Efficacy of Trauma Surgery Technical Skills Training Courses

Colin F. Mackenzie, MD, [*,†] Samuel A. Tisherman, MD, FACS, FCCM, [‡] Stacy Shackelford, MD, FACS, [§] Nick Sevdalis, PhD, [‖] Eric Elster, MD, FACS, [¶] and Mark W. Bowyer, MD, FACS [¶]

[*]Shock Trauma Anesthesiology Research Center, Baltimore, Maryland; [†]University of Maryland School of Medicine, Baltimore, Maryland; [‡]Department of Surgery, Baltimore, Maryland; [§]Department of Defense Joint Trauma System, San Antonio, Texas; [‖]Center for Implementation Science, Kings College, London, UK; and [¶]Department of Surgery, The Uniformed Services University of Health Sciences and the Walter Reed National Military Medical Center, Bethesda, Maryland

OBJECTIVE: Because open surgical skills training for trauma is limited in clinical practice, trauma skills training courses were developed to fill this gap, The aim of this report is to find supporting evidence for efficacy of these courses. The questions addressed are: What courses are available and is there robust evidence of benefit?

DESIGN: We performed a systematic review of the training course literature on open trauma surgery procedural skills courses for surgeons using Kirkpatrick's framework for evaluating complex educational interventions. Courses were identified using Pubmed, Google Scholar and other databases.

SETTING AND PARTICIPANTS: The review was carried out at the University of Maryland, Baltimore with input from civilian and military trauma surgeons, all of whom have taught and/or developed trauma skills courses.

RESULTS: We found 32 course reports that met search criteria, including 21 trauma-skills training courses. Courses were of variable duration, content, cost and scope. There were no prospective randomized clinical trials of course impact. Efficacy for most courses was with Kirkpatrick level 1 and 2 evidence of benefit by self-evaluations, and reporting small numbers of respondents. Few courses assessed skill retention with longitudinal data before and after training. Three courses, namely: Advanced Trauma Life Support (ATLS), Advanced Surgical Skills for Exposure in Trauma (ASSET) and Advanced Trauma Operative Management (ATOM) have Kirkpatrick's level 2-3 evidence for efficacy. Components of these 3 courses are included in several other courses, but many skills courses have little published evidence of training efficacy or skills retention durability.

CONCLUSIONS: Large variations in course content, duration, didactics, operative models, resource requirements and cost suggest that standardization of content, duration, and development of metrics for open surgery skills would be beneficial, as would translation into improved trauma patient outcomes. Surgeons at all levels of training and experience should participate in these trauma skills courses, because these procedures are rarely performed in routine clinical practice. Faculty running courses without evidence of training benefit should be encouraged to study outcomes to show their course improves technical skills and subsequently patient outcomes. Obtaining Kirkpatrick's level 3 and 4 evidence

Conflict of interest: Dr Sevdalis is the director of London Safety and Training Solutions Ltd, which delivers human factors, patient safety, and quality improvement advisory and training services to hospitals and training programs globally. The other authors report no conflicts of interest.

Affirmation: The manuscript has not been published nor is it under consideration to published elsewhere nor has it been presented at a conference meeting.

Sources of support: U.S. Army Medical Research and Materiel Command Contract Number: W81XWH-13-2-0028 and by the National Institutes of Health Research (NIHR) via the "Collaboration for Leadership in Applied Health Research and Care South London" (CLAHRC) at Kings College Hospital National Health Service (NHS) Foundation Trust, London, UK (grant no. CLA-0113-10022). Dr Sevdalis is a member of King's Improvement Science, which is part of the NIHR CLAHRC South London and funded by King's Health Partners (Guy's and St Thomas') NHS Foundation Trust, King's College Hospital NHS Foundation Trust, King's College London and South London and Maudsley NHS Foundation Trust), Guy's and St Thomas' Charity, the Maudsley Charity and the Health Foundation.

Disclaimer: This research and development project was conducted by the University of Maryland, School of Medicine and was made possible by a cooperative agreement which was awarded and administered by the U.S. Army Medical Research and Materiel Command (USAMRMC) and the Telemedicine and Advanced Technology Research Center (TATRC) at Fort Detrick, MD under Contract Number: W81XWH-13-2-0028.The views, opinions and/or findings contained in this publication are those of the authors and do not necessarily reflect the views of the Department of Defense (DoD), the Uniformed Services University of the Health Sciences, or any other agency of the U.S. Government or of the NHS, the NIHR or the Department of Health and Social Care in the UK, and should not be construed as an official position, policy or decision unless so designated by other documentation. No official endorsement should be made.

Correspondence: Inquiries to Colin F. Mackenzie, MD, Shock Trauma Anesthesiology Research Center, 11 S Paca St, Suite LL-01, Baltimore MD 21201; e-mail: cmack003@gmail.com

  1931-7204/$30.00 https://doi.org/10.1016/j.jsurg.2018.10.004

for benefits of ASSET, ATOM, ATLS and for other existing courses should be a high priority. (J Surg Ed 76:832–843. © 2018 Published by Elsevier Inc. on behalf of Association of Program Directors in Surgery.)

