides a theoretical framework that dissects the potential aetiology of errors. The theory explains that accidents are caused by:

- **Active failures:** decisions performed by individuals at the delivery end of a system (these errors are immediately discernible).

Fig. 1. Reason's 'Swiss cheese' model of accident causation.

- **Latent failures:** a result of deficiencies in the organizational and management levels of a system (these errors are much harder to detect and may require considerable analysis to discover or understand).

Latent failures predispose a system to error and may result in adverse events if many deficiencies are present within the levels of an organization [12].

Reason's 'Swiss cheese' model as adapted by Wiegmann and Shappell [13] is illustrated in figure 1. This model illustrates that the organizational influence (climate, resource management, and policies) impact supervisory processes (scheduling, training, and oversight), which in turn establish the preconditions (technological and teamwork related) that produce errors [12].

Each 'slice of cheese' is based on one of the four main levels of the Human Factors Analysis Classification System (HFACS) (table 1). The HFACS framework was developed using over 300 naval aviation accidents obtained from the US Naval Safety Center. The original taxonomy has since been refined using input and data from other military (US Army Safety Center and the US Air Force Safety Center) and civilian organizations (National Transportation Safety Board and the Federal Aviation Administration). It has been used within the military, commercial, and general aviation sectors to systematically examine underlying human causal factors and to improve aviation accident investigations [13].

But there are two scenarios when an error does not result in an adverse event:

Table 1. The Human Factors Analysis Classification System (HFACS)

<i>Organizational influences</i>	
Climate	Vision within the organization including aspects of policy, command structure, and culture.
Process	Means by which the vision of an organization is carried out including operations, procedures, and oversight.
Resource management	How human, monetary, and resources necessary to carry out the organizational vision are managed.
<i>Unsafe supervision</i>	
Inadequate supervision	Oversight, management of personnel, and resources, including training, guidance, and leadership.
Problem correction	Instances when deficiencies among individuals, equipment, training, or other safety areas are 'known' to the supervisor, yet allowed to continue.
Inappropriate operations	Management of work, including aspects of risk management, crew pairing, and operational tempo.
<i>Preconditions to unsafe acts</i>	
<i>Environmental factors</i>	
Technological environment	Design of equipment and controls, display-interface characteristics, checklist layouts, task factors, and automation.
Physical environment	The operational setting and the ambient environment, such as heat and lighting.
Adverse mental states	Psychological and (or) mental conditions, such as fatigue, pernicious attitudes, and misplaced motivation, that negatively affect performance.
Adverse physiological states	Medical and/or physiological conditions such as illness, intoxication, and pharmacological or medical abnormalities known to affect performance.
Physical/mental limitations	Physical/mental disabilities, such as poor vision, lack of skill, aptitude, knowledge, and other mental illnesses, that adversely impact performance.
Teamwork	Communication, coordination, and other teamwork issues that impact performance.
Personal readiness	Off-duty activities, such as adhering to rest requirements, alcohol restrictions, and other mandates, required to perform optimally on the job.
<i>Unsafe acts</i>	
Decision errors	'Thinking' errors represent intended behaviour that proceeds as designed, yet the plan proves inadequate for the situation. Errors manifest as poorly executed procedures, improper choices, or simply the misinterpretation of relevant information.
Skill-based errors	Highly practiced behaviour that occurs with little thought. These errors frequently appear as breakdown in visual patterns, forgotten intentions, and omitted items during procedures. The technique with which one performs a task is included.
Perceptual errors	Errors arise when sensory input is degraded. Faced with acting on imperfect or incomplete information, OR staff run the risk of misjudging procedures as well as responding incorrectly to a variety of visual-vestibular illusions.
Routine violations	'Bending the rules.' This type of violation is habitual by nature and often enabled by management that tolerates departures from the rules.
Exceptional violations	Departures from authority, neither typical of the individual nor condoned by management.

- *Near-miss (close call) events*: an error is realized just in the nick of time and abortive action is instituted to cut short its translation.
- *No harm events*: the error is not recognized and the deed is done but fortunately for the actor, the expected adverse event does not occur [8].

But under controlled conditions, errors have a positive effect on learning and are thus important in training and acquisition of skills [14] as the trainee is able to appreciate the cause of the error, how to correct and, more importantly, how to avoid it [8].

This observation was confirmed by a study [15] which compared two trainee groups: error training versus an

error avoidant training. In subsequent testing, the error-training subjects outperformed the error-avoidant group.

The Operating Room: Between Conflicts and Surgical Errors

The causes of error in medical care [7, 16, 17] may not be easily generalized to surgery because these specialties differ in important ways. In particular, most surgical errors occur in the OR [18–20] and are technical in nature [19–21].

