Training Tools for Nontechnical Skills for Surgeons—A Systematic Review

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OBJECTIVE: Development of nontechnical skills for surgeons has been recognized as an important factor in surgical care. Training tools for this specific domain are being created and validated to maximize the surgeon's nontechnical ability. This systematic review aims to outline, address, and recommend these training tools.

DESIGN: A full and comprehensive literature search, using a systematic format, was performed on ScienceDirect and PubMed, with data extraction occurring in line with specified inclusion criteria.

SETTING: Systematic review was performed fully at King's College London.

RESULTS: A total of 84 heterogeneous articles were used in this review. Further, 23 training tools including scoring systems, training programs, and mixtures of the two for a range of specialities were identified in the literature. Most can be applied to surgery overall, although some tools target specific specialities (such as neurosurgery). Interrater reliability, construct, content, and face validation statuses were variable according to the specific tool in question.

CONCLUSIONS: Study results pertaining to nontechnical skill training tools have thus far been universally positive, but further studies are required for those more recently developed and less extensively used tools. Recommendations can be made for individual training tools based on their level of validation and for their target audience. Based on the number of studies performed and their status of validity, NOTSS and Oxford NOTECHS II can be considered the gold standard for individual- and team-based nontechnical skills training, respectively, especially when used in conjunction with a training program. (J Surg Ed 74:548-578. © 2017 Association of Program Directors in Surgery. Published by Elsevier Inc. All rights reserved.)

KEY WORDS: training, tools, nontechnical, skills, surgery, surgeons

COMPETENCIES: Patient Care, Medical Knowledge, Practice-Based Learning and Improvement, Interpersonal and Communication Skills, Professionalism, Systems-Based Practice

INTRODUCTION

Modern surgery no longer depends entirely on a surgeon's technical prowess.[1] Alongside technical surgical ability, nontechnical skills are fast becoming recognized as major factors in surgical outcome.[2] A study from 2003 identified that 86% of adverse surgical events were due to "system errors" and were not related to technical skills.[3] Overall, 40% of intraoperative errors were found to relate to failures in communication alone.[3] Furthermore, important nontechnical skills identified include teamwork, leadership, situational awareness, and decision-making[4]; all of which have been shown to have a significant effect on surgical success.[3]

Situational awareness involves the surgeon's perception of surrounding events relating to the team and the operation itself. Decision-making involves the surgeon's ability to choose, implement, and communicate the most appropriate solution when faced with a potential problem.[4] Teamwork skills include being entrusted to implement instructions and engage in effective communication with colleagues to achieve a particular goal.[4,5] Leadership skills involve professionalism, motivation, and setting a suitable example.[5] Communication skills involve the transmission and receiving of information in a manner which can be understood.[5]

The safe and effective surgeon identifies nontechnical skills as an ability set that is not necessarily innate, but can be trained and improved throughout their career.[2] As modern surgeons

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face restrictions in working hours, experience alone can no longer be relied upon to allow these skills to reach their full potential.[6] Training tools allow modern surgeons to recognize, develop, and maximize their nontechnical abilities, without necessarily having to spend more time in the operating theater. The common aim of all current nontechnical skill training tools is to improve safety in the surgical setting, while maximizing the surgical benefits that patients receive.

Aims

The primary outcomes of this systematic review are as follows:

(1) Provide up-to-date details of the training tools currently available and comment on their status of validity.
(2) Offer a recommendation for the prominent training tools based on the average quality of studies performed.

METHODS

Definitions

Training tools were considered to be any object (such as an assessment checklist for training purposes), course, curriculum, program, or method of simulation aimed at quantifiably developing a surgeon's nontechnical ability. Frameworks and suggested practice methodologies were not considered to be indicative of a training tool.

Databases and Search Criteria

A comprehensive literature search was performed between October 29, 2015 and December 3, 2015. PubMed and ScienceDirect databases were searched using the following Medical Subject Headings (MeSH) and free-text terms in various combinations. No restrictions were placed on the search results.

- Nontechnical skills surgery
- Nontechnical skills training surgery
- Training tools nontechnical skills
- Nontechnical skills surgical training
- Nontechnical skills surgery
- NOTSS
- Surgical observation—teamwork assessment
- Training surgical leadership
- Training surgical teamwork
- Training and assessment surgical decision-making
- Surgical simulation nontechnical skills
- Surgery situational awareness
- Surgical cognitive skills training
- Intraoperative communication skills
- Intraoperative communication skills training

Inclusion and Exclusion Criteria

Only research articles were searched for and included. Articles meeting the inclusion criteria were those that reported the development or validation or both of identifiable nontechnical skills training tools specifically for the surgeon or the surgical team, where the surgeon remained the central focus of the tool. Articles where technical skills were examined alongside nontechnical skills were also included.

For search terms relating to a specific behavioral domain, such as "leadership" or "cognitive skills," articles meeting the inclusion criteria were required to mention that specific skill domain, and refer to a method of training it.

Exclusion criteria involved articles not in the English language, those relating to technical skills, articles that were not surgical in nature, articles making no reference to the search term, articles that were purely interview or opinion based, previous systematic reviews or meta-analyses, articles not exploring intraoperative nontechnical skills, or nontechnical skills of theater staff members not including surgeons. Articles involving patient perspectives or using patients (simulated or otherwise) as assessors were also not included, owing to the need to standardize the training tools for those who have prior experience with nontechnical skills and the methods of training them. Textbooks and posters were not included.

Data Extraction and Critical Evaluation

Data were to be extracted by a single author, using a standardised extraction form agreed before the searches being performed. Data extracted included demographic details of the participants, specialities the studies were aimed at (or from which the participants came), the study design and setting, the nontechnical skills being trained or assessed, and the outcome of the study.

Study quality was formally evaluated using a modified Oxford Centre of Evidence-Based Medicine score[7,8] and the JADAD[9] score for randomized controlled trials. The criteria for the level of evidence for each study are provided in Table 1, while the recommendations based on each level of evidence is provided in Table 2. Bias was evaluated in association with guidelines from the Cochrane Risk of Bias Tool.[10] Risk of bias has been stated in the critical analysis section of Tables 3-14. Study quality has been included in the critical analysis sections.

RESULTS

Articles

The search terms generated 13,980 potentially relevant articles. Each article was screened according to the aforementioned criteria. A total of 1068 articles were considered to have met these criteria. Identification of duplications, systematic reviews, and meta-analyses were then undertaken. Remaining articles were put forward for abstract screening, of which 163 abstracts met the criteria and underwent full text review. Furthermore, 84 of these articles

TABLE 1. OCEBM Levels of Evidence[7,8]

Level of Evidence	Criteria
1a	Systematic reviews containing at least some trials of level 1b evidence, in which results of separate, independently conducted trials are consistent
1b	Randomized controlled trial of good quality and adequate sample size
2a	Randomised controlled trial of reasonable quality or of inadequate sample size
2b	Nonrandomized trials, comparative research (parallel cohort)
2c	Nonrandomized trial, comparative research (historical cohort)
3	Nonrandomized, noncomparative trials, descriptive research
4	Expert opinions

were considered to conform to the prediscussed inclusion criteria and were subsequently fully reviewed. Figure 1 displays this.

Included articles were categorized into data extraction tables pertaining to 3 broad domains; training tools for the surgical team (with the surgeon as the central focus), training tools for the individual surgeon, and training tools aimed at specific nontechnical skills (e.g., communication skills). Within these categories, we found that there was often repetition of particular training tools across multiple studies. We therefore produced a number of tables within each broad category to accommodate this finding.

Tables 3-14 display the relevant data extracted from all studies examined.

Specialties Identified

Specialities identified included trauma and orthopedics ($n = 8$), general surgery ($n = 28$), vascular surgery ($n = 1$), urological surgery ($n = 8$), obstetrics and gynecology ($n = 2$), otolaryngology surgery ($n = 1$), plastic surgery ($n = 1$), cardiac surgery ($n = 1$), multiple specialities ($n = 21$), speciality unknown ($n = 12$), and medical students ($n = 1$).

Study Types Identified

Study types identified included interrupted time series ($n = 5$), observational study ($n = 22$), randomized controlled trial ($n = 7$), exploratory study ($n = 33$), cohort analysis ($n = 6$), and comparative study ($n = 11$).

Participant Demographics

Figure 2 displays information relating to the experience level of participants across the studies investigated. Those identified included demographics not disclosed ($n = 11$), mixed team (including surgeon) ($n = 16$), trainee/resident surgeons ($n = 34$), surgeon (experience unknown) ($n = 6$), attending/consultant and resident/trainee surgeons ($n = 5$), expert/consultant/attending surgeon ($n = 7$), faculty member ($n = 1$), and medical students ($n = 4$).

Study Settings

In total, 84 studies were examined. Simulated surgery was used in ($n = 42$) studies, live surgery in ($n = 36$) studies, both simulated and live surgery in ($n = 1$) studies, and neither were used in ($n = 5$) studies.

