Systematic review

Training situational awareness to reduce surgical errors in the operating room

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Background: **Surgical errors result from faulty decision-making, misperceptions and the application of suboptimal problem-solving strategies, just as often as they result from technical failure. To date, surgical training curricula have focused mainly on the acquisition of technical skills. The aim of this review was to assess the validity of methods for improving situational awareness in the surgical theatre.**

Methods: **A search was conducted in PubMed, Embase, the Cochrane Library and PsycINFO® using predefined inclusion criteria, up to June 2014. All study types were considered eligible. The primary endpoint was validity for improving situational awareness in the surgical theatre at individual or team level.**

Results: **Nine articles were considered eligible. These evaluated surgical team crisis training in simulated environments for minimally invasive surgery (4) and open surgery (3), and training courses focused at training non-technical skills (2). Two studies showed that simulation-based surgical team crisis training has construct validity for assessing situational awareness in surgical trainees in minimally invasive surgery. None of the studies showed effectiveness of surgical crisis training on situational awareness in open surgery, whereas one showed face validity of a 2-day non-technical skills training course.**

Conclusion: **To improve safety in the operating theatre, more attention to situational awareness is needed in surgical training. Few structured curricula have been developed and validation research remains limited. Strategies to improve situational awareness can be adopted from other industries.**

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Introduction

Modern teaching curricula aim to produce competent professionals in educationally efficient and safe environments[1]. It is commonly assumed that a high level of technical skill predicts the ability of surgeons to perform safe surgery. Training technical skills is therefore often seen as the most important strategy to reduce adverse events in surgery[2,3]. Use of structured assessment scales has improved the objectivity of assessing technical skills[4,5]. Furthermore, laparoscopic[6] and endovascular[7] virtual reality simulators have been shown to be effective tools for teaching technical surgical skills.

To date, teaching curricula do little to incorporate cognitive factors. Errors in the surgical theatre are in fact more likely to result from perceptual or judgemental errors, than from poor surgical technique[8]. Procedural outcome of supervised residents is not associated with more complications than that of skilled surgeons[9,10]. Surgical errors are often caused by errors of judgement, carelessness[11], incomplete understanding of the situation[11], failure of vigilance[8] and misperceptions[12]. Impaired recognition during surgery frequently results in errors, even though the surgeon's technical skills are of a high standard[11,13,14]. From a psychological perspective, functioning in complex situations is related to an individual's perception of key elements in that situation[15]; failure of this situational awareness inevitably leads to inaccurate decisions.

Situational assessment results from a multitude of information sources in the modern surgical theatre. The perception of reality is not always accurate in such complex, continuously evolving situations. This is caused by cognitive, communication, teamwork and environmental factors (*Fig. 1*). The human mind has inherent information-processing limitations under specific circumstances, referred to as inattentional blindness and change

