Clinical review

Non-technical skills for surgeons in the operating room: A review of the literature

S. Yule, PhD,[a] **R. Flin, PhD,**[a] **S. Paterson-Brown, FRCS,**[b] *and* **N. Maran, FRCA,**[c] *Aberdeen and Edinburgh, Scotland*

Background. *This review examines the surgical and psychological literature on surgeons' intraoperative non-technical skills. These are the critical cognitive and interpersonal skills that complement surgeons' technical abilities. The objectives of this paper are (1) to identify the non-technical skills required by surgeons in the operating room and (2) assess the behavioral marker systems that have been developed for rating surgeons' non-technical skills.*

Methods. *A literature search was conducted against a set of inclusion criteria. Databases searched included BioMed Central, Medline, EDINA BIOSIS, Web-of-Knowledge, PsychLit, and ScienceDirect.*

Results. *A number of "core" categories of non-technical skills were identified from 4 sources of data: questionnaire and interview studies, observational studies, adverse event analyses, and the surgical education/competence assessment literature. The main skill categories were communication, teamwork, leadership, and decision making. The existing frameworks used to measure surgeons' non-technical skills were found to be deficient in terms of either their psychometric properties or suitability for rating the full range of skills in individual surgeons.*

Conclusions. *Further work is required to develop a valid taxonomy of individual surgeons' non-technical skills for training and feedback. (Surgery 2006;139:140-9.)*

From the School of Psychology, University of Aberdeen,[a] *and the Departments of Surgery*[b] *and Anaesthesia,*[c] *Royal Infirmary, Edinburgh*

ANALYSES of adverse events in health care[1,2] have found that many underlying causes originate from failures in non-technical aspects of performance rather than a lack of technical expertise. In a recent study, communication was found to be a causal factor in 43% of errors made in surgery.[3] Another study reports that 27% of claims against a health care organization resulted from cognitive and diagnostic errors in the operating room.[4] These findings support the argument that technical skills are necessary but not sufficient to maintain high levels of performance over time. To achieve and maintain high surgical performance, attention needs to be paid to non-technical skills such as team working, leadership, situation awareness, decision making, task management, and communication. These skills are trained in crew resource management (CRM) courses[5] in anaesthesia,[6] civil aviation,[7] oil exploration,[8] and nuclear power but have not yet been taken seriously in surgery. Whereas these competencies have been discussed by surgeons,[9] and the need to address team working has been identified by governing bodies[10] as well as the Royal College of Surgeons of Great Britain and Ireland,[11] surgical education has focused traditionally on developing knowledge, clinical expertise, and technical skills. Aspects of performance such as decision making, leadership, and team working have not been addressed explicitly in training but have been developed in a more informal and tacit manner.[12] This is surprising, given the impact of non-technical skills on patient safety.

Behavioral marker systems are used to structure training and evaluation of non-technical skills

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Reprint requests: Steven Yule, PhD, School of Psychology, King's College, University of Aberdeen AB24 2UB, United Kingdom. E-mail: s.j.yule@abdn.ac.uk.

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in high-demand professions.[13,14] These marker systems are based on skills taxonomies and are used to identify and rate "observable, non-technical behaviours that contribute to superior or substandard performance."[15] Behavioral maker systems are context specific and must be developed for the domain in which they are to be used. For effective non-technical skills assessment, the system needs to be explicit, transparent, reliable, and valid. For example, the taxonomies developed for pilots[7] and anaesthetists[16] have been developed systematically and subjected to experimental and practical evaluation.

The General Medical Council (GMC) is considering introducing licences to practice, supported by periodic revalidation of all doctors in the United Kingdom (including surgeons). The revalidation will be based on the core content of the Good Medical Practice document.[17] Good medical practice includes communication skills, teamwork, and leadership. With the long-term aim of developing training in these areas for surgeons, the objective of the current review is to (1) identify the non-technical skills required by surgeons in the operating room and (2) assess the behavioral marker systems that have been developed for rating surgeons' non-technical skills.