The Operating Theatre

The OR has a unique set of team dynamics, as professionals from multiple disciplines, whose training and goals differ widely, are required to work in a closely coordinated fashion. However, this complex environment provides multiple opportunities for unclear communication, clashing motivations, and errors arising not from technical incompetence but from poor interpersonal skills [22, 23].

Indeed, the OR is the most common site in hospitals for adverse events to occur [24], between 47.7% [25] and 50.3% [26] of adverse events affecting surgical patients. At least half of these events may be preventable [27, 28], for example through corrective feedback [29], error recovery [30], and better team skills [31]. The OR is also the classic zone of conflicting goals between the individual practitioners, surgical teams, and the institution [8].

Booij [32] in his review illustrates and explains the factors that can generate conflicts in what he defines as '*operating theatre*'. The fact that people have to work in a team dealing with difficult cases, and that the team consists of people with a strong personality working in a limited space, creates a special atmosphere in the OR. The surgical specialists, the supporting anaesthetists and the nurses have their own expertise and their own professional responsibilities. Therefore they have their own opinions about how to deal with a case and how to solve an existing problem. There are differences in training methodology, the social esteem amongst the specialists is different and there also are differences in personality amongst the people involved. There are differences amongst personnel (physicians vs. nurses) in perception about what is right or wrong, good or bad. All these factors can likely generate conflicts in the OR. Such conflicting situations frequently start with discussions on topics that can essentially be brought back to the following issues:

- Who is responsible for a particular treatment?
- Who decides what to do (what type of anaesthetic, what postoperative treatment, etc.)?
- Who has the last word on the decision to operate or not to operate?
- Who decides whether a new case is started?
- Who decides what the order of the cases is to be?

Very seldom they concern the ability and expertise of an individual team member. These conflicts are so-called 'task conflicts' (*Who, What, When and Why*). Also, the physician members of the team frequently forget that others (nurses, technicians, etc.) are also members of the team and should play their own role.

The atmosphere in an OR can be easily worried, not only temporarily but likely also more permanently. It largely depends on human behaviour and interrelation, and the way team members communicate. Model roles and behaviour drivers of culture are important factors. Thus, leaders should behave correctly as an example of good manners. Disruptive behaviours affect team dynamics and patient outcome [32].

Surgical Error and Surgical Flow Disruption

Commonly, surgical error has been thought of as the consequence of lack of skill or ability, and is the result of thoughtless actions. However, recent work has shown that error is often the result of a mismatch between the work system and the capabilities and limitations of the human doing the work [10, 30].

It is useful for practical purposes to distinguish two broad categories of surgical errors: *proximal* and *distal* (coal face, front line, sharp end). The former relate to the system and process and the latter to the individual practitioners operating within the system (table 2) [8].

In literature we can find many contributes about human factors/errors and medical/surgical practice. Particularly, these studies are conducted in cardiac and cardiovascular surgery, intensive care units, paediatric surgery, anaesthetic practice, transfusion medicine.

Recently, Wiegmann et al. [33] have distinguished between *surgical errors* and *surgical flow disruptions*. Surgical flow disruptions were defined as deviations from the natural progression of an operation, thereby potentially compromising the safety of the operation. Surgical flow disruptions were categorized additionally according to their underlying systemic nature based on previous human factors studies and a broader human factors model [12]. As listed in table 3, these general categories included issues with equipment/technology, extraneous interruptions, problems with teamwork/communication, supervisory/training-related distractions, and resource-based issues [33]. The ability to manage errors and unexpected events successfully during an operation is a marker of surgical excellence [1, 30, 34]. Even experienced surgical teams, however, can become mired by minor problems that disrupt surgical flow. As the number of minor events increase, the surgical team's ability to cope with a major event decreases.

In the study by Wiegmann et al. [33], about 60% of surgical errors were noticed and managed immediately by the surgical team. Of these errors, 32% were events during which the team experienced difficulty performing a specific technique or procedure. The remaining set

Table 2. Classification of errors in a surgical setting [8]

<i>Proximal: Imposed by the system operated by the organization and the process used by the practitioners, resulting in defects relating to:</i>
Coherence and goal conflicts, between organization and individual departments
Poor leadership
Inadequate team work
Inadequate training/continued professional development of staff
Inadequate resource allocation
Unclear protocols briefings and procedures
Lack of evidence-based practice and inadequate information technology for staff
Non-transparent culture
Overwork
Lack of quality assurance measures
Inadequate system for detection of poor performance

