A Systematic Review of Live Animal Use as a Simulation Modality ("Live Tissue Training") in the Emergency Management of Trauma

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INTRODUCTION: Live anaesthetized animals are used as simulation models to teach techniques in the emergency management of trauma. We aimed to explore how "live tissue training" (LTT) is designed, delivered and evaluated in order to better understand and characterize aspects of educational merit.

METHODS: A systematic review was performed using PRISMA guidance. A combined approach, involving a 3-stage modified narrative synthesis process and reflexive thematic analysis was used to identify key concepts across the published literature.

FINDINGS: Qualitative synthesis of 48 selected articles suggests that LTT is mainly used to teach military and civilian physicians and military medical technicians. The procedures trained vary with the learner population, from simple pre-hospital trauma tasks to advanced operative surgical skills. Many courses use a combination of didactic and practical training, with an animal model used to train practical application of knowledge and procedural skills. Descriptions of the learning interventions are limited, and explicit use of educational theory or pedagogic frameworks were absent within the literature. Four themes were identified regarding aspects of LTT that are valued by learners: "recreating the experience," relating to fidelity and realism; "tick tock" "dynamics of hemorrhage", encompassing the impact of bleeding and urgent pressure to act; "emotional impact" of conducting the training, and "self-efficacy: I believe I can do it."

CONCLUSION: Thematic analysis of published literature suggests that there may be educational benefit in the use of live tissue models due to time criticality and bleeding, which creates a real-life event. LTT also invokes an emotional response, and learners experience an increase in self-efficacy from participation. We consider that these aspects and associated pedagogy should be addressed when researching and developing alternative simulation modalities, in order to intelligently replace, reduce and refine the use of animals in training practitioners in the emergency management of trauma. (J Surg Ed 80:1320−1339. Crown Copyright © 2023 Published by Elsevier Inc. on behalf of Association of Program Directors in Surgery. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/))

KEY WORDS: Simulation, Trauma, Surgery, Critical care, Live tissue training

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

INTRODUCTION

Training in the emergency management of complex, life-threatening traumatic injuries is challenging due to the unpredictable nature of the patient population, the

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complexity of injuries sustained and the environment in which they occur.[1-3] In the context of trauma, uncontrolled hemorrhage is the leading cause of preventable death and early intervention and management of injuries is the key to a successful outcome.[2,4-6] This relies on trained personnel "doing the right thing, at the right time," often in stressful environments under critical time pressure.[3,7]

"Live tissue training" (LTT) is an umbrella phrase used to describe the educational practice of using a live animal as a patient simulation model. Historically, this training was popular amongst surgical specialties and physicians with a practice involving interventional skills such as emergency medicine or anesthesia. The technical skills taught on current LTT courses range from pre-hospital trauma tasks such as the application of a tourniquet or decompressing a tension pneumothorax with needle thoracentesis to the operative skills of "damage control surgery," which includes resuscitative thoracotomy, laparotomy or the management of a catastrophic limb injury.[8-11] Many surgical training courses have replaced animal use with inert simulation models due to increasing attention to the rights of animals, pressure from activists and technological advances producing alternatives.[12] The Advanced Trauma Life Support (ATLS) courses[13] run by the American College of Surgeons phased out the use of animal models in the early 2000s.[14]

LTT has been used extensively by armed forces worldwide to train physicians, nurses, paramedics and nonvocational medical technicians ("medics") in the management of trauma casualties.[12] Military medics are personnel of various nations' armed services who are responsible for providing emergency medical treatment at the point of wounding, in combat or peacetime. They do not have a qualification readily transferable to the civilian setting, have limited clinical access to practice skills and rely heavily on simulation training.[11,15] In contrast, military physicians and other allied health professionals often have an equivalent clinical practice involving the care of civilians, although regular exposure to combat-relevant, complex trauma can be limited.[2]

Previously published systematic reviews[16-18] have sought to compare LTT with alternative simulation models. The training is highly valued by learners and educators, and it is presumed there are educational benefits from using live animals. What these benefits are, however, is unclear. It is important to understand the needs of the learner populations, the types of educational methodology used, which educational domains the training operates within, and how this training is measured in terms of learning objectives and outcomes. The overall aim of our systematic review is to explore how LTT interventions are designed, delivered and evaluated when teaching individuals and teams how to manage complex trauma patients, in order to better understand and to characterize the aspects of LTT which have educational merit.

METHODS

This systematic review follows the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines;[19] the review protocol was registered in advance with the International Prospective Register of Systematic Reviews (PROSPERO) CRD42022334694.[20]

Search Strategy

Our intent was to conduct an extensive search with reasonably wide inclusion criteria. With the assistance of an experienced librarian, a search was constructed to identify studies and articles which discussed use of live tissue training as an educational method exclusively, or compared it to an alternative simulation modality. Key search terms included: live tissue, animal model, simulation. The search strategy was adapted as necessary for various databases; one version of the search is included as an appendix. We did not apply any search limits in terms of geographical location of study, language, or date of publication. A search of databases [MEDLINE (Ovid), Embase, ERIC, Web of Science] was performed on February 02, 2022.

The reference lists of identified review articles were examined to confirm that no potential studies had been inadvertently excluded.

An extensive grey literature search was also performed, using the phrases "live tissue training" followed by "live animal models in trauma simulation." Published guidance was used to create a framework that included keyword searches of Cochrane library, grey literature websites and thesis repositories.[21,22] A media search of the Google News database was also performed (March 01, 2022) using the same phrases. These media articles were then scrutinized to identify sources for inclusion that had not previously been identified via either the database or grey literature search.

Eligibility Criteria

For the purposes of this review, trauma management included any environment and any aspect of care occurring from the initial point of injury through to initial surgical resuscitation ("damage control surgery").

Articles were eligible if they reported observational or interventional studies and included live animals as a simulation modality to train in trauma management; reviews, abstracts and conference proceedings were also included for consideration. Studies involving animal or human cadavers, or *ex vivo* models were only included if acting as a comparator to a live animal model. Any studies which used animals for experimentation rather than training or addressed live animal use for non-trauma clinical reasons were excluded.

Screening and Study Selection

Two independent researchers (CS and HC) screened results based on title and abstract, using electronic article information downloaded to an online tool (Rayyan; https://www.rayyan.ai).[23] Duplicate articles were excluded manually. Initial agreement was assessed using Cohen's K statistic. Articles which received conflicting decisions were included for full-text review. Both researchers subsequently screened full-text articles against eligibility criteria and disagreements were discussed to reach consensus. No studies were excluded at this stage, based on language or assessment of methodological limitations.

Data Extraction and Analysis

Narrative synthesis: A modified narrative synthesis approach was used, comprising 3 stages: developing a preliminary synthesis; exploring relationships within and between studies, and; assessing the robustness of the synthesis.[24]

The preliminary synthesis was developed by abstracting data from full text versions of included papers to a predesigned extraction form. Data were collected regarding study design and aim, context and environment, learner demographic, description of the educational or training intervention, type of tissue/animal model, educational domain, evaluation, and outcome measures. A quality assessment of all included articles was undertaken although these assessments did not influence or weight the analysis. The results of these assessments will be reported separately, alongside a bibliometric analysis of the LTT literature.

Thematic analysis: A 6-phase process of reflexive thematic analysis[25] was subsequently used to identify key concepts across the published research narrative which may contribute to further explaining the educational merit of LTT within the field of emergency trauma management. Following familiarization with the literature achieved during production of the preliminary synthesis, articles were systematically and inductively coded by the lead author (CS), using a qualitative data analysis software package (NVivo 8, QSR International Pty Ltd. (2018); https://lumivero.com/products/nvivo/).