Training Tools Identified

Table 15 outlines the training tools that were identified in the literature. Given that one study would often use more than one training tool as a method of comparison or validation, data presented in Table 15 relates to how many times the training tools were identified across the studies. Modified versions of the same tool were considered separately.

Levels of Evidence

Risk of bias has been stated in the critical analysis section of Tables 3-14. Study quality has been included in the critical

TABLE 2. OCEBM Levels of Recommendation[7,8]

Level of Recommendation	Criteria (based on the OCEBM Levels of Evidence Table)
1	Based on 1 systematic review (1a) or at least 2 independently conducted (1b standard) project
2	Based on at least 2 independently conducted research projects classified as level 2a or 2b, within concordance
3	Based on 1 independently conducted research project of level 2b, or at least 2 trials of level 3, within concordance
4	Based on 1 trial at level 3, or multiple expert opinions (level 4)

TABLE 3. Oxford NOTECHS II. Nontechnical Skills Training Tools for the Surgical Team

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Morgan et al.[17]	101 observed operations	Orthopedic surgery	Controlled interrupted time series	Oxford NOTECHS II to measure nontechnical skills of theater team	Combined intervention increased team's performance, nontechnical skills	OCEBM score 2c
	Surgical teams Participant numbers not disclosed	Live surgery	Procedures and Crew Resource Management Operating theaters—one hospital network	Training using standardised operative	No clinical benefit noted overall	Observers not blinded. Possible observer bias
Robertson et al.[18]	Participant numbers not disclosed	Vascular surgery	Observational study	Development of Oxford NOTECHS II	Construct validity good	OCEBM score 3
	2 observers	Trauma and orthopedics General surgery Plastic surgery Live surgery	5 Hospitals	Construct validity of Oxford NOTECHS II Evaluation of face validity Examination of interrater reliability	Face validity good Interrater reliability of NOTECHS II good and consistent	Possible observer bias
Robertson et al.[19]	287 active operations observed 773 observed control Participant numbers not disclosed	Orthopedic surgery Live surgery	Controlled interrupted time series Specialist orthopedic and reconstructive hospital, UK	Oxford NOTECHS II to assess team nontechnical skills before and after combined intervention program	Scores increased after intervention Mean score: 69.81 to 75.56 for the intervention group, unchanged in control group	OCEBM score 2b Possible observer bias
Morgan et al.[20]	116 operations observed	Orthopedic and reconstructive surgery	Controlled interrupted time series	Changes in Oxford NOTECHS II compared before and after standard operating procedure (SOP) intervention, in active and control groups	Active group mean scores: 74.84 preintervention and 73.79 postintervention	OCEBM score 2c
	Surgical team Participant numbers not disclosed	Live surgery	Tertiary orthopedic and reconstructive center, UK		Control group mean score: 75.52 and 72.88 No effect of the SOP intervention on nontechnical skills	Possible observer bias

TABLE 4. Oxford NOTECHS

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Morgan et al.[11]	72 operations observed	Orthopedic surgery	Controlled interrupted time series	Oxford NOTECHS evaluating usefulness of intervention—course aimed at teamwork training, with 6 weeks follow-up	NOTECHS score improved for intervention group. No change for control group	OCEBMS score 2b
	Surgical team Participant numbers not disclosed	Live surgery	Nondisclosed district general hospital		Improved nontechnical skills of surgical team	Possible observer bias
McCulloch et al.[12]	Participant numbers not disclosed	General surgery	Cohort study	Oxford NOTECHS evaluating teamwork, pretraining and posttraining intervention	Nontechnical skills training had positive effect on technical ability.	OCEBM score 2c
	103 operations observed Live surgery	Vascular surgery	Operating theater, UK hospital		Improvement greater in general surgery than vascular surgery	No bias identified
Mishra et al.[13]	Participant numbers not disclosed	General surgery	Observational study	Oxford NOTECHS evaluating nontechnical skills of surgical team	Good reliability of NOTECHS	OCEBM score 2c
	26 operations observed	Live surgery	Location not disclosed	Interrater reliability	Interrater reliability excellent, even between those who are and are not surgically trained Correlation between situational awareness and technical problems	No bias identified
Mishra et al.[14]	65 observed operations by 1 observer	General surgery	Exploratory study	Comparison of NOTECHS and OTAS	Training improved score, aiding validity	OCEBM score 2c
	Participant numbers not disclosed	Live surgery	Oxford	Interrater agreement, pretraining and posttraining Questionnaire evaluating attitude toward teamwork Reliability and validity of NOTECHS	Attitude toward teamwork after training improved Higher NOTECHS score correlated with reduced errors Interrater agreement excellent. Excellent correlation between OTAS and NOTECHS	No bias identified
Nicksa et al.[15]	43 surgical resident	General surgery, vascular surgery, cardiothoracic surgery	Exploratory study	Nontechnical skills using Oxford NOTECHS on simulation exercise	85% Reported gains in confidence	OCEBM score 2c

	Postgraduate year 1 and 2	Simulated surgery	Operating room and simulation centers of San Francisco VA Medical Centre	Surveys used providing feedback on simulation	Useful for teamwork and diagnostics (51%), communication skills (57%), and problem solving (55%) Realistic and educational Improvement in nontechnical skill domains aside from decision-making or situational awareness for postgraduate year 2 trainees No improvement for postgraduate year 1 trainees	No bias identified
Briggs et al.[16]	20 surgical teams	Trauma team (including surgeons)	Cohort study	Nontechnical skills of team assessed by NOTECHS	Nontechnical skills of team members decreased through the scenario	OCEBM score 2c
	Surgical residents and other health care professionals	Simulated trauma	Brigham and Women's Hospital STRATUS Center for Surgical Simulation	NOTSS used to assess team leader	Interrater agreement for NOTSS—very good Interrater agreement for NOTECHS—less good than NOTSS	No bias identified

TABLE 5. Training Programs and Courses

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Pugh et al.[73]	11 surgical teams	General surgery	Comparative study	NOTSS and Cannon-Bowers Scale	Correlation between NOTSS and Cannon-Bowers was good	OCEBM score 2a
	33 surgical residents	Simulated surgery	Yearly assessment, over 3-year period	Comparison of team performance Academic training program		Small number of participants
Phitayakorn et al.[74]	5 surgical teams	General surgery	Observational study	NOTSS and OTAS	Interrater agreement for NOTSS—0.51 and 0.70 for OTAS. Teamwork and communication found not to affect patient management	OCEBM score 2c
	Participant numbers not disclosed	Simulated surgery	Massachusetts General Hospital Operation Room Simulation	Interrater agreement Effect of communication and teamwork on patient management		Should provide total participant numbers Possible reporting bias
Halverson et al.[48]	Surgeons, other theater staff Participant numbers not disclosed	Speciality not revealed Live surgery	Observational study Northwestern Memorial Hospital	Observations highlighting communication failures, establishing effect of team training curriculum on surgical communication	Team training curriculum does not change communication errors, but does reduce error rate	OCEBM score 2b Should provide total participant numbers Possible observer bias

TABLE 5 *(continued)*

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Seymour et al.[51]	78 participants in total	General surgery	Exploratory study	Questionnaires evaluating teamwork training workshop quality, and confidence level in simulation exercise	Workshop features and importance considered high (mean = 5.4/6)	OCEBM score 2c
	63% Were surgeons, experience unknown	Neurosurgery otolaryngology surgery Simulated surgery	International Meeting on Simluation in Health care, New Orleans ASE (San Antonia and Boston)		Workshop requirement high (5.5/6)	No bias identified
Kellicut et al.[75]	220 military personnel	Trauma-related surgery	Exploratory study	Surgical team assessment training (STAT) to train military trauma–related operating room nontechnical skills	95% Said curriculum should be offered to surgical team members before military placement. 77% Believed it would improve safety and benefit patients	OCEBM score 3
	(61 completed, 11 were surgeons)	Simulated surgery	8 Army surgery centers, Iraq	Surveys completed to rate training system		Military focussed and did not have any surgeons specifically responding to the feedback questionnaire Potential selection bias
Forse et al.[76]	Surgical teams	Speciality not stated	Exploratory study	Training program for operating room staff	Teamwork and communication improved with training program	OCEBM score 2c
	Participant numbers not disclosed. Varied experience	Live surgery	Creighton University, Omaha. Specific location not disclosed	Questionnaire to establish training effectivity		Should provide number of participants
Schulz et al.[50]	9 surgical residents	Otolaryngology, head, neck surgery Simulated surgery	Comparative study Division of otolaryngology-head and neck surgery	Before and after test questionnaires evaluating a training program	Improvement of leadership knowledge and understanding 100% Of participants believed training program was useful	OCEBM score 2b No bias identified
Tibbs and Moss[77]	18 surgical team members	Gynecological surgery	Comparative study	Training program and teamwork rating scale questionnaire to measure teamwork perception after intervention	Team members showed better interpersonal communication skills	OCEBM score 2c
	Experience unknown	Live surgery	Surgical department, military hospital, USA (more specific details not disclosed)		Improvement of overall teamwork skills	No bias identified
Kjellin et al.[54]	2 surgical residents	Speciality not disclosed	Exploratory study	Course for teamwork, self-efficacy, situational motivation	Training course rated very high. Self-efficacy improved after hybrid simulation course (median scores increased from 4-6)	OCEBM score 3
	13 participants total	Simulated surgery	Simulated Operating Room, Center for Advanced Medical Simulation and Training, Karolinska University Hospital, Sweden	Measured using Likert scale. Questionnaire evaluating course	Hybrid simulation feasible for training	No bias identified

