An Evaluation of the Impact of High-Fidelity Endovascular Simulation on Surgeon Stress and Technical Performance

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OBJECTIVE: To measure the physiological stress response associated with high-fidelity endovascular team simulation.

DESIGN: This is a prospective cohort study.

SETTING: This study was performed at St Mary's Hospital (Imperial College London, London, UK), in a tertiary setting.

PARTICIPANTS: Thirty-five participants (10 vascular surgical residents, 4 surgical interns, 12 theatre nurses, 2 attending vascular surgeons, 6 medical students and 1 technician) were recruited from the Imperial Vascular Unit at St Mary's Hospital, Imperial College London by direct approach. All participants finished the study.

RESULTS: Junior surgeons experienced significantly increased sympathetic tone (Low frequency/high frequency (LF/HF) ratio) during team simulation compared to individual simulation (6.01 ± 1.68 *vs.* 8.32 ± 2.84, $p < 0.001$). Within team simulation junior surgeons experienced significantly higher heart rate (beats per minute) than their senior counterparts (82 ± 5.83 *vs.* 76 ± 6.02, $p = 0.033$). Subjective workload scores (NASA Task Load Index [NASA-TLX]) correlated moderately and significantly with sympathetic tone in surgeons across all stages of simulation. ($r = 0.39$, $p = 0.01$).

CONCLUSIONS: A discrete, measurable increase in stress is experienced by surgeons during high-fidelity endovascular simulation and differentially effects junior surgeons. High-fidelity team simulation may have a role to play in improving nontechnical skill, reducing intraoperative stress, and reducing error. (J Surg Ed 76:864−871. Crown Copyright 2018 Published by Elsevier Inc. on behalf of Association of Program Directors in Surgery. All rights reserved.)

KEY WORDS: Simulation, Education, Endovascular, Surgery

COMPETENCIES: Systems-Based Practice

ABBREVIATIONS: GRS-E, global rating scale of endovascular performance LF/HF, low frequency/high frequency NASA-TLX NASA Task Load Index

INTRODUCTION

Failures in nontechnical skill may account for up to half of all of errors that lead to harm in patients undergoing vascular surgery.[1,2] There is a high nontechnical skill demand during endovascular procedures due to device complexity, challenging patients, and the need to work within a large multidisciplinary operating team.[3] This challenge is compounded by modern working patterns which result in a lack of team stability and the need for unrehearsed and unfamiliar multidisciplinary operating practices.

Nontechnical skill is defined as a triad of interpersonal skills, executive cognitive function, and personal resource skills.[4,5] Unlike technical skill, nontechnical skill training is not formalized within surgical curricula.[6] The drastic shortening of postgraduate training[7] and the increasing complexity of endovascular procedures[8] is promoting surgical simulation as the modality of choice to deliver surgical education. Current endovascular simulators are largely designed for technical skill acquisition and practice and generally do not offer the required immersive context for

Sources of support: This project was supported by the National Institute for Health Research (NIHR) Biomedical Research Centre based at Imperial College Healthcare NHS Trust and Imperial College London.

Disclosure of funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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  1931-7204/$30.00
https://doi.org/10.1016/j.jsurg.2018.10.015

the development of vital nontechnical skills.[9] The advent of high-fidelity simulation endovascular suites, such as ORCAMP, offers an ideal platform to recreate the realism required for nontechnical skill acquisition and training. However, this hypothesis is under a multifaceted review.

High-fidelity simulation encourages participants to suspend disbelief and buy into the simulation scenario, resulting in stronger imprinting, rapid acquisition of skill, and a durable impact on future behaviors.[10] High-fidelity endovascular simulator-based training has already shown to reduce technical error, procedure time, and radiation exposure in endovascular aortic procedures.[11,12] If proven, nontechnical skills training may have significant translational potential; especially timely given the introduction of the next generation accreditation system by the Accreditation Council for Graduate Medical Education.[13]

Poor nontechnical skill results in mismanagement of cognitive load. When a task surpasses the individual's cognitive threshold, performance may be impaired, leading to a state known as cognitive overload.[14] Cognitive overload in turn contributes to a physiological stress response, but it is important to note there are multiple causes of physiological stress that are unrelated to cognitive load within high-fidelity simulation and may contribute to a stress response. This study aims to measure the physiological stress response of participants associated with high-fidelity team simulation compared to low-fidelity simulation.