Within each article, data segments of explicit relevance to the exploratory research aim were labelled with a description in a semantic manner. These descriptive coding labels were reviewed and edited throughout the coding phase, in response to author reflexivity and her evolving understanding of the data. Initial themes were generated by clustering codes that shared a similar concept and collated into a thematic map. The latter phases of theme development, refining and defining themes and writing up the analytical findings were conducted in a recursive fashion through discussion with coauthors (RR and KK) to produce the final analysis.

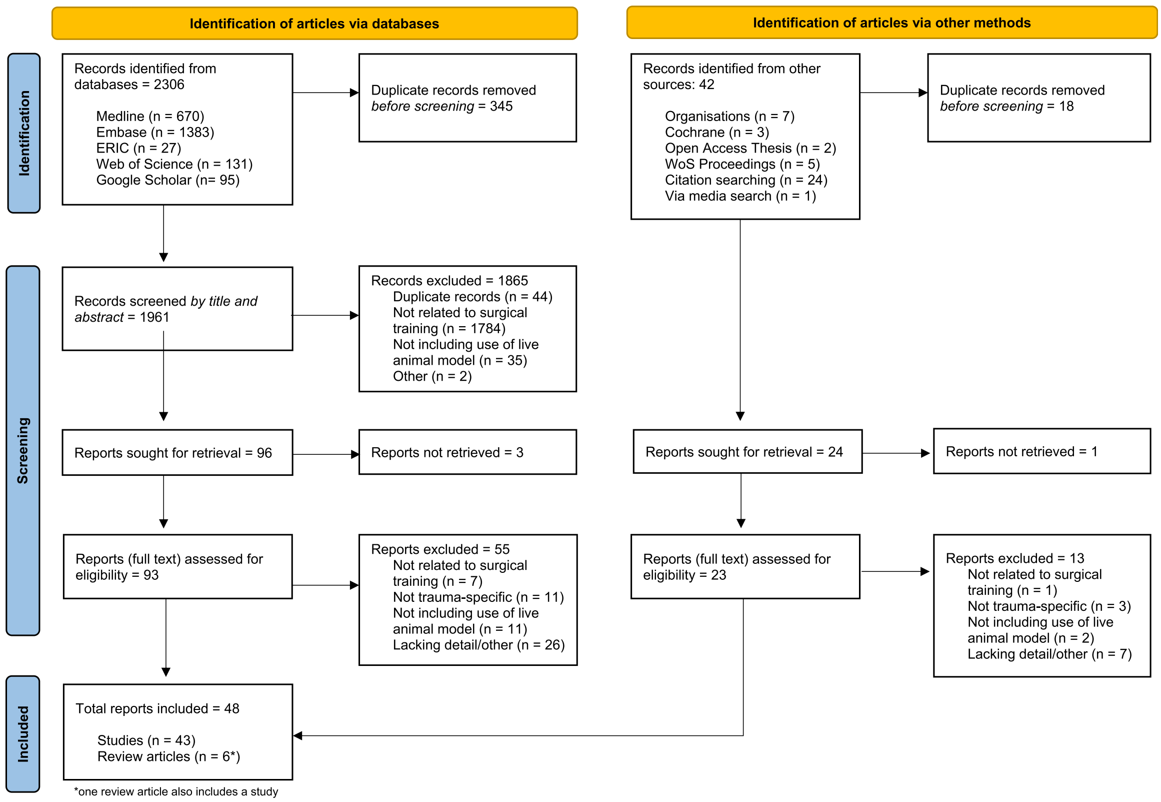
Peer discussion, with varying perspectives, conducted throughout the process increases credibility which, combined with a thorough systematic approach, aims for trustworthiness of the research.

RESULTS

Search Results

The systematic database search yielded 2306 articles, with a further 42 from the grey literature and Google media searches. Title and abstract screening was coherent between the 2 researchers (CS and HC), with a Cohen's K at this stage of 0.802. The PRISMA flow chart illustrates the review process, including rationale for excluding articles. Forty-eight articles were included in the final analysis.

PRISMA chart demonstrating systematic review process.



Article and Study Characteristics

During the preliminary synthesis, articles were divided into 4 broad categories: empirical studies (n = 18) exploring the effectiveness of live animal models in themselves or in comparison with other simulation modalities; articles which reported the evaluation of training programs that involved live animal models (n = 18); empirical studies of a qualitative nature that explored the learner perceptions of LTT and how it was used (n = 9); and review/commentary articles (n = 6). The articles ranged in publication year from 1980 to 2021 with the majority (34/48) published within the last 10 years. The main characteristics of the articles, the categories to which they were attributed, and a description of the learning intervention have been summarized in Table 1. Some articles featured in more than 1 category due to their content and methodology. Articles reporting programme evaluation will be referred to as studies for ease of reporting within this manuscript.

Analysis

This article presents our analysis as 2 elements: a synthesis of qualitative findings, and a thematic analysis relating to what learning provided by an LTT educational experience is valued by the participants.

Table 2 summarizes the key qualitative findings within the design, delivery, and evaluation of LTT courses. LTT is typically part of a course comprising didactic and interactive components, with a live animal model used for the practical application of knowledge and technical skills; the course content and type of skills vary depending on the learner population. Many of the reviewed studies evaluated learners' knowledge and skills in established curricula. Descriptions of the learning interventions are limited in the majority of articles and there is an absence of explicit educational theory or pedagogic framework. Therefore, these findings describe how LTT is being used and by whom but contribute little to identifying which elements have merit as an educational intervention.

We report 4 associated themes, presented in a thematic map (Fig. 1), characterizing aspects of the LTT educational experience that are valued by the learners. These themes and how they are associated are described below with quotations illustrating examples from the analyzed literature.

The "recreating the experience" theme encompasses the features of training fidelity and the concept of realism within LTT; "'tick tock' dynamics of hemorrhage" relates to the urgent pressure to act and manage the impact of bleeding; "emotional impact" relates to the

