Original Communications

The impact of stress on surgical performance: A systematic review of the literature

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Background. *Safe surgical practice requires a combination of technical and nontechnical abilities. Both sets of skills can be impaired by intra-operative stress, compromising performance and patient safety. This systematic review aims to assess the effects of intra-operative stress on surgical performance.*
Methods. *A systematic search strategy was implemented to obtain relevant articles. MEDLINE, EMBASE, and PsycINFO databases were searched, and 3,547 abstracts were identified. After application of limits, 660 abstracts were retrieved for subsequent evaluation. Studies were included on the basis of predetermined inclusion criteria and independent assessment by 2 reviewers.*
Results. *In all, 22 articles formed the evidence base for this review. Key stressors included laparoscopic surgery (7 studies), bleeding (4 studies), distractions (4 studies), time pressure (3 studies), procedural complexity (3 studies), and equipment problems (2 studies). The methods for assessing stress and performance varied greatly across studies, rendering cross-study comparisons difficult. With only 7 studies assessing stress and surgical performance concurrently, establishing a direct link was challenging. Despite this shortfall, the direction of the evidence suggested that excessive stress impairs performance. Specifically, laparoscopic procedures trigger greater stress levels and poorer technical performance (3 studies), and expert surgeons experience less stress and less impaired performance compared with juniors (2 studies). Finally, 3 studies suggest that stressful crises impair surgeons' nontechnical skills (eg, communication and decision making).*
Conclusion. *Surgeons are subject to many intra-operative stressors that can impair their performance. Current evidence is characterized by marked heterogeneity of research designs and variable study quality. Further research on stress and performance is required so that surgical training and clinical excellence can flourish. (Surgery 2010;147:318-30.)*

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Quality and safety have become increasingly crucial elements of modern surgical practice. A "systems view"[1,2] acknowledges technical skill[3] as well as "nontechnical skills" (which include communication,[4] teamwork,[5,6] and decision making[7]) as important determinants of performance in the operating room and, therefore, of patient outcome. All these skills, however, can be compromised by the acute mental stress experienced by the surgeon during an operation. This review posits that such intra-operative stress is thus a key component of surgical performance and that its effective management is a vital facet of a surgeon's competence that affects patient safety directly.

Stress refers to the bodily processes that result from circumstances that place physical or psychologic demands on an individual.[8] Although a certain degree of stress can facilitate task performance,[9] it becomes problematic when the demands outweigh the perceived resources to cope.[10] Excessive levels of intra-operative stress can thus compromise both technical and nontechnical skills.[11,12] This concern is relevant because surgery is inevitably a stressful enterprise. Commonly recognized stressors include

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technical complications,[12] time pressure,[11] distractions, interruptions,[13,14] and increased workload.[15] Initial evidence suggests that although newer surgical techniques, such as laparoscopic and robotic surgery, may result in better patient outcomes, they are often of greater duration and more physically and mentally challenging than traditional open surgery.[16,17]

Being able to operate effectively under such stress-inducing conditions is a hallmark of expertise, and developing such skills should form part of the overt curriculum for surgical training. The surgical community has started to take steps in this direction. For example, the new Intercollegiate Surgical Curriculum in the United Kingdom explicitly includes (and assesses) skills such as clinical judgment and teamwork.[18] These nontechnical skills are key for the management of stressful situations that a trainee may face in the operating room. Moreover, modern surgical education actively encourages self-reflection.[19] These developments are encouraging, and the fact that novice surgeons are receiving training on cognitive and behavioral skills is likely to serve them well when faced with stressful intra-operative crises.[20]

Despite these developments, however, stress is still underacknowledged within the surgical community. Although mentored, trainees are not typically offered explicitly designed training programs that will allow them to learn and practice the various skills in stress-management safely. Such a lack of systematic training can result in surgeons who may be (and feel) poorly prepared for the complex demands of the operative environment.[19] In contrast, high reliability, safety-critical industries (such as aviation and the military) have long acknowledged that even the performance of experienced operators can deteriorate rapidly under stress; these groups have put suitable training programs in place to mitigate its effects.[20,21] Anesthesia has also pioneered crisis training for anesthetic trainees.[22,23]

Surgery has yet to catch up with these developments. To date, there has been no systematic evaluation of the impact of intra-operative stress on surgical performance. Consequently, there is no evidence base to inform the focus, design, implementation, and evaluation of stress/crisis management programs for surgeons, nor any recognition by trainees and program directors that such programs are needed.[24] This review was designed to fill this lacuna.

AIMS

This article aims to review the literature on stress and intra-operative performance systematically, drawing on evidence from surgery, psychology, and human factors research. It addresses the following questions:

1. What are the key stressors that affect surgeons in the operative environment?
2. What methods/tools are used to measure acute stress in surgery?
3. What are the effects of stress on surgical performance?

METHODS

Search strategy. Databases searched included MEDLINE (1965–April 2008), PsycINFO (1967–April 2008), EMBASE (1980–April 2008), and the Central Cochrane Register of Clinical Trials (issue 4, 2005) for trials indexed in 2004. In addition, the "gray literature" was searched to include conference proceedings. The search was triangulated by reviewing the reference lists of all retrieved relevant articles for additional articles. All retrieved articles were reviewed by 1 of the reviewers (S.A.) who screened the titles and abstracts to identify the relevant studies. The last search was conducted on May 15, 2008.

The search strategy employed the following terms (Medical Subject Heading terms and text words) with the appropriate combinations:

Category A = "Stress" (MeSH) OR "stress training" OR "stress management" OR "stress intervention" OR "crisis management" OR "crisis training" AND Category B = "surgeon$" (MeSH) OR "surgical skill$" OR surgical performance" OR "surgical training" OR "surgical competence" OR "surgical education"

After combining category A and category B, limits were imposed to restrict studies to those carried out on human subjects and reported in English language. An initial screen revealed that many studies were related to stress incontinence and stress fractures. Subsequently, the following additional limits were introduced: NOT patient, NOT incontinence, NOT fracture, NOT bone, NOT fixation, NOT replacement.

Inclusion criteria. Retrieved articles were only included if they met the following inclusion criteria by addressing:

1. *Acute stress in surgeons*: Literature describing the long term effects of stress, including health risks to the surgeon (increased cardiovascular disease[25] and burnout[15]), was excluded.
2. *Empiric evidence for impact of stress on performance*: This review is confined to articles reporting empiric data relating to the impact of stress on surgical performance.
3. *Mental and cognitive aspects of stress*: Articles relating to physical stress (such as monitor height during laparoscopic surgery causing physical stress) have been excluded.