METHODOLOGY

Participants

This is a prospective cohort study examining 3 predefined types of endovascular assessment, each with increasing fidelity and complexity. Thirty-five participants (10 vascular surgical residents, 4 surgical interns, 12 theatre nurses, 2 attending vascular surgeons, 6 medical students, and 1 technician) were recruited from the Imperial Vascular Unit at St Mary's Hospital, Imperial College London. Data relating to clinical experience were collected from the 10 surgical residents (6 male, vascular surgery experience [μ, SD] 4.2 years ± 3.8, thoracic endovascular aneurysm repair (TEVAR) as primary operator [μ, SD] 7.3 ± 6.1) and 6 nurse participants (1 male, vascular surgery experience (μ, SD) 2.1 years ± 1.2, TEVAR as primary nurse assistant [μ, SD] 11.4 ± 6.1) acting in principal roles. The remaining participants formed the multidisciplinary surgical team supporting the simulation.

Participants refrained from vigorous activity, caffeine, and tobacco for 2 hours before participation to minimize confounding. "Junior" surgeons (n = 5) were defined as those surgical residents with experience of fewer than 15 cases of EVAR as primary operator. "Senior" surgeons (n = 5) were defined as those with experience of more than 15 cases of EVAR as primary operator. No participants had previous experience of the ORCAMP simulator. Informed consent was obtained from all participants. Approval was obtained from the Imperial College London Educational Ethics Review Service and informed consent was obtained from all participants.

Experimental Design

Surgical residents were assessed during 4 predefined stages of training. The clinical scenario selected for assessment involved an uncomplicated TEVAR in the elective setting. Each stage of the simulation was time limited for standardization, and participants were not necessarily expected to complete the task in the allotted time depending on experience. All stages of simulation were video and audio recorded for subsequent analysis. Surgeons' heart rate (HR) and heart rate variability (HRV) were measured continuously throughout each stage. A simple (unweighted) paper-based NASA-Task Load Index (NASA-TLX) questionnaire[15] was completed by both surgeon and nurse participants after each stage.

Stage 1: "Baseline," 8-minute duration

Participants completed demographic questionnaire but remained otherwise sedentary.

Stage 2: "Verbal rehearsal," 10-minute duration

Surgeons verbally rehearsed the index TEVAR procedure via standardized step-wise questioning from the expert facilitator and asked to identified key endovascular tools.

Stage 3: "Individual simulation," 20-minute duration

Surgeons performed the index EVAR alone on a standard bench virtual reality endovascular simulator (Mentice VIST G5 Simulator, Mentice AB, Gothenburg, Sweden)[16] with an expert facilitator observing. Verbal time warning at 10 and 18 minutes was given.

Stage 4: "Team simulation," 30-minute duration

Team simulation was performed in ORCAMP. ORCAMP is a validated,[17,18] fully-immersive simulated environment (Orzone AB, Gothenburg, Sweden)[19] equipped with an electric adjustable operating table, realistic patient dummy, independent C-arm manipulation, virtual fluoroscopy without exposure to ionizing radiation and access to a full range of endovascular devices and equipment. Dynamic patient physiology was available and there were dedicated work stations for the anesthetist, radiographer, scrub and circulating nurses as well as the interventionalists to facilitate whole team training. Wires, catheters, simulated balloons, and stent grafts could be inserted and deployed; both static and dynamic fluoroscopic imaging were available.

In each team simulation, the surgeon and lead nurse were supported by a multi-disciplinary surgical team consisting of 6 team members: surgeon assistant, circulating nurse, radiographer, anesthetist, technician, and an expert facilitator. Each team member was trained and given a standardized script to follow for each simulation to ensure reliability and consistency. The role of the facilitator and technician was passive with intervention only if requested by the primary participant. The surgeon acting as team leader and was given control of the entire procedure from team brief and organization of the supporting operative team, through to performing the index TEVAR procedure and subsequent team debrief as appropriate. The index case medical notes and radiography were available. Verbal time warnings at 15 and 25 minutes were given.