TABLE 1. Included Article Details and Study Characteristics

Cate-gory	Study design or method	Lead author	Year	Title [type of source]	Journal	Learning intervention / Pedagogic Framework	Notes
Effectiveness	Randomised Controlled Trial (RCT)	Hall[26]	2011	Randomized objective comparison of live tissue training versus simulators for emergency procedures [journal article]	American Surgeon	Lecture followed by supervised group practical simulation training	
		Hall[27]	2014	Comparison of self-efficacy and its improvement after artificial simulator or live animal model emergency procedure training [journal article]	Military Medicine	Lecture followed by supervised group practical simulation training	
		Hart[28]	2018	Training and Assessing Critical Airway, Breathing, and Hemorrhage Control Procedures for Trauma Care: Live Tissue Versus Synthetic Models [journal article]	Academic Emergency Medicine	Group practical training session with formative feedback from instructors	Same study as reported as an abstract by Sweet[65]
		Keller[30]	2018	The Physiologic Stress Response of Learners during Critical Care Procedures: Live Tissue vs Synthetic Models [conference poster abstract]	Chest	Not described	Same population sample as Hart[62]
		Peng[31]	2018	Biological Response to Stress During Battlefield Trauma Training: Live Tissue Versus High-Fidelity Patient Simulator [journal article]	Military Medicine	TACMED course - classroom instruction; simulation training of five tasks (detail not described); assessment in operating room environment and a simulated battlefield scenario	Likely same population sample used for studies by Savage[51] , Peng[55] and Vartanian[54]
		Savage[32]	2015	A comparison of live tissue training and high-fidelity patient simulator: A pilot study in battlefield trauma training [journal article]	Journal of Trauma and Acute Care Surgery		
		Sweet[34]	2015	Priming the pump: Improvement in performance of life-saving airway, breathing, and hemorrhage skills after pre-testing and training on a simulator versus live tissue: An analysis of critical failures [conference abstract]	Academic Emergency Medicine	Not described	Likely same study population as Sweet[65] and Hart[62]
		Sweet[29]	2015	Comparing simulators to live tissue for teaching and assessing life-saving hemorrhage, airway and breathing procedures: Evaluation of critical failures [conference abstract]	Academic Emergency Medicine	Not described	Same study published by Hart[62]
		Vartanian[33]	2017	Battlefield trauma training: a pilot study comparing the effects of live tissue vs. high-fidelity patient simulator on stress, cognitive function, and performance [journal article]	Military Psychology	TACMED course - classroom lecture; simulation training (detail not described) familiarisation session; individualised training with instructors; two evaluation sessions	Likely same population sample as Peng[55] and Savage[51]
		Barnes[35]	2016	Live tissue versus simulation training for emergency procedures: Is simulation ready to replace live tissue? [journal article]	Surgery	Standardised didactic presentation; simulation training of twelve tasks (detail not described)	Primary study
		Custalow[36]	2002	Emergency department resuscitative procedures: Animal laboratory training improves procedural competency and speed [journal article]	Academic Emergency Medicine	Instructional video presentation +/- intensive animal laboratory training with 1:1 instruction of three procedures	
		Izawa[37]	2016	Ex-vivo and live animal models are equally effective training for the management of a penetrating cardiac injury [journal article]	World Journal of Emergency Surgery	Simulation training; supervised individual practice of procedure	
	Prospective cohort	Dawe[38]	2018	Tele-mentored damage-control and emergency trauma surgery: A feasibility study using live-tissue models [journal article]	American Journal of Surgery	No training prior to assessment; procedures performed with tele-mentored assistance	
		Chapman[39]	1993	Critical Emergency Medicine Procedural Skills: A Comparative Study of Methods for Teaching and Assessment [report]	US Department of Education	Critical content instruction during 30-min training laboratory; video demonstration of procedural steps; 30-min computer-based practice; written, computer and animal simulation assessments	
		Stefanidis[40]	2013	Cadavers versus pigs: which are better for procedural training of surgery residents outside the OR? [journal article]	Surgery	Procedural workshop with supervised practice ratio 2:1	
		Tobin[41]	2017	Is it ethical or effective? Comparison study of live porcine and human cadaver models in resident training of invasive procedures [conference abstract]	Academic Emergency Medicine	Procedural training (pedagogic detail not described)	
	Cross-sectional study	Sergeev[42]	2012	Training modalities and self-confidence building in performance of life-saving procedures [journal article]	Military Medicine	Not described	
		McCarthy[43]	2002	Accuracy of Cricothyroidotomy Performed in Canine and Human Cadaver Models During Surgical Skills Training [journal article]	Journal of American College of Surgeons	ATLS course - initial verbal instruction by instructors followed by direct supervision of practice in simulation laboratory	

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Evaluation	Program evaluation	Back[44]	2017	Concept and evaluation of the German War Surgery Course - Einsatzchirurgie-Kurs der Bundeswehr [journal article]	Journal of the Royal Army Medical Corps	20 theoretical lessons consisting of expert teaching, clinical case discussion and interactive seminars; practical skills training using cadaver and live animal model	Method: questionnaire
		Gerhardt[11]	2008	An experimental predeployment training program improves self-reported patient treatment confidence and preparedness of Army combat medics [journal article]	Prehospital Emergency Care	Didactic lectures; practical simulation training	Method: questionnaire
		King[45]	2006	Simulation training for a mass casualty incident: two year experience at the army trauma training center [journal article]	Journal of Trauma and Acute Care Surgery	Didactic classroom lesson; multidisciplinary team preparation of equipment and facility; mass casualty simulation using live animals; individual self-assessment and faculty review	Method: review of learner data
		Mattsson[46]	1980	Advanced casualty care training using animal models [journal article]	Military Medicine	Detail on type of procedures; no detail on pedagogy	Unclear learner population, presumed military Evaluation method not clearly reported
		Sohn[9]	2006	From the combat medic to the forward surgical team: the Madigan model for improving trauma readiness of brigade combat teams fighting the Global War on Terror [journal article]	Journal of Surgical Research	Tactical Combat Casualty Care (TCCC) course - didactic session; simulation with HPS for anatomical correlation of procedures and team building; war-based case presentations and triage scenarios with associated skill stations; live animal simulation +/- field exercise with multiple simulation modalities	Method: questionnaire
		Sohn[47]	2007	Training physicians for combat casualty care on the modern battlefield [journal article]	Journal of Surgical Education		Method: questionnaire and review of learner data
		Gaarder[8]	2004	Advanced surgical trauma care training with a live porcine model [journal article]	Injury – International Journal of the Care of the Injured	Didactic lectures; practical simulation station using live animal models in a field hospital setting	Method: questionnaire
		Villamaria[48]	2014	Endovascular Skills for Trauma and Resuscitative Surgery (ESTARS) course: curriculum development, content validation and program assessment [journal article]	Journal of Trauma & Acute Care Surgery	Pre-course instructional manual; didactic lectures; familiarisation session; simulation practice with task trainer and live animal models	
		Ali[49]	2008	The Advanced Trauma Operative Management course in a Canadian residency program [journal article]	Canadian Journal of Surgery	ATOM course - pre-course CD-ROM with learning objectives and video demonstration, instructional manual and textbook; didactic lectures; practical simulation session with 1:1 instruction using live animal model	Method: questionnaire
		Bredmose[10]	2021	Live Tissue Training on Anesthetized Pigs for Air Ambulance Crews [journal article]	Air Medical Journal	Multidisciplinary group simulation training with 1 instructor; group debrief following each procedure moderated by instructor (multiple techniques including rapid-cycle deliberate practice, debrief-on-demand, peer-led debriefing)	Method: questionnaire
		Goodloe[50]	2014	Tactical emergency medicine care in a military medicine, law enforcement, and emergency medicine collaborative training program [conference abstract]	Canadian Journal of Emergency Medicine	TCCC course - didactic teaching; practical exercises; tactical field exercise involving live animal model	Evaluation method not clearly reported
		Jacobs[51]	2002	Development and Evaluation of the Advanced Trauma Operative Management Course [journal article]	Journal of Trauma, Injury, Infection & Critical Care	ATOM course - pre-course CD-ROM; didactic lectures; surgical laboratory exercise using live animal model	Method: questionnaire
		Tugnoli[52]	2006	Initial evaluation of the “trauma surgery course” [journal article]	World Journal of Emergency Surgery	Theoretical aspects using slides and video presentations, simulated case discussion and interactive debate; surgical laboratory exercise on live animal model with 3:1 instruction	Method: questionnaire
		Tugnoli[53]	2019	Learning on animal models: a 16-year experience with the theoretical-practical course on surgery of polytrauma [journal article]	Annali Italiani di Chirugia		Further report on same course as Tugnoli(35)
		Washington[54]	2014	Trauma training course: innovative teaching models and methods for training health workers in active conflict zones of Eastern Myanmar [journal article]	International Journal of Emergency Medicine	Modular training comprising review of anatomy and physiology, discussion of injury patterns and diagnosis using multiple simulation models; assessment with live animal model	Method: questionnaire