MATERIAL AND METHODS

The literature search was carried out by consulting a number of different sources:

- Databases and University library catalogues, including BioMed Central, Medline, Web-of-Knowledge, EDINA BIOSIS, PsychLit, and ScienceDirect.
- Proceedings from recent applied health care, psychology, and human factors conferences.
- The Library of the Royal College of Surgeons of Edinburgh.
- Bibliographies from relevant research articles and book chapters.
- Previous research on non-technical skills in aviation, nuclear power, and anaesthesia.
- Search of key journals: eg, *Surgery, Annals of Surgery, British Journal of Surgery, British Medical Journal, Human Factors, Quality and Safety in Healthcare,* and *Safety Science.*

The following search terms were used: *non-technical/skills/surgeon/surgeons/surgical/communication/decision making/leadership. cognitive/training/trainees/operating theatre/Protein levels of proinflammatory cytokines and chemokines in BALF. assessment/competence/error/CRM/risk/patient. safety/behaviour/behavioural markers/simulation/medicine/medical.* The criteria for inclusion in this review were (1) addresses surgeons' non-technical skills (trainee or consultant), (2) based on intraoperative environment, and (3) published in English. This review is subdivided by the following sources:

i. Questionnaire and interview studies with surgeons
ii. Observational studies of surgeons (in-vivo, videotaped, simulated)
iii. Surgical adverse event analyses
iv. Surgical education, training and competence assessment

RESULTS

Questionnaire and interview studies. *The Surgical Team Assessment Record (STAR)*: The STAR questionnaire was designed to study the role of human factors in surgical outcomes[18] and measure the organizational, situational, team, and personal factors thought to contribute to surgical performance. Questions on team factors cover dealing with unexpected events, communication between theater teams, preoperative briefings, confidence in other team members' abilities, and the level of harmony or disharmony among team members. Personal factors include technical skill, mental preparedness, and keeping pace with events. This questionnaire was used by de Leval et al[18] to collect postoperative rating data from all cardiac theater staff involved in 243 neonatal arterial switch operations. Logistic regression analysis found the ratings of these factors did not significantly predict surgical outcomes. However, because the psychometric properties of the rating form did not appear to have been assessed, and staff did not appear to have been trained to make such judgements, the reliability of their ratings is open to question.

The Operating Room Management Attitudes Questionnaire (ORMAQ): The ORMAQ[19] is a survey instrument that measures the attitudes of operating theatre personnel toward safety, error, teamwork, leadership, and authority. Helmreich and Schaefer[20] analyzed ORMAQ data from 53 surgeons, 45 anaesthetists, and 54 theatre nurses in a European hospital. There was general agreement that communication and coordination were as important as technical proficiency for safety and efficiency in the operating theater. Surgeons (and nurses) were more supportive of a culture in which junior members of staff do not question the decisions made by senior staff members, and surgeons were less accepting than anaesthetists that a preoperative briefing was important for teamworking. In related research, cross-department planning and debrief meetings for individual cases were associated with improved team coordination and

Table I. Non-technical skills for surgical trainees identified by Baldwin et al[26] and tested for feasibility by Paisley et al[63]

Skills	*Median weighting*
Teamwork	
Seeks advice when beyond limits of confidence	4
Can be trusted to carry out instructions	4
Able to communicate clearly with other staff members	3
Accepts feedback on own performance	3
Can keep to time	3
Understands other staff members' points of view	3
Delegates to others when appropriate	3
Aware of the role of other specialities	3
Able to offer constructive criticism to others	3
Can cope with unreasonable colleagues	2
Other non-technical skills	
Reviews diagnosis and management regularly	3
Adapts quickly if problems in operating/management arise	3
Knows when not to intervene	3
Decides quickly in an emergency	3
Can improvise where necessary	3

faster learning rates in an analysis of the implementation of a new cardiac procedure in 16 different hospitals.[21]

Another ORMAQ study of theater staff in 2 hospitals[22] (locations not specified), found that surgeons generally advocated a structured hierarchy of authority (anaesthetists and nurses valued a flatter team hierarchy). Surgeons were also reluctant to recognize personal vulnerability to stress. Similar results are reported by Sexton et al[23] who analyzed ORMAQ data from 851 surgical and anaesthetic consultants, nurses, and residents in 12 teaching and nonteaching hospitals in the United States and Europe. Surgeons were more confident about their ability to perform well when fatigued than surgical trainees, anaesthetic consultants, or theater nurses. Consultant surgeons were also more in favor of a strict hierarchy in the operating room and less likely to encourage junior team members to question the decisions made by more senior team members (ie, consultants). These results are in contrast to those presented by Edmondson[24] who found that the ability to speak up in the operating room was crucial to the successful implementation of new technology in cardiac surgery. She found that the most effective leaders minimized power and status differences rather than endorsed them.