Stress Measures

HR and HRV were measured continuously by a wireless heart monitor (Polar RS800CX, Polar Electro Ltd, Warwick, UK) throughout all stages of simulation. The heart monitor recorded the electrocardiogram R-R intervals (NN, milliseconds) and transferred the data wirelessly to a computer using Polar Precision Software (Polar Electro Ltd, Warwick, UK). For each of the 4 simulation stage epochs, HR, the R-R intervals, and the ratio of low-frequency (LF) and high-frequency (HF) of the power spectral analysis (LF/HF) were calculated using the fast Fourier transform algorithm in MATLAB 8.0 (The MathWorks, Inc., Natick, Massachusetts). HRV analysis was performed using 5-minute interval readings and HR was graphically displayed at 1-minute intervals for ease of point identification. The LF component is thought to increase in response to sympathetic activity and the HF component is thought to increase in response to vagal tone. The LF/HF ratio is linearly proportionate to sympathetic tone and can be equated to sympathetic tone.[20] The relationship between LF/HF ratio and sympathetic tone is considered valid and sensitive.[21] The LF/HF ratio is a commonly used primary outcome measure in stress-performance studies,[22,23] and is preferred to repeated blood pressure measurements as it produces more data points and is less invasive.

Technical Skill Measures

In Stage 2, 3, and 4, surgeon global technical skill was assessed by an expert observer via video analysis using the global rating scale of endovascular performance (GRS-E) scale to evaluate the impact of stress on technical performance. The GRS-E scale comprises of 7 generic components of operative skill that are marked on a 5-point Likert scale with the middle and extreme points anchored by explicit descriptors.[24]

Statistical Analysis

Descriptive data are presented as mean (μ) and standard deviation (SD). Data were tested for normal distribution using the Shapiro–Wilk test. A coupled repeated measures ANOVA statistical test was used to compare the differences between the 4 stages of simulation in HR, HRV (or sympathetic tone), and NASA-TLX scores. An independent t-test was used to compare 2 unrelated groups for continuous, dependent variables. Univariate linear correlation analysis of subjective NASA-TLX and objective stress was calculated using Pearson's rank correlation coefficient.

The significance level was set at $p < 0.05$ (2-tailed). All statistical data analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 24.0 (IBM Corporation. 2012, IBM, Armonk, New York).

RESULTS

Shapiro-Wilk statistical test showed data to be normally distributed ($df[60] = 0.94$, $p = 0.59$).

Between Group Stress Comparisons

HR remained at baseline during verbal rehearsal and individual simulation but increased in team simulation for both groups of surgeons (Fig. 1). During team simulation junior surgeons had a significantly increased HR compared with senior surgeons (76 ± 6.02 *vs.* 82 ± 5.83, $p = 0.033$).

Sympathetic tone of both junior and senior surgeons increased incrementally in all 4 stages of simulation (Fig. 2). The increase in sympathetic tone for junior surgeons from individual to team simulation was significant, indicating an increase in stress (6.01 ± 1.68 *vs*. 8.32 ± 2.84, $p < 0.001$) that was not present for senior surgeons. Within team simulation, junior surgeons' sympathetic tone was significantly higher than that of senior surgeons (8.32 ± 2.84 *vs.* 5.57 ± 1.90, $p < 0.001$). These results suggest that when exposed to high fidelity team simulation surgeons with less surgical experience a higher objective stress response.

Subjective NASA-TLX scores were moderately correlated with objective measurements of sympathetic tone ($r = 0.39$, $p = 0.01$) (Fig. 3), and there was no difference in subjective stress reported by nurses and surgeons. ($r = 0.21$, $p = 0.81$).