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	Pilot or feasibility study	Evans[55]	2019	Comparison of simulation models for training a diverse audience to perform resuscitative endovascular balloon occlusion of the aorta [journal article]	Journal of Endo-vascular Resuscitation and Trauma Management	Didactic lectures focusing on cognitive aspects of procedure; familiarisation with equipment; observation of expert performance; practical simulation using mannequin, virtual reality, animal model and perfused cadaver	
		Borger van der Berg[56]	2019	Vascular access training for REBOA placement: a feasibility study in a live tissue-simulator hybrid porcine model [journal article]	Journal of the Royal Army Medical Corps	Demonstration of procedure via animation video; 1:1 instruction on anatomical landmarks and procedural steps; verbalisation of procedure; assessment using live animal model	Unclear learner population, presumed civilian
	Cross-sectional study	Gala[57]	2012	Use of animals by NATO countries in military medical training exercises: an international survey [journal article]	Journal article	Detail on numbers of institutions; no detail on pedagogy	Method: survey
Perceptions	Qualitative: interview study	Barnes[35]	2016	Live tissue versus simulation training for emergency procedures: Is simulation ready to replace live tissue? [journal article]	Surgery	Not described and/or not applicable for type of study or research question	Secondary study design reported in same article. Likely same population is reported by Bukoski[43]
		Bukoski[58]	2018	Perceptions of Simulator- and Live Tissue-Based Combat Casualty Care Training of Senior Special Operations Medics [journal article]	Military Medicine		Likely same population sample as reported by Barnes(41)
		Mahoney[59]	2020	Experiences of medical practitioners in the Australian Defence Force on live tissue trauma training [journal article]	BMJ Military Health		
		Savage[32]	2015	A comparison of live tissue training and high-fidelity patient simulator: A pilot study in battlefield trauma training [journal article]	Journal of Trauma and Acute Care Surgery		Secondary study design reported in same article.
	Qualitative: mixed methods	Booth-Kewley[60]	2015	Perceived strengths and weaknesses of highly realistic training and live tissue training for Navy corpsmen [report]	Naval Health Research Centre		Method: interview & survey
		Kim[61]	2017	The Value of Live Tissue Training for Combat Casualty Care: A Survey of Canadian Combat Medics With Battlefield Experience in Afghanistan [journal article]	Military Medicine	TACMED course - lectures; instructional videos; procedural demonstrations using simulation models with increasing physical fidelity; two assessment scenarios	Method: survey
	Cross-sectional study	Bergmeister[62]	2020	Simulating Surgical Skills in Animals: Systematic Review, Costs & Acceptance Analyses [journal article]	Frontiers in Veterinary Science	Detail on types of team training (cardiac, transplant surgery, traumatic bleeding) and microsurgery with cost analyses; no detail on pedagogy.	Secondary study design reported in same article. Method: survey
		Bilello[63]	2021	Procedural training models among emergency medicine residency programs [journal article]	Clinical and Experimental Emergency Medicine	Detail on numbers of institutions and type of procedures; no detail on pedagogy	Method: survey
		Godoroja[64]	2016	Impact of an educational program for airway management using anaesthetized live pigs on anesthetists practice [conference abstract]	Anesthesia and Analgesia	Lectures; simulation training on mannequins and animal models (detail not described)	Method: survey
Review	Systematic review	Bergmeister[62]	2020	Simulating Surgical Skills in Animals: Systematic Review, Costs & Acceptance Analyses [journal article]	Frontiers in Veterinary Science	Not applicable	91 included articles
		Da Luz[16]	2015	Current use of live tissue training in trauma: a descriptive systematic review [journal article]	Canadian Journal of Surgery		12 included studies
		Goolsby[17]	2017	Systematic Review of Live Tissue Versus Simulation Education for Prehospital Trauma Providers [journal article]	Military Medicine		12 included studies
	Literature review	Galloway[65]	2000	Alternatives to the use of live animals in military medical trauma training [thesis]	US Command and General Staff College		
		Hart[18]	2016	Literature Evidence on Live Animal Versus Synthetic Models for Training and Assessing Trauma Resuscitation Procedures [journal article]	Journal of Special Operations Medicine		
		RTG-HFM-242[12]	2020	Technology Alternatives for Medical Training: Minimizing Live Tissue Use [report]	NATO		Expert opinion working group

Note: Grey shaded cells indicate studies which involve a military learner population or a military focus.

TABLE 2. Summary of Qualitative Findings

No.	Category	Summary	Detail
1	Learner population	The 2 main learner populations trained using LTT are physicians (both military and civilian) and military medics. Medical professions trained to a lesser reported extent include nurses, paramedics, and physician associates.	The physicians trained using LTT are mostly consultant or residency level surgeons in trauma/general/vascular surgery[8,37,40,41,44,48,49,51,52,55,56,59] with other surgical specialties included, but trained less commonly. Nonsurgical medical specialties most regularly involved are emergency medicine (EM) physicians[36,38,39,41,50,55,56,59] and anesthetists or intensivists.[10,47,59,64] In the majority of studies, the military and civilian learner populations remain distinct, except for 2 examples[8,35] which combined military and civilian learners in a military environment, and another example of a multidisciplinary faculty including military medical providers and civilian EM physicians providing EM residents with tactical pre-hospital care training.[50]
2	Training location	LTT is reported to occur most commonly in countries within North America and Europe.	Literature reports that LTT has been undertaken by civilian learners in USA,[40,41,51,63] Canada[49] Austria,[62] Sweden,[56] Norway,[8,10] Germany,[44,62] Italy,[52,53] Romania,[64] Japan[37] and Myanmar.[54]
		LTT is conducted in both the military and civilian environment.	Most research relating to military populations and use of LTT has taken place in the USA and Canada. Denmark, Poland, Norway and the United Kingdom also reported that their militaries use live animal models to train in the surgical management of trauma in a 2012 survey of NATO countries.[57] The Australian[59] and Israel Defence Forces[42] also use LTT and potentially other nations who have not published research in this area.
3	Use of a live animal simulator model	The pig (porcine) model is the animal most used for LTT.	The use of a pig (porcine) model is reported in 29/48 articles. One review reported 70% of simulations conducted with a porcine model.[62] There is limited clarification in the literature as to the rationale for this, except that the pig's thorax and abdomen most closely resembles the size and anatomy of a human.[51,65] Goat (caprine) models have featured mostly in US military training interventions, with rarer, likely historic, use of dog (canine) models.[18] **Key related themes**: recreating the experience; "tick tock" dynamics of hemorrhage
4	Cost of live animal simulator model	Live animal models are expensive with high management costs.	The use of live animal models is expensive with high management costs;[36,39,42,53,55,62,65] some programs have discontinued live animal use due to finance and resource limitations.[63] There are reported costs of US$2150[37] to $2506[62] for a single pig model, consumable equipment including anesthesia, and associated institutional costs. However, in a comparison of live animal model to perfused cadaver model, the latter was reported to be significantly more expensive due to the additional cost of hiring fluoroscopy equipment.[55]
5	Use of alternative simulator model	LTT courses use alternative types of simulator model for practical training, typically prior to use of a live animal model.	Some LTT courses use a combination of modalities in their practical training with a human patient mannikin[9,11,47] (e.g. Laerdal SimMan, Caesar Trauma Patient simulator) or a human cadaver[44] typically used for training prior to use of the live animal model. Studies which compared a live animal model to an alternative simulator to assess training effectiveness used these alternative modalities as comparators[26–28, 31–33,35,40,41,43] **Key related themes**: recreating the experience;

(continued)

TABLE 2 (*continued*)