In the study by Sexton et al,[23] both consultant and trainee surgeons rated the quality of teamworking with anaesthetic staff highly (62%). This was in contrast to the 41% of anaesthetic staff who rated teamworking with their surgical colleagues highly. Corroborating evidence for this mismatch is provided in an ORMAQ study of anaesthetists (n = 222) in Scottish hospitals[25] where anaesthetists rated the quality of teamwork with surgeons as lower than that with other theater personnel.

Surgeons' opinions of critical surgical skills: Many studies have used opinions of subject matter experts (senior surgeons) to identify the skills required by good surgeons. Some of these form the basis for assessment tools. The elements incorporated in the Edinburgh Basic Surgical Training Assessment Form (EBSTAF) were based on a survey of consultant surgeons[26] who identified 5 domains of skill required for surgeons: (1) technical skills, (2) clinical skills, (3) communication with patients and relatives, (4) teamwork skills, and (5) application of knowledge. A delphi technique was used to rank each skill within the 5 domains on a 4-point scale, from (4) "absolutely essential," to (1) "irrelevant." Table I lists the teamwork skills that were identified. Two of these (seeking advice and trusted to carry out instructions) were deemed "absolutely essential" and were regarded often as more important than technical skills. Other skills listed relate to communication and maintaining situation awareness as well as monitoring the performance of self and others and managing workload and time (Table I).

Cuschieri et al[27] conducted a survey of 58 "master" surgeons' opinions of surgical trainees. More than 70% agreed that the top 3 attributes for trainee surgeons were (1) cognitive ability, (2) innate dexterity, and (3) personality. The dominant view among master surgeons was that the impact of cognitive ability and personality traits (ie, nontechnical skills) on eventual operative technical competence was less important than dexterity (ie, technical skill).

Analysis from a similar interview study with 33 Canadian surgeons[28] found that 49% of the sample rated mental skills as most important in surgery, compared with 41% technical and 10% physical. This study also found several emerging themes related to mental preparation in the operating theater, including commitment, self-belief, positive imagery, mental readiness, and distraction

control. Surgeons in all specialities also reported significantly lower levels of readiness (particularly mental readiness) before unsuccessful operations. Other surgeons have endorsed these views, for example, Youngson[29] recognized the importance of communication skills and cognitive ability such as decision making in surgical performance but conceded that the craft aspect of surgical competence receives "heavy emphasis" and "decision-making, as an entity in its own right, is poorly tutored."

Observational studies of surgeons. *Observations of actual operations—in vivo*: de Leval et al[18] observed 243 neonatal arterial switch operations performed by 21 cardiac surgeons in 16 UK centers. On the basis of this research and studies of excellence in surgery,[28,30] Carthey et al[31] developed a "framework of the individual, team and organisational factors that underpin excellence in paediatric surgery." Non-technical skills were rated in their taxonomy at the individual (surgeon) level, in addition to "technical" skill (Table II). Leadership, communication, and coordination were listed as team level behavioral markers.

This framework was used by Carthey et al[32] to rate the behavior of 16 surgeons (from the original sample) during 166 operations. Logistic regression models were run to provide "procedural excellence scores" using 2 outcomes: probability of death and the probability of death or near miss. Although no statistical analyses were carried out, they examined the behavioral marker scores to explain differences in case outcome (surgical excellence). For example, 3 of 4 surgeons who were rated highly on all of the individual markers experienced no "uncompensated major events" (errors leading to the event that were not recovered). On the basis of these finding, the authors argue that behavioral markers can be used to explain differences in performance between cardiac surgery teams.

Surgical team behavior during "live" operations in the United States was studied by Roth et al.[33] In this study, a surgeon and a human factors engineer each took notes about communications, information flow, and task execution during 10 complex intestinal tract or liver operations. These notes were analyzed to reveal system strengths and vulnerabilities, adverse events, near misses, and compensation strategies. This revealed several non-technical issues, such as cognitive and collaborative demands of surgeons (ie, competing tasks), adaptive strategies, conflicting goals, and discipline-spanning goals. A structured method of observing performance in theater was not used; this study focused instead on descriptions of behavior to uncover emerging themes.