KEY WORDS: Trauma Training, Open surgical procedures skills, Hemorrhage control skill, Educational measurement, Efficacy of training

COMPETENCIES: Practice-Based Learning and Improvement, Medical Knowledge, Patient Care, Systems-Based Practice

INTRODUCTION

Surgeons in training receive limited operative surgery time during their residency as a consequence of the United States. Accreditation Council for Graduate Medical Education resident duty-hour restrictions[1-3] and even shorter work hours in European surgical training programs.[2] In addition, trauma care now includes nonoperative management and endovascular treatment of injuries that were previously operated upon. This decreased experience results in surgeons who may lack proficiency in open surgical procedures for trauma, particularly open vascular procedures. Such skills are difficult to develop de novo or to maintain within the usual scope of modern civilian surgical practice. These issues become particularly acute for surgeons facing military deployment. Trauma skills training courses have been developed to fill this gap. However, little is known to-date about what these courses are, their training efficacy, and evaluation evidence to support them. Our aim in this paper is to draw conclusions from the available literature on such courses including: (1) the objectives of currently available courses, (2) the content, scope, cost, and format of these courses, and (3) published evidence showing course efficacy.

METHODS

A systematic review was conducted including search of PubMed using the terms Trauma Training, Surgical Trauma Training, and Open Surgery. Additional relevant articles were identified using specific course names, Google Scholar, Ebsco's Discovery Service searching 50 databases, as well as the University of Maryland's Health Sciences, and Human Services Library's catalog. Searches were complemented by a review of the reference lists of relevant studies found with these searches and by discussion with 4 of the authors (MB, ES, NS, and SS) who have published in the trauma training course literature, or been involved in development or teaching of many of these trauma surgical training courses for civilian and military surgeons. Papers were included for review if designed to teach open trauma surgery skills to physicians and surgeons. Courses were not included if the training was solely for nontrauma, endovascular, endoscopic, laparoscopic, orthopedic, neurosurgical, obstetric/gynecological, or pediatric procedures. Courses were also not included if they were designed to train nonsurgeon clinicians such as physician assistants, nurses, or medics.

The data synthesis used Kirkpatrick's well-established framework for evaluating complex educational interventions, to describe the results of the search and level of evidence for efficacy.[4] Kirkpatrick's framework used in the context of trauma skills courses is as follows:

Level 1: reactions: self-reported satisfaction with the trauma training course, subjectively evaluated, usually with questionnaires, or interviews postcourse.

Level 2: learning: acquisition of new knowledge in managing trauma patients applying open techniques, objectively evaluated, usually with multiple choice questions and similar approaches, pre-/postcourse. Skill retention testing was examined to show newly acquired knowledge was retained weeks/months postcourse.

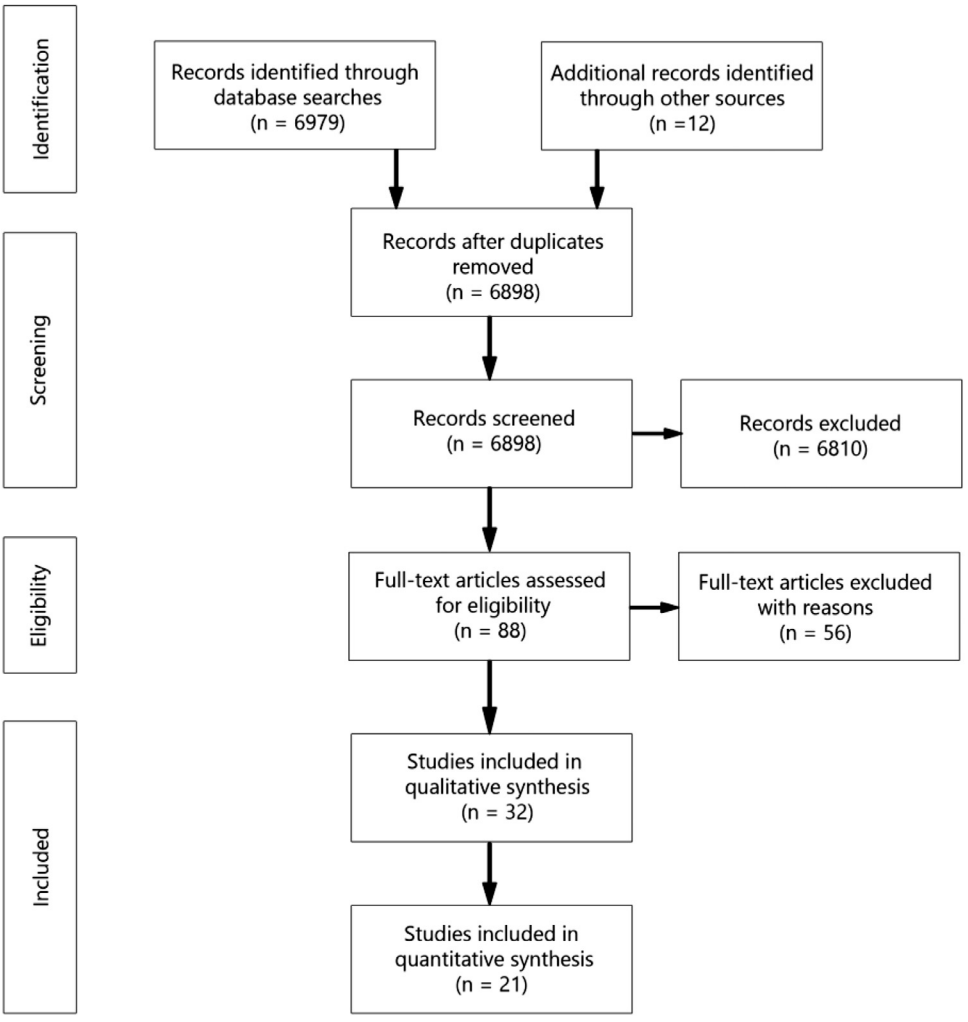
Level 3: behaviors: objectively evaluated acquisition of skills to manage procedures/patients better following the course, including nontechnical skills. Behaviors evaluated through objective skills assessment, e.g., via simulation modules, or real-life data analyzed for skill quality pre-/postcourse and skills retention testing.