No.	Category	Summary	Detail
6	Comparison of live animal models and human cadaveric models	There is no consensus regarding primacy of a given model.	There is no consensus regarding primacy of either live animal or human cadaveric models in the literature. In a study of EM and general surgery residents which specifically addressed educational effectiveness, human cadaveric models were deemed more realistic and effective than a live porcine model for surgical procedural training.[41] In a different study, another cohort of surgical residents disagreed that a human cadaver model was preferable to a live animal model.[49] 41% of surgical residents in a third study felt that both LTT and cadaveric training had value, with 26% indicated differences in model preference depending on the procedure being trained.[40]
			These models arguably address different training goals. For example, the cadaveric model will provide relevant human anatomy and accurate anatomical relationships, while the porcine model allows for training in vascular control. Authors of 1 article write that "the 2 models are complementary and should be viewed as a symbiotic combination that maximizes the benefits of training for surgical emergency procedures."[44]
		The preference of using either live animal model or human cadaveric model for surgical training is likely multifactorial.	Preference may be related to extant use of a modality for training; in a study of EM training programs, those who reporting not using live animals regarded them as inferior to human cadavers, but of similar quality to commercial simulation models when ethical or financial concerns are excluded.[63]
			Key related themes: recreating the experience; "tick tock" dynamics of hemorrhage
7	LTT delivery	LTT typically begins with didactic and/or interactive training components, which vary in duration and content. Subsequent simulation training using a live animal model focuses on practical application of knowledge and procedural skills.	Some courses provide pre-course information to their learners in the form of a textbook or visual media (photographs, videos) as either a physical or an online resource[36,48,49,51] allowing for familiarization or revision of the course content.
			LTT courses typically start with delivery of didactic training (i.e. lectures, video demonstrations) and/or interactive seminars using clinical case examples. Possible topics can include principles of combat casualty care or damage control surgery, pathophysiology of trauma, diagnostic methods and/or surgical techniques.[8,44,47,51,53] These didactic training components vary in duration from thirty minutes to several hours, can be divided over multiple days and incorporated around some practical training sessions.
			The practical training using a live animal model is commonly procedural in nature and involves between 4-12 hours of practical training. The animal model can be used during training as an opportunity to practice skills with guidance from faculty, during an assessment scenario or both. Some articles report training which used a live animal model with learners being subsequently tested using an alternative simulator model or vice versa.[11,26,28,30,31,37,43,44,54] A familiarization session may take place with the equipment and the environment before practical training, including discussion around simulator or animal care practices, and anatomic differences between model and human.
			Learner-to-faculty, and learner-to-animal model ratio varies, but is generally low: 1:1[36,49] 2:1[48] 3:1[53] 4:1[9] 6:1[10]. There is minimal information in the literature about teaching and mentoring practices.
			Key related themes: self-efficacy: "I believe I can do it"

(*continued*)

TABLE 2 (*continued*)

No.	Category	Summary	Detail
8	LTT content	Procedures trained using a live animal model vary from pre-hospital trauma tasks to advanced operative surgical skills.	Critical pre-hospital trauma tasks are taught, for example, on an ATLS course,[66] and can be considered initial or temporizing medical management performed by various medical professions. Examples of tasks are cricothyroidotomy or surgical airway (n = 24; the main focus in 3 studies[38,43,64]), needle thoracentesis (n = 13), chest tube thoracostomy (n = 15), application of extremity tourniquet (n = 14), junctional hemorrhage control (n = 14), intraosseous access (n = 8). This group of technical skills were taught to military medics in various studies[27-29,32-35] with more advanced operative surgical skills typically performed by surgeons.[8,44,49,51,52]
		Content varies depending on the learner population.	The most common examples of operative surgical skills are: resuscitative thoracotomy (n = 11), cardiac procedures such as pericardiotomy, management of cardiac trauma (n = 8), damage control laparotomy (n = 7), management of open fractures including fasciotomy (n = 6). Many of the operative skills taught are "maneuvers uncommon in normal surgical practice, such as thoracic access to the superior vena cava or suture of heart injuries"[52] or novel hemorrhage resuscitation techniques such as Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA).[48,55,56] These skills are taught in a sequential way from simple to highly complex scenarios, to develop learner skills and to maximize the animal's ability to survive for the duration of training.[44,51] **Key related themes**: recreating the experience; "tick tock" dynamics of hemorrhage
9	Learner evaluation: knowledge and skills	Knowledge is typically assessed using a written examination; skills and performance are judged by observation of an evaluator.	Written examinations to assess knowledge gained using MCQ or true/false question stems are delivered following training or both pre/post-training.[35, 36, 47-48,51] Learner performance is typically judged by evaluator observation,[26,35,39,45,48,51,52,55,56,] with or without a validated assessment tool. Few studies stated the tool used, provided a detailed description, or signposted to where a copy could be accessed; examples of validated tools which were used were OSATS,[37] Global Rating Scale,[48] ASSET checklist.[56]
		Self-assessment questionnaires evaluate learners' subjective development, with confidence the most used marker. Assessment of learners and evaluation of training usually happens on completion of the educational intervention i.e. at the end of the course.	Assessment of learners and evaluation of training usually happens on completion of the educational intervention i.e. at the end of the course.[8,1026-29,32,33,35,37,38,40,41,44,45,48,49, 51,56,] In those studies researching training effectiveness, assessment occurred at varying intervals following the intervention e.g. same day of training,[31,35,38,43,] 1 week[26,27,37] or 6 months later.[36] Self-assessment questionnaires where the learner evaluates their development, and for example, their confidence relating to skills, are provided at the end of training and often feature Likert scales.[8-10,27,35-38,41,44,47,49,51] **Key related themes**: self-efficacy: "I believe I can do it"
10	Learner evaluation: stress response	There is no conclusive evidence that use of a live animal model provides a different type or greater stress response compared to an alternative model.	Four studies[30,31,33,35] used biomarkers such as salivary amylase,[30,31] cortisol measurements,[30,33] DHEA,[33] plasma catecholamines[31] or electrodermal activity[35] to attempt to demonstrate a physiological stress response to LTT. The results are not conclusive. **Key related themes**: emotional impact

(*continued*)

TABLE 2 (*continued*)

No.	Category	Summary	Detail
11	Learner evaluation: value and enjoyment	The literature indicates a preference for live animal models and LTT, especially by military and surgical learners.	The literature overall indicates a preference for live animal models and LTT,[9,27,32,35,49,58] with courses rated highly, enjoyed by learners,[44] and considered to be a valuable part of training,[11,45,52] Where courses involving LTT were evaluated by learners, in studies which explored the opinions of learners and educators, (6 of 8 involving a military population)[32,35,58-62,64] there was significant bias for LTT, although the use of combined training modalities was supported.[35,58] **Key related themes**: all

participants' feelings when involved with LTT. These all broadly relate to the design and delivery of the training, interacting with each other and contribute to the final theme "self-efficacy: I believe I can do it" which relates to the evaluation of LTT interventions and the learning outcomes most described in the literature.

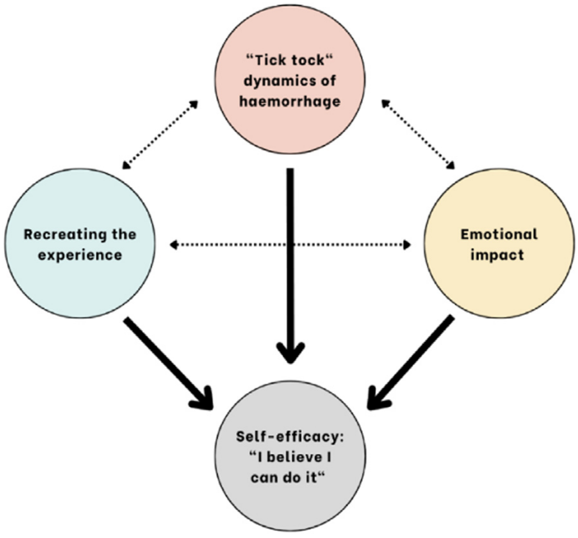

FIGURE 1. Thematic map of 4 themes relating to educational value for learners. Dotted arrows indicate interaction between themes; thick arrows indicate unidirectional influence of 1 theme on another.