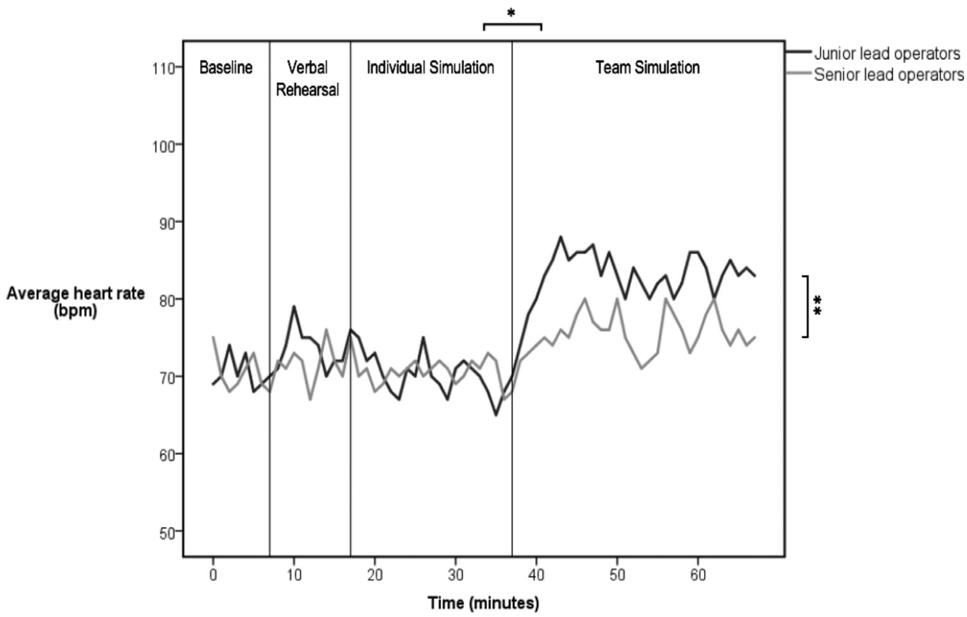

FIGURE 1. Between group comparison of mean heart rate (beats per minute, bpm) across the 4 study stages. A coupled repeated measures ANOVA test with a Greenhouse-Geisser correction demonstrates a significant difference between mean heart rate and simulation stage (F (9.26, 28.56) = 23.09, p < 0.001). *Post-hoc Bonferroni correction reveals a significant increase in junior surgeons (black) mean heart rate from individual simulation to team simulation (69 ± 8.13 vs 82 ± 5.83, p = 0.016). **Within team simulation, junior surgeon mean heart rate was shown to be significantly higher than senior surgeons (grey) (76 ± 6.02 *vs.* 82 ± 5.83, p = 0.033). */** represents p < 0.05.

Technical skill

There was no global difference in technical performance between the simulation scenarios. Individually, across the scenarios, increased sympathetic tone of participants was associated with poorer global technical performance, but this difference was not significant ($r = -0.703$, p = 0.078). This association can be explained by the observation that senior trainees who