Level 4: results: clinical translation of better skills in carrying out the procedures and managing these patients better to reduce patient mortality and/or morbidity.

RESULTS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram[5] of the systematic review results is shown in Table 1. After reviewing 6979 titles and abstracts identified using the search criteria and excluding 6810 that were not relevant using our exclusion criteria above, or were duplicates, 88 full-text articles were assessed. Of these 56 did not meet inclusion criteria, e.g., training included medical students, or nonopen surgery procedures or irrelevant to trauma surgery. Thirty-two studies met criteria after full-text review, describing 21 different open surgery trauma skills training courses. The identified courses are summarized alphabetically, numbered by course acronym in Table 2. The intended participants, format, course costs, frequency of administration, duration, uniform resource locators, and Kirkpatrick levels of evidence are provided

TABLE 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Flow Diagram



in Table 2. There were large variations in course costs, frequency of administration, duration, and evidence for training benefit. A brief description of each open trauma surgery skills course that met inclusion criteria is provided as Supplementary Material, together with the identified evidence for course efficacy.

There were no prospective randomized clinical trials of trauma skills course impact. Published evidence of course training benefit was not identified for many established courses including: Definitive Surgical Trauma Skills, Emergency Management of Battlefield Injuries, Endovascular Skills for Trauma and Resuscitative Surgery, Emergency War Surgery Course (EWSC), Military Operational Surgical Training, Specialty Skills in Emergency Surgery and Trauma, Surgical Training for Austere Environments, or Surgical Trauma Response Techniques. However, as described in the Supplementary Material, many of these courses have incorporated features of other courses, e.g., Advanced Surgical Skills for Trauma (ASSET), Advanced Trauma Operative Management (ATOM), Advanced Trauma Life Support (ATLS) whose training efficacy has been independently confirmed. Definitive Surgical Trauma Skills, Endovascular Skills for Trauma and Resuscitative Surgery, EWSC, and Specialty Skills in Emergency Surgery and Trauma used live tissue (usually porcine). Courses utilizing human cadavers included ASSET, ATLS (some sites), Definitive Surgical Trauma Care course, EWSC, Military Operational Surgical Training, and Trauma Exposure Course. Simulated models or laboratory exercises were used in Surgical Training for Austere Environments and Surgical Trauma Response Techniques.

The highest level of evidence for benefit for any trauma skills courses was Kirkpatrick's level 3. ATLS, with content developed by consensus panels with

TABLE 2. Skills Training Courses, Their Intended Trainees, Duration, Cost, Frequency of Offering, Accompanying Educational Material, Reference, Whether Skill Retention was Tested, Summary With List of Kirkpatrick's Level 1 to 4 Evidence and Evaluation Metrics Used

Course Name	Intended Trainees	Duration and Cost	Course Format	Frequency Courses: Lectures:	Course Manual or DVD	URL or Ref	Pre-/Post-Retention	Kirkpatrick's Evidence Level 1-4 Controls Y/N	Evaluation Metrics Used; # studies, End-point for Evaluations. Publication reference #
1. ACDS	Surgeons in France. Compulsory for junior military surgeons	3 d modules × 5 (112 h) ɑ 2000 per module	Human cadavers and live tissue (pigs)	7 Annual Courses (35 Modules) Lectures	Yes, 5 course modules	J R Army Med Corps 2016;162:34-347	Pre-/post-testing No retention	Level 1-2 Own controls	Knowledge and oral exam end-point: graduation after completion of 5 Modules and oral exam and written tests
2. ASSET	Surgical residents, fellows and attendings	$500-$2000	Unpreserved human cadavers	No Lectures Monthly Courses in 135 locations	Yes, DVD and Manual	https://www.facs.org/quality%20programs/trauma/education/asset	Pre-/postretention at 14 months, and 30 months	Level 3. Control Yes: Expert and practicing surgeon controls	Metrics: IPS; GRS: Errors. Vascular control (end-point <20 min); 4 compartment LE fasciotomy (end-point # compartments decompressed) References: 8-10
3. ATLS	Physicians (primarily),	2-2.5 d $ 750	Task Trainers and simulated patients. Cadavers and animals (some)	Lectures Monthly Courses in 15-20 US locations	Yes	https://web4.facs.org/ebusiness/ProductCatalog/product.aspx?ID=863	All	Level 2-3 Yes: some studies with controls	Written test score, evaluator ratings, Reference: 6
4. ATOM	Surgeons	1 d $ 1750	Live bleeding porcine models	Lectures. 26 Sites incl. Danish Armed Forces	Yes	http://atomcourse.com	Pre-/post-tests and self-reported retention	Level 2. No controls	Subjective self-reported satisfaction References: 12-14
5. BATLS	Surgeons/ Nurses/ Technicians	1 d $ NA	Moulage, Simulation Models	Lectures. 6 courses/y. in Sweden	Yes	J R Army Med Corps 2000;146:*110-114*	No	Level 1 No controls	No metrics
6. DSTC	Advanced surgical trainees	2 d $ 3445	Human cadavers and live tissue	Lectures 38 courses in 20 countries in 2014 became MOST (below)	Yes and slides	http://www.iatsic.org/DSTC.html	Pre-/post-tests	Level 0-1	DSTC is included as part of MOST

(*continued on next page*)

TABLE 2 (*CONTINUED*)