<i>Distal (coal face, front line, sharp end): Enacted by surgeons working within the system throughout the perioperative process</i>
Input error (knowledge and perception): the input data are incorrectly perceived, leading to the wrong/inappropriate action
Intention (mind-set) error: although the input data are correctly perceived, an incorrect intention is formed or is not changed as the situation evolves, resulting in the wrong action
Execution (psychomotor) error: both perception of the input data and intention are correct, but the wrong action is performed; subtypes:
Omission: omitting an essential component step in the process
Commission (consequential/inconsequential)

Table 3. List of flow disruption categories for events that were categorized [33]

Category	Example/definition
Teamwork	Issues revolving around communication, team coordination, team familiarity, and team monitoring
Extraneous interruptions	Disruptions occurring during a procedure that did not directly pertain to the treatment of the patient and resulted in disruption of surgical flow
Equipment and technology	Malfunction of technologic equipment or delays secondary to equipment design or performance resulting in surgical delays
Resource-based issues	Failure to progress to the next stage of the operation because of a lack of resources available at the operative table
Supervisory/training-related issues	Failure to progress to the next stage of the operation because of management of personnel, guidance, and training of members of the OR team

of errors that were detected quickly (68%) also tended to have an immediate impact on the patient/operative site. Approximately 40% of the surgical errors were not detected immediately but were recognized and compensated for at a later time during the operation. Disruptions in surgical flow associated with problems in teamwork/communication accounted for the greatest percentage of these events (52%). Generally, these teamwork events clustered around issues of communication, coordination, monitoring and team familiarity. Of the remaining surgical flow disruptions, 17% were caused by external/extraneous interruptions. Twelve percent of surgical flow disruptions were associated with supervisory/training-related distractions. Equipment/technology problems constituted 11% of flow disruptions. Finally, issues of resource accessibility accounted for the remaining 8% of the observed events. Examination of statistical analysis (multiple regression model) indicates that teamwork/communication was the only factor that contributed significantly to the overall model [33].

In conclusion, teamwork and communication issues demonstrated the strongest correlation with technical error, in addition to accounting for the majority (52%) of disruptions [33]. These data also demonstrated the importance of teamwork in the broader context of error management. The teamwork environment plays a role not only in error causation but also in error capture when errors do occur [35].

HFACS: A Human Factors Analysis in Operating Room

ElBardissi et al. [12] have tested the application of the HFACS in cardiovascular surgery (table 1). Skill-based errors were believed to be the most common type of *unsafe acts*. A common theme related was the impact of high staff turnover necessitating recruitment of team members directly out of school or training. The high rate of staff turnover degrades the collective experience in the OR such that educators of new staff are themselves relatively inexperienced.

Routine violations or bending of the rules was the second major area identified (respondents stated that when rushed, they are more prone to bending rules).

Preconditions to unsafe acts as a whole were not excessively frequent. Teamwork issues predominated in this category. Inappropriate communication was thought to occur most often; these issues mainly involved surgeon communication with other team members. Other issues revolved around the surgeon's inability to effectively lead in the OR.

When asked in an open-ended manner to characterize surgeon personality and its impact in the OR environment, 35% of individuals stated that surgeons are arrogant or demeaning, negatively affecting team function, 24% stated that surgeons have a strong or intense personality, also negatively affecting team function, 22% felt that surgeon personality was variable among surgeons (ranging from arrogant or demeaning to strong-to-intense to lackadaisical), 12% stated that surgeons behave in a professional manner positively affecting teamwork.

With regard to teamwork issues, 59% of respondents indicated that a surgeon's personality negatively affects the way members of the OR team function.

Preconditions for unsafe acts had a number of correlations with unsafe acts: as the physical-mental status deteriorates, the tendency to commit skill-based errors, decision-based errors, routine violations, and exceptional violations were thought to increase. Physiologic compromise of an individual by medical illness, medication side effects, or other means was thought to contribute to committing skill-based errors and decision-based errors. Compromise of teamwork was also thought to make individual members more prone to decision-based errors, skill-based errors, perceptual errors, and routine violations.

In the category *unsafe supervision*, the subcategory 'planning' has ulteriorly investigated: OR staff performing too many jobs at once, ORs overbooked, OR team

members working excessive amounts of overtime, and continually pairing of OR team members despite known conflicts. Respondents also indicated that while excessive overtime hours and overbooked ORs were significant problems 5–10 years ago, there are still issues that have not been completely eradicated. While there is usually a critical mass of scheduled staff members and available ORs to meet demand, situations frequently occur when surgeons underestimate the duration of an uncomplicated procedure and occupy ORs to a greater degree than expected. These situations consume staff members for longer than anticipated, resulting in longer work hours and surgery start times pushed back late into the evening.