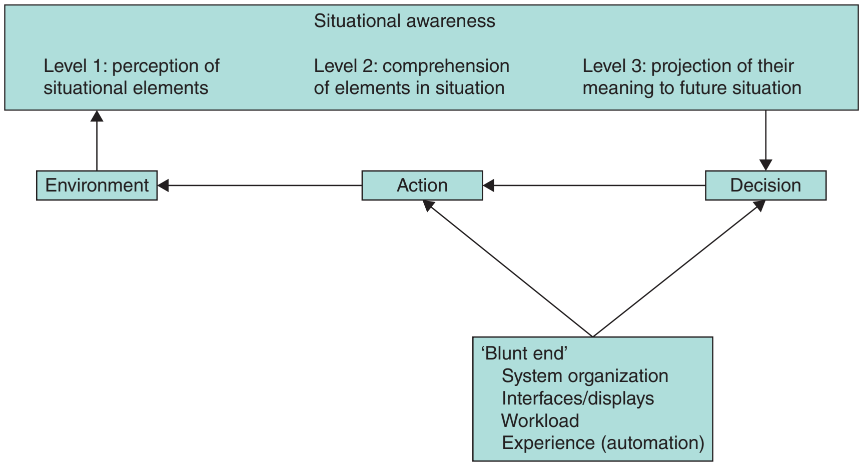

Fig. 1 Elements contributing to situational awareness in the operating room

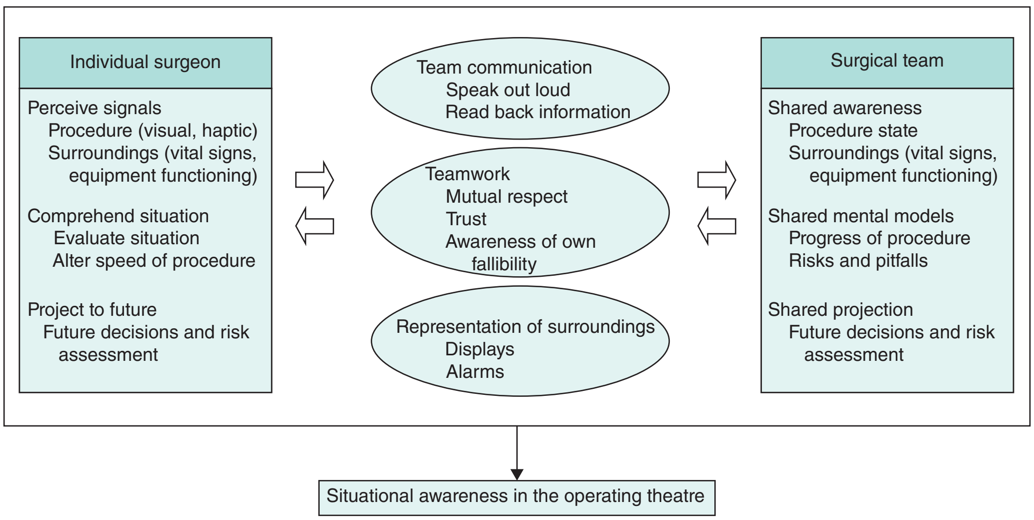

Fig. 2 Endsley's model of situational awareness in complex dynamic environments

blindness. Situational awareness can be viewed as the product of an individual's perception and comprehension of the available information, and expectations towards the future course of the procedure[15] (*Fig. 2*). Situational awareness is thought to occur at both individual and team level, both relying heavily on teamwork and communication[16].

Failure to maintain situational awareness inevitably leads to impaired judgement with potentially harmful outcome. Mishra and colleagues[17] showed a strong and independent correlation between surgeons' situational awareness and their technical outcome in a series of 26 consecutive laparoscopic cholecystectomies. Way and co-workers[12] assessed 252 bile duct injuries after cholecystectomy and concluded that the majority of such injuries stem from incomplete recognition of abnormal situations.

Structured training and assessment of situational awareness is currently lacking in surgical residency training curricula[13,18]. This systematic review explores the opportunities to improve situational awareness in the context of the surgical theatre. The aim was to assess the validity of the interventions described, according to the customary validation criteria[19].

Methods

Search and study selection

A systematic search was performed of peer-reviewed studies on methods to improve or train situational awareness in the surgical theatre. The aim was to assess the effectiveness of the interventions in terms of validity criteria[20]. Methods