Course Name	Intended Trainees	Duration and Cost	Course Format	Frequency Courses: Lectures:	Course Manual or DVD	URL or Ref	Pre-/Post-Retention	Kirkpatrick's Evidence Level 1-4 Controls Y/N	Evaluation Metrics Used; # studies, End-point for Evaluations. Publication reference #
7. DSTS	Advanced surgical trainees	2 d £1295	Demonstration on anatomical surgical prosections.	Yes	Yes	www.rcseng.ac.uk/coursearch/dsts.html	No	Level 0	No metrics identified. MOST ASSET and ATOM included 1 non-peer reviewed paper Trauma.4:184-188; 2002
8. EMIB	NATO Trainee Course	5 d	Cadavers	2 to 3×/y, Lectures	No	www.coemed.org	No	Level 0	No metrics identified
9. ESTARS	Trauma Surgeons	2 d	Live tissue and simulation	Modular Lectures	Yes	www.med.umich.edu/surgery/vascular-trauma	No	Level 1 No Controls	No metrics. Publication on animal lab but none on course benefits to skill, or retention of skills
10. EWSC military service specific variations	DoD trauma surgeons	3 d $ NA	Human cadavers and animal models	Yes lectures	Yes	https://health.mil/Training-Center/Defense-Medical-Readiness-Training-Institute/Emergency-War-Surgery-Course	No	Level 1 No controls	War Surgery handbook Describes course. No publications. Contains ASSET and ATOM are included and these have been independently shown to have training efficacy
11. MOST	Junior and Senior trainees in team	4-5 d	Cadaver and models	2×/y. Mandated every 3 y	Yes	https://publishing.rcseng.ac.uk/doi/pdf/10.1308/147-363513X13-50050891-7215	None identified	Level 1-2 No controls	No metrics described. ASSET ATOM and DSTS course components included.
12. SSET	Junior surgical trainees with an interest in general surgery	2 d $ N/A	Porcine specimens	Yes	No	https://www.rcseng.ac.uk/courses/couresearch/	No	1 Anecdotal report No Controls	No formal assessment. Certificate given On completion

(*continued on next page*)

TABLE 2 (*CONTINUED*)

Course Name	Intended Trainees	Duration and Cost	Course Format	Frequency Courses: Lectures:	Course Manual or DVD	URL or Ref	Pre-/Post-Retention	Kirkpatrick's Evidence Level 1-4 Controls Y/N	Evaluation Metrics Used; # studies, End-point for Evaluations. Publication reference #
13. STAE	Predeployment course for surgeons with an interest in humanitarian and disaster medicine	5 d £ 2000	Modules and case-based laboratory setting scenarios	Lectures. Frequency of course offering NA	No Manual or DVD	www.rcseng.ac.uk/courses/course-search/surgical-training-for-austere-environments	No	Level 0-1 No controls	No Metrics no end-points found
14. STRT	Surgeons or those deployed to disasters	5 d $NA	Didactic lectures and hands on laboratory exercises	Yes	Yes, Emergency War Surgery Handbook	http://www.dimo.af.mil/shared/media/document/AFD-110720-026.pdf	No	Level 0-1 No Controls	No Metrics no end-points found
15. Trauma Surgery Course (Italy)	General Surgeons or General and Emergency surgeons	2 d € 1200	Lectures and Live Tissue (porcine)	Yes, Course twice per y: 18 participants	Slides and Video	Ann Ital Chir 2016;87:68-74	Pre-/Post-Testing. No retention	Level 2 Yes. No Concurrent controls	Metrics demo benefit. Pass/Fail test on 3 scores. Certificate Follow-up showing reduced mortality in 1 hospital after taking course. Reference: 11
16. Course offered 1× TEC	Trauma Fellows and Chief Residents	1 d (8 h)	Cadaver-based	Offered once 10 y ago to 18 participants	Structured curriculum	J Trauma 2009; 67:1093-96	Pre-/Postself report and operative score	Level 2. Some pretesting, no controls. F/U self-evaluations 7 months after course	Metrics: Self-reported confidence and self-perceived operating score. Repeated evaluations 7 months after training.
17. CBAR	Surgery Residents	5 × 4 h skills laboratories	Cadaver-based	Offered once PGY) 3 (n = 12) and PGY 4 (n = 10)	Oral exam, Step-wise guide	FASEB J. 1st Apr 2016: Abstract Number:567	Pre-/postexam operative score, confidence	Level 2	

(*continued on next page*)

TABLE 2 (*CONTINUED*)

Course Name	Intended Trainees	Duration and Cost	Course Format	Frequency Courses: Lectures:	Course Manual or DVD	URL or Ref	Pre-/Post-Retention	Kirkpatrick's Evidence Level 1-4 Controls Y/N	Evaluation Metrics Used; # studies, End-point for Evaluations. Publication reference #
18. CPAC	14 General Surgery Residents7 intervention group and 7 controls:	8 weeks No cost	procedural anatomy course. Intervention: cadaver dissection. Controls: Course materials without participation in cadaver dissection	Offered once	Course Material Yes	*J Surg Res* 2016;201: 22-28.	Pre-/Post-testing No retention	Level 2 Yes: Controls	Oral examination using standardized templates and (2) a questionnaire assessing operative confidence. Oral exam showed increased knowledge. Confidence increased for most of 5 procedures studied
19-21. Internet Advertised: ACTS, LTS, TALON	Surgical Trainees	1-2 d	Lectures. Intention to repeat unknown.	Some with Course Manual	See text for URL's	No published Data	No controls	Level 0	No Metrics described. No publications

