ORIGINAL REPORTS

A Systematic Review of Trauma Crew Resource Management Training: What Can the United States and the United Kingdom Learn From Each Other?

James Ashcroft, MRCS, [*,†] Aimee Wilkinson, BSc, [*] and Mansoor Khan, PhD, FRCS, FEBS, FACS [‡,]

[*]Imperial College London, London, United Kingdom; [†]Department of Surgery & Cancer, St. Mary's Hospital, London, United Kingdom; and [‡]Brighton Oesophagogastric Centre, Brighton and Sussex University Hospital, Brighton, United Kingdom

OBJECTIVE: Crew Resource Management (CRM) training incorporates methods such as simulation, debrief, and teamwork training to emphasize human factors skills. This systematic review aimed to assess differences in CRM between UK and USA trauma personnel.

DESIGN: A structured search of the databases MEDLINE and Embase in addition to unstructured reference review and Google Scholar search was undertaken without time restraint to identify articles describing CRM training courses of trauma personnel. Predetermined criteria for inclusion included comprehensive reports of CRM training in trauma personnel with participant assessment. Articles were analyzed for course details and descriptions, Kirkpatrick domains and levels utilized, and measure items and outcomes.

RESULTS: Twenty-nine full-text articles (24 USA, 5 UK) met predetermined criteria. UK-based CRM had a heavy emphasis on doctors while USA-based CRM reached a range of multidisciplinary civilian and military professionals. UK-based CRM focused on skills outcomes using pre- and post-training questionnaires, whereas USA-based training focused on behavior and nontechnical skills utilizing validated standardized measures. CRM-based training, and particularly courses incorporating simulation and multidisciplinary methods, resulted in significantly improved preparedness for trauma, emergency skills, and clinical behavioral change.

CONCLUSIONS: CRM training has the potential to give significant benefits to participant learning, teamwork behaviors, and clinical care outcomes. The USA appears to utilize a focused multidisciplinary and human factors approach to trauma training, which could be adopted by UK institutions to improve cohesive team performance and patient care. (J Surg Ed 000:1−20. © 2020 Published by Elsevier Inc. on behalf of Association of Program Directors in Surgery.)

KEY WORDS: crew resource management, curriculum, teamwork, training, trauma

COMPETENCIES: Practice-Based Learning and Improvement, Patient Care

INTRODUCTION

Nontechnical human factors skills are defined as "the cognitive, social and personal resource skills that complement technical skills and contribute to safe and efficient task performance including situational awareness, decision−making, communication, teamwork, leadership, and management of stress, fatigue and disturbances."[1] The study of error in high-risk environments and industries has revealed that human factors and nontechnical skills are essential for error-free performance.[1-3] Trauma management is a complex, fast paced, high pressure component of healthcare which requires personnel to function efficiently and effectively as a team.[1-3] An effective trauma team will successfully manage a vast array of unpredictable life-threatening traumatic presentations from rapid assessment and coordination of resources to definitive management of trauma.[4,5] These tasks are often diverse in nature and require a range of specialist input necessitating that trauma teams are constituted from a broad multi-disciplinary background.[4,5] Nontechnical skills in

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Correspondence: Inquiries to Mansoor Khan PhD, FRCS, FEBS, FACS, General and Trauma Surgeon, Honorary Clinical Professor of Trauma Surgery, Brighton and Sussex University Hospital, Eastern Rd, Brighton BN2 5BE, United Kingdom; e-mail: manskhan@doctors.org.uk

trauma management are essential where complex and time dependent tasks are imperative for survival.[1-3] In a study of 5,803 trauma patients presenting with blunt, penetrating, or other trauma to a level 1 trauma center, the introduction of consistent trauma teams reduced overall trauma mortality rates from 6.0% to 4.1% (absolute risk reduction 1.9%; 95% confidence interval 0.7%-3.0%) and mortality rates in those severely injured with ISS scores >25 from 30.2% to 22.0% (absolute risk reduction 8.3%; 95% confidence interval 2.1%-14.4%).[6] When measured by the validated T-nontechnical skills scale for trauma nontechnical skills scoring tool, better teamwork, and nontechnical performance have been found to be associated with significant decreases in trauma disposition time from 35 minutes (IQR, 23-53) to 20 minutes (IQR, 16-25; $p = 0.046$) in 50 trauma calls in the UK[7] and faster resuscitation time ($r = -13$, $p < 0.05$) and fewer unreported resuscitation tasks ($r = -0.16$, $p < 0.05$) when measured in 244 trauma patient resuscitations in the USA.[8]

Analysis of human factors and error in the aviation industry resulted in the creation of Crew Resource Management (CRM) training.[9] As opposed to traditional training techniques which emphasize quantitative technical outcomes, CRM emphasizes nontechnical human factor skills in order to develop teams that work efficiently and utilize all available people and procedures.[9] CRM may include didactic teaching of nontechnical skills, demonstrations such as behavioral modelling, simulation-based training, debriefing with discussion, and may incorporate technical skills teaching and practice.[1-3,10] The UK and USA are 2 areas of the world where major trauma is a rising cause of death and disability, with similar trends in dominating trauma such as knife and gun crime.[11] However the UK and USA have developed different approaches to CRM based on their primary participant target and content, with both areas of the world leading in this domain.[1,2] In the USA programs have been designed to improve patient safety broadly by teaching healthcare providers how to better collaborate with each other, as exemplified by the Team Strategies and Tools to Enhance Performance and Patient Safety (TeamSTEPPS) program which has been used in hospital-based acute care, nursing and assisted living facilities, and in primary care clinics.[12] The UK have placed greater emphasis on individual acute care teams focusing on emergency medicine, intensive care units, anesthesiology, and operating room teams as exampled by the Non-Technical Skills for Surgeons program.[13] This systematic review aimed to assess the differences between CRM training in UK and USA trauma personnel and through reviewing these differences identify where consensus regarding CRM content, replicable outcome measurement, and collaboration in trauma personnel should be sought.