TABLE 6. Simulation Specifically

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Gettman et al.[78]	19 surgical residents Senior and junior residents	Urological surgery Simulated surgery	Observational study Simulated operating room, specific location not disclosed	Simulated scenarios with instructional feedback Teamwork scale with participants and experts assessing Questionnaires for content and face validity	Teamwork improved between scenarios for expert and resident analysis. Face and content validity considered good for both. Effective method of teaching and assessing nontechnical skills	OCEBM score 2c No bias identified
Andrew et al.[49]	15 surgical residents	General surgery Simulated surgery	Exploratory study Feinberg School of Medicine, Northwestern University, Chicago	Simulation assessing teamwork and decision-making skills. Assessment by participants and independent observers using survey	Participants scored communication ability higher than observers (4.3/5 and 3/5, respectively) Simulation can be used for communication and teamwork training	OCEBM score 2c No bias identified
Undre et al.[52]	20 surgical teams, 80 participants Trainee surgeon in each team	Speciality not stated Simulated surgery	Observational study Virtual operating theater, specific location not disclosed	Simulation-based nontechnical skills training module Evaluation of nontechnical skills of subspecialties of the surgical team Measured using modified NOTECHS	Surgeons scored lower for communication and teamwork than other team members Leadership and decision-making skills rated lowest overall Training considered useful by participants	OCEBM score 2c No bias identified

TABLE 7. OTAS, OTAS-S, and OTAS-D

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Wetzel et al.[79]	16 surgical residents	Vascular surgery	Randomized controlled trial	OTAS evaluating teamwork behavior	Intervention group improved teamwork performance	OCEBM score 2a
		Simulated surgery	Imperial College London	Compared OTAS score against measures of intraoperative stress	Decreased stress, increased ability to cope Improvement in decision-making	JADAD score 2/5 Small number of participants
Arias et al.[22]	98 cases observed Participant numbers not disclosed	General surgery Live surgery	Exploratory study Location not disclosed	Content validation of the translated version of OTAS to OTAS-S in Latin America, using expert interrater agreement to validate	High interrater agreement determined for OTAS-S Content validation achieved	OCEBM score 3 Observer bias accounted for
Arora et al.[25]	32 surgeons 16 attending 16 resident	General surgery Simulated surgery	Randomized controlled trial Location not specified	Teamwork assessed using OTAS Randomized between mental practice and control (online lecture) to determine which was more beneficial	High interrater reliability for OTAS. Teamwork more effective as a result of mental practice, rather than online lecture (control group)	OCEBM score: 2a JADAD score: 4/5 No bias identified
Arias et al.[23]	40 operations Surgical teams Participant numbers not disclosed	Obstetrics General surgery Live surgery	Cohort study Columbia (Specific location not reported)	Training program aimed at improving teamwork. Use of OTAS-S to evaluate the usefulness of program, before and after intervention	Training program considered an effective intervention Up to 2 points difference between before and after intervention scores	OCEBM score 2c No bias identified
Passauer-Baierl et al.[24]	11 operations observed Participant numbers not disclosed	General surgery Vascular surgery Live surgery	Observational study Location not disclosed	Interrater and content reliability evaluated for the refined OTAS-D scoring system	Interrater reliability was high ($\kappa > 0.8$) Reliability acceptable level (>0.72 was the intraclass correlation coefficient)	OCEBM score 2c Possible observer bias
Hull et al.[21]	30 operations observed 5 expert surgeons (plus further staff) as assessors	General surgery Live surgery	Observational study London teaching hospital, UK	Development and refinement of OTAS, using theater staff to assess content validity of assessment domains	Interrater agreement high for observable components of assessment. Content validity considered very good. Valuable tool in training and assessing teamwork nontechnical skills	OCEBM score 2c Possible observer bias

Undre et al.[26]	50 operations observed	Urological surgery	Observational study	Reliability of OTAS in urology	Interobserver reliability high, (Pearson correlation coefficient >0.5) but lower for communication	OCEBM score 2c
	Surgical team Expert and junior Expert and junior residents	Live surgery	Teaching hospital and specialist treatment center, specific location not disclosed	Reliability evaluation of interobserver ratings	Surgeons obtained lower ratings for communication, and scores deteriorated as the procedure progressed	No bias identified
Undre et al.[27]	50 procedures observed	General surgery	Observational study	Development of OTAS using observations of teamwork behaviors in the operating theater	High ratings of team performance	OCEBM score 3
	Experience unknown Teamwork observations	Live surgery	Operating theater, specific location not disclosed		Communication rated lower than other observable behaviors	No bias identified

TABLE 8. Uncategorised Team-Focussed Training Tools

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Paige et al.[53]	3 teams	General surgery	Observational study	Teamwork assessed by checklist, assessing clinical decisions and patient outcome	Participants found program beneficial	OCEBM score 3
	10 participants	Simulated surgery	Virtual operating room	Questionnaire using 5-point Likert scales, assessing effectiveness of simulated training system for surgical teamwork	8/10: program would benefit actions in an operating theater	Small number of participants
	Senior resident in each team		Isidore Cohn Jr. MD Learning Centre School of Medicine		9/10: program was effective	
Paige et al.[28]	38 team participants	General surgery	Exploratory study	Likert scale to measure teamwork before and after the "Mobile Mock Operating Room" used as teamwork training tool	MMOR improves self-efficacy in surgical teamwork	OCEBM score 2c
	Senior/ attending surgeon in each team	Simulated surgery	Louisiana State University Health Sciences Center, New Orleans, USA		Mean gain from training: 0.4 units	No bias identified

TABLE 8 *(continued)*

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Huang et al.[29]	50 operations observed. Participant numbers not disclosed	Multiple specialities Live surgery	Observational study Greenville Memorial Hospital	Interrater reliability of Surgical Teamwork Tool, using Cohen's *k*	Cohen's $k = 0.84$, Surgical Teamwork Tool considered good for interrater reliability	OCEBM score 2c Potential observer bias
Paige et al.[80]	28 medical students	Simulated surgery	Cohort study	Pretask and posttask Likert style questionnaire evaluating simulation-based training, aimed at developing team behaviors in operating room	Self-efficacy increased from before to after task. Mean observer scores improved after task. For teamwork, differences found when observer scores compared with participant scores	OCEBM score 3
	66 participants in total		Specific location not disclosed		Effective training method	No bias identified

TABLE 9. NOTTSdk. Nontechnical Skills Training Tools for the Individual Surgeon

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Spanager et al.[31]	13 trainee surgeons	General surgery	Exploratory study	Determination of elements of NOTSSdk used for nontechnical skills assessment	Internal consistency of NOTSSdk found to be good	OCEBM score 3
	12 supervisors	Live surgery	2 hospitals, Capital Region, Denmark,	Number of scenarios requiring assessment before NOTSSdk can provide reliable assessment	5 procedures found to provide reliability when using NOTSSdk	Small sample size Possible individual observer bias
Spanager et al.[32]	13 trainee surgeons	General surgery	Exploratory study	NOTSSdk to provide framework for postoperative feedback	Feedback based on NOTSSdk tool, while being considered useful and effective by supervisors and trainees (median rating was 4 from trainees, and 4 from supervisors)	OCEBM score 3
	12 supervisors	Live surgery	Two general surgery departments in a university hospital, Denmark	Questionnaire responses from supervisors and trainees (rating of 1-5 per question component)		Potentially a small sample size Possible recruitment bias

Spanager et al.[33]	15 general surgeons as assessors 9 video recordings	General surgery Simulated surgery	Exploratory study Danish Institute for Medical Simulation	Content validity of NOTSSdk Evaluation of surgeon's ability to rate nontechnical skills, and interrater reliability Ability to use NOTSSdk to rate nontechnical skills: improve after training? Evaluation of number of raters needed to reliably assess nontechnical skills	High interrater reliability using NOTSSdk Training did not improve assessment ability Good content validity Reliability using NOTSSdk can be gained by using 1 trained or 2 untrained raters	OCEBM score 3 Training program used was a reduced version compared to how it normally would be