Two reviewers (S.A. and N.S.) independently identified and screened the search findings for potentially eligible abstracts, and full articles were obtained for detailed evaluation. Any disagreements during the selection process were resolved by discussion with a third author (R.L.K.).

Data extraction. A data extraction form (available on request) was generated. Before starting data extraction, 2 reviewers (S.A. and N.S.) evaluated 10 articles independently to ensure reliability. Subsequently, 1 reviewer (S.A.) carried out the data extraction for all retrieved articles. For quality-assurance purposes, another reviewer (R.L.K.) reviewed a random sample of 5 articles using the same form. The data fields covered on the form are the fields presented in Table I. The heterogeneity of study designs and results prevented direct comparison and statistical pooling of the data. Instead, a critical evaluation of each study was conducted by the reviewers.

RESULTS

Selected articles. The search yielded 3,547 citations, of which 2,887 articles were excluded after limits were applied. During the process of study selection, 619 of the remaining 660 abstracts did not fit the inclusion criteria and were excluded. Of the remaining 41 articles, 13 were removed because of duplicate publication across different databases. The full texts of the remaining 28 articles were evaluated in detail, and another 6 articles were eliminated as not meeting our inclusion criteria. This left a total of 22 articles included in the final analysis. The flow of articles through the selection process is depicted in the Figure.

The remainder of this results section is organized as follows: Table I presents the characteristics of the included articles, the key stressors, and the methods used to measure them, as well as measures of performance and limitations of the studies. Table II (which appears in the online version) then presents a detailed picture of the observed stress levels and their impact on technical and nontechnical performance in the reviewed studies. The contents of both tables are discussed in the relevant sections below.

Areas covered by included studies. *Surgical specialty and level of expertise*: Reported studies were carried out within general (n = 12), ophthalmic (n = 2), cardiothoracic (n = 1) and plastic (n = 1) surgery. Six studies compared surgeons with other professionals—including musicians,[26] nurses,[27,28] anesthetists,[29] ODPs (ie, anaesthetic assistants),[29] and pilots.[30]

Methodologies: Most articles were prospective experimental studies (n = 14). Four studies were

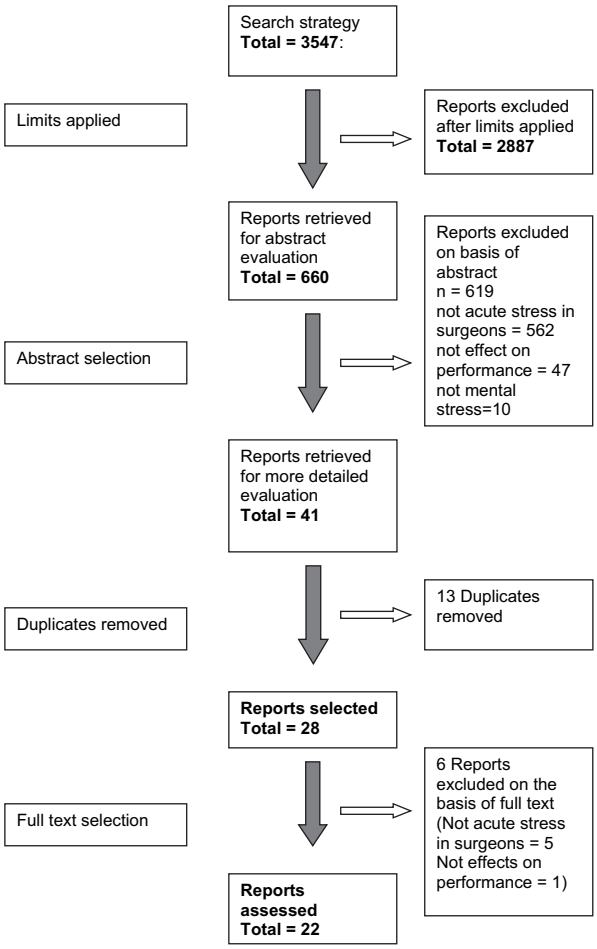


Figure. Flow of articles in study.

prospective observational studies, 1 study involved a cross-sectional survey,[30] and 2 were qualitative interview studies.[11,12]

Terminologies used: Twelve studies aimed explicitly to examine "stress." Alternative terminologies used include "mental strain,"[31,32] "mental workload," "emotional state,"[33] and "surgical crisis"[29,34] (these studies were also included in this review, as they were identified by the search strategy).

Stressors. Potential stressors identified by the studies included operating itself (versus ward work,[31] office work,[35] and not being at work[26]). The role of the surgeon (ie, primary operator or assistant) was identified as a potential stressor in 3 studies,[31,32,35] whereas the level of experience was investigated as a potential cause of stress in 8 studies. Laparoscopic surgery was a common potential stressor, compared with robotic surgery [17,32] and open surgery.[16,32] Other technical stressors include complexity of a procedure,[19,26,28] bleeding,[29] and equipment problems.[11,29] Nontechnical sources of stress include distractions,[36] time pressure,[36]

Table I. Characteristics of studies, stressors, and measures of stress and performance