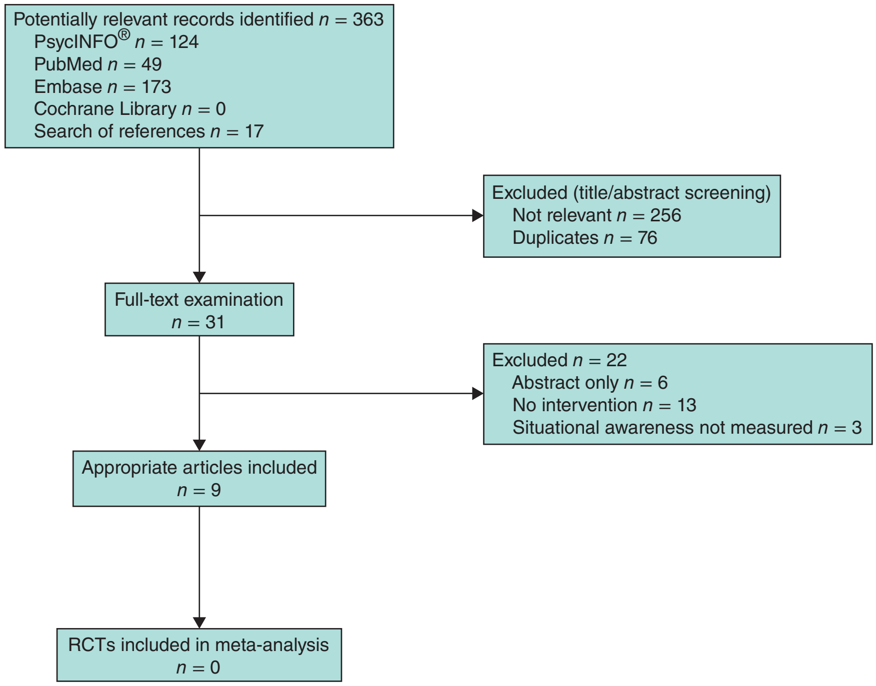

Fig. 3 Flow chart showing selection of articles for review. RCT, randomized controlled trial

should specifically include the surgical team and/or the primary surgeon. Studies that included settings other than the surgical theatre were excluded. All study types were considered eligible.

The search included PubMed, Embase, the Cochrane Library and PsycINFO® (American Psychological Association) using the terms 'situational awareness', combined with 'training', 'improvement', 'education', 'surgery' and 'operation' up to June 2014. A hand search of references for relevant articles was performed. No exclusion criteria were applied. All articles deemed relevant, dubious or unknown were examined in full text.

Review

From relevant studies, data on study setting, methods for improving situational awareness, study design, outcome assessment, results and conclusions were extracted into an electronic database. The predominant question in validity research is the extent to which the training method improves what it intends to improve. Validity was assessed using previously described criteria[21]. Five main types are described in a validity process (content, face, construct, concurrent and predictive validity).

The quality of relevant studies and risk of bias was assessed using the Methodological Index for Non-Randomized Studies (MINORS), a validated instrument assessing 12 items (8 for non-comparative studies)[22].

Results

The search identified 287 potentially relevant articles; nine were suitable for inclusion (*Fig. 3*, *Table 1*)[23–31]. Seven articles described crisis management training in simulated operating theatres, and two described a non-technical skills training course. None of the studies described interventions other than training methods. Eight articles[23,25–31] reported prospective cohort studies and one[24] a cross-sectional survey. None of the studies was randomized. The studies were small (minimum 10, maximum 83 participants). Systematic assessment for risk of bias revealed one study with a low risk of bias, six with moderate and two with a high risk (*Table S1*, supporting information). Pooling of data was not performed owing to heterogeneity of the study designs, outcome measures and settings.

Training situational awareness in minimally invasive surgery

Four studies[23,25,29,30] described crisis training for surgical teams in minimally invasive surgery (*Table 1*). In a simulated surgical environment using high-fidelity simulators and mannequins, critical events were simulated. Abdelshehid and colleagues[23] performed a prospective cohort study in which non-technical skills of nine urology residents were analysed and stratified according to their experience. The