TABLE 10. Simulation, Training Programs, and Courses

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Shamim Khan et al.[81]	33 senior resident surgeons	Urological surgery Simulated surgery	Observational study Simulation and Interactive Learning Centre, Guy's Hospital, King's College London	Face and content validity of simulation program aimed to address all nontechnical skills Questionnaires, semistructured interviews	90% of trainees: training models realistic. 95% of trainees approved simulation training. Senior trainees better at nontechnical skills than junior trainees	OCEBM score 3 Potentially a small sample size
Heskin et al.[56]	58 core trainee surgeons in present study group 51 from previous year	Core surgical training Training program	Cohort study National surgical Training Centre, RCSI	Multiple Choice Questionnaire (MCQ) evaluating technical and nontechnical skill knowledge, gained from 5-day surgical boot-camp. Questionnaire for confidence assessment	Mean MCQ score (both technical and nontechnical skills) improved from 53.8% to 68.4%, pretest to posttest Improved confidence in ability, including nontechnical	OCEBM score 2c No distinguishing statistics between technical and nontechnical skill improvement reported

TABLE 10 *(continued)*

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Ahlborg et al.[82]	28 surgical residents	Obstetrics and gynecology	Cohort study	Self-efficacy questionnaire and visuospatial ability assessed before and after simulator training	Visuospatial ability and self-efficacy not found to correlate. Visuospatial ability not found to correlate with maximal simulator training	OCEBM score 2c
		Simulated surgery	Center for Advanced Medical Simulation and Training, Karolinska University Hospital, Stockholm, Sweden		Self-efficacy found to improve after intense simulation training	Nonstandard nontechnical skills examined
Kwayke et al.[55]	13 senior resident surgeons	Nonspecified specialities	Exploratory study	4-week apprenticeship rotation teaching nontechnical skills for trainees	87.5% faculty and 85% of residents would recommend	OCEBM score 3
	12 faculty members	Live surgery	Brigham and Women's Hospital, Boston, Massachusetts	Opinion-based survey (using 5-point Likert scale) after rotation to establish effectiveness	Improvements in trainee nontechnical skills Considered overall to be useful method of training nontechnical skills	No bias identified
Nguyen et al.[83]	13 surgical residents (Postgraduate Years 1-5)	General surgery	Exploratory study	Intraoperative and perioperative checklist assessing skills for surgical simulation across 2 sessions, with debrief	Improvement in nontechnical skills from session 1 to session 2	OCEBM score 2c
	11 participants	Simulated surgery	Center for Medical Education and Innovation, Riverside Methodist Hospital, Columbus	Survey obtaining opinions on simulation	Rated simulation realistic and effective	Does not evaluate all nontechnical skills recognized
					Considered a valuable tool for training	Biases accounted for
Harrysson et al.[84]	5 trainee surgeons	General surgery	Observational study	Development of curriculum (including simulation) to train nontechnical skills	Considered feasible for procedure-specific training	OCEBM score 3
		Simulated surgery	Imperial College London	Feasibility of the study evaluated by the residents		Nontechnical skill elements not taught to the same level as technical skills

Halverson et al.[85]	25 surgeons	General surgery	Exploratory study	Development of training course. Questionnaire for surgeons' opinions on skills development upon course completion	89% of surgeons believed course improved their ability in communication and interactive skills	OCEBM score 3
	Unknown experience	Gynecology Urology Plastic surgery Neither live nor simulated	Specific location not disclosed—USA		Good reaction to course content	No bias identified
Bearman et al.[86]	12 trainee surgeons	Multiple specialities	Exploratory study	Feasibility assessment of course for surgical trainees. Evaluation forms rating course	All participants believed course: good /very good	OCEBM score 3
		Simulated surgery	Monash University, Australia		Educationally valuable Highly realistic	No bias identified
France et al.[57]	9 surgeons	Cardiac surgery	Observational study	CRM training course	Team performance regarding CRM and safety was low	OCEBM score 3
	Unknown experience	Neurosurgery Live surgery	Academic center operating room, location undisclosed, USA	Use of checklist to evaluate nontechnical skills	Compliance with practices was only at 60% overall	No bias identified

TABLE 11. NOTSS Specifically

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Yule et al.[30]	27 consultant surgeons	General, orthopedic & cardiac surgery	Exploratory study 11 hospitals throughout Scotland	Identification of nontechnical skill components using cognitive task analysis	Development of the NOTSS behavioral marker system for surgical nontechnical skills training and assessment	OCEBM score 3 No bias identified
Yule et al.[6]	44 consultant surgeons	Multiple specialities	Comparative study	Comparison of "novice" ratings using NOTSS to "expert" ratings to establish reliability of results	Experts more skilled in assessing areas novices found to be not applicable	OCEBM score 2b
		Live surgery	Location not disclosed		Reliability may be improved with training of novice raters	No bias identified
Phitayakorn et al.[34]	Surgical residents and other staff	General surgery	Comparative study	Interrater agreement using NOTSS and OTAS	Interrater agreement:	OCEBM score 2b
	Participant numbers not disclosed	Simulated surgery	Department of Surgery, Massachusetts General Hospital	Reliability assessed Feasibility assessed	NOTSS 0.47 to 0.82. OTAS 0.13 to 0.83	Potential that some teamwork activities were not adequately recorded through being carried out off screen
			Simulation in operating theater	Validity assessed	1/2 of raters said OTAS is more useful for video scenario, 1/2 said more useful live	

TABLE 11 *(continued)*

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Crossley et al.[35]	85 surgical trainees	Multiple specialities	Observational study	NOTSS used by assessors with minimal training	Experts scored nontechnical skills lower than novice assessors. 25% of assessors believed NOTSS likely to benefit patient safety	OCEBM score 2b
	Aimed to assess 450 cases. Actual number unknown	Live surgery	3 teaching hospitals, Sheffield	Questionnaire to rate feasibility, acceptability, and validity of NOTSS	75% rated NOTSS easy Scores using NOTSS rated good or acceptable	Trainee data not related to NOTSS
Arora et al.[39]	26 surgeons	General surgery	Exploratory study	NOTSS used by participating surgeons and expert assessors.	Interrater reliability good.	OCEBM score 2b
	13 junior residents 13 senior residents	Simulation-based	Department of Surgery and Cancer, Imperial College London	Evaluation of interrater reliability. Association between self and expert assessment	No association for self and expert assessment. Less experienced surgeons overestimated nontechnical ability, whereas experienced surgeons underestimated.	Low number of participants
Yule et al.[36]	44 consultant surgeons	Orthopedic	Exploratory study	Evaluation of NOTSS using recording video scenarios following training	Sensitivity acceptable Consistent internal structure	OCEBMS score 2c
		Pediatric General Urology Breast Cardiothoracic Simulated surgery	Scotland. Specific location undisclosed	Participant and expert ratings Interrater reliability assessed and internal structure assessed	Rating accuracy greater than 60% Interrater reliability acceptable for communication, teamwork and leadership, but not for the remaining categories	Limited NOTSS training within time allocated, may have been reflected in assessments
Beard et al.[38]	152 mixed medical and surgical staff	Obstetrics and gynecology, upper GI, colorectal, cardiac, vascular, orthopedic surgery	Observational study	Questionnaires to assess satisfaction and acceptability of NOTSS compared to PBS and OSATS—technical skill training tools	NOTSS reliability lower than PBA	OCEBM score 2b
	Experience level unknown	Live surgery	3 Sheffield teaching hospitals	Multiple forms of validity examined	NOTSS was shown to have valid and good internal structure NOTSS construct validity shown to be good Little interrater variability	No bias identified
Dedy et al.[87]	37 simulations, 10 live procedures 2 raters validated the tool Participant numbers not disclosed	Both simulation and live surgery General surgery	Observational study University of Toronto, Canada	Objective Structured Assessment of Nontechnical skills tool development (OSANTS) Validation determined in relation to NOTSS. Interrater agreement, internal consistency	High interrater agreement overall Good correlation between ratings from OSANTS and ratings from NOTSS High internal consistency	OCEBM score 2c No bias identified