Authors	*Subjects and specialty*	*Methodology and setting*	*Aim*	*Stressor*	*Measure of stress*	*Measure of performance*	*Limitations* Italics = recognized by author *Not in italics = our critical appraisal*	*Author conclusions*
Arora et al 2008[12]	15 surgeons	Qualitative interview study, not in operating room	1.To identify key stressors and coping strategies 2. To determine surgeons' requirements from training program	1. Technical factors 2. Patient factors 3. Team factors 4. Time factors 5. Distractions 6. Lack of experience	1. Self-report	1. Self-report	*1. Reluctance to talk about stress* *2. Insight into own performance may be lacking*	Stress affects technical and nontechnical skills. Surgeons would welcome a training program.
Becker et al 1983[31]	10 surgeons: 5 senior, 5 junior	Prospective experimental study, real operating room	1. To determine if there is a rise in HR during operating and if it is due to increased mental strain	1. Operating versus ward work versus leisure versus sleep 2. Role of surgeon: primary or assistant	1 24 h ECG recording to give mean and max HR 2. Mean oxygen consumption	Not measured	1. No direct measure of stress experienced by the surgeon or of performance 2. No *P* values reported although "significant difference" quoted between HR on wards and in operating room 3. Used HR as a measure which may rise due to other factors	Raised intra-operative HR unlikely to be due to mental stress. Senior surgeons adapted to stress.
Berguer et al 2006[47]	28 general surgeons attending conference	Prospective experimental study, laparoscopic task	1. To determine if laparoscopic surgery is more stressful than open	1. Laparoscopic versus robotic surgery	1. Skin conductance level (SCL) 2. Ergonomics workstation used to record measures of physical stress (EMG)	1. Laparoscopic task time 2. Task-error 3. Physical measures (EMG signal from arm muscles)	*1. SCL finding not statistically significant* *2. Laparoscopic task not realistic of real surgical procedure* *3. Small sample size* 4. Ergonomics workstation not widely available	Stress maybe lower with robotic surgery.
Berguer et al 2001[16]	10 general surgeons attending conference	Prospective experimental study, laparoscopic task	1. To compare mental and physical workload in laparoscopic versus robotic surgery	1.Laparoscopic (video-endoscopic) versus open surgery 2. Experience of surgeon	1. SCL 2. Electrooculogram 3. Self-report: concentration 4. Self-report: mental stress	1. No of knots tied on laparoscopic task on bench station	1. Ergonomics workstation not widely available	Laparoscopic surgery more stressful than open.
Bohm et al 2001[32]	2 general surgeons, experienced and inexperienced	Prospective experimental study, real operating room	1. To determine whether mental strain differs during laparoscopic and open surgery	1. Laparoscopic surgery versus open surgery 2. Experience of surgeon 3. Role of surgeon: primary or assistant	1. Heart rate variability (HRV)	1. Mean operative time	1. HRV could be due to physical part of operation 2. Small sample size 3. *No upper critical limit for mental strain* 4. No correlation between stress and operative time	Laparoscopic surgery causes more mental strain than open. Inexperienced surgeons and primary surgeons experience more mental strain.

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Table I. (*continued*)

Authors	Subjects and specialty	Methodology and setting	Aim	Stressor	Measure of stress	Measure of performance	Limitations Italics = recognized by author Not in italics = our critical appraisal	Author conclusions
Czyzewska et al 1983[33]	7 general surgeons	Prospective observational study, real operating room	1. To evaluate cardiac arrhythmia, for changes during decision making 2. To evaluate emotional state	1. Surgical procedure/ different stages of operation: skin incision versus actual operating versus closing versus postoperative (control)	1. ECG recordings to give indices of cardiac arrhythmia – HRV 2. modal value of R-R intervals to measure tonus of ANS	Not measured	1. No measure of performance	Increased mental load during operating
Demirtas et al 2004[35]	12 plastic surgeons (5 staff, 7 resident)	Prospective experimental study, real operating room	1. To elucidate mental burden of surgeons 2. To determine impact of primary operator versus assistant on stress level	1. Operating versus office days (control) 2. Role of surgeon: primary versus assistant	1. HRV (LF, HF, HF/LF ratio and HR)	Not measured	1. Most procedures were rhinoplasties - not very stressful in themselves 2. Control was office days (ie, outpatients – this can be stressful in itself) 3. No correlation of stress and surgical performance	Operative stress associated with change in HRV HRV and sympathetic activity greater on operating days and for primary surgeons.
Hassan et al 2006[19]	12 final year medical students and 12 inexperienced residents	Prospective observational study, laparoscopic task	1. To explore impact of habitual stress coping strategies on laparoscopic performance	1. Difficulty of laparoscopic task 2. Distractions: "dull witted comments from investigators"	1. SVF78 stress coping questionnaire to assess negative stress coping strategies	1. Time to complete laparoscopic task 2 No of errors (sum of tissue damage and drop failure) 3. Economy of motion for each task	1. Coping with stress only through self-report; no objective measure 2. Study on laparoscopic task not real procedure 3. Only study to correlate performance with coping	Ineffective stress coping strategies and distractions correlate with poorer laparoscopic performance.
Jezova et al 1992	11 research workers, 18 surgeons, 15 musicians	Prospective experimental study, real operating room	1. To evaluate the stress response in surgeons and musicians using salivary cortisol (SC)	1. Operating versus nonwork day 2. Difficulty of procedure	1. Surgeons' salivary cortisol 2. Musicians' salivary cortisol	Not measured	1. Did not record the time sample taken for each subject; may vary 2. Did not compare cortisol to stress subjectively experienced 3. Did not explain what surgeons did on non work days (maybe stressful)	Cortisol levels higher on working day indicating higher stress. Cortisol levels in seniors higher for difficult operation No difference in cortisol between juniors and seniors.
Kikuchi et al 1995[27]	5 ophthalmic surgeons of varying experience and 7 nurses	Prospective experimental study, real operating room	1. To measure stress levels in surgeons and assistants	1. Surgical procedure; different stages of operation	1. Heart rate measured day before surgery, pre-operative, pre-incision, at various stages of procedure 2. ECG and BP (abandoned)	Not measured	1. Very small sample size so difficult to generalize 2. Only looked at HR	HR increases at start of surgery, HR is higher and changes more for inexperienced = higher stress.

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Table I. (*continued*)

Authors	*Subjects and specialty*	*Methodology and setting*	*Aim*	*Stressor*	*Measure of stress*	*Measure of performance*	*Limitations* Italics = recognized by author *Not in italics = our critical appraisal*	*Author conclusions*
Lee et al 2005	13 subjects: 4 medical students and 9 medical/surgical residents	Prospective experimental study, laparoscopic task	To compare manual and telerobotic endoscopic surgery in terms of postural and mental stress	1. Telerobotic versus manual surgery	1. Self-report questionnaire to measure perceived stress	1. Measures of physical stress	1. Cannot compare subjects (ie surgical residents have more experience) 2. No correlation of stress with performance 3. No objective measure of mental stress	No significant difference in mental stress between laparoscopic and telerobotic surgery
Moorthy et al 2003[36]	20 general surgeons divided into 10 senior and 10 junior	Prospective experimental study, simulated operating room	1. To develop a surgical crisis simulation 2. To evaluate its feasibility and validity	1. Distractions (mathematical task, operating room noise) 2. Time pressure 3. All 3 stressors combined	Not measured	1. Laparoscopic task: motion analysis (ICSAD path length) 2. Error score (dropped/inaccrate placement of objects)	1. No idea about previous laparoscopic experience of subjects 2. *Lab setting so difficult to replicate the operative environment* 3. No measure of stress	Time pressure, operating room noise, and mathematical tasks lead to poorer performance (impaired dexterity) and greater number of errors
Moorthy et al 2006[34]	13 general surgeons with varied level of experience	Prospective experimental study, laparoscopic task	1. To evaluate the effect of adverse conditions on surgical performance	1. Bleeding	Not measured	1. Time measure; time to diagnose bleeding (TD), to inform team members (TT), call for help (TH), achieve control (TC), close laceration (TL) 2. Blood loss 3. Global rating scale for assessment of technical skills 4. Observer notes 5. Human factors rating scale 6. Communication and utterance frequency	1. No details on immediate feedback offered 2. No construct validity for NOTECHS score 3. No measure of stress	Seniors have better technical skills, but not necessarily better human factors skills when encountered with stressor of bleeding.
Payne et al 1986[39]	8 cardio thoracic surgeons, 8 anaesthetists	Prospective observational Study, real operating room	1. To determine if HR responds to stress 2. To compare mean HR from 2 occupations	1. Operating	1. ECG used to measure HR		1. HR rise may be due to factors other than stress	Surgeons have higher HR than anaesthetists when operating.