Table 1 Summary of included studies

Reference	Participants	Intervention	Study design	Conclusions
Abdelshehid *et al.*[23] (2013)	MIS teams (9 urology residents, 7 anaesthesia residents)	Surgical crisis training for MIS teams in HF simulator	Prospective cohort study. Non-technical skills of junior and senior urology residents compared during simulated laparoscopic partial nephrectomy (at individual level)	Construct validity for training SA at individual level
Flin *et al.*[24] (2007)	Surgeons (21 licensed surgeons)	Non-technical skills course for surgeons (lectures, videos), including SA	Cross-sectional survey. Course evaluation on attitudes, relevance and usefulness	Face validity for improving non-technical skills (including SA) at individual level
Gettman *et al.*[25] (2009)	19 urology residents	Surgical crisis training for MIS teams in HF simulator	Prospective cohort study. Before and after test. Non-technical skills assessment on custom scale (5-point Likert, at individual level)	Inadequate design for conclusions on validity for SA training at individual level
McCulloch *et al.*[26] (2009)	Surgical teams (83 surgeons, anaesthetists, operating theatre nurses)	Non-technical skills course for surgical teams hospital-wide (lectures, videos), including SA	Historical prospective cohort study. Team performance compared before and after intervention. Outcome measured in operating theatre setting (non-technical skills and technical performance)	Construct validity for improving problem-solving and teamwork; not for SA
Moorthy *et al.*[27] (2005)	27 surgical trainees	Surgical team crisis training in vascular surgery teams in HF simulator	Prospective cohort study. Performance compared at individual level between junior, intermediate and senior trainees on non-technical skills	Construct validity for leadership training; no construct validity for SA training at individual level
Moorthy *et al.*[28] (2006)	20 surgical trainees	Surgical team crisis training in vascular surgery teams in HF simulator	Prospective cohort study. Performance compared at individual level between junior and senior trainees on non-technical skills	No construct validity for SA training at individual level
Powers *et al.*[29] (2008)	10 surgeons and surgical trainees	Surgical crisis training for MIS residents in HF simulator	Prospective cohort study. Performance compared between experienced and inexperienced trainees on non-technical skills at individual level	Construct validity for SA training at individual level
Powers *et al.*[30] (2009)	12 surgeons	Surgical crisis training for MIS surgeons in HF simulator	Prospective cohort study. Performance compared between experienced and ‘seasoned’ surgeons on non-technical skills at individual level	Inadequate design for conclusions on validity for SA training at individual level
Undre *et al.*[31] (2007)	17 surgeons, 17 anaesthetists, 13 ODPs, 18 nurses	Surgical team crisis training in vascular surgery teams in HF simulator	Prospective cohort study. Performance compared between experienced and inexperienced trainees on non-technical skills at individual level	Inadequate design for conclusions on validity for SA training at individual level

MIS, minimally invasive surgery; HF, high-fidelity; SA, situational awareness; ODP, operating department practitioner.

senior resident group showed significantly better situational awareness at individual level than the junior group, proving that the training environment has adequate construct validity for assessing situational awareness among trainees. Powers *et al.*[29] carried out a prospective cohort study in which ten surgeons were assessed in a similar setting. Experienced surgeons performed significantly better than inexperienced trainees on situational awareness at individual level, indicating the method's construct validity for assessing situational awareness in the surgical theatre. Studies by Gettman and co-workers[25] and Powers *et al.*[30] did not provide information on the validity of the training methods applied.

Training situational awareness in conventional surgery

Three studies[27,28,31] described crisis training for surgical teams using a model for a saphenofemoral junction ligation. Moorthy and co-workers[27] compared non-technical performances of 27 junior, intermediate and senior surgical trainees during one scenario of surgical bleeding. They found significant differences at an individual level in leadership skills, but not in situational awareness. Moorthy *et al.*[28] performed a second study in which they used the same model to train and assess non-technical performances of 20 junior and senior trainees. Again, no differences in non-technical skills were found. The study by Undre *et al.*[31], using the same training setting to teach surgical teams non-technical skills at individual level, did not provide information on the validity of the method applied.

Non-technical skills training courses

Two studies[24,26] described training courses for non-technical skills, using lectures, videos and discussions. McCulloch *et al.*[26] applied a hospital-wide non-technical skills programme, in which 83 members of surgical teams were enrolled (surgeons, anaesthetists, operating theatre nurses). They evaluated non-technical performances at team level, technical and procedural errors, and complications after laparoscopic cholecystectomy and carotid artery surgery before and after the 9-h training course. They found significantly fewer procedural and technical errors, predominantly in minimally invasive surgery. Although teams scored significantly better in problem-solving and teamwork skills afterwards, situational awareness did not change significantly. There was a high independent correlation between technical errors and surgical team situational awareness ratings[26]. Flin *et al.*[24] enrolled 21 licensed surgeons in a 2-day non-technical skills training course that encompassed lectures on situational awareness. The majority of the surgeons rated the course as useful and relevant to their everyday work. However, there were no specific outcome measures.

Not all articles described training strategies. Two[32,33] described an intervention aimed at improving information displays in the operating room to create improved shared awareness of the surgical team concerning the procedure. One study[16] described methods to improve distributed communication between cardiac surgeons and the operating theatre personnel. Because these articles did not describe a scientific evaluation study, they could not be included in the analysis.