METHODS

Search Strategy and Information Sources

This systematic review utilized the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement to guide all methodology and write up.[14] Before undertaking this systematic review, inclusion criteria were predetermined. Reports met inclusion criteria if they described CRM training of trauma personnel which: focused on improving nontechnical skills, utilized objective or subjective precourse and/or postcourse assessments, and measured outcomes of either trainee satisfaction, trainee attitudes, knowledge, or skill acquisition, behavioral change, or clinical performance. Studies were included only if they contained a detailed report of the training implementation. Exclusion criteria defined were as follows: nontrauma personnel related training, non-UK or non-USA personnel training (regardless of current location or deployment), noninterventional concept/curriculum design articles, review articles, commentary articles, case studies for training, evaluation of an assessment tool for training, articles not in English for analysis, and if no access was available to the full article. A systematic search of MEDLINE and Embase in addition to unstructured reference review and Google Scholar search was undertaken in March 2020 with no time limit. An initial search for the identification of CRM training in healthcare articles utilized the search terms: "teamwork," "communication," "crisis resource management," "human factors," "crew resource management," "CRM," "team," "nontechnical skill," "behavioral skills," "team dynamics," "TeamSTEPPS," "MED TEAM," and "patient care team," "nursing team," "institutional management teams," "management quality circles," "doctors," "nurses," "physicians," "surgeons," "surgical team," "anesthesiologists." This search was used in addition to the terms "trauma" and "training" and additional unstructured searches of Google Scholar and article references in order to give 509 articles.

Study Selection and Data Extraction

Duplicates were removed and 2 reviewers (JA and AW) independently screened abstracts and/or full texts of these 509 publications in reference to study design, study population, and study location as outlined in the inclusion and exclusion criteria. Full screening resulted in the capture of 29 -ext articles which met the predetermined criteria for inclusion into the systematic review. This process is displayed in full in Figure 1. Prior to data extraction it was

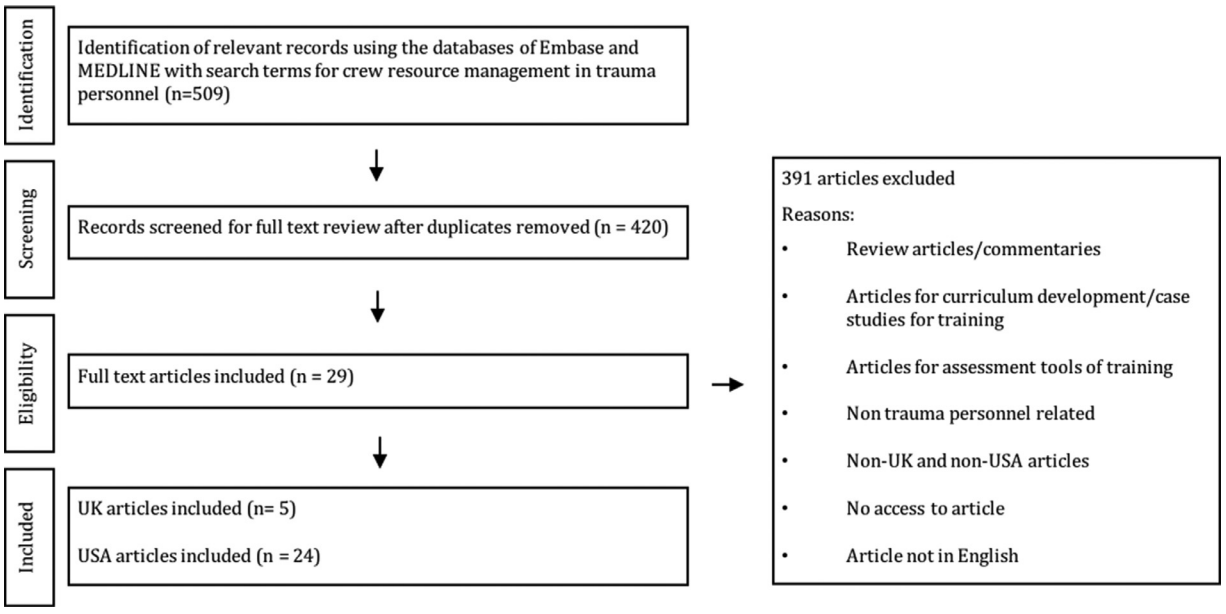

FIGURE 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram displaying the screening process for included and excluded articles.

decided that a meta-analysis would not be undertaken due to the heterogeneity of both training implementations and outcome measurements.

Summary Measures and Synthesis of Results

Two reviewers (JA and AW) independently extracted relevant information from each training report using a standardized data extraction proforma in keeping with Best Evidence Medical Education recommendations and 1 author with medical training expertise (MK) reviewed all extracted data.[15] This review captured: administrative information including authorship, institution, and year of publication; training-related data including details and duration of intervention, participants, and teaching methods; and quantitative and qualitative outcome measures. Interventions were assessed against Kirkpatrick criteria and Kirkpatrick's levels were assigned: impact on learners' satisfaction (level 1), changes in learners' attitudes (level 2a), measures of learners' knowledge and skills (level 2b) change in learners' behavior (level 3), changes to clinical processes/organizational practice (level 4b), and benefits to patients (level 4b).

Assessment of Data Quality

The quality of training intervention and risk of bias in reporting of results was assessed using the ROBINS-1 for nonrandomized controlled trials.[16] Meta-analysis was not performed on the training outcomes assessed due to the wide heterogeneity in training interventions and reporting of results. Descriptive analysis was performed instead.