TABLE 12. NOTSS Combined With Training Program

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Jones et al.[41]	33 junior surgical trainees	Surgical training simulation Simulated surgery	Comparative study Bristol Medical Simulation Centre	Human Factors Training course based on NOTSS. Comparison of self-assessed rating of confidence before and after human factors training course	91% of trainees would change their practice based on the training course. Increase in confidence following course. All nontechnical skills gained on course applicable to reality	OCEBM score 2b Limitation: infrequency with which course is run. Greater quantities of data could otherwise be produced
Dedy et al.[42]	11 senior surgical residents	General surgery	Nonrandomized, single-blinded study interrupted time series	NOTSS measuring skills before and after intervention	NOTSS score improved from 3.2 to 3.5 after the feedback intervention	OCEBM score 2b
		Live surgery	Tertiary care center Operating theater observation	Usefulness of intervention using questionnaire	All trainee surgeons found feedback intervention useful	Planned observation numbers different from actual observation, and only 1 speciality used
Pena et al.[88]	40 trainee surgeons	Speciality not revealed	Comparative study	NOTSS	Nontechnical skills workshop lead to no change in NOTSS scores when compared to the nonworkshop group	OCEBM score 2b
		Simulated surgery Trainee surgeons	Simulation took place in operating theaters of 2 teaching hospitals in Adelaide	Questionnaire analyzing face validity of simulation, and ability of activity to help with interpersonal skill development	Both groups had better NOTSS ratings in second scenario. All participants felt that posttask debrief was useful	No bias identified
Pena et al.[40]	40 surgical trainees	Speciality not reported	Observational study	NOTSS used by independent raters to assess videos	Mean self-efficacy: 47.55 before, improved to 48.35	OCEBM score 2c
		Simulated surgery	Simulated operating theater, Adelaide	Evaluation of self-efficacy using a questionnaire pretraining and posttraining program	Nontechnical skills scores improved following training, despite no improvement in self-efficacy rating	Limitations of participants scoring their own ability
Brunckhorst et al.[71]	32 medical students	Speciality unknown	Comparative study	Comparison between NOTSS and technical skill elements.	Technical skills correlated with nontechnical performance.	OCEBM score 2b
		Simulated surgery	Simulation and Interactive Leaning Centre, Guy's Hospital, London.	½ of participants had skills training through simulation, ½ undertook didactic session	Improved NOTSS scores with simulation training. Nontechnical and technical skill domains showed strong correlation regardless of intervention	Novices used—no trainee surgeons involved in study.

TABLE 12 *(continued)*

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Louridas et al.[37]	20 senior surgical trainees	General surgery	Single-blinded randomized trial	NOTSS evaluating nontechnical skills of residents performing	No difference between nontechnical skills ability between either group	OCEBM score 2a
		Simulated surgery	Canada	procedure, after traditional training or mental practice	Interrater agreement considered very high (correlation coefficient 0.80)	JADAD score 3/5 No bias identified
Brunckhorst et al.[72]	32 medical students	Urological surgery	Randomized Controlled Trial	NOTSS to evaluate nontechnical benefits of a ureteroscopy curriculum	100% of experts agreed curriculum useful for nontechnical skills training	OCEBM score 2a
	(16 to intervention group, 16 to no intervention)	Simulated surgery	Simulation and Interactive Leaning Centre, Guy's Hospital, London	Surveys and questionnaires to assess effectiveness of curriculum	Curriculum trained group had greater NOTSS scores than the untrained group	JADAD score 4/5
					100% of participants felt simulation training needed to be introduced	Use of medical students and not trainee surgeons. May have alternate impact on learning curve
Abdelshehid et al.[89]	8 surgical residents 16 participants total	Urological surgery Simulated surgery	Exploratory study Irvine School of Medicine Simulation Centre, University of California	Evaluation of Simulation-Based Team Training (SBTT) Nontechnical aspects measured using NOTSS	Nontechnical skill scores correlated with stage of training SBTT improved nontechnical skills. All residents believed SBTT useful in improving communication skills	OCEBM score 3 No bias identified
				Interrater reliability	Good interrater reliability	

TABLE 13. Uncategorised Nontechnical Skill Training Tools

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Glarner et al.[90]	Participant numbers not disclosed	General surgery	Observational study	Tool assessing resident performance using components from NOTSS. Face,	Face and content validation achieved	OCEBM score 2b
	PG3 to 5 surgical residents	Live surgery	University of Wisconsin	construct, and content validity examined	Construct validity shown by the improved nontechnical skills from PG3 to PG5 level	No bias identified
Osborne et al.[47]	25 surgical trainees	General surgery	Comparative study	Self-assessed procedure-based assessment	Significant differences found between self-	OCEBM score 2b
		Live surgery	Location not disclosed	and external procedure-based assessment using global summary scores and checklists	and external assessment of nontechnical skills	Potential selection bias although accounted for
Lee et al.[43]	16 participants total (8 surgical residents)	Urological surgery	Exploratory study	Global rating scales to assess nontechnical skill ability in simulated training	94% scored simulation useful for communication skills	OCEBM score 2b
		Simulated surgery	Toronto, Canada		Self-assessment by residents scored own nontechnical skill ability higher than expert faculty assessors	No bias identified
Brewin et al.[91]	20 surgeons	Urological surgery	Comparative study	Comparison of expert and trainee surgeons' nontechnical skills using NOTECHS	Experts better at nontechnical skills than trainees. Distributed simulation: realistic for	OCEBM score 2b
	10 trainees 10 more experienced	Simulated surgery	Surgical Skills Simulation Suite, Kings Health Partners	Face and content validity analyzed using questionnaires	skills training. Good face and content validity	Small study size
Sevdalis et al.[92]	Trainee surgeons Participant number not disclosed	Simulated surgery Specialities not specified	Exploratory study Imperial College London (precise location not specified)	Reliability of revised NOTECHS for surgeon and surgical teams. Internal consistency measured	Internal consistency "adequate." Self- and external assessments provided consistent results —NOTECHS can be used for assessment and self-assessment	OCEBM score 2b Number of participants not disclosed
Nurudeen et al.[44]	385 attending surgeons	Cardiac	Exploratory study	360-degree evaluation tool rating	63% of participants changed their practices	OCEBM score 3 Use of one hospital
		Thoracic Vascular	8 Harvard hospital facilities	nontechnical skills of surgeon Survey to evaluate:	87% of participants believed feedback to be accurate	Institution and poor response rate to the survey compared to sample size
		Orthopedic Plastic General surgery Live surgery		accuracy usefulness willingness to repeat	77% of surgeons would willingly repeat the 360-degree process	Potential selection bias
Moorthy et al.[93]	27 surgical trainees	Simulated surgery	Comparative study	Expert analysis for nontechnical skills using Line Operations Safety Audit checklist[93]	No correlation between self and expert assessment	OCEBM score 2c
			Imperial College, St Mary's Hospital Simulation Group	Trainee surgeons then asked to assess their nontechnical skills using the same tool	Higher correlation between self- and expert assessment for junior surgeons Senior trainees—less accurate in self-assessment	No bias identified
Michinov et al.[45]	6 h observed procedures	Live surgery	Exploratory study	Interrater reliability and sensitivity of neurosurgical scoring system BMS-NNTS	Good interrater reliability overall	OCEBM score 2c
	Participant number not provided		Rennes University Hospital		High sensitivity of BMS-NNTS	No bias identified
Russ et al.[46]	50 procedures observed	General surgery	Observational study	METEOR (Metric for Evaluating Task Execution in the Operating Room)[46]	Tool considered easy to use	OCEBM score 3
	15 expert assessors	Live surgery	Specific location not disclosed	Development. Content validity evaluated	Variable content validity (0.13-1) Validity implied for new tool	No bias identified

TABLE 14. Specific Training Tools for Cognitive Skills, Decision-Making Skills, Leadership Skills, Situational Awareness, and Communication Skills

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Alvand et al.[58]	120 surgeons	Orthopedic surgery	Exploratory study	Precourse and postcourse cognitive skills test establishing effect of training course	Odds ratio for test score before vs after the course was 4.36. Indicates cognitive skills training of course-effective	OCEMB score 2b
	Consultants and senior trainees		Orthopaedic Skills Academy, Bristol		Cognitive skills did not necessarily improve following course	Precourse and postcourse test scores unable to be paired for individual participants
Luker et al.[59]	10 surgical residents	Plastic surgery	Exploratory study	Evaluation: cognitive task analysis multimedia teaching tool	Residents' decision-making skills improved between first and second sessions	OCEBM score 2c
			Precise location of study not disclosed, University of Southern California	Specific trainer targeting surgical decision-making	Multimedia training intervention—decision-making skills had improved	Largely aimed at technical skills but there is a decision-making focus
Loveday et al.[60]	58 junior trainee surgeons	General surgery	Randomized controlled trial	Evaluation of usability and effectiveness of a surgical cognitive skills trainer	Problem solving skills improved for first-year trainees. No improvement for second year trainees	OCEBM score 2a JADAD: 3/5
			University of Auckland. Precise location not disclosed	Examines procedural problem solving skills using 2 questionnaires and an MCQ style examination	Usability and usefulness scored high in questionnaires	No bias identified
Pugh et al.[61]	16 faculty members	General surgery	Exploratory study	New simulation model development to train intraoperative decision-making. 5-point Likert survey to establish need for training and assessment of surgical decision-making	Agreement that intraoperative decision-making requires training and assessment	OCEBM score 3
		Simulated surgery	Precise location of study not disclosed		Engagement rating for the simulation was 4.9	Small sample size
Scott et al.[62]	22 surgical residents	Trauma surgery	Exploratory study	Pretraining and posttraining course assessment relating to decision-making in surgery, through SAQ style examination to evaluate decision-making skills	Retention test displayed good reliability of training course	OCEBM score 2c
		Simulated surgery	University of British Columbia		Construct validity shown to be good	Small sample size
Servais et al.[63]	62 medical students	Pediatric and general surgery	Exploratory study	Likert scale questionnaire evaluating benefits and effectiveness of	87% scored educational benefit of decision-	OCEBM score 2c