Table II. Individual level behavioral markers of surgical excellence

Mental readiness
Cognitive flexibility (ability to switch between strategies/hypotheses)
Anticipation (of problem before they get out of control)
Team adaptation (reaction to changes in the team)
Safety awareness (how the surgeon handles various safety related goals)
Situational awareness
Communication style

Reprinted with permission from Carthey et al.[32]

Helmreich and Schaefer[20] observed operations in a European teaching hospital using 9 categories of "specific behaviours that can be evaluated in terms of their presence or absence and quality… that are essential for safe and efficient function." Using this behavior categorization (Table III) for the observations, they identified a number of instances of error relating to inadequate teamwork, failures in preparation, briefings, communication, and workload distribution. As this did not provide a quantitative database against which to measure interventions such as training. Helmreich et al.[34] designed the Operating Room Checklist (ORCL), which was based on a behavioral marker system from aviation[15,35] and consisted of a list of behavior categories with rating scales that could be used to assess the non-technical performance of operating teams. The ORCL system was principally designed to measure team behaviors rather than to rate the non-technical skills of individual surgeons, and there do not appear to be any published reports on its use as a teaching or research tool.

The Observational Teamwork Assessment for Surgery tool (OTAS) was used by Healey et al[36] to observe 3 phases of surgery: pre-, intra-, and postoperative. The OTAS is a measure of team rather than individual performance in surgery and is based on a generalized model of teamwork.[37] It incorporates concurrent observation of task completion and teamwork by 2 independent raters, a similar method to that used by Roth et al.[33] Teamwork was assessed using 7-point behavioral observation scales that cover cooperation, leadership, coordination, awareness, and communication for relevant roles in the theater. After taking notes on task-related behaviors, the observer provided ratings for the "overall impression of team behaviour" in each phase. Preliminary results from a sample of 50 general cases indicate that behavior ratings differ for each scale and that a potential relationship exists between coordination and communication.

Table III. Errors observed in operating theaters classified by behavior category

Behavior category	*Error*
Communications/decisions	Surgeon's failure to inform anaesthetist
Preparation/planning/vigilance	Failure to anticipate events during complex procedure
	Failure to monitor other team activities
Workload distribution/distraction avoidance	Consultant distracted from making a decision by problems reported from another operating theatre
Briefings	Failure to brief own team
Inquiry/assertion/advocacy	Failure to discuss alternative procedure
Interpersonal relationships/group climate	Hostility and frustrations owing to poor team coordination
Team self-critique	Failure to debrief operation to learn from situation
Leadership/followership/concern for tasks	Failure to establish leadership for operating room team
Conflict resolution	Unresolved conflicts between surgical team and anaesthetists

Reprinted with permission from Helmreich and Schaefer.[20]

However, no formal statistical analyses have been published, and the authors acknowledge that establishing the validity of such an assessment of surgical team performance is a "substantial undertaking."[36]

Observations of actual operations—from videotape: Using video recording to conduct behavioral analysis is ideally suited to complex domains because events involving dynamic decision making and teamwork can be replayed to analyze the full range of behaviors. Medical videotaped studies to date focus on trauma teams[38] or anaesthetic procedures.[39] Probably because of current ethical and legal constraints, there seem to be very few centers videotaping surgical operations and using these for non-technical skills analysis. In one study, Dominguez[40] interviewed 20 surgeons asked to role-play as the supervising surgeon for the case, as they watched a videotape of a "challenging" laparoscopic gallbladder removal. This revealed particular cognitive skills relating to risk assessment, anticipation, prediction of difficulty, and decisions about possible actions.