RESULTS

Characteristics of Included Studies

Twenty-nine studies met inclusion criteria, describing 24 (82.8%) courses which were undertaken in the USA and 5 (17.24%) in the UK as displayed in Table 1. No multinational studies identified in the screening process for inclusion. A range of educational settings and methods were described throughout the course reports including induction boot camps, low and high-fidelity simulation courses, field training, didactic teaching, online interactive teaching, and guided clinical management of patients in the clinical environment. Participant populations included senior and junior surgeons, senior and junior emergency department doctors, other doctors of different specialties, nurses including trauma and nonspecialized nurses, paramedics, combat medics, healthcare technicians, and students. All 29 studies included in this review were prospective cohort studies measuring various impacts of their training intervention. Training time ranged from 1 day to 1 year in duration, with the majority being 1 day ($n = 17$, 58.6%), with the median training duration being 1 day (IQR 1 − 4.25) with one report omitting a description of training duration. Only 6 studies[17,18] reported data that assessed longitudinal learning beyond the year of course implementation. Common limitations of study design included training being limited to a single institution with all studies reporting pre- and postcourse outcomes being single centered, trials evaluating the efficacy of methodology or technology, or studies reporting limited or

TABLE 1. Course Characteristics, Structure, and Content

Lead Author, Year, Institution, Country	Course Structure and Teaching Methods	Participant Population	Duration of Intervention	Education Setting
UK				
Ellington,[15] 2019 University of Cambridge, Cambridge.	Small group tutorials and practical, high-fidelity battlefield and prehospital simulations.	46 medical students	1 day	Simulation suite
Bamford,[16] 2018 Nine acute NHS trusts, Bristol.	Boot Camp utilizing lectures and practical interactive workshops.	25 junior surgical residents	3 days	Classroom
Smith,[17] 2016 St Mary's and the Royal London Hospitals, London.	Premilitary deployment simulation training using an outside simulated environment	26 participants consisting of doctors, nurses, and allied health professionals.	7 days	Outdoor simulated environment
Sadideen,[18] 2015 Three acute NHS trusts, Birmingham.	Team-based simulation of a burn-trauma scenario.	12 doctors and 10 nurses.	1 day	Simulation suite
Morrison,[19] 2007 Army Medical Service Training Centre (AMSTC), York.	Exercises of a medium-fidelity simulator prehospital and hospital environment using small group simulation.	British army and territorial army units of a multidisciplinary background.	3 months	Simulation suite and outdoor simulated environment
USA				
Litzinger,[20] 2019 Florida Hospital Memorial Medical Center, Florida.	Formal small group trauma training program centered around leadership, teamwork and communication.	88 trauma nurses	Not stated	In situ hospital based
Rosenmann,[21] 2019 Institute for Simulation in Healthcare, University of Washington, Seattle, Washington.	Simulation mannikin-based intervention supplemented by a facilitated group discussion, lecture and debriefing session.	36 second- and third-year emergency medicine and surgery residents on a trauma team leader rotation.	1 day	Simulation suite
Paige,[22] 2019 LSU Health Orleans Health Sciences Center, Louisiana.	High fidelity trauma case mannikin-based simulations.	48 participants, including general surgery residents, emergency medicine residents and senior undergraduate nursing students.	1 day	In situ hospital based
Onufer,[23] 2018 Washington University in St. Louis School of Medicine, Missouri.	Lab simulation-based training approach on technical skills in trauma scenarios performed under time pressure on prosthetics.	119 general, vascular, urology and plastic surgery PGY1 to PGY5 residents.	1 day	Classroom and simulation suite
McLaughlin,[24] 2018 University of Southern California, Los Angeles, California.	In situ, multidisciplinary pediatric trauma simulation-based training program followed by 40-minute structured debriefing post-simulation.	190 participants, including pediatric doctors, emergency department trauma nurses, critical care nurses.	1 day	In situ hospital based
George,[25] 2018 University of Virginia Health System, Virginia.	Simulation in a surgical trauma burn intensive care unit setting followed by a semi-structured debriefing session.	22 clinicians, including 16 nurses and 6 first to fourth year surgical, emergency or anesthesiology resident physicians.	1 day	Simulation suite

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TABLE 1 (*continued*)

Lead Author, Year, Institution, Country	Course Structure and Teaching Methods	Participant Population	Duration of Intervention	Education Setting
Sullivan,[26] 2017 University of Wisconsin, Wisconsin.	Trauma simulation scenario run for 26 exercises.	13 teams of 5 trauma trainees: surgical residents an emergency medicine resident, and 2 emergency medicine nurses.	1 day	Simulation suite
Peters,[27] 2017 Carilion Roanoke Memorial Hospital, Virginia.	A trauma crash course with didactic education on technical and non-technical skills and simulation.	82 nurses with 18 months emergency nursing experience	1 day	Simulation suite
Rice,[28] 2016 University of Kentucky, Lexington.	A simulation exercise utilizing a modified TeamSTEPPS teamwork system.	7 nurses with less than 2 years of intensive care unit and nursing experience.	1 day	Simulation suite
Siriratsivawong,[29] 2016 Naval Medical Center San Diego, San Diego.	Didactic lectures with hands-on mannikin simulation culminating in a daylong scenario.	123 personnel, 21 doctors, 17 nurses, and 85 corpsmen.	6 days	Classroom and simulation suite
Hoang,[30] 2016 Rocky Vista University, Parker, Colorado.	Didactic hours and hands-on mannikin simulation sessions culminating in a daylong scenario.	11 U.S. Navy Fleet Surgical Teams including physicians of various specialties, corpsmen, nurses, and nurse anesthetists.	5 days	Classroom and simulation suite
Perkins,[31] 2015 Legacy Research Institute, Portland, Oregon.	Didactic teaching, practical sessions and alternating role play during injury scenarios.	22 surgical technicians and nurses	1 day	Classroom
Baker,[32] 2015 Morosky College of Health Professions and Sciences, Gannon University, Erie.	Online web-based training and a trauma teamwork simulated resuscitation scenario.	48 nursing, physician assistant, radiologic science, and respiratory care students, in 12 teams	1 day	Simulation suite
Hughes,[33] 2014 Trauma Services, York Hospital, Pennsylvania.	Didactic classroom program consisting of lectures only.	324 multidisciplinary staff including emergency medicine doctors and surgeons, nurses, and management staff.	1 day	Classroom
Kellicut,[34] 2014 Tripler Army Medical Center, Honolulu.	Two multipatient scenarios and didactic instruction of principles of TeamSTEPPS using human-based simulation.	220 military personnel	1 day	Simulation suite
Roberts,[35] 2014 Southern Illinois University School of Medicine, Springfield.	A pretest simulated trauma encounter and postinstruction simulated trauma using human-based simulation.	57 medical hospital staff members who provided level 1 trauma care.	1 day	Simulation suite
Mar,[36] 2012 New York University School of Medicine, New York.	Six simulated trauma scenarios followed by a debriefing period using mannikin-based simulation.	30 surgical residents and 14 emergency medicine residents.	6 months	Simulation suite
	A 1-hour web-based didactic followed by 3 human-based	137 trauma team members including doctors, nurses, respiratory	1 day	Online and simulation suite