Recreating the Experience

The design of courses involving LTT is influenced by the perceived need of learners, to address gaps in clinical practice which cannot easily be achieved: lack of alternative training opportunities,[51,54,62,65] lack of trauma exposure[8,16,46,51] or augmentation and transfer of skills to a military environment.[44,45,47,65] The acquisition and practice of technical skills (psychomotor domain) during LTT is considered of greater importance than increasing knowledge of the principles of trauma surgery (cognitive domain).[49] Generally, training is focused on individual learners revisiting techniques and practicing them, rather than learning them for the first time.[10,47] Educational objectives and curricula are determined by subject matter experts, often using adaptations from existing programs and regularly evaluated to maintain currency,[8,44,51-53,55] with teaching faculty comprised of professionals with relevant and credible experience.[9,26,44,45,47-49,55]

Many of the training programs that incorporate LTT have environmental fidelity in the form of a military field exercise[9,45] as in the Norwegian trauma care[8] and German War Surgery courses,[44] or are based in an operating theatre setting[52] such as the Advanced Trauma Operative Management (ATOM) course.[49] Beyond the appearance of the surroundings and associated sounds and smells, the participation of other team members such as nurses[10,49,53] and paramedics[10] introduces additional realistic elements of leadership and teamwork (non-technical skills)[8,45] to the experience, allowing for "the opportunity to improve relational skills under stress conditions..."[53]

> "Most students report that the visual, auditory and actual experience during the operative so mimic the human environment that they have no difficulty believing that this is a similar experience to the human penetrating trauma."
>
> Statement from a discussion by Jacobs et al.[51]

There are noted difficulties for learners in transferring performance between simulator models.[34] The pig (porcine) model is the animal most used for LTT (reported in 29/48 articles), but there is limited clarification in the literature as to the rationale for this, except that the pig's thorax and abdomen most closely resembles the size and anatomy of a human.[51,65] Nonhuman anatomy of animal models is recognized as a limitation, as is the requirement for veterinary involvement and advanced anaesthesia.[12,35,58,60] For example, the REBOA technique is reportedly more challenging in a pig model due to the small artery size and depth and tougher tissues in comparison to humans.[56] When performing cricothyroidotomy, the thicker strap muscles and increased subcutaneous fat will mean learners have to continuously palpate their landmarks and manipulate more tissue.[26] The choice of simulation model is significant. McCarthy et al. demonstrated cricothyroidotomy placement accuracy in a canine model was low (69.9% vs 96.4% in a cadaveric model)[43] whereas Hall et al. demonstrated that learners using a porcine model achieved greater success rates. It was noted that learners experienced confusion due to the lack of a hyoid bone in the synthetic human patient simulator (HPS) model, resulting in an incorrectly sited incision when tested on a human cadaver model.[26]

Some authors raised a concern about false confidence due to learning tasks using an alternative simulator that is perceived as easier than performing the same tasks on humans in real life.[58]Although a HPS can be spatially accurate, it does not prepare learners for anatomic deviation, bleeding, the tactile feedback of manipulating real tissues, nor to allow for recognition and management of complications. Some authors argue that the difficulties experienced using an animal model prepare learners better for simpler human anatomy. Increased procedural difficulty can solidify previous learning experiences, allows for clinical problem-solving and may increase skill retention.[65]

> "Traditional simulation training is not ideal for improving procedural skills that require tactile sensation and sensory feedback to the performer as well as an adequate physiological response."
>
> Statement from introduction of article by Bredmose et al.[10]

When considering fidelity in terms of recreating the experience, the fact that the animal model has less physical fidelity (i.e. it does not look human), does not appear to be problematic for learners. 88% of participants interviewed by Booth-Kewley, the majority of whom were military medics, highlighted the importance of being able to work on a live patient, giving the feel of what working on a human is like.[60] Likewise, Mahoney et al. reported the most valued aspect of LTT was the tactile experience of handling animal tissues, with none of their 15 interviewees feeling that this was replicable with inert models.[59] This is especially significant when training for complex or delicate interventions, with management of penetrating cardiac trauma commonly cited.[59] Bredmose et al. believe that "tissue feeling and tactile sensation cannot be properly practiced without hands-on practical in vivo training," commenting they felt this to be especially true for practitioners without a surgical background.[10]

"Tick-Tock" Dynamics of Hemorrhage

Some injuries require time-critical decisions to be made[8] and the demand for independent, proficient performance at the first attempt is greater in the context of trauma than in other types of surgery.[65] Time to complete a procedure was used as a quantitative measure in multiple studies[26,36,37,39,48,55,56] and words such as "critical," "urgency," "rapid" and "pressure" feature throughout the literature. Tugnoli et al. stated that in their Surgery of Polytrauma course, the "importance of the effectiveness and speed of intervention is frequently stressed."[52]

The functional fidelity of real-time, reactive physiology obtained from live animal models is identified as an unarguable advantage compared to alternative simulators.[53,55,58] Surgical resident engagement and motivation tends to be limited when the realism of the model is not optimised.[40] Human cadavers and many simulators do not bleed. For those that do, they do not respond in the same biological manner that a human patient would.[12] Live animals are dynamic in nature, and their tissues allow for bleeding and coagulation,[12] which adds to the realism[32] and may promote learner engagement along with the possibility of autonomous performance,[65] where learners can see the impact of their interventions[12,60] and inappropriate actions produce immediate negative feedback.[65] The physiologically accurate, active responses of a live animal model can evoke a visceral response and demand critical thinking;[58] this aspect of functional fidelity is likely a key contributor toward the reported learner preference.

> "The most challenging surgical situations in trauma care are caused by severe hemorrhage. The concept of damage control surgery is based on getting control of bleeding and contamination. Cadaver dissections can demonstrate the procedures in principle, but the packing of a liver injury will always be ''successful'', which is not guaranteed in a real injured person. What makes the live porcine model superior to other simulated models is the live tissue feeling combined with the presence of real hemorrhage that does not stop unless controlled."
>
> Statement from a discussion by Gaarder et al. (2004)[8]

Emotional Impact

The emotional component of LTT creates a sense of urgency and mental stress that is difficult to replicate,[35,55] with stress and emotion generally felt to be a positive aspect of the training experience.[32,55,59] In LTT, premature death—before the end of the clinical scenario and the planned time of euthanasia—is a real possibility. Treating a living being is associated with psychological gravity; witnessing bleeding from injuries in live animals appears to convey a level of stress and urgency that is not as present with other types of simulators.[12,61] Animal survival is expected until training is completed.[46] This aspect of psychological fidelity is unique to this type of training - other types of simulator modalities cannot die and therefore no real loss is experienced when a task is not successfully completed.[58]

Sohn et al. reported a nonquantifiable teaching aspect; they repeatedly observed hesitance in military medics', including some who exhibited a "frozen in place stance" when they were initially "exposed to seemingly uncontrollable hemorrhage from a proximal femoral artery injury" in an animal model, which required them to be encouraged to act by faculty in order to save life.[9]

> "Live tissue was noted most commonly to build confidence, instilling both a sense of urgency and a visceral response in the trainee to a model that can expire with more realistic responses to treatment and better tactile response."
>
> Results quoted from Barnes et al. (2016)[35]

Four studies[30,31,33,35] used biomarkers such as salivary amylase,[30,31] cortisol measurements,[30,33] DHEA,[33] plasma catecholamines[31] or electrodermal activity[35] to attempt to demonstrate a physiological stress response to LTT. The results are not conclusive. Barnes et al. could not conclusively identify a single training modality as superior for any of the emergency trauma skills they evaluated, although they did comment that a dynamic porcine model compared to a static caprine model may account for some differences in electrodermal activity.[35] Another study stated that "the wounding of animal models elicited a more realistic stress response in the participants than the simulators."[32] In contrast, other authors reported that synthetic models produced an equivalent stress response to that produced by LTT and concluded that this was evidence that programs could reduce live animal use without sacrificing educational quality.[30]