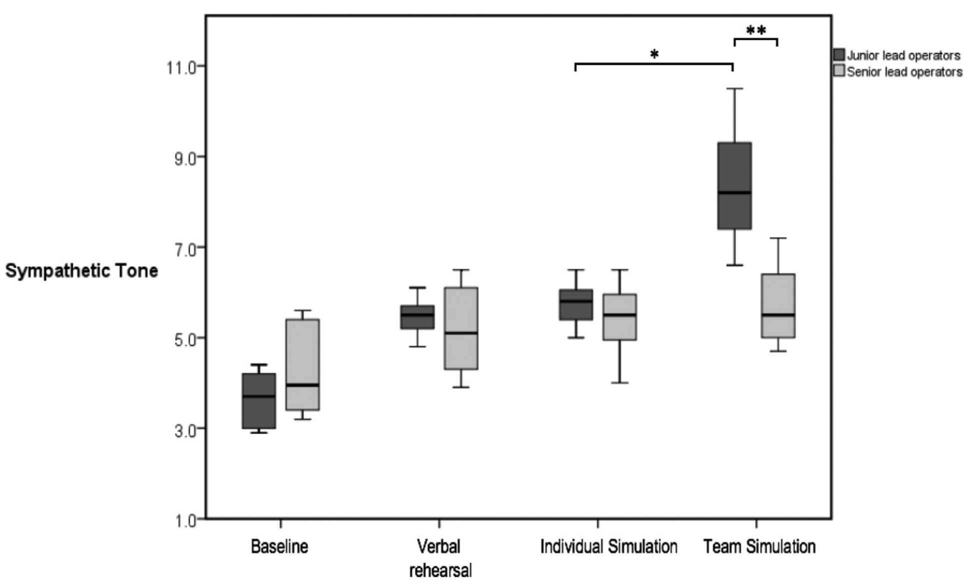

FIGURE 2. Comparison of sympathetic tone (LF/HF ratio) between junior surgeons and senior surgeons across the 4 stages of simulation. A coupled repeated measures ANOVA test with a Greenhouse-Geisser correction demonstrates a significant difference between mean heart rate and simulation stage (F [1.22, 19.13] = 15.34, p = 0.02). * Post-hoc Bonferroni correction shows a significant rise in the sympathetic tone of junior surgeons (dark gray) from individual simulation to team simulation ([μ, SD] 6.01 ± 1.68 *vs.* 8.32 ± 2.84, p < 0.001). ** Within team simulation, junior surgeons exhibited significantly higher sympathetic tone than their senior counterparts (light gray) ([μ, SD] 8.32 ± 2.84 *vs.* 5.57 ± 1.90, p < 0.001). */** represent p < 0.05.

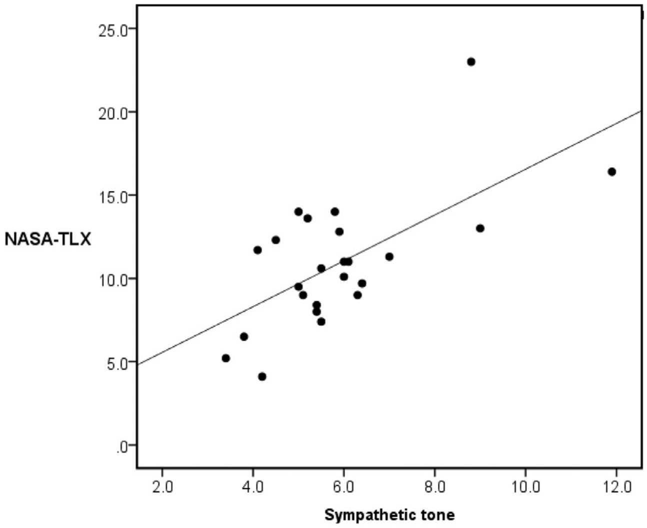

FIGURE 3. Subjective workload scores (NASA-TLX) correlate moderately and significantly with sympathetic tone in surgeons across all stages of simulation. ($r = 0.39$, $p = 0.01$).

exhibited less stress, were more technically competent than their junior counterparts with a mean difference of (μ, SD) 3.5 ± 2.26 on the GRS-E scale ($p = 0.081$, 95% CI -1.13-5.87) as would be expected. Importantly. this association supports the internal validity of this study.

DISCUSSION

Surgical residents were assessed during 3 distinct assessment stages, with increasing fidelity to determine the additional physiological stress associated with the increased demands of high-fidelity team simulation. Junior surgeons demonstrated a significant increase in stress during high-fidelity team simulation compared to lower fidelity individual simulation. In contrast, senior surgeons did not exhibit any significant changes in stress.

Potential confounders in this study were eliminated by the step-wise increase in fidelity of the different assessment stages. Stress associated with background levels, cognitive recall, technical skill performance and the environment was accounted for in the first 3 stages. Therefore, the increase in stress seen in junior surgeons during high-fidelity team simulation may be attributable to the additional cognitive load associated with team engagement.

Whilst other studies have found a similar stress response in high-fidelity team simulation,[25–27] there are no studies that specifically isolate the stress associated with team engagement in high-fidelity simulation to the authors knowledge. This present study demonstrates the strength of association between self-reported stress and objective measures of stress which, whilst moderately and significantly correlated appeared weaker than other reports in the literature.[28,29] This in part may be explained by the well-described phenomenon of questionnaire 'response fatigue'[30] with surgical residents in this study completing a total of 5 questionnaires.

Nevertheless, participant awareness of own stress is known to be conducive to engagement and adherence to simulation-based education programs.[31,32] The good agreement between self-reported stress and objective stress support the lone use of self-reported stress measures as metrics of stress in future studies with regards to time, financial, and logistical efficiency savings.

Association Between Technical Performance and Stress

Although technical skill was poorer in those participants with higher sympathetic tone response, the study did not elicit a significant inverse association. The reason for this may be 2-fold. First, this study has a small sample size, and secondly the association between stress and performance is nonlinear. The Yerkes-Dodson Law[33] suggests that the relationship between stress and technical skill follows a parabolic curve. Increasing stress improves technical performance but only up to a point, thereafter increasing stress reduces performance. This is difficult to detect without graded stages of planned stressors within a single simulation.