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TABLE 1 (*continued*)

Lead Author, Year, Institution, Country	Course Structure and Teaching Methods	Participant Population	Duration of Intervention	Education Setting
Steinemann,[37] 2011 University of Hawaii, Honolulu, Hawaii.	simulation training sessions with video debriefing.	therapists and emergency department technicians.		
Capella,[38] 2010 Virginia Tech Carilion School of Medicine, Virginia.	A didactic session including a review of TeamSTEPPS Essentials before a trauma simulation session using mannikin-based simulation.	28 surgical residents, 6 faculty surgeons, and 80 nurses.	1 day	Simulation suite
Pereira,[39] 2010 University of Miami Miller School of Medicine, Miami.	Didactic lectures over 4 days, cadaver and simulation exposure, followed by guided clinical management of real patients.	178 members of US Army forward surgical teams.	14 days	In situ hospital based
Falcone,[40] 2008 Cincinnati Children's Hospital Medical Center, Cincinnati.	Online education and trauma simulation sessions using high-fidelity mannikin simulators.	90 doctors (pediatric/surgeon/emergency medicine), 60 nurses, 4 critical care fellows, 2 paramedics, 4 respiratory therapists.	1 year	Simulation suite
Sohn,[41] 2007 Madigan Army Medical Center, Tacoma, Washington.	Extensive course consisting of lectures, technical simulation, group skills sessions, live tissue simulation, and animal field simulation	327 combat medics	4 days	Classroom, simulation suite and outdoor simulated environment
Grogan,[42] 2004 Vanderbilt University, Nashville.	Didactic lectures on CRM concepts and principles and case studies involving role playing in simulated scenarios.	288 nurses and technicians, 104 doctors, and 97 administrative personnel	1 day	Classroom
Holcomb,[43] 2002 Baylor College of Medicine, Houston, Texas.	Hands-on clinical experience, trauma case reviews, 24 trauma lectures, and 4 human simulation stations.	30 Army, Air Force, and Navy doctors, nurses, nurse anesthetists, and medics	1 month	Simulation suite

TABLE 2. Pre- and Postcourse Test Outcomes

Lead Author, Year, Institution, Country	Participants Assessed	Outcome	Kirkpatrick Criteria	Precourse Test Outcome	Postcourse Test Outcome	Measure	p Value
UK							
Ellington,[15] 2019 University of Cambridge, Cambridge.	46 medical students	Crisis resource management confidence as subjective global ranking scale 0 - 7	Attitude	2.91 (0.99)	5.35 (0.62)	Mean (SD)	<0.000
Bamford,[16] 2018 Nine acute NHS trusts, Bristol.	25 junior surgeons	Subjective management of surgical specialty emergency conditions (pooled outcomes across 7 emergency specialties) on 5-point Likert scale	Skill	2.52	3.06	Mean	-
USA							
Litzinger,[20] 2019 Florida Hospital Memorial Medical Center, Florida.	68 trauma nurses' precourse, 88 postcourse	Written knowledge-based examination, objective with no cut off score stated	Knowledge	74% (10.39)	94% (6.98)	Mean	<0.01
George,[25] 2018 University of Virginia Health System, Virginia.	20 clinicians, 15 nurses	Knowledge measured by a 9-question objective test		6.41 (1.37)	8.23 (1.02) immediate	Mean (SD)	<0.000
			Knowledge		7.5 (0.95) 1 month	Mean (SD)	<0.000
		Team skills as measured by self-reported validated scale of eighteen 5-point Likert type scales		68.86 (5.69)	69.23 (SD 8.31) immediate	Mean (SD)	<0.000
			Skill		71.53 (SD 9.05) at one month	Mean (SD)	<0.000
Peters,[27] 2017 Carilion Roanoke Memorial Hospital, Virginia.	82 nurses	Knowledge assessment using 22 item multiple choice test	Knowledge	68.29% (18.35)	88.48% (5.44)	Mean (SD)	<0.000
		Pooled skills self-confidence rating for trauma crash course	Attitude	3.11	4.05	Mean	-
		Behavior assessment using a validated 5-point Likert type scale	Behavior	3.12	3.70	Mean	<0.001
Rice,[28] 2016 University of Kentucky, Lexington.	7 nurses	Self-evaluation teamwork attitudes questionnaire (reduction represents improvement)	Attitude	131.1 (8.8)	121.4 (7.6)	Mean (SD)	0.041
		Self-evaluation teamwork perceptions questionnaire (reduction represents improvement)	Attitude	72.85 (11.3)	69.00 (10.1)	Mean (SD)	0.021

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TABLE 2 (*continued*)