Interpersonal conflicts, which constituted the biggest problem area in inappropriate planning, occur when OR team members are broken off from the team with whom they regularly work. Conflicts originate when surgeons have expectations of these staff members regarding intricacies of OR decorum that vary from surgeon to surgeon. When conflicts do occur because of misunderstandings regarding surgeon preferences, frustration on behalf of the surgeon and OR team member occur. Additionally, occasions exist when poor chemistry occurs during the initial contact between a team member and a surgeon, tainting any further operative experience they may share together in the future. Deficiencies in the ability of management to perform adequate planning (management and assignment of work including risk management, crew pairing, and operational tempo) negatively affect physical-mental status, personal readiness, and teamwork. When there are deficiencies in problem correction (deficiencies among individuals, equipment, training, or other areas that are 'known' to the supervisor yet are allowed to continue uncorrected) physical-mental status, personal readiness, and teamwork were perceived as being negatively effected.

Between *organizational influences*, failures in resource management and organizational process occurred more frequently than organizational climate. Issues with resource management were thought to be due to staff turnover, a lack of appropriate staff, and a lack of staff with proper education or training. Statistical analysis revealed that the perception of deficiencies in organizational process (the process by which the vision of an organization is carried out including operations, procedures, and oversight) was found to negatively affect the ability of management to correct known problems (problem correction) and plan effectively (the ability to manage and assign work). Deficiencies in organizational resource manage-

ment (how human, monetary, and equipment resources carry out the vision of the organization) were believed to negatively affect the ability of management to correct known problems (problem correction) and manage personnel and resources (supervision).

The Cycle of Human Factors

In conclusion, the goals of human factors are accomplished through several procedures in human factors cycle, which depicts the human operator (brain and body) and the system with which he or she is interacting. Firstly, it is necessary to diagnose or identify the problems and deficiencies in the human-system interaction of an existing system. After defining the problems there are five different approaches that can be approached to in order to implement the solution.

In general, there are as follows:

- *Equipment design*: changes the nature of the physical equipment with which humans work.
- *Task design*: focuses more on changing what operators do than on changing the devices they use. This may involve assigning part of tasks to automated components.
- *Environmental design*: implements changes in the physical environment where the task is carried out.
- *Training the individuals*: better preparing the worker for the conditions that he or she will encounter in the job environment by teaching and practicing the necessary physical or mental skills.
- *Selection of individuals*: is a technique that recognizes the individual differences across humans in almost every physical and mental dimension that is relevant for good system performance. Such a performance can be optimized by selecting operators who possess the best profile of characteristics for the job.

Recently in the literature strategies to improve surgical practice have been proposed, including a preoperative briefing, restructuring of the method of staffing surgical teams, standardized intraoperative communication, and a postoperative debriefing [36].

Preoperative briefings have been shown to increase team satisfaction [37, 38], patient safety [37], and safety climate [39] while decreasing the frequency of nursing turnover [38] and wrong-site surgery [37]. The importance of this intervention has recently been highlighted by the World Health Organization's Safer Surgery Project – a global effort which uses a basic intraoperative checklist as a mechanism to improve surgical outcomes

in various surgical subspecialties [40]. The surgical team should obtain familiarity with the operating surgeon, particularly in complex or unusual cases. In many settings there is an informal ad hoc means of accomplishing this, with teams self-selecting to the case/surgeons in which they feel most comfortable. By implementing a standardized communication pattern where the speaker's message is repeated by the recipient (speak-repeat, read-repeat, etc.), the communicator creates a closed-loop communication model where both parties are acutely aware of the status of the message. Standardized language has also long been used in high-risk industries to prevent the occurrence of communication mishaps; this analysis further emphasizes its applicability to the OR setting.

Concerning postoperative debriefing, it can be a potentially powerful component of this process. In a postoperative debriefing the surgical team can reflect on the surgical case, discussing positive and negative aspects that might benefit from modification or reintervention. It may simply consist of a brief discussion, assuming that an environment of psychological safety has been created. Any recommendations that result from this debriefing should then be implemented into the preoperative briefing and/or operative setting. By creating a dynamic process, surgical teams gain the ability to identify and correct their short comings as well recognize their strengths.

This study [36] and others [41] found that teamwork was critically important to the capture and compensation of errors, a finding which may not be intuitive to those without formal training. Thus, once stable teams, standardized communication methods, and effective briefings have been developed, a process of formal training and education in human factors and human error should be instituted. If surgical teams are carefully selected, this training and process change will provide teams with the knowledge and environment that will facilitate the breakdown of the hierarchical structure that currently impedes the development of effective patient safety programs [36].

Clinicians have to work closely with human factors specialists in future studies. By improving processes already in place in many operating theatres, safety will be enhanced and quality increased.

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