ACDS, Advanced Course for Deployment Surgery; ASSET, Advanced Surgical Skills for Exposure in Trauma; ATLS, Advanced Trauma Life Support System; ATOM, Advanced Trauma Operative Management; BATLS, Battlefield Advanced Trauma Life Support, CBAR, Cadaver-Based Anatomic Relationships in Vascular Surgery; CPAC, Cadaveric Procedural Anatomy Course; DSTC, Definitive Surgical Trauma Care; DSTS, Definitive Surgical Trauma Skills; EMBI, Emergency Management of Battlefield Injuries Course; ESTARS, Endovascular Skills for Trauma and Resuscitative Surgery; F/U; follow-up; GRS, Global Rating Scale; LE, lower extremity; MOST, Military Operational Surgical Training; NA, not available; SSET, Specialty Skills in Emergency Surgery and Trauma; STAE, Surgical Training for Austere Environments; STRT, Surgical Trauma Response Techniques; TEC, Trauma Exposure Course; ACTS, Advanced Cadaveric Trauma Surgery Course; LTS, King's College, London Trauma Skills course; TALONS, Trauma LONdon Surgery.

frequent revisions, fulfilled some level 3 criteria with evidence for improved outcomes for educational and organizational patient management[6] persisting with long-term follow-up. A recent systematic review and meta-analysis of the impact of trauma systems structure on injury outcomes found that prehospital ATLS was associated with significant reduction of hospital length of stay, but not mortality, only trauma system maturity resulted in significant reduction in mortality.[7] The ASSET course has level 3 evidence demonstrating improved performance after training and skill retention and an objective rating scale.[8-10] ASSET training had content developed by consensus among members of the American College of Surgeons (ACS) Committee on Trauma, the longitudinal studies reporting results of testing used trained evaluators and standardized scripts for evaluating multiple learners levels (untrained surgeons, post-training, skill retention, and practicing surgeons and experts). Individual Procedure Score (IPS) in residents was low before ASSET training and higher in residents after training; IPS was higher in experts 40 months after training than residents or practicing surgeons 30 months after training. Increased IPS was associated with shorter time to complete vascular control procedures; IPS <0.6 in residents predicted an increased occurrence of technical errors. Global Rating Scores and Overall Performance ratings give similar ranking to IPS, but did not identify errors or point to individual surgeon retraining interventions as did IPS.

The Trauma Course (Italy) met some level 3 criteria with reduced mortality and shorter time to the operating room after training (see below),[11] although nonsurgeons in the team also took the course. The ATOM course[12-14] reported high postcourse satisfaction surveys, improved skill self-assessment, and subjective value to surgical practice. The ATOM course also demonstrated sustained increase in self-efficacy for trauma management, rated as level 2 evidence.

The remaining courses (described in Supplementary Material) have level 1 to 2 evidence using subjective self-evaluation and satisfaction surveys, including pre- and post-testing in some courses. Few courses have evaluated skill retention.

DISCUSSION

Trauma surgery skills courses using human cadavers, live tissue models, and simulation play an invaluable role in surgical training and skill sustainment, particularly for infrequent but highly lethal injuries. As with numerous other training and simulation courses, objective evidence for the effectiveness of such training, particularly in real-world scenarios, remains challenging. To our knowledge, no published evidence from prospective controlled trials exists suggesting that surgical skills training courses change trauma patient outcome, or improve performance of the skills taught, when performed in the real-world operating room.[15,16] While nearly every type of training examined demonstrated benefit compared to no training, the most effective and efficient types of trauma skill training remain unknown. The effect of trauma skill simulation training on real-world patient outcomes was examined in only 1 trial from Italy, following implementation of the Trauma Surgery Course; this study found that team and surgeon training was associated with reduced time to operating room and reduced mortality, although the use of nonconcurrent controls, a large increase in patient admissions in the intervention years and another confounding variable of training the entire team, not just the surgeon, limited the strength of these findings of outcomes related to training the surgeon.[11] "Hospital Exercise" (HOSPEX) was another effort to improve team and operative training before deployment and obtain evidence of benefit in the real military environment.[17] HOSPEX is a fully immersive live-in simulation experience that covers the entire environment of a military hospital with all departments, not just surgery. Participants undertake a 3-day training program within HOSPEX before deployment to war zones. Primary outcome measures were assessed with the Imperial Military Personnel Assessment Tool. the Imperial Military Personnel Assessment Tool measures crisis management, trauma care, hospital environment, operational readiness, and transfer of skills to civilian practice. Reliability, skills learning, and retention in the conflict zone were assessed. Pre-/post-HOSPEX comparisons revealed significant improvements in decision-making, situational awareness, trauma care, and knowledge of hospital environment. No skills decayed over time when assessed several months later in the real conflict zone. All skills transferred to civilian clinical practice. Such macrosimulations may be the way forward for integrating the complex training needs of expert clinicians and testing organizational "fitness for purpose" of entire hospitals.[17]

Robustly designed studies are also needed to determine the most effective training methods and models for open trauma surgery, the optimal duration of training courses, and the ideal training interval. The ability to detect improved performance of individual surgeons in a training environment is a challenge since the effects of team versus individual surgeon performance and other nontechnical factors such as communication and leadership skills may also affect patient outcomes.[18] Future research designs should include both technical and nontechnical skill performance metrics that allow standardized evaluation, (including use of standardized patients) before and after training, as well as follow-up, to determine when and if skill degradation occurs and whether performance gains

realized from training can be shown in the operating room. Continued efforts in demonstrating training benefits of course curricula should occur for trauma skills courses targeting Kirkpatrick's level 2 or higher evidence of their benefits. Assessment of real-world performance after simulation training is needed. Obtaining level 3 and level 4 evidence for ASSET, ATLS, and ATOM and other existing skills courses should be a high priority.