Lead Author, Year, Institution, Country	Participants Assessed	Outcome	Kirkpatrick Criteria	Precourse Test Outcome	Postcourse Test Outcome	Measure	p Value
		Trauma team performance observation tool (TPOT)	Skill	64.85 (1.2)	93.28 (3.5)	Mean (SD)	0.000
Siriratsivawong,[29] 2016 Naval Medical Center San Diego, San Diego.	Physicians and physician assistants, number not stated	A standardized measure out of 100% of team performance in trauma scenarios		76% (14%)	90% (9%)	Mean (SD)	<0.001
	Nurses and nurse anesthetists, number not stated		Skill	66% (13%)	83% (11%)	Mean (SD)	<0.001
	Corpsmen, number not stated			45% (12%)	64% (13%)	Mean (SD)	<0.001
Hoang,[30] 2016 Rocky Vista University, Parker, Colorado.	11 U.S. Navy Fleet Surgical Teams	Time to disposition in a simulated training exercise	Skill	24 mins (4 mins)	13 mins (22 mins)	Mean (SD)	<0.000
		Number of critical errors made during training exercise	Skill	5 (1)	1 (1)	Mean (SD)	<0.000
Perkins,[31] 2015 Legacy Research Institute, Portland, Oregon.	16 surgeons	A 17 multiple choice question and short based answer test in trauma knowledge and skills	Knowledge	84% (7.4%)	93% (6.3%)	Mean (SD)	<0.000
Baker,[32] 2015 Morosky College of Health Professions and Sciences, Gannon University, Erie.	48 multidisciplinary students	Trauma team performance observation tool (TPOT)	Skill	3 (2 – 3.5)	3 (3 – 4)	Median (IQR)	0.29
		Observed team emergency assessment measure (TEAM)	Behavior	6 (3 – 6.75)	6 (5 – 7.75)	Median (IQR)	0.14
Hughes,[33] 2014 Trauma Services, York Hospital, Pennsylvania.	160 multidisciplinary healthcare staff	Measurements of Communication and Teamwork Skills (CATs) metrics over 25 sessions with pooled overall score.	Behavior	20.7%	82.4%	Mean	-
Marr,[36] 2012 New York University School of Medicine, New York.	30 surgical residents and 14 emergency medicine residents.	Presence of a trauma team leader at real-life trauma alerts either side of simulation training, percentage stating yes	Behavior	64%	90%	Proportion	<0.05
		Time to intubation at real-life trauma alerts either	Skill	3.9 mins (3.1 mins)	2.8 mins (1.7 mins)	Mean (SD)	<0.05

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TABLE 2 (*continued*)

Lead Author, Year, Institution, Country	Participants Assessed	Outcome	Kirkpatrick Criteria	Precourse Test Outcome	Postcourse Test Outcome	Measure	p Value
		side of simulation training					
		Percentage of personnel in role positions at real-life trauma alerts either side of simulation training	Behavior	57.8% (22.1%)	83.6% (21.7%)	Mean (SD)	0.46
Steinemann,[37] 2011 University of Hawaii, Honolulu, Hawaii.	136 multidisciplinary team members precourse, 99 postcourse	The T-NOTECHS debriefing and assessment measuring teamwork domains out of a score of 25	Skill	16.7	17.7	Mean	<0.001
		Observation of 244 trauma scenarios, mean resuscitation time	Skill	32 min	26 min	Mean	<0.05
		Observation of 244 trauma scenarios, number of scenarios with ≤ 1 unreported task	Behavior	48	62	Number	<0.001
Capella,[38] 2010 Virginia Tech Carilion School of Medicine, Virginia.	33 multidisciplinary team members precourse, 40 postcourse	Teamwork score on Likert type 5-point scales using the validated TeamSTEPPS framework	Skill	3.12	3.70	Mean	<0.001
Pereira,[39]2010 University of Miami Miller School of Medicine, Miami.	178 members of US Army forward surgical teams.	Awareness of trauma team roles and function as a percentage of agree/strongly agree on a Likert 5-point scale	Attitude	26%	84%	Mean	-
		Awareness of their own roles and function as a percentage of agree/strongly agree on a Likert 5-point scale	Attitude	71%	95%	Mean	-
Sohn,[41] 2007 Madigan Army Medical Center, Tacoma, Washington.	327 multidisciplinary combat medics	Confidence in approaching military trauma on a 5-point Likert type scale, percentage as strongly agreed or agreed	Attitude	44%	91%	Proportion	<0.01
	164 multidisciplinary combat medics	Written examination marked as a percentage with unclear total score	Knowledge	73%	91%	Score	<0.01

TABLE 3. Study Outcome Measures and Main Findings

Lead Author, Year, Institution, Country	Outcome Assessment	Main Summarized Findings	Kirkpatrick Level
UK			
Ellington,[15] 2019 University of Cambridge, Cambridge.	Self- and faculty-reported evaluation of leadership and crisis resource management skills, using the Ottawa Crisis Resource Management Global Ranking Score (OCRMGRS).	Statistically significant increase in self-reported and faculty reported OCRMGRS scores in all 6 domains which remained high at 1 year. There was significant improvement post- vs. precourse in overall performance, leadership, problem solving, and resource utilization amongst other measures ($p < 0.05$)	1, 2B, 3
Bamford,[16] 2018 Nine acute NHS trusts, Bristol.	Pre- and postcourse questionnaires to assess technical and non-technical skills.	Significant improvement in technical skills, leadership, communication, situational awareness, patient handover, ward round skills and outpatient skills. Trainees reported significantly greater confidence in their ability to assess a trauma patient ($p = 0.016$) and understanding of a how a trauma patient is managed ($p = 0.001$).	2A, 2B
Smith,[17] 2016 St Mary's and the Royal London Hospitals, London.	A cross-sectional questionnaire-based survey of participants, pre- and postcourse questionnaires, written reports.	Majority of participants (89%) felt prepared for a technical operational role, but no significant difference to the selected participants' personal perception of their own technical preparedness.	2A
Sadideen,[18] 2015 Three acute NHS trusts, Birmingham.	A realism evaluation containing 10 items for face validity; 10 items for content validity. A focus group and individual semistructured interview postsimulation.	In qualitative feedback, participants felt satisfied with the training and that the experience was authentic with high psychological and social fidelity. Participants felt simulation focusing on nontechnical skills should be readily available. No significant differences were found in doctors or nurses in validation of the program.	1
Morrison,[19] 2007 Army Medical Service Training Centre (AMSTC), York.	Observational measures throughout the 3-month period of technical performance.	Procedural issues were highlighted during the simulations and solutions were tested by further simulations. Several clinical care outcome issues were addressed and improved, rehearsal of various set-piece procedures such as rapid sequence induction of anesthesia.	4B
USA			
Litzinger,[20] 2019 Florida Hospital Memorial Medical Center, Florida.	Pre- and postintervention knowledge tests and 5-point Likert type scale for course feedback.	The average pretest knowledge score was 74%, whereas the average post-test score was 94%. The majority (94%-96%) of nurses were in strong agreement to all 4 positive statements in the feedback questionnaire.	1, 2B 1, 2B, 3

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TABLE 3 (*continued*)