The exact cause of the stress in these studies is unclear. There could technically be multiple stressors experienced during LTT: environmental conditions (such as a battlefield scenario) causing fear or anxiety, concern about performance and being evaluated or appraised, and the emotional strain of potentially losing or being unable to help a patient. A military expert working group reported that factors such as empathy for, and camaraderie with the patient, coupled with other high-stakes challenges, such as a hostile, austere environment are unique to the military context.[12] Other authors have discussed how trauma medicine is inherently stressful and postulate that there is a need to 'inoculate' military medical practitioners against the deleterious effects of excessive arousal."[59]

Self-Efficacy: "I Believe I Can Do It"

> "The most commonly articulated advantage of [LTT] is that this 1 training event defined the student's acceptance that he, personally, was prepared to 'cut' another living human being. Neither model nor cadaver use prior [to] the animal facilitated training event instilled this level of confidence."
>
> Statement from thesis published by Galloway (2000)[65]

Although LTT is most focused on psychomotor skills, rather than the use of technical standards to evaluate success, most studies included outcome measures in the form of learner-assessed confidence or self-efficacy. Self-confidence is how assured an individual feels about themselves, whereas self-efficacy relates to individuals' judgements regarding their capabilities to perform successfully. In the ATOM course, for example, a high self-efficacy score is associated with a high likelihood of success in performing the task, whereas a low self-efficacy score is associated with behaviors such as task avoidance or low level of performance.[49] Sergeev et al. assert that the principal goal of any training program is to increase the self-confidence of trainees, "under the assumption that a more confident soldier or medic will better execute his or her duties."[42] However, self-confidence or self-efficacy are not an accurate reflection of competence, especially in less experienced, novice and underperforming learners.[18]

Psychologically, multiple factors interact to contribute to this characteristic including ability in skills, personal judgement, and preparedness to perform, and it is a measure subject to bias. For example, in 1 LTT study, average self-confidence levels were higher for paramedics than for physicians, with males expressing higher or equal self-confidence to females.[42] In a study about managing cardiac trauma, where LTT was compared with an *ex-vivo* training model and pump, objective scores showed no evidence of differences in terms of psychomotor skill ability, yet confidence was scored significantly higher after training for the LTT group.[37] Data from 2 other studies comparing effectiveness of training modalities showed significant improvement in learner-rated self-efficacy scores regardless of modality.[27,35] In military populations, learners specifically attribute LTT to increasing the confidence in handling battlefield casualties,[9,32,58-61] even for experienced practitioners, due to limited opportunities to hone skills in civilian practice. The average improvement in self-confidence for infrequently performed procedures exceeds that for familiar procedures performed more frequently.[8] For many who have a civilian practice and access to simple procedures, live tissue does not extend the experience of surgeons beyond their daily practice.[59] Unsupervised experience had the highest influence on confidence across all procedures, with a plateau level identified where increasing experience contributed minimally to increasing confidence.[42] In contrast, however, other authors reported that all groups of surgeons had significant increases in self-efficacy, reflecting that practice can frequently increase confidence even in those who are already quite confident.[51]

Few studies reviewed how long confidence lasted. Where this was measured, results are not congruent. Izawa et al. reported that the LTT group had statistically significantly more self-confidence than their *ex-vivo* group. However, when assessed 1 week later, although the self-confidence of both groups was significantly greater compared to pre-training there was no longer a difference in the self-confidence level between the 2 groups.[37] In a study by Custalow and colleagues, the leaner group who had received LTT to teach thoracotomy experienced statistically significantly higher confidence in performing the procedure compared to the group who had just watched an instructional video, and maintained this confidence when tested 6-month later.[36]

Sohn et al. followed up 140 learners 1 year after their course, and who had deployed to Iraq for military operations in the interim; "99% indicated that the principles taught on the TC3 [Tactical Combat Casualty Care] course helped with battlefield management of injured casualties during their deployment."[9] Gerhardt et al. evaluated a 3 day RUTU ("Ramp-Up Train Up") training course, comprising environmentally-contextualized, individual LTT, delivered 1 month prior to military deployment. They noted that medics who had attended the course maintained a higher level of confidence compared to medics who had not attended, across 3 time-phases: arrival in theatre, at their first casualty encounter and at the end of deployment. There was, however, progressive improvement toward parity with the RUTU group by the end of the deployment period, suggesting self-reported confidence among combat medics increases with active clinical and field experience.[11]

DISCUSSION

This is an inclusive review of live animal use in the emergency management of trauma, and the only 1 to consider the educational utility of the modality. It is also timely, with many included articles published in the last 10 years, potentially reflecting a combination of increasing use of simulation-based medical education in response to reduced clinical exposure for trainees, patient safety concerns and increasing public awareness regarding animal usage and animal welfare.

Our thematic analysis demonstrates common traits about LTT across the literature. Three of the themes related to design and delivery of educational interventions are associated with fidelity, and it appears that a combination of types of fidelity is felt to be educationally valuable by learners, broadly physical, functional, and psychological.

A live animal model has characteristics that add to the perception of clinical realism, including biological variation, increased level of difficulty compared to other simulators, dynamic physiological responses and the possibility for both patient and procedural treatment complications. These characteristics influence environmental realism, and an emotional response of stress or pressure, both of which appear to contribute to commitment or "buy in" to the training scenario.

When considering physical fidelity, it is recognized that a pig does not look like a human, and perhaps learners do not see the animal model as a human patient substitute during LTT. If characteristics other than physical appearance, however, are considered more valuable, learners may respond to the animal not as a model, but as a living being, which may be why anatomical dissimilarity appears to be forgiven.

The functional fidelity of psychological cues appears to be important to learners, but descriptions in the literature only indicate the dynamic nature of bleeding. For example, there is no discussion of the impact that hemorrhage may have on the senses. It is undoubtedly much more difficult to perform skills when one cannot see structures properly, and the tissues and one's hands are sticky or slippery, and yet there was no explicit mention in the reviewed literature about the technical challenges associated with performing techniques in the presence of major hemorrhage. It is likely that these factors would also influence a potential emotional, stress response observed during LTT interventions.

Previous systematic reviews[16-18,62] addressed live animal use across different research questions, concluding that the body of evidence is poor to moderate,[17] and neither adequate nor robust enough to determine whether LTT is superior to other simulation methods[16-18] in trauma education. We identified a significant paucity of information regarding pedagogy, even within those articles where curricula have been developed or training programs evaluated. The design and delivery of educational interventions are not described in detail,[10] although many articles described supervised practical instruction, which may have involved individualized feedback. In terms of comparing research and drawing conclusions, heterogeneity within the literature remains a significant issue, in terms of comparison of simulation modalities, educational interventions and learner evaluation and assessment tools.

A significant focus in the literature appears to be on justifying the use of the training. Our qualitative synthesis means we understand who is being trained, the type of content and procedures being taught and practiced, but what we don't know from this review is how this educational intervention is being delivered, nor its formal educational impact. A learner's preference for a certain modality does not mean that it is educationally more beneficial compared to another modality. We identified that the educational content of the different LTT interventions varies according to the type of learner. It follows that the requirements of an LTT intervention and the associated educational merit attributed to it, by a surgeon and a combat medic, for example, is likely to differ. Regardless, within reviewed articles, a clear preference for live animal models and LTT exists,[9,27,32,35,49,58] with courses rated highly, enjoyed by learners,[44] and considered to be a valuable part of training.[11,45,52] This appears to be especially true for military personnel about to deploy operationally.[9,47] Mahoney et al. commented on "unique aspects of the live tissue training experience"[59] with Goolsby et al. stating that LTT advocates argue that the [military] learner population requires "an experience that only live animals can offer";[17] our thematic analysis contributes to understanding what constitutes that experience and why learners value it.