Difficulties in Determining Trauma Skills Course Benefits

A major challenge in assessing the impact of trauma surgical skills training courses is a lack of trauma surgery performance metrics; such metrics are needed to study outcomes after trauma skills training.[7,15,16] A further difficulty is the lack of standardization of training course material and disparities in training conditions (e.g., length and content of courses) and inclusion of different levels of trainees in the courses.[16] In currently reported studies examining trauma skill training courses, few courses report evaluations of senior attending or consultant surgeons participating as trainees; such participation may be beneficial, given the low incidence in routine clinical practice of injuries taught in these courses. Many of the courses share common trauma procedural core competency ingredients. The ACS and Association of Program Directors in Surgery (APDS) reviewed Technical Skills Assessment Tools and found 23 assessment tools for 35 ACS/APDS core competency skills.[19] Two tools, OSATS[20] and Objective Structured Assessment of Technical Skills,[21] have been tested in more than 1 procedure. These Objective Structured Assessment of Technical Skills and OSATS tools were designed for assessing elective procedures, not to evaluate performance of trauma skills during time-critical emergency open surgical procedures. Thirty of the ACS/APDS modules had at least 1 assessment tool with some common surgical procedures being addressed by several tools, while 5 modules had no tools applied. This finding, when applied to trauma skills course with similar content, suggests that standardization of content and metrics should occur. "Best of breed" trauma skills course components should be included based on evidence of training efficacy.

Design of Studies for Complex Educational Interventions

Alternatives to Live Tissue Training

Simulated models of abdominal surgery have user interface problems and physical models of vascular procedures have limitations in fidelity and realism in comparison to cadavers.[22] The use of perfused cadavers has been promoted,[23] but perfused cadavers require expertise and time to prepare, become edematous and may only be sustainable for a few hours, limiting the full-day use of both sides of a cadaver, although perfusion with expired blood may reduce edema. A review of studies of open surgical simulation that included live animals, cadavers, bench models, virtual reality, and software-based computer simulators showed benefit of all models in developing surgical skills of surgical trainees. However, such studies utilized a variety of assessment metrics and most were focused on short-term results with no follow-up evaluations.[24] While there is some evidence relating to skill retention for other types of surgical training, such evidence is still lacking for trauma skill courses. In a randomized trial, optional deliberate suturing practice reduced skill decay at 6 months after training, with similar performance when comparing weekly and daily practice.[25] Simulator training has been shown to improve resident performance of basic surgical tasks such as suturing in the operating room.[26] However, no metrics applicable to open surgery training to assess the entirety of technical skills employed by expert trauma surgeons in the operating room[27-30] nor assess different procedures performed by the same surgeon.[15,28,30] There is some preliminary evidence that hand-motion analysis may be useful to document surgical training and provide objective measure of skill retention.[31]

Military Surgical Skills Training

In battlefield surgery, the types of surgical cases and the state of preparedness of the deployed surgeons has been reported. These publications included suggestions for improving predeployment training.[32-36] The Defense Health Board (DHB) report of March 9, 2015 "Combat Trauma Lessons Learned for Military Operations of 2001 to 2013"[34] states: "The lack of comprehensive, standardized training for military health care providers creates an operational gap that affects unit-level training as well as effective utilization of the military system to reduce combat mortality". The Defense Health Board suggested that ATOM and ASSET could be augmented to incorporate combat casualty care-specific training, and also recommended that the Department of Defense develops a surgical skills course, including war surgery skills.[34] This recommendation supports the reality that curriculum contents from ATLS, ASSET, and ATOM have been widely incorporated into other courses, often with various modifications to support austere or military environments. Hoencamp et al. reported that civilian surgical training does not adequately prepare residents for military surgery and suggested that introduction of a North Atlantic Treaty Organization military and disaster standard may facilitate the recognition of military surgery as a subspeciality within general trauma surgery.[35] This lack of experience in traumatic thoracic, abdominal, and

vascular surgery is also reported by Brooks et al. among British consultant and junior surgeons.[36] Additional training methods should be considered that may be complementary, including just-in-time training, such as heads-up display of instruction, which make up for absent skills,[37] deliberate practice,[38] multimedia or mental rehearsal tools,[39] and mobile training platforms which help maintain skills.[40] Simulation Training for Operational Medicine Providers teaches procedural skill competencies to Navy General Medical Officers and uses 5 validated standardized patient with review of instructional videos, reference materials, and practice with partial task trainers before small group sessions with subject matter experts. Learners demonstrated competency or were remediated. Simulation Training for Operational Medicine Providers was found to an effective tool for primary care skill training and credentialing.[41]

Toward the Future of Technical Skills Training for Trauma Care

Surgeons at all levels of training and experience who may care for critically injured patients should participate in trauma skills courses for these procedures, rarely encountered in clinical practice. Those faculty running courses lacking evidence of benefit should be encouraged to study the outcomes of these courses utilizing metrics developed for assessment of similar courses. Further development of performance metrics to assess trauma team organization as well as individual surgical skills is needed. Identification of the best instructor to student ratio, combination of training models, length of training courses, and training intervals is needed. Real-time evaluation using a tablet with a simple checklist and global rating scale scores[6] and video-recording could be used by observers to score performance, allow participants to understand the details involved in evaluations and help provide feedback. Study designs are needed to show Kirkpatrick's level 3 and 4 evidence for existing courses, rather than development of new courses and incurring considerable cost. It should be possible to design a prospective controlled trial of skills training courses in trauma centers with multiple succinct teams, the effects of skills training could be studied with the members of the team providing operative care alternating between trained and untrained (control) surgeons. Standardized patients could be included in these trials. Macrosimulations predeployment could be useful for integration of complex military surgeon training skills, with those of co-worker clinicians and testing organizational "fitness for deployment" of the surgical team.[17] Workplace-based assessments could assist military surgeon "readiness" and have been included in the revised Intercollegiate Surgical Curriculum Programme in the UK.[42]