		Simulation multimedia based education tool	University of Boston	multimedia modular based decision-making training tool	making training modules as average to excellent	Unknown how valid this will be in teaching surgeons. Learning curve may be greater for students
Chatterjee et al.[65]	25 participants	Urological surgery	Exploratory study	Use of Surgical Decision-Making Rating Scale (SDMRS) rating judgement skills of urologists at different stages of training	SDMRS found to be reliable in its assessment for all stages of training	OCEBM score 2c
	Medical students, residents and senior surgeons	Live surgery	Department of Urology, McMaster University, Canada	SDMRS used by blinded external assessors and for self-assessment	Performance increased with increasing level of training High internal consistency shown Correlation between self-rating and external rating at all stages of training	No bias identified
Shariff et al.[64]	43 surgical trainees	General surgery Simulated surgery	Randomized controlled trial	Use of survey (Likert scale) establishing improvement in decision-making skills after multimedia training	67% of participants improved in decision-making skills 96% believed multimedia tool beneficial to surgical education	OCEBM score 1b JADAD score 4/5 Selection bias accounted for
Hu et al.[66]	5 surgeons	General surgery	Exploratory study	Investigating whether Multifactor Leadership Questionnaire correlates with Surgical Leadership Inventory	Interrater reliability high (0.95)	OCEBM score 2c
	Unknown experience	Oncology surgery Live surgery	Location not disclosed	Examination of interrater reliability	Potential use for MLQ in surgical leadership training and assessment	Small study number
Parker et al.[67]	29 videos	General surgery	Exploratory study	Use of the Surgeon's Leadership Inventory Tool (SLI) comparing leadership behaviors of attending surgeons with resident surgeons	Attending surgeons displayed more leadership attributes than residents	OCEBM score 3
	Participant numbers not disclosed	Live surgery	Three UK teaching hospitals		Attending surgeon aimed decision-making forms of leadership at the resident more than other team members	Potential bias during videos
Parker et al.[68]	5 videos	General and vascular surgery for video analysis	Exploratory study	Development and validation of the Surgeon's Leadership Inventory tool (SLI)	Face validity not concluded	OCEBM score 2c
	6 surgeons checked for face validity	Live surgery	University of Aberdeen	Face validity and accuracy assessed by surgeons Interrater agreement for reliability	Acceptable interrater reliability using Cohen's k. (Cohen's $k = 0.7$)	Potential researcher bias

TABLE 14 *(continued)*

Primary Study	Subjects/ Observations	Speciality	Study Design and Setting	Nontechnical Skills Training and Outcome Measure	Outcome	Critical Evaluation and OCEBM Score[7,8]
Guerlain et al.[70]	10 operations observed	Surgeons, residents and medical students	Observational study	Remote Analysis of Team Environments (RATE) tool Development of a recording device for surgical team situation awareness assessment	Tool found to allow analysis of judgement, teamwork, and communication ability	OCEBM score 3
	6 attending surgeons 13 residents 4 medical students 20 other theater staff	Live surgery	University of Virginia		Considered to be useful tool for teaching	Does not look into validation. Relatively narrative No bias identified
Fouilloux et al.[69]	9 surgical trainees	Cardiac	Randomized controlled trial	Production of new simulation curriculum training bypass surgery, including nontechnical skills. Measure of communication skills using Global Rating Scale	Trainees undertaking new curriculum performed better with communication skills	OCEBM score 2B
		surgery	Random assignment of core trainees to either curriculum	Measure of interclass correlation	Interclass correlation consistently high from raters	JADAD score 3/5
		Simulated surgery	Surgical Research and Educational Centre at Faculty of Medicine of Marseilles, France			Small number of participants for study

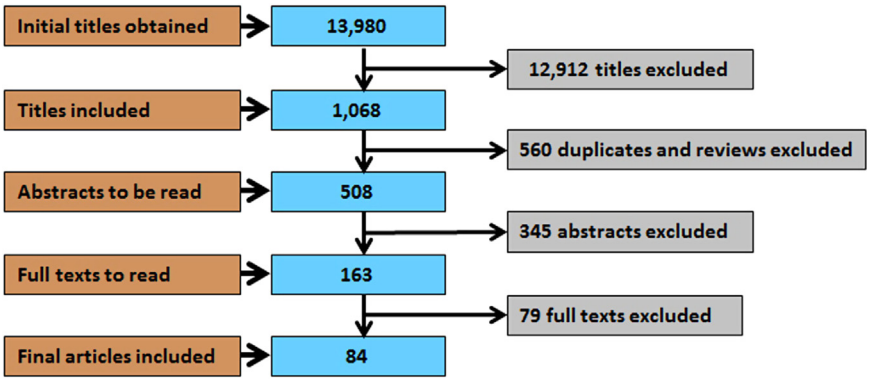

FIGURE 1. PRISMA flow diagram.

analysis sections. The results were Level 1b ($n = 1$), Level 2a ($n = 6$), Level 2b ($n = 20$), level 2c ($n = 34$), and Level 3 ($n = 23$). Most studies were therefore average to low in quality, which can be attributed to the heterogeneous nature of the studies included. Quality of randomized controlled trials was reasonably good, with JADAD[9] scores used to assess the quality. JADAD scores were 2/5 ($n = 1$), 3/5 ($n = 3$), and 4/5 ($n = 3$).

DISCUSSION

Nontechnical Skills Training Tools for Surgical Teams

Oxford NOTECHS and Oxford NOTECHS II

There have been a range of training tools for surgical teamwork developed, and a number of these have undergone validation and extensive use in training already.

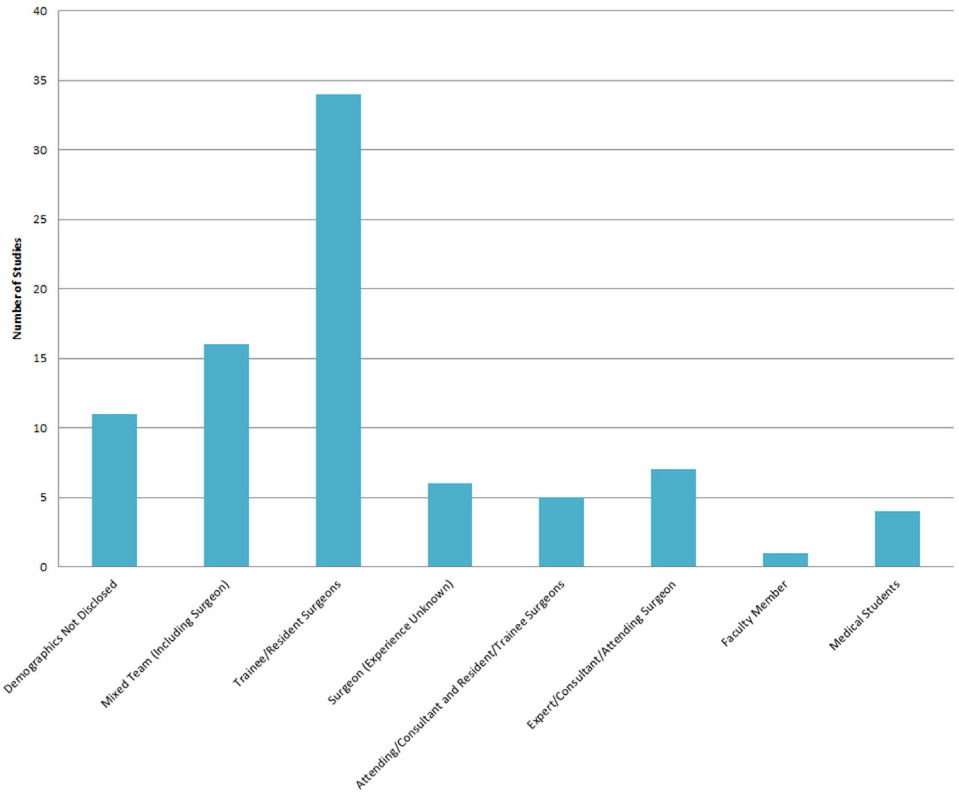

FIGURE 2. Participant demographics.