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Table I. (*continued*)

Authors	Subjects and specialty	Methodology and setting	Aim	Stressor	Measure of stress	Measure of performance	Limitations Italics = recognized by author Not in italics = our critical appraisal	Author conclusions
Schuetz et al 2007[38]	18 general surgeons at a conference	Prospective experimental study, laparoscopic task	1. To investigate whether individual stress responses are associated with altered manual skills and technical errors	1. Distractions (mathematical task) 2. Bleeding 3. Time pressure 4. Increased volume of pulse oximitery and HR 5. Social stress: external visitor	1. Skin resistance with sympathicograph	1. Economy of motion in laparoscopic task (path length) and degree of deviation from normal pathway (angular path) 2. Intra -operative failures/ no of errors = blood loss, missing clips, vessels ripped	1. Do not describe difference between the groups in terms of baseline technical ability 2. *Small sample of group* *3. No self-report of stress*	Mental load may be optimized by continuous activity of SNS. Unclear as to what extent of stress produces adverse effects.
Sexton et al 2000[30]	1,033 doctors, 30,000 cockpit crew members	Cross sectional survey, not in operating room	1. To survey operating room, ICU staff, and airline crew regarding attitudes concerning error, stress, and teamwork	1. Attitude to stress	1. Cockpit management attitudes questionnaire 2. Operating room management attitudes questionnaire		*1. Small number of hospitals* *2. No responder bias* *3. Limited by reliance on self-report*	Medical staff deny effect of stress on performance.
Smith et al 2003[46]	10 general surgeons attending a conference	Prospective experimental study, laparoscopic task	1. To compare performance and workload (physical and mental) for manual versus robotic surgery, using ergonomics	1. Robotic versus manual laparoscopic surgery	1. EMG for physical stress 2. SCL for mental stress 3. Self-report of difficulty 4. Self-report of level of discomfort	1. Laparoscopic task time 2. Accuracy error (pin in correct circle) 3. Control error (pin falls down)	1. Small sample at a conference 2. Experience level of participants unknown 3. No ECG/HR recording 4. Poor performance in robotic may be attributable to no experience	Robotic surgery reduces stress levels but degrades performance.
Smith et al 2000[17]	28 general surgeons attending a conference	Prospective experimental study, laparoscopic task	1. To compare surgeons' mental workload during simulated open and laparoscopic surgery	1. Laparoscopic versus open surgery	1. SCL 2. EOG 3. Self-report of level of mental concentration 4. Self-report of level of mental stress	1. No of knots tied for laparoscopic task	*1. Eye blink rate cannot be used alone to indicate stress* *2.* Sample from a conference 3. No correlation	Laparoscopic surgery is more stressful than open with poorer performance.
Tendulkar et al 2005[37]	28 general surgical residents, 10 interns, 9 junior, 9 senior residents	Prospective experimental study, not in operating room	1. To monitor HR and WBC as a measure of stress on call 2. To relate maximum HR and WBC on call to surgical resident training level	1. Surgical "on call"	1. HR recorded by 24 h ECG 2. WBC		*1. HR can be affected by pre existing conditions; did not check* 2. Did not describe what subjects did on call 3. Did not describe if increased HR affected performance	Being on call increases stress. Inverse relationship of stress with level of training.
Undre et al 2007[29]	80 people in 20 surgical teams(general surgeon, anaesthetist, nurse, ODP)	Prospective observational study, simulated operating room	1. To develop a team training crisis management module in a SOT 2. To explore differences in nontechnical skills across professions	1. Bleeding 2. Equipment problems	Not measured	1. OSATS - trainee and trainer rating 2. NOTECHS modified to produce human factors rating scales	*1. Small scale pilot study* 2. Did not measure stress	MDT simulation team training feasible. Nontechnical and technical skills are affected by potential stressors.

(continued)

Table I. (*continued*)

Authors	*Subjects and specialty*	*Methodology and setting*	*Aim*	*Stressor*	*Measure of stress*	*Measure of performance*	*Limitations* Italics = recognized by author *Not in italics = our critical appraisal*	*Author conclusions*
Wetzel et al 2006[11]	16 surgeons	Qualitative interview study, not in operating room	1. To explore key surgical stressors, their impact on performance, and coping strategies used by surgeons	1. Complications (eg, bleeding) 2. Advanced tasks(time pressure) 3. Equipment problems 4. Distractions 5. Personal factors	1. Self-report	1. Self-report	1. All from 1 hospital 2. Interview study; surgeons reluctant to talk about stress 3. Reliance on self-report	Stress affects technical and non technical performance. Seniors have coping strategies.
Yamamoto et al 1999[28]	12 ophthalmic surgeons: 5 inexperienced, 5 intermediate, 2 experienced,and 3 nurses	Prospective experimental study, real operating room	1. To determine the intra-operative stress on surgeons and assistants during cataract surgery	1. Difficulty of procedure 2. Experience of surgeon 3. Live broadcast	1. HR recorded by wireless ECG 2. Urine adrenaline levels	Not measured	*1. Small sample size* *2. No controls* *3.* Performance not measured 4. Different procedure for junior and senior	Stress decreases with experience.

being on call,[37] external visitors in the operating room,[38] and having the operation being broadcast live.[28]

Measures of stress. No single best tool exists for measuring stress directly. Consequently, the only way to make an approximation of the level of stress is by measuring its effects, either on subjects' perceptions of themselves (subjective measures) or on their physiologic state (objective measures).