There is evidence that LTT leads to improvements in knowledge and skills. Self-efficacy is most significant for learners. Overall learner outcome measures are variable, and the use of evaluator observation is often subjective (i.e. assessor opinion) and not clearly quantified in the literature. Although confidence is highly valued, there is the potential for higher-fidelity simulation to lead to overconfidence,[67] and it is especially important for learners to be aware of their limits, and what they do not know to prevent causing inadvertent harm.[68] This is further support to the argument that it is important to tailor fidelity to the learner population, the simulated scenario and desired learning outcomes.[69]

The literature does not demonstrate translational outcomes, subsequent behavioral and performance change by learners within a clinical environment affecting actual patient care. The focus is primarily on learner reactions and attitudes and a change in the learners' knowledge and skills. However, it has been reported historically that outcome measurement from simulation-based medical education is one of the greatest challenges of the field. Research demonstrates that results do transfer from a learning environment to a patient care setting, but studies aiming to show improvements in patient care are difficult to design and execute.[70] This would be especially difficult in trauma patients, where the health outcome is highly multifactorial and multidisciplinary, and additionally in military settings, where patients may be more easily lost to follow-up.

The benefit of the use of live animals in training "critical trauma skills" compared to more advanced trauma skills is less clear. The most common procedures featured in the literature are cricothyroidotomy or "surgical airway," needle thoracentesis and chest tube thoracotomy (used to manage pneumothorax) and hemorrhage control techniques. Studies have demonstrated no difference in performance when training on a synthetic or live tissue model for various procedures,[28,32] with learners conceding that some skills could be taught using a simulator (i.e., tourniquet application, intraosseous device insertion, surgical airways and chest thoracentesis)[58] and could actually be considered preferable for first-time learners to avoid distractions.[71] Animal use is better suited for testing competency of terminal performance.[65] These "critical trauma skills" are successfully taught on ATLS courses, without the use of animals in the majority of countries.

It has been stated that trauma patient volume is the most significant factor in the rate of attrition of ATLS-acquired skills. In a review by Hart et al. the authors reported that multiple studies found an initial improvement in performance after training on a model (cadaver/live animal/HPS), lasting 3 to 4 weeks, but this skill had not been retained at the 6-month mark in learners with minimal experience and/or subsequent exposure to the procedure during that time period.[18] Previous experience (seniority) is a poor predictor of both performance time and accuracy,[39] indicating refresher training in rare, critical procedures is important. Similarly, most physicians lost a significant proportion of their acquired cognitive knowledge after 3.5 years.[47]

There is insufficient data to understand frequency of retraining required for various trauma skills in different learner populations. Additionally, much of the literature focuses on individual learning, as opposed to team training, which is another important aspect of the emergency management of trauma.

"Skill fade" is a current concern, especially within military medical services.[72] Ten studies specifically investigated the effectiveness of LTT for military medics[26-35] with a further 5 evaluating LTT programs[9,11] or investigating participant views regarding the simulation modality.[58,60,61] Military medics do not have a qualification readily transferable to civilian settings, frequently have limited clinical access to practice skills and rely heavily on simulation training. In contrast, military physicians often have an equivalent clinical practice, although regular exposure to trauma can be limited and simulation training is used to bridge this gap.[44,47,51,59]

There is an undoubtable bias in the literature toward LTT, particularly from the military community[32,35,58-61] and civilians employed by, or associated with, military organizations. Barnes et al. postulated bias could be secondary to perceived historical training success, the rigors of training to provide medical care in an austere environment, or a visceral response providing psychological preparation.[35] A NATO report stated that LTT use within predeployment training is associated with the lowest recorded case fatality rates in spite of increased injury severity.[12] This supports the reported perception from learners that discontinuing LTT would impact negatively on the quality of casualty care training and subsequently lives saves on the battlefield;[58] current NATO military opinion is that LTT should not be replaced, but that use of the animal model should be reduced and the techniques for its use refined.[12] Without a clear understanding of the specific pedagogical benefits that LTT delivers, attempts to replace, reduce and refine our use of animals in training will be done blindly and risk substituting simulation methodologies that do not prepare individuals and teams to competently deliver high quality emergency trauma care from and at the moment it is required.

Limitations

We recognize that the topic of LTT is controversial, can be emotive, and may lead to interpretive bias (voluntary and involuntary) by authors, including ourselves. We have attempted, with equipoise, to provide a credible, transparent approach to our research process and present our findings in a trustworthy manner in accordance with quality principles in qualitative research.[73] Although an attempt was made to search extensively for published articles, the authors acknowledge the potential for sources to have been missed from this review. Some full text articles could not be retrieved.

Aspects of educational merit have been considered for all learners of LTT, regardless of profession or specialty. There are nuances relating to educational requirements of learner groups (i.e., military versus civilian, junior versus senior clinicians, different specialties) which will be explored in future research.

This article is limited to an exploration of the educational use of live animals, without addressing the important ethical implications of their use.

Finally, LTT is not solely conducted in training to manage complex trauma, but occurs in wider surgical fields also; although there may be transferability of some these findings, this analysis has been limited to the emergency management of trauma.

CONCLUSION

LTT is used as a simulation modality in trauma education, to teach both military and civilian medical practitioners. A previous review concluded that adequately powered and methodologically sound randomized controlled trials (RCT) are required to prove a positive effect on outcome.[16] Another reported insufficient evidence to evaluate whether synthetic simulation models can replace live animals.[18]

Thematic analysis of published literature suggests that there may be educational benefit in the use of live tissue models due to time criticality and bleeding, which creates a real-life event. LTT also invokes an emotional response, and learners experience an increase in self-efficacy from participation. We consider that these aspects and associated pedagogy should be addressed when researching and developing alternative simulation modalities.

Importantly, the question of LTT effectiveness does not have a binary outcome, in the sense that all contexts and specific uses provide the same response. There is no single truth and we are of the view therefore that an RCT is the incorrect methodology; further qualitative research could explore the specific contexts where LTT may have more or less educational benefit, in order to allow us, where possible, to intelligently replace, reduce and refine the use of animals in trauma training.

CONFLICT OF INTERESTS

C S Swain and R F Rickard are employed by the Royal Navy of the United Kingdom and work within the Academic Department of Military Surgery and Trauma – part of the UK Defense Medical Services. H M L Cohen is employed by the British Army. This study forms part of a wider PhD project, undertaken by C S Swain, that is funded by the UK Defense Medical Services and the Royal Navy. No employing organization has been involved in the design of this review or in drawing its conclusions. The views expressed are those of the authors alone and do not necessarily reflect the views of the UK Ministry of Defense, or His Britannic Majesty's government. K Karlgren and G Helgesson are employed by the Department of Learning, Informatics, Management and Ethics at the Karolinska Institutet and work for the Health Informatics Centre and Centre for Healthcare Ethics respectively, and declare no conflicts of interest.

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ETHICS STATEMENT

The review was reported to the Swedish Ethical Review Board (2022-01884-01), which deemed that a formal ethical approval was not required.

APPENDIX: SEARCH STRATEGY

This version of the search was used for MEDLINE on January 31, 2022.

#	Searches
1	exp Models, Animal/su
2	([animal model* or porcine model* or bovine model* or canine model* or rodent model* or animal experiment* or animal research*] adj3 [education* or training*]).ab, kf, ti.
3	(live tissue* or live cadaver*).ab, kf, ti.
4	1 or 2 or 3
5	exp "Wounds and Injuries"/
6	exp Emergency Medical Services/
7	exp Military Medicine/
8	(trauma* or surgery or surgeries or emergency or emergencies or prehospital or pre-hospital or blast* or explosion* or weapon* or bullet* or gun*).ab, kf, ti.
9	exp Specialties, Surgical/
10	5 or 6 or 7 or 8 or 9
11	4 and 10

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