Future studies will identify the appropriate point-level of stress at which performance drops. This is vital to informing the ideal stress level, known as the "zone of proximal development"[34,35] in pedagogical theory, which is just beyond the learner's skill level, yet not overwhelmingly challenging, at which learning is most efficient. An alternative explanation to the maintenance of technical skill is, reassuringly, that surgical residents are capable of maintaining their performance despite increased stress levels. This stress reserve can be surmounted by planned additional stressors. Finally, the results show a positive direction of agreement between surgeon and nurse self-reported stress. This observation may indicate a whole-team effect by proxy. As surgeon stress correlates with team stress, the converse may be true where any benefit gained by surgeons in a future high-fidelity team simulation training program may extend to the whole team. A future study should seek to test this important and plausible hypothesis.

Clinical Relevance

This study indicates the appropriateness of high-fidelity simulation as a tool for nontechnical skill training, however, more work is required to validate this link. Further objective evidence will help bring nontechnical skill training to the forefront of surgical education and guide translation of surgical education from the operating room to simulators. Already, there are examples of improved patient safety arising from technical skill focused immersive team simulation. Desender et al.[36] in a randomized control trial demonstrated immersive team simulation led to significant improvements in technical metrics and a reduction in minor and major errors in the operating room. As nontechnical skill failures are a substantial contributor to errors, a focus on whole team nontechnical skills training may have a similar impact on patient care.

Limitations

A statistical power calculation was not possible due to paucity of pre-existing data in the literature and thus we recognize the increased risk of Type II error. Ergo, the results of this study should be used to guide future studies and generate hypotheses.

The failure of outcome metrics to identify changes in stress in senior surgeons may be a result of a ceiling effect attributable to both the relative simplicity of the index TEVAR simulation and the absence of planned stressors. Indeed, studies in the field of urology,[37] anesthetics[38] and emergency medicine[39] have shown senior surgeons do benefit from high-fidelity team simulation.

Retrospective single expert video analysis of technical skill may have introduced bias as video footage would certainly have unblinded the assessor. However, the direction of bias would be toward significance in technical performance and stress association testing, and therefore did not affect the results of this study.

The outcome measures used in this study give no qualitative information on which, if any, of the 3 domains of nontechnical skill the observed changes in stress are associated with. Qualitative data is critical to the design of curricula and so future work should seek to use medical imaging technologies, such as Functional Near Infrared Spectroscopy (fNIRS),[40] which may better inform the differential contribution of specific executive function subdomains in times of operative stress.

Finally, this study has not considered the cost and cost-effectiveness of ORCAMP, nor how this disruptive technology will impact on the work-stream of surgical training. These are important factors in the translatability of simulation technology in improving patient safety and outcomes.

Conclusions

Junior surgeons showed increased stress in high-fidelity team simulation compared to low-fidelity simulation. This study is the first to isolate and identify a discrete stress load associated with team engagement in high-fidelity team simulation. The index endovascular procedure used in this study is not intrinsic to the performance of the participants and therefore the results of this present study are potentially applicable across most specialties. These findings indicate high-fidelity team simulation may be a useful adjunct for nontechnical skill training and may have a role in postgraduate surgical and endovascular education.

ACKNOWLEDGMENTS

We would like to extend our gratitude to Mr Matthew Gold, Mr Hemel Modi, Mr Yaroslav Shkanov, Miss Imogen John, Mr Nikhil Lal, Mr Joseph Rassam, and Mr Sceyon Mohan for their valuable contributions.

REFERENCES

1. Lear R, Riga C, Godfrey AD, et al. Multicentre observational study of surgical system failures in aortic procedures and their effect on patient outcomes. *Br J Surg.* 2016;103:1467–1475.

2. Morbi AH, Hamady MS, Riga CV, et al. Reducing error and improving efficiency during vascular interventional radiology: implementation of a preprocedural team rehearsal. *Radiology.* 2012;264:473–483.

3. Desender LM, Van Herzeele I, Lachat ML, et al. Patient-specific rehearsal before EVAR: influence on technical and nontechnical operative performance. A randomized controlled trial. *Ann Surg.* 2016;264:703–709. Nov 1.