Objective (physiologic) measures of stress: Heart rate (HR). The normal physiologic response to stress ("fight or flight") results in an endogenous catecholamine release leading to increased cardiac activity, which can be determined by measuring the HR. Six studies[27,28,31,33,37,39] used HR as a proxy measure for stress. The mean HR was found to increase during a procedure,[31,39] and the mean HR for senior surgeons was less than that of their junior colleagues.[27]

Heart rate variability (HRV) is the oscillation in the interval between consecutive heart beats[32,35,40] and an indicator of the sympathovagal balance during operation.[41] Because stress is linked to increased sympathetic and parasympathetic activity,[42] changes in stress/autonomic activity affect HRV. HRV was used in 3 studies as an indirect measure of stress.[32,33,35] In these 3 studies, HRV was increased by operating,[35] as well as by different types of operations (eg, greater HRV in laparoscopic than in open procedures) and expertise (eg, greater HRV in novices than in experts).[32]

Skin conductance level (SCL) rises with increased stress[43] and has been used as an objective measure to evaluate the activity of the sympathetic nervous system by 5 studies.

The electrooculogram uses an ergonomic workstation to count the number of eye blinks. It was used in studies by Berguer[16] and Smith[17]—both showing that the number of eye blinks increases as stress level rises.

Salivary cortisol rises as a result of the neuroendocrine response to a stressful situation. Although used widely in the nonsurgical literature, this review found only 1 study that used salivary cortisol.[26] In that study, cortisol levels were greater on an operating day for both junior and senior surgeons compared with a non-work day. Furthermore, the cortisol levels of senior surgeons were greater for difficult procedures, which reflects their increased stressful nature.

Subjective measures of stress: The subjective assessment of stress typically involves subjects reporting the amount of stress that they experience. Self-report was conducted in 6 of the reviewed studies.

Some studies used questionnaires,[6,9,21,22] whereas others used interviews,[11,12] thereby making a comparison of the findings difficult. This lack of standardization in the use of measurement tools contrasts with stress-related research in domains outside surgery, where validated measures of stress are used widely (eg, Stress Trait Anxiety Inventory [STAI][44,45]).

Combined subjective and objective measures: Only 3 studies[16,17,46] combined subjective self-report with objective indices of stress. Although such an approach would seem an optimal research design by embracing both physiologic response and subjective experience of stress, no correlational analyses between the 2 sets of measures were reported in any study that adopted this approach.

Measures of performance. To examine the impact of stress on performance, it is important to note whether performance was measured objectively and specify which outcomes measures were used.

Measures of technical performance: The time to complete a task was used as a measure of performance in 4 studies[17,20,41,45] and mean operative time was used in 2 others.[32,35] In laparoscopic procedures, the measures of performance included the number of knots tied,[19] economy of motion,[38] and motion analysis using the Imperial College Surgical Assessment Device (ICSAD).[36] Simulation-based studies included inaccurate placement of object, dropping an object, blood loss, vessels ripped, and tissue damage.

Measures of nontechnical performance: Nontechnical performance was assessed in only 2 studies. The assessment tools were standard human factors rating scales modified for surgery[29,34] and communication and utterance frequency.[34]

Effects of stress on technical performance. *Laparoscopic versus open surgery*: In 3 studies,[16,17,32] the stress levels (as assessed by self-report, SCL, and eye blinks, respectively) were greater in laparoscopic than in open surgery, and fewer knots were tied in laparoscopic surgery—which suggests that stress impaired psychomotor performance. In another study,[32] laparoscopic surgery increased operative time and was associated with greater stress (HRV); however, none of these studies reported a correlational analysis between stress and performance levels.

Laparoscopic versus robotic surgery: Two studies[46,47] found lower levels of stress (SCL) and poorer performance (increased task time and errors) in robotic surgery with to laparoscopic surgery. No correlational analyses were conducted, however, preventing the poorer performance being attributed to stress. Another study[48] also found worse performance in robotic surgery but no difference in stress (self-report).

Experienced versus novice surgeons: Four studies[16,27,28,32] found less stress in experienced than in novice surgeons (HR,[27,28] HRV/SCL,[32] self-report/eye blinks[16]). In 2 studies, all surgeons performed worse with laparoscopic versus open surgery (fewer knots tied[16] or more time taken[32]), but experienced surgeons performed better than their inexperienced counterparts.

Effect of distractions: Three studies[19,26,28] showed that increased distraction correlated with poorer performance (increased task time, number of errors, and poorer economy of motion) on difficult laparoscopic tasks—which suggests that such tasks require more concentration and are potentially more stressful. In 2 qualitative studies, surgeons self-reported that distractions in the operating room are stressful—but these studies used no performance measures.[11,12] In none of the above studies, however, were direct measures of stress obtained, so a relationship among distractions, stress, and technical performance can only be speculated.

Effect of role of the surgeon (ie, primary operator or assistant): Three studies[31,32,35] revealed significantly greater stress for the primary operating surgeon compared with the assisting surgeon. In 1 study, technical performance was assessed objectively (using operative time).[32]

Effect of multiple stressors: Some studies[29,34] have examined multiple stressors—an important topic, as stressors in the operating room can and do occur simultaneously with potentially additive effects on performance. Moorthy et al[36] found that time pressure, noise, and distractions led to impaired dexterity (increased path length) and increased number of errors, but they did not assess stress per se.

Effect of stress on nontechnical performance. Only 4 studies examined the effect of stressors on nontechnical performance. Moorthy et al[34] examined the effect of bleeding (stressor) on nontechnical performance but did not measure stress directly. They found no significant differences on the nontechnical skills that they assessed. Undre et al[29] also used bleeding as a stressor to evaluate surgeons' nontechnical skills and found that during crises, leadership, and decision making were poorer than the other skills. Two other studies[11,12] also found that excess stress leads to impaired communication, judgment, and decision making, although this was not measured objectively.

DISCUSSION

The decision to operate is made after balancing the risks and benefits for the patient. The level of

stress experienced by the surgeon is seldom factored in as a potential contributor to outcome, although it is intuitive that excessive levels of stress can affect performance adversely—especially for novice surgeons. This review aimed to identify key stressors, capture methods for measuring intraoperative stress, and gauge the impact of stress on surgical performance. Clearly, the evidence base is heterogeneous. This finding is not surprising considering that stress is hard to define and measure. Nonetheless, this review raises awareness of the impact of stress, outlining the problems in the field and suggesting best practices for future robust research on stress and performance.