Observations of simulated operations: Simulation studies with electronic manikins are more common in anaesthesia than in surgery for both training[41] and assessment.[42] However, simulators have been used with surgical teams, such as the Team-Oriented Medical Simulation which incorporated both a computer-controlled anaesthetic mannequin and a laparoscopic simulator.[43] This affords increased integration of training for surgeons and anaesthetists.[44] Lower-fidelity forms of simulation such as computer-based tasks have been used to test and train cognitive skills in surgeons. In one such study, a simulation with 6 30-minute decision tasks was run with 15 surgical residents who each had at least 2 years' experience.[45] The scenarios were apparently well validated, challenging, and standardized. The computer provided performance measures, such as response speed. Expert assessments of each surgeon's skills were made on an assessment form by 3 faculty members most familiar with the clinical performance of the participant. A number of non-technical skills (list derived by the researchers, Table IV) were assessed along with aspects of technical proficiency, and both "objective" simulation measures and "subjective" expert judgements. Satish et al[45] reported that computer task scores correlated significantly with the expert ratings. On the basis of these findings, they argued that the role of critical thinking in surgery should be enhanced as it is "of equal, if not greater, significance" than factual and problem-solving abilities and is particularly relevant to dealing with complex and unanticipated medical scenarios.

There are several studies that focus on the use of virtual reality (VR) simulators with surgeons, although they focus mainly on using this technology to improve technical proficiency.[46] However, cognitive skills, such as planning and decision making, can be incorporated into the technical training of a surgeon using VR simulators.[47]

The limited evidence from observational studies indicates that non-technical skills constitute a critical component of surgical competence. Breakdowns in teamworking and communication (especially with anaesthetists), lack of situation awareness, and flawed decision making can lead to poor outcomes for patients.[18,20] Conversely, effective surgeons can be seen to demonstrate their non-technical skills as an integral part of their expertise.[31]

Adverse event analysis. *Incident reporting in surgery*: The systematic analysis of near misses, incidents, and accidents is an essential diagnostic process for safety management in industry.[48] The current adverse event reporting regimes in surgery

do not capture failures in non-technical skills as well as they do in other industries. In the United Kingdom, there are 2 main audits that monitor deaths associated with surgery, the National Confidential Enquiry into Perioperative Deaths (NCEPOD), and the Scottish Audit of Surgical Mortality (SASM).[49] The nature of data fed back to individual hospitals and in case assessments highlights that SASM is strong on providing technical feedback and on reporting the proximal causes of error but provides relatively little in the way of human factors information and limited insight into non-technical skills in surgery. There are 2 likely causes: (1) the forms used to collect data do not adequately capture human factors or non-technical contributions to incidents and (2) the coding framework used to analyze the incident reports does not adequately deal with non-technical skills. These conditions explain the current technical (ie, what happened) bias in published audit reports in favor of non-technical (ie, why it happened) causes of adverse events.

Studies of medical error: Several methods have been used to identify the human factor causes of medical error, including task analysis,[50] focus groups[51], and human reliability analysis of operations.[52] Such studies of adverse events commonly cite failure of teamworking and communication in the etiology of medical incidents.[53] From an interview study in the United States, Gawande et al[3] report that 43% of adverse events in surgery occured as a result of breakdowns in communication. Sheridan et al[54] also explored the inherent complexity of surgery and identified 2 factors that appear to be most pertinent to non-technical skills causes of error: individual factors (eg, judgment, risk-aversion, risk tolerance, stress, fatigue), and team factors (eg, prior team history, experience working as a team, communication, coordination).

Reduction of error in medicine may be achieved by improvements in medical education, although the changes required may need to address deep-seated attitudes of denial and collusion regarding error in medicine.[55,56] There is also growing acknowledgement of the importance of instituting early human factors training into undergraduate curricula.[57]

The studies of adverse events and errors have not yet provided a rich database for the identification of surgeons' non-technical skills, principally because of a historical lack of attention to the nonclinical causes of outcome. This appears to be altering with the renewed emphasis on the need to understand human error across the medical profession.