TABLE 15. Training Tools Identified

Training Tool Identified	Number of Studies (*n*)	Outcomes
NOTSS (Non-Technical Skills for Surgeons)[6,16,34-42,71-74,87-90]	19	Experts more skilled in its use[6,35] Good interrater agreement/ reliability[34,37,39,71] Good rating accuracy[36] Acceptable sensitivity[36] Validity recognised[6,34-38]
Training course/program/curriculum[41,48,50-56,75-78,81,84-86]	17	Multiple outcomes depending on program/course curriculum[41,48,50-56,75-78,81,84-86]
Oxford NOTECHS[11-16,52,91,92]	9	Excellent interrater reliability[13,14] Validity achieved[13]
OTAS (Observational Teamwork Assessment for Surgery)[14,21,25-27,34,74,79]	8	Interrater reliability high[21,26] Content validity good[21]
Simulation-Based Training[49,52,56,80,89]	5	Multiple outcomes based on type of simulation
Oxford NOTECHS II[17-20]	4	Construct and face validity achieved[18] Good interrater reliability[18]
NOTSSdk[31-33] (Non-Technical Skills for Surgeons in Denmark)	3	Content validity achieved[33] Interrater reliability achieved[33] Good internal consistency[31]
Global summary scores[43,47] or checklists[83]	3	Differences found between self- and expert assessment[43,47]
SLI/Surgeon's Leadership Inventory[66-68]	3	High interrater reliability[66,68]
OTAS-S (Observational Teamwork Assessment for Surgery—Spanish)[22,23]	2	High interrater reliability[22] Content validity achieved[22]
OTAS-D (Observational Teamwork Assessment for Surgery—Deutsch)[24]	1	High interrater reliability[24]
OSANTS (Objective Structured Assessment of Nontechnical Skills)[87]	1	Good interrater agreement[87]
(METEOR)[46] (Metric for Evaluating Task Execution in the Operating Room)	1	Validity implied, variable content validity[46]
360-degree evaluation tool[44]	1	Questionnaire: 63% of participants changed nontechnical practices[44]
BMS-NNTS[45] (Behavioural Marker System for Assessing Neurosurgical Non-Technical Skills)	1	Good interrater reliability[45] High sensitivity[45]
Canon-Bowers[73]	1	Good correlation with NOTSS[73]
Surgical teamwork tool[29]	1	Good interrater reliability[29]
Teamwork scale[53]	1	No reliability or validity information reported
Cognitive skills trainer[59]	1	No reliability or validity information reported
SDMRS[65] (Surgical Decision-Making Rating Scale)	1	Reliability achieved[65] Consistent for expert or self-assessment[65]
RATE tool[70] (Remote Analysis of Team Environment tool)	1	No reliability or validity information reported
MLQ[66] (Multifactor Leadership Questionnaire)	1	High interrater reliability[66]

Regarding teamwork training, the first and most extensively investigated nontechnical skills training tool is Oxford NOTECHS[11-16] (Quality, Reliability, Safety and Teamwork Unit, Nuffield Department of Surgery, University of Oxford, Oxford, UK), and its refined version Oxford NOTECHS II[17-20] (Quality, Reliability, Safety and Teamwork Unit, Nuffield Department of Surgery, University of Oxford, Oxford, UK). These are scoring systems used for assessment in the operating theater, which can be used to grade and develop the nontechnical skills of the surgical team collectively.[11-20] When used in combination with other training interventions (such as a team-focussed training program),[11,12,14,15,17,19,20] Oxford NOTECHS can be used to numerically represent the surgical team's improvement in their nontechnical skill domains.[11,12,14] This makes them effective at highlighting the strengths and weaknesses of team-based nontechnical practice.

Both Oxford NOTECHS and Oxford NOTECHS II have been shown to have interrater reliability ranging from good to excellent,[13,14,18] with construct and face validity being consistently achieved across multiple studies.[14,18]

Observational studies, cohort studies, and controlled interrupted time series have reported positive findings regarding the training benefits of these tools, therefore concluding that both of these scoring systems are beneficial for team-based nontechnical skills training.

OTAS, OTAS-S, and OTAS-D

Observational Teamwork Assessment for Surgery (OTAS)[21] (Department of Surgery and Cancer, Imperial College London, UK) is another team-based nontechnical skills scoring system; further developed into OTAS-S[22,23] (Clinical Research Institute, Faculty of Medicine, Universidad

Nacional de Colombia, Colombia), and OTAS-D[24] (Department of Surgery and Cancer, Imperial College London, UK). All variations of this particular scoring system have displayed good interrater reliability,[21,22,24-26] with content validity being confirmed for both OTAS[21] and OTAS-S.[22] Across multiple studies, the same positive aspects of team-based nontechnical ability have been repeatedly rated highly when using these scoring systems.[25] Separate studies have also highlighted the same nontechnical domains that require improvement (such as communication skills of the surgeon).[26,27] Given that this consistency of data has highlighted the same strengths and weaknesses of the surgical team across multiple studies, OTAS and its newer variations can be considered as reliable in their assessments of the surgical team.

Other Team-Based Nontechnical Skill Training Tools

Both the Mobile Mock Operating Room (MMOR) (Departments of Surgery, Anesthesia and Medicine, Louisiana State University Health Sciences Centre, New Orleans, USA) consisting of a portable patient simulator combined with a fully simulated operating suite[28] and the Surgical Teamwork Tool[29] (Department of Health Policy and Management, Harvard School of Public Health, Boston, USA), which measures teamwork among members of the surgical team have only undergone very limited validation. Although each training tool has been shown to enhance team-based nontechnical skills, further research would have to be undertaken using these tools to establish their reliability and validity statuses. Only then could these tools be considered to possess the same level of training benefit as those more extensively investigated.

Nontechnical Skills Training for the Individual Surgeon

NOTSS and NOTSSdk

The most extensively used and validated training tool for nontechnical skills for individual surgeons is the Nontechnical Skills for Surgeons (NOTSS) behavioral marker system[30] (School of Psychology, University of Aberdeen, Aberdeen, Scotland, UK) and its more recent counterpart Nontechnical Skills for Surgeons in Denmark (NOTSSdk[31-33]) (Danish Institute for Medical Simulation, Capital Region of Denmark, Denmark). This has been developed purely for the Danish surgical system.

The NOTSS[30] nontechnical skills behavioral marker system can be used to assess a surgeon's nontechnical skills. Its training benefit would follow discussion or self-reflection of the way in which each skill had been rated.

The interrater reliability and validation status of NOTSS have been consistently recognized,[6,34-38] with minimal training needed to accurately use it in practice.[35] Objective experts in its use have been shown to be more accurate in their judgement of what qualifies good nontechnical skills,[6] as self-assessment tends to yield discrepant results (junior surgeons score their abilities higher than the experts, while the opposite is true for the senior surgeons).[39,40] This could raise accuracy concerns depending on who is using it and would imply the advantage of basic training before it is used by individual surgeons. It has also been used effectively alongside other training methods, such as simulation or training courses, as a tool to monitor nontechnical skill progression.[37,41,42] Although not being quite so extensively examined, NOTSSdk[31-33] has also been shown to be both consistent and effective in nontechnical skills training in the Danish surgical system.[31-33]

It can therefore be suggested that the use of NOTSS[30] (or indeed a derived version thereof),[31-33] is both effective and of high quality. This is regarding personal training and assessment following live operations, or alongside another training tool or program to monitor nontechnical skills development over time.

Other Training Tools

Other surgeon-specific nontechnical skill training tools have been developed and have largely reported positive findings.[43-46]

The 360-degree evaluation tool (produced by a collaboration of hospitals associated with Harvard), using the online PULSE 360 Program to assess the surgeon's nontechnical ability using a series of questions, has been shown to be beneficial, as it improved the nontechnical daily practice of 63% of participants in the study.[44] The Metric for Evaluating Task Execution in the Operating Room (METEOR) (Imperial College London, UK), which identifies gaps in nontechnical ability by objectively capturing task completion had its validity implied based on the study that developed it.[46] The Behavioural Marker System for Assessing Neurosurgical Non-Technical Skills (BMS-NNTS[45]) (Rennes University Hospital, France) cannot be applied to all surgical fields, as this is a behavioral observation tool specific to nontechnical skills in neurosurgery. In this surgical domain, however, it was shown to be a highly sensitive behavioral observation system.[45]

Despite indicating generalized nontechnical training benefits, further research should be undertaken with all of these training tools to fully establish their validity statuses.

Accuracy concerns are present for these tools, with discrepancies between assessors of differing experience. Expert assessment using Global Rating Scales produced lower nontechnical skill ratings than self-assessment did.[43] Significant differences were also found between self and expert use when using Procedure-Based Assessments.[47] The indication therefore is that these tools are of less quality when training and assessing nontechnical skills.