LIMITATIONS

This review focused on training courses that contained open trauma surgical procedural skills. Only a small portion of the content of some courses (such as ATLS) included open surgical procedures. This systematic literature review did not include skills training for nurses, dentists, paramedics and training in aviation, and other professions or industries that might include training useful for improving open surgical skills.

CONCLUSION

A high priority requirement for the future is to obtain Kirkpatrick's level 3 and 4 evidence for existing surgical trauma training courses and consolidate the best content of courses. An essential part of this process is the development of trauma surgery performance metrics for assessing the specific competencies of military and civilian trauma surgeons and for measuring the adequacy of training courses. Such metrics will become increasingly important as trauma care evolves toward less surgery and more critical care.[43,44] Pre- and post-training and retention skills assessments should be available to permit personalized approaches to skills refreshment. Large variations in course content, duration, didactics, operative models, resource requirements, and cost suggest that standardization of content and performance metrics are needed to show efficacy of trauma skills training courses.

AUTHOR CONTRIBUTIONS

Colin Mackenzie and Mark Bowyer conceived the idea of a literature summary of trauma training courses. Colin Mackenzie wrote the manuscript drafts and Stacy Shackelford, Samuel Tisherman, Nick Sevdalis, Eric Elster and Mark Bowyer provided critical reviews.

ACKNOWLEDGMENTS

Thanks to Andrea Shipper MLS, Kristy Pugh MS, and Ashton Engdahl BS who assisted with the literature review. Lynn Stansbury MD, MPH, MFA, copy edited and made editorial suggestions to an early version of the manuscript.

REFERENCES

1. Accreditation Council for Graduate Medical Education. Resident duty hours in the learning and work environment: comparison of 2003 and 2011 standards. Available at: http://acgme-2010standards.org/

pdf/dh-ComparisonTable2003v2011.pdf. Accessed June5, 2018.

2. Ulmer C, Wolman DM, Johns MM, eds. Committee on Optimizing Graduate Medical Trainee (Resident) Hours and Work Schedule to Improve Patient Safety, National Research Council. Resident Duty Hours: Enhancing Sleep, Supervision, and Safety, Editor 2009, National Academies Press. p. 341.

3. Bruce PJ, Helmer SD, Osland JS, et al. Operative volume in the new era: a comparison of resident operative volume before and after implementation of 80-hour work week restrictions. *J Surg Educ*. 2010;67:412–416.

4. Kirkpatrick DL. Evaluation of Training. Evaluation of Short-Term training in Rehabilitation. Eugene, Oregon: College of Education, Department of Special Education, University of Oregon; 1970. p. 35–56.

5. Moher D, Liberati A, Tetzlaff J, Altman DG. The Prisma Group. Preferred reporting items for systematic reviews and meta analyses. *Prisma Statement PLoS Med*. 2009;6. https://doi.org/10.1371/journalpmed10000097. e10000097.

6. Jayaraman S, Sethi D, Chinnock P, Wong R. Advanced trauma life support training for hospital staff. *Cochrane Database Syst Rev*. 2014;8. Aug 22CD 004173.

7. Moore L, Champion H, Tardif P-A, et al. Impact of trauma system structure on injury outcome: a systematic review and meta-analysis. *World J Surg*. 2018;42:1327–1339.

8. Mackenzie CF, Garofalo E, Shackelford S, et al. Using an individual procedure score before and after the advanced surgical skills exposure for trauma course training to benchmark a hemorrhage-control performance metric. *J Surg Educ*. 2015;72:1278–1289.

9. Mackenzie CF, Garofalo E, Puche A, et al. Performance of vascular exposure and fasciotomy among surgical residents before and after training compared with experts. *JAMA Surg*. 2017;152:1–8.

10. Mackenzie CF, Bowyer MW, Henry S, et al. Cadaver-based trauma procedural skills training: Skills retention 30 months after training among practicing surgeons in comparison to experts and more recently trained residents. *J Am Coll Surg*. 2018;227:270–279.

11. Bellanova G, Buccelletti F, Berletti R, et al. How formative courses about damage control surgery and non-operative management improved outcome and survival in unstable politrauma patients in a Mountain Trauma Center. *Ann Ital Chir*. 2016;87:68–74.

12. Jacobs l, Burns K, Luk S, Hull S. Advanced trauma operative management course: participant survey. *World J Surg*. 2010;34:164–168.

13. Ali J, Ahmed N, Jacobs LM, Luk SS. The advanced trauma operative management course in a canadian residency program. *Can J Surg*. 2008;51:185–189.

14. Kaban JM, Stone ME, Dayama A, et al. Does resident trauma exposure affect advanced trauma operative management course experience. *Am Surgeon*. 2016;82:212–215.

15. 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.

16. van Hove PD, Tuijthof GJM, Verdaasdonk EGG, et al. Objective assessment of technical surgical skills. *Br J Surg*. 2010;97:972–987.