Table IV. Non-technical skills assessed in SMS

Non-technical skills assessed	*Method of assessment*
Initiative	Simulator and expert
Information seeking	Simulator
Information utilization	Simulator
Emergency responses	Simulator
Use of strategy	Simulator
Response to immediate context	Simulator
Response to broad context	Simulator
Flexibility in thinking	Simulator
Motivation	Expert
Sustained efforts to optimize patient outcomes	Expert
Critical thinking	Expert
Flexibility of approach	Expert
Communication with team members	Expert
Use of information	Expert
Sensitivity to changes in patient condition	Expert

Adapted from Satish et al.[45]

Surgical education, training, and competence assessment. Current assessment formats for surgical trainees test core knowledge and technical skills. However, in doing so, they may also underemphasize some important domains, including interpersonal skills, professionalism, and integration of core knowledge and non-technical skills into clinical practice.[58] Competence assessment systems have been developed such as the Objective Structured Clinical Examination[59] (OSCE) and the Objective Structured Assessment of Technical Skills,[60] (OSATS) although these currently focus on technical skills. Newble and Southgate[61] provide a set of literature-based guidelines for "high stakes" assessment for certification of consultant surgeons, but they do not consider assessment of non-technical skills. Notwithstanding considerable attention to technical competence, Sidhu et al[62] recently argued that "despite its importance to surgeons, technical competence has historically been assessed poorly and continues to receive little attention among the core competencies defined by CanMEDS and the ACGME [Accreditation Council for Graduate Medical Education]." Despite this assertion, the ACGME has recently established 6 competencies for resident and fellow development. These include technical and non-technical skills including patient care, medical knowledge, practice-base learning, interpersonal and communication skills, and systems-based practice.

The BST assessment form was the first standardized method of assessing the overall surgical

Table V. Main categories of surgeons' non-technical skills identified in this review

Identified non-technical skills	*Source*			
	Questionnaire/interview	*Observation*	*Adverse events*	*Medical education*
Interpersonal skills				
Communication	✓	✓	✓	✓
Leadership	✓	✓		✓
Teamwork	✓	✓	✓	✓
Briefing/planning/preparation		✓	✓	
Resource management	✓	✓		
Seeking advice and feedback	✓			
Coping with pressure/stress/fatigue	✓		✓	
Cognitive skills				
Situation awareness	✓			
Mental readiness	✓			
Assessing risks		✓		
Anticipating problems		✓		
Decision making	✓	✓		✓
Adaptive strategies/flexibility		✓		
Workload distribution	✓	✓		

competence of trainees and was developed in Edinburgh as discussed previously.[26] It has been tested successfully for feasibility (by response rate), reliability (by test–retest and internal consistency), and construct validity (by determining improvement after 1 year of training) in a sample of 36 UK trainee surgeons.[63] Recent analysis found the BST to have an acceptable level of concurrent validity.[64]

Galasko[65] suggests a theoretically derived set of competencies for surgeons necessary for a Certificate of Completion of Specialist Training. These include communication with members of the surgical team, decision making, judgment, teaching, teamworking, analytic skills, and management skills. In the United Kingdom, the Joint Committee on Higher Surgical Training currently assesses SpR trainees' judgment, teamworking, leadership, and communication, and is developing a new curriculum for standards-based training for higher surgical competence (www.jchst.org). The greatest challenge in developing non-technical training in surgery is to identify explicitly the skills that are necessary for good practice and hence the skills that should be trained.

DISCUSSION

This review attempted to identify surgeons' non-technical skills from the surgical and psychological literature and then establish whether there was a valid and reliable taxonomy and associated behavioral marker system available for the assessment of surgeons' non-technical skills.

Identified non-technical skills. This review provides an emerging set of core skills, and the sources consulted offered slightly different perspectives on which non-technical skills are most important in surgery. The most commonly studied skill categories were communication, leadership, teamworking, and decision making. Table V lists the core skills, cross-referenced with the sources in which they were identified. Whereas the evidence gathered has confirmed the importance of non-technical skills in surgery, very few studies attempted to decompose these major skill categories (eg, decision making) into their component behavioral elements.

One of the reasons for the lack of emphasis on non-technical skills in surgery may be that tacit skills are not easily identified by traditional task analysis techniques (such as observation and direct questioning), because they form the basis of expertise and are difficult to verbalize.[66] Techniques such as cognitive task analysis[67] are more subtle and have been used successfully in a recent project to identify the non-technical skills required by anaesthetists.[16] This technique involves identifying the key cognitive skills and resources required to complete tasks, often by using a structured interview to probe goal generation, decision making, and expert judgements. Structured qualitative analyses have been used also to examine different perspectives of team communication in the operating theatre.[68]