Lead Author, Year, Institution, Country	Outcome Assessment	Main Summarized Findings	Kirkpatrick Level
Rosenmann,[21] 2019 Institute for Simulation in Healthcare, University of Washington, Seattle, Washington.	Participants completed an evaluation survey at 7-24 months following training.	23 of 36 participants (64%) responded to the survey, and the majority (96%) felt that the training was a valuable part of their residency education. All respondents reported ongoing use of at least one behavior learned in the trauma training, e.g., prearrival briefing or prioritization.	
Paige,[22] 2019 LSU Health Orleans Health Sciences Center, Louisiana.	Participants undertook validated assessments on learning, teamwork and communication following each scenario on the course, with no pre- and postcourse measures.	Significant difference was found over the course longitudinally in all items of learning, teamwork, and communication, not included in Table 2. Three themes identified through feedback were improvement in practice of clinical skills, autonomy, and interprofessional collaboration.	2B
Onufer,[23] 2018 Washington University in St. Louis School of Medicine, Missouri.	Pre- and post-training multiple-choice assessment of trauma knowledge. Survey of the number of trauma technical skills performed before and after the training.	Significant improvement in knowledge of trauma management with most significant improvement seen in PGY1 and PGY2 residents with improvement in score of 21% ($p < 0.001$) and 13% ($p < 0.001$), respectively. Similarly, PGY2 and PGY3 residents had a significant increase in the number of new technical skills gained with a median increase of 4 (range 2-6, $p < 0.001$) and 3 (range 1-5, $p < 0.001$), respectively. No raw data values given.	2B
McLaughlin,[24] 2018 University of Southern California, Los Angeles, California.	Anonymous survey 1 month before (pre-), 1 month after (post-) and 2 years after implementation, evaluating participant subjective experience and perception of team behavior.	Multiple questions were used to survey participants with no overall scores amenable to Table 2. Postsimulation participants reported more anxiety ($p = 0.01$) and less confidence ($p = 0.02$) than 1-month postsimulation. At 2-year follow-up, trained providers reported less anxiety ($p = 0.02$) and greater confidence ($p = 0.01$), compared to untrained providers.	2A, 3
George,[25] 2018 University of Virginia Health System, Virginia.	A 9-point knowledge test including teamwork knowledge before and after the intervention. An 18-point Teamwork Skills Scale, a self-reported perception of teamwork tool, completed before and after the intervention as week as at 1-month follow-up.	Mean knowledge test and Teamwork Skills Scale scores both significantly increased after the simulation and remained significantly elevated at 1-month follow-up. 100% of participants felt the training would help them care for traumatic brain injury patients. 96% of respondents felt the training would assist them with advanced cardiac life support.	1, 2A, 2B

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TABLE 3 (*continued*)

Lead Author, Year, Institution, Country	Outcome Assessment	Main Summarized Findings	Kirkpatrick Level
Sullivan,[26] 2017 University of Wisconsin, Wisconsin.	The T-NOTECHS pre- and postcourse debriefings and qualitative debriefing using the PEARLS framework.	Differences were analyzed between first scenario and second scenario, not pre- and postcourse. Performance in all domains increased during the second simulation, but the only significant improvement was communication and interaction 3.62-4.19 ($p < 0.05$).	2B
Peters,[27] 2017 Carilion Roanoke Memorial Hospital, Virginia.	Participant course evaluation, knowledge-based testing format using a 22-item multiple-choice test, questionnaire to rate confidence in assessment and management of trauma patients, trauma team performance evaluation, pre- and post-teamwork training efficiency metrics and clinical outcomes.	The majority of attendees stated that the course will have a positive impact on their practice. There was a statistically significant increase in knowledge scores, self-confidence measures in procedures, multidisciplinary teamwork in trauma patient efficiency outcomes $p < 0.000$. Significant improvements in the facility in time to arrival in the computed tomography scanner, time to arrival in the operating room, and time to endotracheal intubation all $p < 0.05$, not reported in Table 2.	1, 2B, 4A, 4B
Rice,[28] 2016 University of Kentucky, Lexington.	The TeamSTEPPS Teamwork Attitudes Questionnaire (T-TAQ), TeamSTEPPS Teamwork Perceptions Questionnaire (T-TPQ), and the Trauma Team Performance Observation Tool (TTPOT).	Significant improvement was shown in perception of team structure and communication, observed situation monitoring and mutual support all $P < 0.05$. A decrease was shown in attitudes of mutual support and communication. Mean satisfaction scores were 21.5 of a possible 25 points. Mean self-confidence scores were 38.83 out of a possible 40 points.	1, 2A
Siriratsivawong,[29] 2016 Naval Medical Center San Diego, San Diego.	Teams evaluated with a simulated trauma resuscitation scenario then retested on the same scenario after completing the course. A survey was administered to assess the participants' perceived effectiveness of the course on overall team training.	A decrease in the meantime needed to perform a simulated trauma resuscitation and number of critical events missed. Demonstrated value in improving teamwork and communication skills of participants, immediately upon completion of the course, and after 5 months had passed through longitudinal results.	3, 4A, 4B
Hoang,[30] 2016 Rocky Vista University, Parker, Colorado.	A pretest was administered before the course, a post-test upon completion, and a sustainment test 5 months following course completion. The evaluation process measured changes in patient time to disposition and critical errors made during patient care.	Time to disposition improved significantly and critical errors decreased. This course showed value in improving teamwork and communication skills of participants, immediately upon completion of the course, and after 5 months had passed.	3, 4A, 4B
Perkins,[31] 2015 Legacy Research Institute, Portland, Oregon.	A 9 point pre- and postcourse examination was administered to participants to assess for	A significant improvement in didactic knowledge was found postcourse (83%-92%, p =	1, 2B

(*continued on next page*)

TABLE 3 (*continued*)