Key stressors in surgery. Carrying out a procedure as the primary operator is stressful in itself—especially so if the procedure is laparoscopic. In addition to patient-related technical issues (eg, bleeding), many features of the operating room environment (such as noise, visitors, and distractions) can also be stressful. Experience seems to moderate stress levels, with seniors seemingly better adapted to stressful situations. These findings are consistent with research on long-term stress and burnout in surgeons,[49,50] which suggests a link between acute and chronic stress.

Methods for measuring stress. Typically, stress is measured via its physiologic (objective) and psychologic (subjective) effects. Objective measures in the literature include cardiac indices (HR and HRV), salivary cortisol, and eye blinks. All these indices increased with increased demands on the surgeons.

Subjective measures of stress involve the self-report of perceived stress levels. Although validated self-report tools do exist (eg, STAI[45]), these were surprisingly absent in all the reviewed studies. A significant limitation of the evidence base is that no systematic *combination* of objective and subjective measures has been implemented. Such an approach seems almost methodologic common sense: First, it would allow cross-validation of subjective with objective stress measures. Second, it would permit the validation of standardized self-report tools (eg, STAI) in the context of surgery, which are lacking currently.

Effect of stress on performance. Establishing a link between stress and performance is not easy; indeed, few studies (7) have assessed both concurrently. From these studies, the following themes can be extracted:

1. Laparoscopic procedures are associated with greater stress levels and poorer technical performance than open and robotic surgery. It must be noted, however, that the key tasks required in laparoscopic surgery may be more complex than open surgery—and consequently, laparoscopic performance may be open to a wider range of influences (reduced to "stress" in the reviewed studies).
2. Experienced surgeons have lower levels of stress compared with juniors and better technical performance.
3. Surgeons who have coped successfully with stress perform technically better than those who did not experience stress at all or failed to cope with it. This finding suggests that mitigating the effects of stress is likely to emerge as a key skill in dealing with situations that are unavoidably stressful.[23]
4. The limited data on the effects of stress on nontechnical performance suggests that stressful crises do impair surgeons' nontechnical skills (eg, leadership and decision making).

Limitations. For this review, care was taken to design a sensitive and specific search strategy and analyze the retrieved articles systematically and informatively. Wide variations within the published evidence ruled out a formal meta-analysis. The heterogeneity of research designs and study quality, unstandardized outcome measures, and wide variation in level of detail made a quantitative synthesis of the research evidence impossible. Specific deficiencies of the current literature include a lack of consistent stress measures and the concurrent assessment of stress and performance parameters. These deficiencies are discussed below.

Stress measurement: Determining reliable and valid markers of stress is essential, but the issue is problematic methodologically. Focusing on any isolated measure may give an oversimplified view of a complex, multifactorial, and dynamic picture. For instance, many studies have used SCL, HR, salivary cortisol, electrooculogram, or cardiac indices as proxy measures for stress. An increase in these measurements, however, cannot be attributed solely to increased stress levels. Ergonomic, workstation-based measures, urinary epinephrine, and white cell count are intrusive and impractical. Self-report can explore subjective aspects of stress (which are crucially important), but the assessment methods described in the surgery literature are inconsistent and not always fit for the purpose. Finally, an important limitation in the literature is that regardless of which method has been used by researchers, each tool has been implemented in isolation—hence precluding tool cross-validation or cross-study comparisons.

Linking stress and surgical performance parameters: Most studies in this review focused on stress without any assessment of performance. In no studies were nontechnical aspects of surgeons' performance assessed concurrently with stress—despite evidence to suggest that nontechnical skills are

most likely to suffer when stressful situations occur in the operating room.[12] Within other highly skilled, safety-critical industries (eg, the military), evidence suggests that stress may have an effect on decision making by distracting attention from the primary task, disrupting the ability to use working memory, and by limiting the opportunity to gather enough information to make a decision.[51] Within surgery, however, a distinct lack of performance data precludes evidence-based conclusions to be drawn on the effects of stress or the mechanisms involved. Literature pertaining to other industries suggests that a degree of stress may actually enhance performance.[52] Robust, concurrent assessment of stress, technical skill, and nontechnical skill will determine whether the same applies to surgeons.

Implications for surgical patient safety. Despite the limitations outlined above, this review suggests a link between stress and surgical performance. This finding might have substantive implications for patient safety. Although some stressors (eg, distractions) can be reduced by changes to operating room practices, for other stressors this is not possible: Patients will still be critically ill, colleagues may be inexperienced, and rapid decisions with serious consequences may need to be made, often under time pressure. In all these examples, reliable technical and nontechnical performance is key to safe surgical practice. By affecting these functions, stress can jeopardize patient care and can lead to adverse events. Surgeons may even have a legal responsibility to consider the potentially negative impact of stress on their performance,[35] with obvious implications for litigation.

Implications for surgical training. As highlighted in the introduction, stress is experienced when perceived resources are outweighed by demands.[53] Therefore, increasing perceived resources is an obvious priority. Current surgical training programs have started to provide trainee surgeons with opportunities to gauge their skill and reflect on their performance with input from clinical and educational supervisors.[54] In addition, nontechnical skills are significantly emphasized as part of modern surgical training[18]; however, structured programs are yet to be put in place for junior trainees to hone their skills in stress management. In contrast, aviation-inspired training and crisis resource management training using simulators is being offered to trainees in anesthesia.[23]

Training in crisis management can follow a similar route. Training in fully simulated operating rooms, with an operating room team has been trialled successfully[29,34] and seems to be a key direction for future surgical training. It must be recognized, however, that simulation is not a "silver bullet." Simulators are not real patients and simulated operating rooms are not real operating rooms; thus, simulated "crises" may never be as stressful as real operating room crises. We are not arguing that simulation-based training should replace training under supervision in the operating room; indeed, it cannot and should not do so. Simulation-based training can, however, complement traditional training in the operating room. Simulation offers the opportunity to sample crises that are not common in real operating rooms (eg, catastrophic bleeding), and allows trainees to make errors in a safe environment, receive individualized feedback on their performance, and "precondition" themselves against the once-in-a-lifetime events before actually encountering them in the real operating room.[12,37]

Future research agenda. Based on this review, the following best practice guidelines regarding stress-related research in surgery are recommended:

1. *Measurement of intra-operative stress*: Both objective and subjective measures of stress should be used in concert and analyzed concurrently, building evidence on validity and reliability for measuring stress in the operating room. For real operating room usage, such measures should be nonintrusive, such as cortisol and HR, to capture the surgeons' physiologic stress response objectively. STAI should be considered, as it is a well-validated questionnaire to capture self-reported stress.
2. *Investigation of the link between stress and surgical performance*: An assessment of stress levels should be carried out in conjunction with an assessment of performance. Technical performance can be rated with global rating scales, such as Objective Structured Assessment of Technical Skill (OSATS),[55] whereas nontechnical skills can be assessed by expert observers using validated tools such as the Observational Teamwork Assessment for Surgery[56] or NOTECHS.[57] Initially, simulation could be instrumental in establishing a link between performance and stress. This approach should be followed by observational studies in real operating rooms to ensure the robustness and generalizability of conclusions.
3. *Stress management training*: Stress training programs should be designed, implemented, and rigorously evaluated. Such programs could become part of standard training curricula for junior surgeons. A recent training needs analysis by our research group[12] suggests that this type of program should be simulation based, with feedback on technical and nontechnical

performance and an opportunity to experience and deal with stressful situations first hand.

4. *Individual differences*: Some people are inherently better at managing stressful situations, and surgeons are no exception. Individual characteristics, such as "personality hardiness," or the courage and motivation to face stressors, have been shown to enhance coping with stress.[37] The extent to which these personality factors and emotional intelligence moderate the impact of stress on performance needs to be explored. Future research should seek to determine the optimal levels of stress for surgeons and to investigate how those individuals most affected can be supported with structured programs in crisis management. A robust assessment of individuals' responses to stress may also prove a useful adjunct to selection procedures for surgery and vocational guidance for medical students contemplating a surgical career.

In conclusion, undoubtedly, surgeons are exposed to a large number of stressors. The current evidence suggests that excessive stress may compromise performance, especially in novice surgeons. Within the profession, cultural pressures not to admit to stress have led to missed opportunities for improving practice, despite considerable evidence and progress in other industries. The challenge is to explore and expand the science underlying this complex domain, developing methodologies that are apt for the unique conditions of surgical practice without oversimplifying its realities. This review aims to raise awareness of this important issue within our own community of surgeons and surgical educators. In doing so, we hope it will provide a springboard for developing effective training interventions, reducing harmful levels of stress, and improving both surgical performance and patient safety.

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Table II. Impact of stress on intra-operative performance

		Measures of stress				
Study	*Stressor*	*HRV*	*HR (beats/ min)*	*SCL (Uhoes)*	*Self-report*	*Other*
Arora et al[12] 2009	Technical, patient, team, and time factors; distractions; equipment problems				Self-report via interview	
Becker et al[31] 1983	Operating versus ward work		99.4 80			O_2 usage 0.26–0.411 min^{-1}
Berguer and Smith[47] 2006	Robotic versus lap surgery			*12 15 ($P = .05$)		
Berguer et al[58] 2001	Lap surgery versus open surgery			* 5.6 (S) 6.5 (J) 5.4 (S) 5.2 (J) ($P < .05$)	*Stress scale (1–7) 5 (S) 5 (J) 2 (S) 4 (J)	*Eye blinks 6 (S), 8 (J) 5 (S) 5 (J) ($P < .05$)
Bohm et al[32] 2001	Lap surgery versus open surgery	LF: 92 (S), 94 (J), 91.4 (P), and 86 (A) HF: 14 (S), 11 (J), 13.5 (P), and 17.8 (A) LF/HF: 7.5 (S), 10.5 (J), 8.4 (P) and 5.6 (A) LF: 87 (S) and 92 (J) HF: 15 (S) and 13 (J) LF/HF: 7.0 (S) and 8.0 (J) $P < .05$	* 93 (S) 87 (J) 94 (P) 84 (A) 97 (S) 90 (J)			
Czyzewska et al[33] 1983	Operating versus not operating	VR: 0.22 s CHRV: 6.3 s R-R: 0.61 s VR: 0.29 s CHRV: 8.5 s R-R: 0.66 s				
Demirtas et al[35] 2004	Operating versus office day	LF: 86.9 (P) and 81 (A) HF: 10.8 (P) and 14 (A) LF/HF: 9.76 (P) and 7.62 (A) LF: 79.8 (P) and 77 (A) HF: 15.7(P) and 18.2 (A) LF/HF: 5.98 (P) and 5.61 (A) $P < .001$	90 (P) 85 (A) 80 (P) 87 (A)			
Hassan et al[19] 2006	Difficult Lap task versus easy Lap task				NSC assessed by self- report questionnaire	
Jezova et al[26] 1992	Operating step (easy) 7 AM Incision (I) 15 min post I 45 min post I versus non-work 7 AM 9:15 AM 9:45 AM 10 AM					*Salivary cortisol (ng $ml^{-1)}$ 5.5 (S) 6 (J) 4 (S) 4.5 (J) 5 (S) 5 (J) 4 (S) 4.5 (J) 3.5 (S) 3 (J) 3 (S) 3 (J) 2.5 (S) 2.5 (J) 2 (S) 2 (J) All $P < .05$

A, assistant surgeon; *J*, junior surgeon, usually taken to mean more inexperienced when compared with senior surgeons (junior resident or trainee); *Lap*, laparoscopic; *NSC*, negative stress coping strategy; *P*, primary or main surgeon; *S*, senior surgeon, usually taken to mean more experienced when compared to junior surgeon (eg, senior resident/attending or consultant); *SNS*, sympathetic nervous system; *MDT*, multi-disciplinary team.

*Data extracted from graph (no exact figures provided in study).

Table II. *(continued)*

	Measures of performance			
Task measure	*Task time*	*Errors*	*Economy of motion*	*Author conclusions*
Technical ability, communication, teamwork and decision making affected by stress				Stress affects technical and nontechnical skills. Surgeons would welcome a training program. Raised intraoperative HR unlikely to be caused by mental stress. Senior surgeons adapted to stress
	*90 s *40 s ($P = .0001$)	More less ($P = .047$)		Stress may be lower with robotic surgery.
Number of knots tied: 4 (S) 1.5 (J) 15 (S) 15.5 (J) ($P < .05$)				Laparoscopic surgery more stressful than open surgery.
	135 min (S) 210 min (J) 85 min (S) 105 min (J) $P < .05$			Laparoscopic surgery causes more mental strain than open surgery. Inexperienced surgeons and primary surgeons experience more mental strain.
				Increased mental load during operating
				Operative stress associated with change in HRV. HRV and sympathetic activity greater on operating days and for primary surgeons.
	Correlation with NSC (rs = .46, $P = .042$) and distraction (rs = 0.60 $P = .002$) correlation with NSC (rs = 0.46, $P = .025$)	Correlation with NSC (rs = 0.58, $P = .014$) and Distraction (rs = 0.58, $P = .014$)	Correlation with NSC (rs = 0.54, $P = .006$) and Distraction (rs = 0.54, $P = .006$)	Ineffective stress-coping strategies and distractions correlate with poorer laparoscopic performance.
				Cortisol levels greater on working day indicating higher stress. Cortisol levels in seniors greater for difficult operation. No difference in cortisol between juniors and seniors.