Assessment of existing behavioral maker systems. Five complete or partial taxonomies of surgeons' non-technical skills were identified in the

literature (Baldwin et al,[26] Carthey et al,[31,32] Helmreich et al,[34] Healey et al,[36] Satish et al[45]). Research in other acute domains (eg, anaesthesia, civil aviation) has established design criteria for the development of behavioral rating systems, stipulating that they should comprise specific, observable behaviors that are well defined and contribute to superior or substandard performance; be parsimonious but encompass the most important behaviors; use domain-specific language and terminology; and be explicit, transparent, valid, and reliable. Additionally, the skills and behavioral markers should either be directly observable in the case of social skills or inferred from observing communication or other behaviors in the case of the cognitive skills.[15,69,70] The frameworks developed for surgery are assessed against these criteria in this section.

In general, these frameworks appear to be developed on the basis of surgeons' opinions with a relative lack of supporting empirical work. The systems are parsimonious and use domain-specific terminology; however, most are at an early stage of evolution or cover only a subset of non-technical skills.[31,32,34,36] The relative lack of conceptual clarity, psychometric evaluation, and user training with these frameworks may be the cause of mixed results when ratings are run against surgical outcomes.[18,32] The BST system developed by Baldwin et al[26] offers arguably the best-developed taxonomy of technical as well as some non-technical skills, and the assessment form that accompanies it appears to have acceptable psychometric properties.[63,64] However, this has been developed for trainees rather than qualified surgeons; hence, the predictive power of this tool has not yet been established in terms of its ability to discriminate the competent from the incompetent surgeon. The study by Satish et al[45] is able to do this but concentrates on cognitive skills in simulated computer-based scenarios rather than behaviors in the operating room.

This review has failed to identify an adequate behavioral marker system for rating the full range of surgeons' non-technical skills, but synthesising the results from the literature reviewed in the current report allows us to propose a draft taxonomy. This is presented in Table VI and will be used as a basis for further development in this field, a strategy for which is outlined in the following section.

Table VI. Proposed draft non-technical skills taxonomy

Interpersonal skills	*Cognitive skills*
Communication	Situation awareness
Leadership	Mental readiness
Teamwork	Assessing risks
Briefing/planning/ preparation	Anticipating problems
Resource management	Decision making
Seeking advice and feedback	Adaptive strategies/flexibility
Coping with pressure/ stress/fatigue	Workload distribution

CONCLUSIONS AND STRATEGY FOR FURTHER RESEARCH

The current state of assessment of surgeons' non-technical skills is in its infancy. Although imperfect, the studies reviewed here have sought to identify, develop, and rate surgeons' non-technical skills and established important groundwork in this field. Because the systems assessed in this review do not conform to the suggested criteria for behavioral marker systems, a project sponsored by the Royal College of Surgeons of Edinburgh and NHS Education for Scotland (NES) is now underway to identify the non-technical skills necessary for good intraoperative surgical practice and to develop a behavioral marker system to support surgical training[71] (http://www.abdn.ac.uk/iprc/notss). This work is a cross-disciplinary collaboration between surgeons and psychologists, in conjunction with anesthetists from the Scottish Clinical Simulation Centre who are developing non-technical skills training. This project has been designed explicitly to concentrate on the development of the system and to establish its psychometric properties before it is used in theater to rate and provide feedback on performance. The system is being developed in accordance with a 3-phase model of systems design,[72] which emphasizes (1) task analysis, (2) iterative development, and (3) evaluation. Five methods of data collection are being used in phase 1, including this literature review, analysis of theater personnel attitudes to teamwork and safety, cognitive interviews with consultant surgeons and theater nurses, observations in the operating room, and analyses of adverse events. In phase 2, the system will be developed by independent panels of surgeons using an iterative process. The reliability of the rating system will be tested using standardized scenarios filmed in the operating room and operating room simulator.

The output from this research will be a taxonomy of surgeons' non-technical skills with an associated behavioral marker system and training package on how to use the system. The system will be structured into category and element levels. Observable behaviors (markers) indicative of good and poor

performance will be developed for each element. Once a skills taxonomy and behavioral marker system have been developed, and their validity and reliability established, they can be used as the basis for syllabus development, design of course materials debriefing and as a formative assessment tool for evaluating surgeons' non-technical skills.

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