Lead Author, Year, Institution, Country	Outcome Assessment	Main Summarized Findings	Kirkpatrick Level
	improvements in team members' didactic knowledge.	0.0008). Most participants (90.5%) completing postcourse surveys reported being "highly satisfied" with course content and quality.	
Baker,[32] 2015 Morosky College of Health Professions and Sciences, Gannon University, Erie.	All resuscitations were recorded and scored offline by 2 blinded research assistants using both the Team Emergency Assessment Measure (TEAM) and Trauma Team Performance Observation Tool (TPOT) scoring systems.	Team leadership, situational monitoring, and overall communication improved as assessed by the TPOT scoring system (p = 0.29). The team's ability to prioritize tasks and work together to complete tasks improve but to a lesser extent.	2B
Hughes,[33] 2014 Trauma Services, York Hospital, Pennsylvania.	The 23-item Human Factors Attitude Survey and Communication and Teamwork Skills assessment tool were used to evaluate training postresuscitation scenario.	In the post-CRM survey, respondents indicated improvement in team leader identity, communication of plan, and role assignment. There was a substantial improvement in communication with an overall course benefit from 20.7% to 82.4%.	2B
Kellicut,[34] 2014 Tripler Army Medical Center, Honolulu.	Anonymous surveys were completed pre and post-training by participants for their feedback on the course and its usefulness only.	The majority of participants (77%) felt that this course would improve patient outcomes, 78% said it would likely contribute to saving lives in combat, and 98% felt it should be provided to military Emergency Medicine and Surgical residents.	1
Roberts,[35] 2014 Southern Illinois University School of Medicine, Springfield.	Teams completed simulated trauma scenarios and gave subjective feedback on the benefits of the course.	15 of 17 targeted team and leader behaviors significantly improved immediately after the training. One area in which team and leader behaviors did not improve was team members' efforts to clarify ambiguous orders.	2B
Marr,[36] 2012 New York University School of Medicine, New York.	Trauma alerts were assessed by a standardized video review process either side of simulation training with no subjective debrief.	Positive factors such as time to intubation from paralysis and time to leave the trauma bay for either a CT scan or to go to the operating room decreased. There was not a statistically significant difference in the presence of cervical spine stabilization, number of healthcare workers engaged or time to attain the first imaging study.	4A, 4B
Steinemann,[37] 2011 University of Hawaii, Honolulu, Hawaii.	Pre- vs. post-training performance through structured debriefing and teamwork assessment was performed with a modified NOTECHS scale for trauma (T-NOTECHS).	Significant improvement in mean teamwork scores from the pre-to post-training resuscitations. This was manifested by a 76% increase in the frequency of near-perfect task completion and a reduction in the mean overall emergency department resuscitation time. There was no impact on ICU length of stay, overall length of stay, or death.	4A, 4B 4A, 4B

(*continued on next page*)

TABLE 3 (*continued*)

Lead Author, Year, Institution, Country	Outcome Assessment	Main Summarized Findings	Kirkpatrick Level
Capella,[38] 2010 Virginia Tech Carilion School of Medicine, Virginia.	The Trauma Team Performance Observation Tool (TPOT) was used by trained evaluators to assess teams' performance during trauma resuscitations. Real life scenarios were observed with clinical parameters assessed.	Significant improvement in all teamwork domains from pretraining to post-training were found $p < 0.001$. The times from arrival to the CT scanner, endotracheal intubation, and the operating room were decreased significantly after the training, however no significant impact was found on clinical outcomes.	
Pereira,[39] 2010 University of Miami Miller School of Medicine, Miami.	Participants are surveyed before and after their experience regarding clinical and combat experience as well as knowledge of their purpose within the team.	Substantial improvement in participant perception of team performance as well as role within the team. Minimal subjective feedback on course, subjects preferred team training more than skills training.	1, 2A
Falcone,[40] 2008 Cincinnati Children's Hospital Medical Center, Cincinnati.	Team performance was assessed and score by reviewed based on real life trauma scenarios with multidisciplinary teams.	Longitudinal measures over a year not included in Table 2. An improved mean percentage of appropriately completed tasks observed in initial assessment, airway management, management of pelvic fractures, and cervical spine care were seen late in the year 75%, when compared to early in the year 65% $p < 0.05$).	3, 4A, 4B
Sohn,[41] 2007 Madigan Army Medical Center, Tacoma, Washington.	Questionnaire surveys, pre- and post-tests, and after-action comments.	Improved confidence and ability to treat combat casualties $p < 0.01$. Students who took the course reported following a 1-year deployment stating the course helped with battlefield management of injured casualties during their deployment.	2A, 3, 4B
Grogan,[42] 2004 Vanderbilt University, Nashville.	Participants completed an 11-question end-of-course critique and 23 item Human Factors Attitude Survey.	489 multidisciplinary team members pre-course, 463 postcourse completed 23 human factors items demonstrating increases in participant attitudes towards the roles of leadership, coordination, and communication, recognizing red flags participant agreement. Participants felt training provided knowledge, skills, or both.	1, 2A
Holcomb,[43] 2002 Baylor College of Medicine, Houston, Texas.	Marking of 5 scored and 8 timed tasks through videotape review following a 28-day course and rotation.	Teams of constructed of 30 participants demonstrated significant improvement in 4 of the 5 scored ($p \leq 0.05$) and 6 of the 8 timed ($p \leq 0.05$) tasks during the test scenario, however no raw data was provided. The trauma teams felt more comfortable caring for critical trauma patients after the 28-day rotation.	2A, 2B

pooled outcomes with multiple healthcare professionals (Table 3).

The most frequently occurring teaching method utilized in the identified training courses was simulation (total $n = 24$, 82.8%; UK $n = 4$, 80%; USA $n = 20$, 83.3%). Three of the UK and 6 of the USA-based training courses were directed by military personnel. In the 5 UK training curriculum included in this systematic review, duration of training ranged between 1 day and 3 months. One UK-based training course utilized didactic lectures and practical workshops only, focusing on technical skills. Two UK-based training courses were truly multidisciplinary (40.0%) attended by multispecialty doctors, nurses, and allied health professionals with the further 3 being restricted to doctors and nurses, or entirely doctors or medical students. In the 24 USA articles included in this systematic review, 16 out of 24 training courses took place over 1 day. The further courses took place over 4, 5, 6, and 14 days, 1 month, 6 months, and 1 year. Those courses not utilizing simulation ($n = 4$, 13.8%) revolved around lectures ($n = 2$), role play ($n = 1$) and in situ hospital training with real clinical patients ($n = 1$). Fourteen USA-based training courses (58.3%) were multidisciplinary beyond being attended by single specialty doctors and nurses, with participation from multiple health professionals and other emergency service personnel, including civilian and military members.