Nontechnical Skill Training Programs and Courses

The evidence gathered from the studies examined casts a positive light over training programs and courses, particularly with regard to simulation. Team-based nontechnical skills training courses have shown a reduced rate of surgical errors,[48] improved teamwork and communication skills within the operating theater,[49] and an improved understanding of leadership.[50] Feedback from participants of the studies examined was overwhelmingly high when participants were asked how beneficial the program was to them,[49-53] and whether training and simulation programs are feasible.[49,52,54]

Training courses for the individual surgeon worthy of mention are a tailored 4 weeks long apprenticeship rotation (Department of Surgery, Brigham, and Women's Hospital, Boston, Massachusetts) that involved assigning a resident surgeon to an attending surgeon in order to teach intraoperative nontechnical skills, with a follow-up survey to establish its effectiveness. This was highly recommended by participants involved.[55] A 5-day surgical boot-camp (National Surgical Training Centre, Royal College of Surgeons in Ireland, Dublin, Ireland) using simulation and surgical faculty to train both technical and nontechnical skills, with a follow-up Multiple Choice Questionnaire (MCQ) for evaluation, was shown to improve knowledge of nontechnical skills and self-confidence.[56] Crew resource management training (using a checklist to specifically target nontechnical skills in the operating theater)[57] and a human factors training course based on NOTSS, with a before and after confidence self-assessment, were shown to teach nontechnical skills that can be used in daily practice.[41] It is worth noting that Crew Resource Management and Human Factors Training are both very broad terms and do not always relate specifically to nontechnical skills in surgery. These aforementioned programs did meet our inclusion criteria, given that they were strongly associated with surgical training. This detail is therefore not a source of bias.

Each of these programs can be considered effective resources for nontechnical skills training in its own right.

Training courses need to be properly tailored and delivered, but the evidence thus far is suggestive that they are beneficial to both individual and surgical team nontechnical skills training.

Specific Nontechnical Skill Training Tools

Cognitive Skills

Studies exploring cognitive skills training did so with the use of a training course,[58] multimedia teaching,[59] and a cognitive skills trainer to promote self-directed training (using the SIMTICS Integrated Cognitive Simulator) (Department of Surgery, University of Auckland, New Zealand).[60] The multimedia teaching tool (Department of Surgery, University of Southern California, USA) to teach surgical decision-making through cognitive task analysis appeared to provide promising results,[59] whereas the cognitive skills trainer improved the problem solving skills of first year trainees, but had no effect on the second year trainees.[60] A cognitive skills training course (Nuffield Department of Orthopaedics, University of Oxford, UK) involving didactic lectures, surgical demonstrations, and workshops was also found to be useful, although the authors could not clarify whether improvement in cognitive ability (as assessed by 2 questionnaires and an MCQ style examination) was purely related to undertaking the course.[58] The results of these studies were therefore promising overall. However, given that improvement was found only for the less experienced group in a study,[60] and improvements in cognitive skills for a separate study may not have been due to the training course at all,[58] universal success may not always be achieved when using these training tools. More research therefore needs to be undertaken in cognitive skills training specifically.

Decision-Making Skills

Studies evaluating decision-making skills training have included the use of simulation,[61] a decision-making training course (Department of General Surgery, University of British Columbia, Vancouver, Canada) consisting of didactic lectures, animal laboratories and short answer question examinations,[62] multimedia tools,[63,64] and the Surgical Decision-Making Rating Scale (SDMRS)[65] (Department of Urology, McMaster University, Ontario, Canada). They have all provided favorable results with regard to improving surgical decision-making[64,65] and have shown good construct validity when tested.[62] Studies have shown their educational benefit,[63,64] in light of improved decision-making performance from using these tools.[65]

Leadership Skills

Leadership skills training can be achieved by using the nontechnical skills taxonomy, known as The Surgeon's Leadership Inventory (SLI)[66-68] (School of Psychology, University of Aberdeen, Aberdeen, UK) or the Multifactor Leadership Questionnaire (MLQ)[66] that consists of 45 items of leadership and effectiveness behaviors. Both have been shown to have good interrater reliability.[66-68] Although there has been no definitive proof of the validity of either, the Surgeon's Leadership Inventory has been studied to a greater extent.[66-68] Further studies are therefore required to grant its validity status (as face validity was unable to be confirmed); however, it is currently the most effective tool available to provide performance feedback on the surgeon's leadership ability.[68]

Communication Skills

Communication skills training can be achieved through a specific simulation-based curriculum (Surgical Research and Educational centre, Faculty of Medicine of Marseille, France) that was shown to improve the communication skills of the participants.[69] Further validation of the curriculum is required, however.

Situational Awareness

Situational awareness can be trained using the Remote Analysis of Team Environments (RATE) tool[70] (Department of Systems and Information Engineering and Department of Surgery, University of Virginia, Charlottesville, USA). This uses video recorded feedback to score and analyze a team's performance for training purposes.[70] It has been shown to improve situational awareness skills; however, it requires further validation.

Recommendations

As can be seen by the OCEBM levels of evidence in Tables 3-14, study quality was mixed with a large proportion of low- and medium-quality studies.

Randomized trials were found to be of relatively good quality, demonstrated by the moderate-to-high JADAD scores; however, they were not numerous enough to base solid recommendations on them.

Furthermore, on analysis, we have been able to conclude that all bias identified across the studies is unlikely to significantly affect the outcomes of this review; however, the low number of randomized studies prevents us from drawing more robust conclusions.

The recommendations for training tools have been based on the OCEBM levels of evidence analysis. Table 16 provides levels of recommendation based on the OCEBM levels of evidence,[7,8] which have been provided in the critical analysis section of Tables 3-14.

The training tools included are those that have shown validation and consistent results across multiple studies. Training tools that were only found to be included in 1 study have not been considered for recommendation, pending future comment on their status of validity. For the same reason, we have also refrained from including training courses and programs in our recommendations, owing to the fact that each course is unique and individual.

To obtain the highest level of recommendation, Level 1, the evidence must have been based on 1 systematic review (1a) or at least 2 independently conducted research projects (1b).[8] Studies with a level of evidence of less than level 3 were omitted from our recommendations (supposing that further studies of a greater level of evidence using the same tool could not be found).

Based on analysis, 6 studies can be recommended as training tools for nontechnical skills. NOTSS and Oxford NOTECHS were given a level 2 recommendation (defined by the OCEBM levels of evidence table as based on at least 2 independently conducted research projects classified as level 2a or 2b), whereas NOTSSdk, OTAS, Oxford NOTECHS II, and Surgeon's Leadership Inventory were recommended at level 3 (defined by the OCEBM levels of evidence table as based on 1 independently conducted research project level 2b, or at least 2 trials of level 3).

TABLE 16. OCEBM Level of Recommendation for Training Tools

Tool	Recommendation
NOTSS[6,16,34-42,71-74,87-90]	Level 2
NOTSSdk[31-33]	Level 3
OTAS[14,21,25-27,34,74,79]	Level 3
Oxford NOTECHS[11-16,52,91,92]	Level 2
Oxford NOTECHS II[17-20]	Level 3
Surgeon's Leadership Inventory[66-68]	Level 3

Limitations, Funding, and Conflict of Interest

The heterogeneous study designs of studies included in this systematic review is a limit to complete analysis. As can be the case with any literature search, articles may have been overlooked during title selection, but all measures were taken to minimize this. By focussing entirely on interventions for surgeons, and surgical teams including a surgeon, training tools targeting other team members (such as an anesthetist) will not have been included. We do not believe this to be a source of bias, as our inclusion and exclusion criteria target articles with the surgeon as the main focus. The quality of studies reviewed was mixed, with only a small number consisting of randomized controlled trials. Bias was included in the critical analysis sections for all studies in which it was identified, as it has the potential to produce erroneous conclusions.

No funding was received for this systematic review.

One author of this review was the primary author of 2 curricula[71,72] identified in the data extraction table. No other author of this review has authorship or ownership over any of the nontechnical skill behavioral marker systems or training programs identified in this study.

CONCLUSION

A collection of training tools for surgical nontechnical skills exist that can be considered useful, effective, and ready for use in surgical training. However, there are a large number of training tools that are grounded in single studies designed for their initial development, and they therefore lack validity. Future studies should aim to further investigate these training tools and validate them for use in nontechnical skills training.

NOTSS[30] is the gold standard training tool for nontechnical skills for the individual surgeon. It can be highly recommended based on the quality of studies performed, and the consistent status of validity it has achieved across multiple studies.

Regarding team-focussed nontechnical skills training, there is little to separate Oxford NOTECHS,[11-16] Oxford NOTECHS II,[17-20] and OTAS.[21] The validity statuses reported would indicate that Oxford NOTECHS II[17-20] is perhaps the most favorable. The only nontechnical skills training tool for a specific domain able to be recommended is the Surgeon's Leadership Inventory,[66-68] used for surgical leadership training.

Nontechnical skills are recognized to contribute significantly to surgical safety and promote beneficial outcomes.[2-4] The valid training tools outlined in this systematic review can be considered as suitable training methods to maximize this objective.

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SUPPLEMENTARY MATERIAL

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