4. Agha RA, Fowler AJ, Sevdalis N. The role of non-technical skills in surgery. *Ann Med Surg.* 2015;4:422–427.

5. Bourrier Y, Jambon F, Garbay C, et al. An Interaction Centred Approach to the teaching of Non-technical Skills in a Virtual Environment [Doctoral dissertation]. Laboratoire d'Informatique de Paris 6; Laboratoire d'Informatique de Grenoble; 2016.

6. Neequaye SK, Aggarwal R, Van Herzeele I, Darzi A, Cheshire NJ. Endovascular skills training and assessment. *J Vasc Surg*. 2007;46:1055–1064. Nov 30.

7. Holt PJ, Poloniecki JD, Khalid U, et al. Effect of endovascular aneurysm repair on the volume-outcome relationship in aneurysm repair. *Circ Cardiovasc Qual Outcomes.* 2009;2:624–632.

8. See KW, Chui KH, Chan WH, Wong KC, Chan YC. Evidence for endovascular simulation training: a systematic review. *Eur J Vasc Endovasc Surg*. 2016;51:441–451. Mar 1.

9. Rudarakanchana N, Van Herzeele I, Desender L, Cheshire NJ. Virtual reality simulation for the optimization of endovascular procedures: current perspectives. *Vasc Health Risk Manage*. 2015;11:195.

10. Agha RA, Fowler AJ. The role and validity of surgical simulation. *Int Surg*. 2015;100:350-357. Feb.

11. Chaer RA, Derubertis BG, Lin SC, et al. Simulation improves resident performance in catheter-based intervention: results of a randomized, controlled study. *Ann Surg*. 2006;244:343-352.

12. Sturm LP, Windsor JA, Cosman PH, et al. A systematic review of skills transfer after surgical simulation training. *Ann Surg*. 2008;248:166-179.

13. Nasca TJ, Philibert I, Brigham T, et al. The next GME accreditation system—rationale and benefits. *N Engl J Med*. 2012;366:1051-1056.

14. Avrunin GS, Clarke LA, Conboy HM, et al. Toward improving surgical outcomes by incorporating cognitive load measurement into process-driven guidance. In: 2018 IEEE/ACM International Workshop on Software Engineering in Healthcare Systems (SEHS), IEEE:2-9.

15. Young G, Zavelina L, Hooper V. Assessment of workload using NASA Task Load Index in perianesthesia nursing. *J PeriAnesth Nursing*. 2008;23:102-110. Apr 1.

16. Aggarwal S, Choudhury E, Ladha S, Kapoor PM, Kiran U. Simulation in cardiac catheterization laboratory: need of the hour to improve the clinical skills. *Ann Cardiac Anaesth*. 2016;19:521.. Jul.

17. Lonn L, Edmond JJ, Marco J, Kearney PP, Gallagher AG. Virtual reality simulation training in a high-fidelity procedure suite: operator appraisal. *J Vasc Interv Radiol*. 2012;23:1361-1366. Oct 31.

18. Van Herzeele I, Aggarwal R, Neequaye S, et al. Experienced endovascular interventionalists objectively improve their skills by attending carotid artery stent training courses. *Eur J Vasc Endovasc Surg*. 2008;35:541-550. May 31.

19. ORCAMP - Endovascular/Interventional setup [ORCAMP AB web site]. Available at: http://orzone-webmaster.wixsite.com/orzone2015/simulationev. Accessed February 02, 2018.

20. Camm AJ, Malik M, Bigger JT, et al. Heart rate variability: standards of measurement, physiological interpretation and clinical use. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Circulation*. 1996;93:1043-1065.

21. Pagani M, Furlan R, Pizzinelli P, Crivellaro W, Cerutti S, Malliani A. Spectral analysis of RR and arterial pressure variabilities to assess sympatho-vagal interaction during mental stress in humans. *J Hypertens*. 1989;7:S14-S15. Dec.

22. Lin LY, Wu CC, Liu YB, Ho YL, Liau CS, Lee YT. Derangement of heart rate variability during a catastrophic earthquake: a possible mechanism for increased heart attacks. *Pacing Clin Electrophysiol*. 2001;24:1596-1601. Nov 1.