Discussion

Surgeons are ultimately responsible for a patient's safety during the perioperative process, including possible technical errors as well as errors originating from the operating room environment. Whereas surgical residency programmes focus on teaching technical skills, a major part in the surgeon's experience is related to decisions and judgements[34]. Surgical team crisis training is an acceptable and reliable method of assessing trainees' situational awareness in minimally invasive surgery. No validated training methods were found for training situational awareness in open surgical procedures. A possible explanation could be that the simulated single-scenario crisis training in the respective studies proved insufficient for adequate measurement or improvement of situational awareness[27,28].

Correct situational assessment and subsequent handling is a key component for the surgeon to manage a complex procedure successfully. The modern surgeon requires the ability to filter relevant information in order to perceive situational deviations correctly. This is especially relevant to laparoscopic and natural orifice transluminal endoscopic surgery[35,36], and it is therefore not surprising that most research has been piloted in these settings. Most misperceptions of anatomical landmarks, equipment failure and physiological state of the patient occur when the mental workload is high. The increase in electronic systems, displays and operating room technology has drastically enlarged the mental workload of the modern surgeon. It is difficult to filter out relevant signals from the data clutter while focusing on performing surgery. For surgical residents, gaining proficiency regarding situational awareness currently occurs by gaining clinical experience. This Halstedian approach should be a topic of debate to the same extent as it is in technical skills training[37].

Training for non-routine events (abnormal anatomy, surgical crises and instrumentation problems) could be more effective in improving residents' vigilance, task management and diagnostic reasoning[18,38]. Dedy and colleagues[39] proposed a model for comprehensive simulation training for surgical residents that includes cognitive, technical and non-technical skills training, before commencing surgery in the operating theatre. Furthermore, serious games have also been suggested as promising methods for non-technical skills training. Serious games are video game-based training environments that do not require an extensive simulated operating theatre[21].

This study shows that no situational awareness-directed training methods have been validated fully or implemented in surgical curricula. Most of the studies emphasize situational awareness improvements at an individual level. To enhance surgical crisis management training, strategies from other industries could be of value[40,41]. Training effective task management strategies[42], dealing with non-routine events[41,43], planning and preparation strategies[44], and rechecking information on which a procedural strategy is based, are considered effective ways to prevent or deal with inappropriate perceptions in the airline industry[41].

It has become clear that a surgical team's situational awareness emerges from coordination and communication of the surgical team[16,45]. More emphasis on teamwork and communication styles should become part of situational awareness-directed training methods.

A different strategy to improve the surgical team's situational awareness could be to integrate information for all operating team members into one system with a single visual display. Parush and colleagues *et al.*[32] described the development of an augmentative display for the cardiac surgery theatre, integrating patient information, vital signs, procedure progress and main event taking place, all in one screen. This aims to improve team situational awareness and reduce communication breakdowns. Wearable technology using head-mounted displays (such as Google Glass™; Google, Mountain View, California, USA) could place this monitor directly in the surgeon's field of vision[46]. Although evidence on display design in operating rooms remains scarce in terms of patient-related outcomes, shared displays of this sort significantly reduce decision-making time in aviation teams[47].

This study has several limitations. First, the studies identified were small, and the risk of bias was moderate or high in eight of nine studies. Therefore, the strength of conclusions concerning the validity of the training methods is limited. Practical concerns play a part in small participant numbers, whereas high-fidelity simulation operating theatres are costly. Additionally, situational awareness can be measured only by structured rating scales and by trained assessors.

Situational awareness in the surgical theatre depends on many individual and team-related factors and should not be confused with the ability of the surgeon. Such a viewpoint could potentially result in a renewed blame-and-shame culture similar to that in aviation, where individual pilots were increasingly being held responsible during calamities[48].

Given other advances in surgery, now is the time to set a stronger focus on improving situational awareness, in both training and surgical practice. Surgical team crisis management training using simulators and serious games should be integrated into surgical residency programmes. Technological innovations that integrate data from different sources could be used to declutter information and give timely warnings to surgeons. Evidence is mounting that improving situational awareness in surgical theatres leads to better surgical outcomes.

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Supporting information

Additional supporting information may be found in the online version of this article:

Table S1 Strength of included studies (Word document)