(*continued*)

Table II. (*continued*)

		Measures of stress				
Study	*Stressor*	*HRV*	*HR (beats/min)*	*SCL (Uhoes)*	*Self-report*	*Other*
Kikuchi et al[27] 1995	Operating step Rest Preincision Incision Intra-operative closure		* 53 (S) 72 (J) 70 (S), 115 (J) 62 (S) 100 (J) 68 (S) 110 (J) 60 (S) 80 (J)			Electrocardiogram and blood pressure: No changes in any of the subjects despite altered HR so not used
Lee et al[36] 2005	Telerobotic surgery versus Lap surgery				*(1 s scale of 1–10 4 4.2 rr 4.25 5 5.0 $P < 0$, $P < .40$	
Moorthy et al[48] 2003	Distractions Nil Maths task (M) Noise (N) Time (T) M + N+T					
Moorthy et al[34] 2006	Bleeding					
Payne et al[39] 1986	Operating (surgeons) versus not operating (anesthetists)		100.5 78.3			
Schuetz et al[38] 2008	Distractions (maths task, bleeding, time pressure, patient problem, social stress)			Three groups SSR1 (stress without recovery) SSR2 (stress but recover) SSR3 (no stress)		
Sexton et al[30] 2000	Attitude to stress					70% consultants deny effect of stress (26% pilots)
Smith et al[46] 2003	Robotic versus Lap surgery			SCL lower with robotic for both tasks	Self-assessment of difficulty and discomfort similar for both	
Smith et al[17] 2000	Lap versus open surgery			6.1 5.9	Stress scale (1–7) 5.1 3.2	Eye blinks 10.7 5.6
Tendulkar et al[37] 2005	Being on call for 24 h		Mean HR: 88 (J) and 80 (S) Max HR: 136 (J) and 116 (S)			WBC 7.1 (J)

(*continued*)

Table II. *(continued)*

Measures of performance				
Task measure	*Task time*	*Errors*	*Economy of motion*	*Author conclusions*
				HR increases at start of surgery. HR is higher and changes more for inexperienced surgeons, which leads to greater stress levels.
	300 s (task 1) 300 s (task 2) 90 s (task 3) 150 s (task 1) 150 s (task 2) 50 s (task 3) All $P < .007$			No significant difference in mental stress between laparoscopic and telerobotic surgery.
		1 3 1 3 4	*path length (cm) Right and left hand: 0.25/0.23 0.3/0.35 0.28/0.3 0.4/0.35 0.3/0.35	Time pressure, theater noise, and mathematical tasks lead to poorer performance (impaired dexterity) and greater number of errors.
Blood loss (mL): 300 (S) and 600 (J) Nontechnical scores in %: Utterance frequency: 4.8 (S) and 3.1 (J) Communication: 60.4 (S) and 60.4 (J) Vigilance: 80 (S) and 55 (J) Team skills: 62.5 (S) and 64.5 (J) Leadership: 82.3 (S) and 72.9 (J) Decision making: 66.6 (S) and 62.5 (J)	*Time to (s): 1. Diagnose bleeding: 100 (S) and 180 (J) 2. Inform team: 190 (S) and 280 (J) 3. Achieve control: 220 (S) and 900 (J) 4. Close laceration: 650 (S) and 900 (J)			Seniors have better technical skills but not necessarily better human factors skills when encountered with stressor of bleeding.
				Surgeons have greater HR than anesthetists when operating.
Blood loss (mL) 22.9 (SSR1) 26.5 (SSR2) 54.2 (SSR3)		Missing clips; 0.5 (SSR1) 3 (SSR2) 1 (SSR3) Vessels ripped 0 (SSR1) 1 (SSR2) 1 (SSR3)	Cumulative path length (m) 14.4 (SSR1), 8.6 (SSR2) 10.9 (SSR3) Cumulative degree of deviation from path: 2,780 (SSR1) 1,575 (SSR2) 1,839 (SSR3)	Mental load may be optimized by continuous activity of SNS. Unclear as to what extent stress produces adverse effects.
				Medical staff deny effect of stress on performance.
	Pin move task took longer robotically	More error robotically		Robotic surgery reduces stress levels but degrades performance.
Number of knots tied: 3.7 19.1				Laparoscopic surgery is more stressful than open surgery with poorer performance.
				Being on call increases stress. Inverse relationship of stress with level of training.

(*continued*)

Table II. (*continued*)

		Measures of stress				
Study	*Stressor*	*HRV*	*HR (beats/ min)*	*SCL (Uhoes)*	*Self-report*	*Other*
Undre et al[29] 2007	Crisis scenarios (eg, bleeding and equipment failure)					
Wetzel et al[11] 2006	Patient and equipment problems, time, distractions, personal					Self-report via interview
Yamamoto et al[28] 1999	Increasing difficulty of procedure		*Rest: 75 (J) and 62 (S) Pre-operative: 121(J) and 74 (S) End: 105 (J) and 74 (S)			*Urine adrenaline (μg/g of creatine) Preoperative: 17.2 (J) and 15 (S) End: 26 (J) and 18 (S)

Table II. *(continued)*

Measures of performance				
Task measure	*Task time*	*Errors*	*Economy of motion*	*Author conclusions*
OSATS (min = 8, max = 40) = 26.33 Modified NOTECHS (1 = not done, 6 = done well) Communication: 4.00 Vigilance: 4.11 Teamwork: 3.96 Leadership: 3.78 Decision making: 3.95				MDT simulation team training feasible. Nontechnical and technical skills are affected by potential stressors.
Technical ability, communication, decision making, and judgment affected by stress				Stress affects technical and nontechnical performance. Seniors have coping strategies. Stress decreases with experience.