23. McCraty R, Atkinson M, Tiller WA, Rein G, Watkins AD. The effects of emotions on short-term power spectrum analysis of heart rate variability. *Am J Cardiol*. 1995;76:1089-1093. Nov 15.

24. Mitchell EL, Arora S, Moneta GL, et al. A systematic review of assessment of skill acquisition and operative competency in vascular surgical training. *J Vasc Surg*. 2014;59:1440-1455. May 1.

25. Ghazali DA, Darmian-Rafei I, Nadolny J, Sosner P, Ragot S, Oriot D. Evaluation of stress response using psychological, biological, and electrophysiological markers during immersive simulation of life threatening events in multidisciplinary teams. *Aust Crit Care*. 2017;31:226-233. Jul 1.

26. Ghazali DA, Ragot S, Breque C, et al. Randomized controlled trial of multidisciplinary team stress and performance in immersive simulation for management of infant in shock: study protocol. *Scand J Trauma Resusc Emerg Med*. 2016;24:36.. Dec.

27. Phitayakorn R, Minehart RD, Pian-Smith MC, Hemingway MW, Petrusa ER. Practicality of using galvanic skin response to measure intraoperative physiologic autonomic activation in operating room team members. *Surgery*. 2015;158:1415-1420. Nov 1.

28. Jones KI, Amawi F, Bhalla A, Peacock O, Williams JP, Lund JN. Assessing surgeon stress when operating using heart rate variability and the State Trait Anxiety Inventory: will surgery be the death of us? *Colorectal Dis*. 2015;17:335-341. Apr 1.

29. Wetzel CM, Black SA, Hanna GB, et al. The effects of stress and coping on surgical performance during simulations. *Ann Surg*. 2010;251:171-176. Jan 1.

30. Egleston BL, Miller SM, Meropol NJ. The impact of misclassification due to survey response fatigue on estimation and identifiability of treatment effects. *Stat Med*. 2011;30:3560-3572. Dec 30.

31. Datta R, Upadhyay KK, Jaideep CN. Simulation and its role in medical education. *Med J Armed Forces India*. 2012;68:167–172. Apr 1.

32. Aggarwal R, Mytton OT, Derbrew M, et al. Training and simulation for patient safety. *Qual Saf Health Care*. 2010;19(Suppl 2):i34–i43. Aug 1.

33. Cohen NJ, Squire LR. Preserved learning and retention of pattern-analyzing skill in amnesia: dissociation of knowing how and knowing that. *Science*. 1980;210:207–210. Oct 10.

34. Kneebone RL, Scott W, Darzi A, Horrocks M. Simulation and clinical practice: strengthening the relationship. *Med Educ*. 2004;38:1095–1102. Oct 1.

35. Shalhoub J, Vesey AT, Fitzgerald JE. What evidence is there for the use of workplace-based assessment in surgical training? *J Surg Educ*. 2014;71:906–915. Dec 31.

36. Desender LM, Van Herzeele I, Lachat ML, et al. Patient-specific rehearsal before EVAR: influence on technical and nontechnical operative performance. A randomized controlled trial. *Ann Surg*. 2016;264:703–709. Nov 1.

37. Rashid P, Gianduzzo TR. Urology technical and non−technical skills development: the emerging role of simulation. *BJU Int*. 2016;117:9–16. Apr 1.

38. Higham H, Baxendale B. To err is human: use of simulation to enhance training and patient safety in anaesthesia. *Br J Anaesth*. 2017;119:i106–i114. Dec 1.

39. Cant RP, Porter JE, Cooper SJ, Roberts K, Wilson I, Gartside C. Improving the non−technical skills of hospital medical emergency teams: the Team Emergency Assessment Measure (TEAM™). *Emerg Med Australasia*. 2016;28:641–646. Dec 1.

40. Leff DR, Orihuela-Espina F, Elwell CE, et al. Assessment of the cerebral cortex during motor task behaviours in adults: a systematic review of functional near infrared spectroscopy (fNIRS) studies. *Neuroimage*. 2011;54:2922–2936. Feb 14.

SUPPLEMENTARY INFORMATION

Supplementary data associated with this article can be found, in the online version at https://doi.org/10.1016/j.jsurg.2018.10.015.