17. Arora A, Cox C, Davies S, et al. Towards the next frontier for simulation-based training: full-hospital simulation across the entire pathway. *Ann Surg*. 2014;260:252–258.

18. Mishra A, Catchpole K, Dale T, McCulloch P. The influence of non-technical performance on technical outcome in laparoscopic cholecystectomy. *Surg Endosc*. 2008;22:68–73.

19. Ghaderi I, Manji F. MD, Park YS, et al. Technical skills assessment toolbox: a review using the unitary framework of validity. *Ann Surg*. 2015;261:251–262.

20. Martin JA, Regehr G, Reznick R, et al. Objective structured assessment of technical skill (OSATS) for surgical residents. *Br J Surg*. 1997;84:273–278.

21. Williams RG, Verhulst S, Colliver JA, et al. A template for reliable assessment of resident operative performance: assessment intervals, numbers of cases and raters. *Surgery*. 2012;152:517–527.

22. Holzmacher J, Sarani B, Puche A, et al. Can hyperrealistic physical models of peripheral vessel exposure and fasciotomy replace cadavers for performance assessment? *J Trauma Acute Care Surg*. 2017;83(1 Suppl 1):S130–S135. Jul.

23. Reihsen TR, Alberti L, Speich J, et al. Feasibility of a perfused and ventilated cadaveric model for assessment of life-saving traumatic hemorrhage and airway management skills. *J Trauma Acute Care Surg*. 2016;80:799–804.

24. Davis J, Khatib M, Bello F. Open surgical simulation: a review. *J Surg Educ*. 2013;70:618–627.

25. De Win G, Van Bruwaene S, DeRidder D, Miserez M. The optimal frequency of endoscopic skill labs for training and skill retention on suturing: a randomized controlled trial. *J Surg Educ*. 2013;70:384–392.

26. Fernandez GL, Page DW, Coe NP, et al. Boot camp: educational outcomes after 4 successive years of preparatory simulation-based training at onset of internship. *J Surg Educ*. 2012;69:242–248.

27. Jelovsek JE, Kow N, Diwadkar G. Tools for the direct observation and assessment of psychomotor skills in medical trainees: a systematic review. *Med Educ*. 2013;47:650–673.

28. Kogan J, Holmboe E, Hauer K. Tools for direct observation and assessment of clinical skills of medical trainees: a systematic review. *JAMA*. 2009;302:1316–1326.

29. Maruthappu M, El-Harasis MA, Nagendran M, et al. Systematic review of methodological quality of individual performance measurement in surgery. *Br J Surg*. 2014;101:1491–1498.

30. Maruthappu M, Gilbert BJ, El Harasis MA, et al. The influence of volume and experience on individual surgeon performance. *Ann Surgery*. 2015;261:642–647.

31. Shaharan S, Nugent E, Ryan DM, Traynor O, Neary P, Buckley D. Basic surgical skill retention: can patriot motion tracking system provide an objective measurement for it? *J Surg Educ*. 2016;73:245–249.

32. Tyler JA, Clive KS, White CE, Beekley AC, Blackbourne LH. Current US military operations and implications for military surgical training. *J Am Coll Surg*. 2010;211:658–662.

33. Remick KN, Dickerson J.A. II, Nessen SC, Rush RM, Beilman GJ. Transforming US Army Trauma Care: an evidence-based review of the trauma literature. *US Army Med Dep J*. 2010: 4–21. Jul-Sep.

34. Jenkins D. Defense Health Board Trauma and Injury Subcommittee Report: Combat Trauma Lesson Learned from Military Operations of 2001-2013, (Committee Chair). Released March 9 .

35. Hoencamp R, Tan EC, Idenburg F, et al. Challenges in the training of military surgeons experiences from Dutch combat operations in southern Afghanistan. *Eur J Trauma Emerg Surg*. 2014;42:421–428.

36. Brooks A, Butcher W, Walsh M, Lambert A, Bowne J, Ryan J. The experience and training of British general surgeons in trauma surgery for the abdomen, thorax and major vessels. *Ann R Coll Surg Engl*. 2002;84:409–413.

37. Shariff U, Seretis C, Lee D, Saba BP. The role of multimedia in surgical skills training and assessment. *Surgeon*. 2016;14:150–163.

38. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med*. 2004;7:S70–S81. Suppl.

39. Davison S, Raison N, Khan MS, et al. Mental training in surgical education: a systematic review. *ANZ J Surg*. 2017;87:873–878.

40. Mackenzie C.F., Fitzgerald M., Mouzakis K., et al. Mobile platform to evaluate individual surgeon technical skills. *Military Health Services Research Symposium. Abstract #109 Fort Lauderdale Aug 18-21*, 2014

41. Polk TM, Greer J, Alex J, et al. Simulation training for operational medicine providers (STOMP): design and implementation of a novel comprehensive skills-based curriculum for military general medical officers. *Mil Med*. 2018;83:40–46.

42. Shastri-Hurst N, Naumann DN, Whitbread T. Military surgery in the new curriculum: whither general surgery training in uniform? *J R Army MedCorps*. 2015;161:100–105. Jun.

43. Cothren CC, Moore EE, Hoyt DB. The U.S. trauma surgeon's current scope of practice: can we deliver acute care surgery? *J Trauma*. 2008;64:955–965.

44. Pottenger BC, Galante JM, Wisner DH. The modern acute care surgeon: characterization of an evolving surgical niche. *J Trauma Acute Care Surg*. 2015;78:120–125.

SUPPLEMENTARY INFORMATION

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jsurg.2018.10.004.