Training Evaluation and Main Findings

Of the studies included in this review, 16 studies in total measured pre- and postcourse outcomes. Of these 16 studies, knowledge was measured in 5 studies (31.25%) all of which utilized objective knowledge measurements. However, none of objective measures of knowledge were previously described or undertaken with validated measures. All 5 courses demonstrated a significant improvement in participant knowledge following their respective training. A total of 5 studies (31.25%; UK $n = 1$, USA $n = 4$) measured attitude as either confidence in trauma CRM skills ($n = 3$ including the UK) or attitudes toward other members of the trauma team ($n = 2$). Trauma skills were measured in 9 studies (56.3%; UK $n = 1$, USA $n = 8$). The 1 UK-based skill outcome was that of individual technical skills (e.g., suturing wounds) whilst the 8 USA-based skills outcomes all measured teamwork-based skills, including technical skills such as time to intubation in trauma assessed in groups. Behavior was assessed in 5 studies (31.25%; USA $n = 5$) with 4 studies utilized objective observed measures of team behavior through methods such as videotape review.

Level 1: trainee satisfaction

Trainee satisfaction was assessed in 11 of 29 included studies (37.9%; USA $n = 9$; UK $n = 2$). In the majority of studies trainees were asked to rate course quality on Likert type scales and decide on whether they would recommend the course to colleagues for trauma preparedness. Satisfaction of courses was generally very high and appeared to be enhanced by multimodal approaches to curriculum design including the incorporation of simulation and teamwork behavior aimed training. A recurrent theme across the UK and USA was the preference of teamwork training and higher teamwork-based feedback when compared to individual skills.

Level 2a and 2b: trainee attitudes, knowledge, and skill acquisition

Attitudes or perceptions of knowledge (Level 2a) in trauma personnel were assessed in 9 studies (31.0%; USA $n = 7$; UK $n = 2$). Attitudes were broadly assessed as Level 2a following courses measuring across the UK and USA either a subjective measurement of a trainee's preparedness for trauma medicine or by mapping trainee responses to learning objectives including teamwork attitudes. Level 2b was measured by a total of 14 studies (48.3%; USA $n = 12$; UK $n = 2$) which assessed trainee knowledge or skill acquisition. In USA courses training multidisciplinary teams in skills such as simulated resuscitation scenarios, discrete and measurable team skills such as time to intubation and first imaging were easily assessed using videotape footage. In the UK 2 courses revolved around Level 2b outcomes which measured individual subjective surgical skill and subjective problem-solving ability in trauma scenarios. Attitudes, knowledge, and skills were assessed pre- and post-training through multiple choice question tests, written examinations, questionnaires, and simulation evaluations.

Level 3: behavioral change

As behavioral change is a difficult area to measure in trauma due to its sporadic nature and difficulty in follow-up. Of all 29 included studies, 7 (24.1%; USA $n = 6$, UK $n = 1$) were deemed to adequately assess behavioral change through longitudinal assessment of the impact of trauma training. These studies assessed confidence and perceived stress in managing complex trauma patients as in situ measures at least 5 months following the initial course. Studies in the USA commonly used validated assessment tools to measure behavioral change which were NOTECHS or variations of NOTECHS, the Human Factors Attitude Survey, TeamSTEPPS, Teamwork Attitudes Questionnaire, TeamSTEPPS Teamwork Perceptions Questionnaire, Trauma Team Performance Observation Tool, Team Emergency Assessment Measure.

Level 4: clinical performance

Of all included studies, 7 (24.1%) investigated the impact of trauma training on clinical performance (level 4a)

which were all courses undertaken in the USA. A range of methods were used to assess clinical care outcomes including pre- and postcourse questionnaires and examinations, written reports, observation of clinical skills, and standardized videotape review of skills. All of these studies measured in situ events such as error rates and successful intubations by members of the trauma team. Organizational delivery of care (level 4b) was measured in 9 studies (31.0%; USA $n = 8$; UK $n = 1$) through cohesive improvements in clinically applied training, although throughout the studies no significant differences were found pre- and post-trauma training on patient ICU stay or morbidity and mortality.

Risk of Bias

All included studies were cohort studies and risk of bias was assessed using ROBINS-1.[16] Risk of bias was overall determined to be low to moderate (Fig. 2). Confounding bias was moderate overall with some studies not presenting present pretest control data. There was critical overall bias in the selection of participants as courses were often not open to all possible participants, for example, self-selected recruitment from trauma military groups. Classification bias and bias due to deviation from intended interventions was low with studies clearly delineating their intervention and course curriculum. Overall missing data bias was moderate as studies had some form of missing data and were not able to adjust for this in their analysis. Measurement of outcomes had serious bias overall, as many questionnaire evaluations were subjective without any objective measures. Selection and report of results had serious bias overall, while some studies did note ethical approval there was no priori registration of the results and some studies had limited reporting of results.

DISCUSSION

This systematic review identified approaches used to train trauma personnel in CRM principles in order to suggest future training courses. This review is the first to directly compare CRM training methods in trauma personnel between the UK and USA. One previous review has assessed CRM implemented in all acute care services (20 included studies)[1] and another review has assessed trauma team training limited to simulation articles (13 included studies),[2] with both finding learning and behavioral benefit but no proven impact on patient care outcomes. The primary aim of this review was to identify contrasts between UK and USA trauma CRM course structure, participants, and outcomes. The secondary aim of this review was to identify any key trends which result in successful CRM training in a field that is increasingly identifying nontechnical skills as a key component of practice. All trauma training reviewed in this study were positively evaluated by participants and improved confidence and preparedness in approaching trauma scenarios. All interventions reviewed resulted in improved knowledge, skill, and attitudes, however, complex multimodal simulative experiences were the only intervention type to result in persisting behavioral change in trauma personnel. Successes in CRM training revolve around participant reaction, nontechnical behavioral skills, and clinical care outcomes achieved. All of the trauma team courses included in this review focused on the index evaluation and management of critically unwell patients, with no courses explicitly incorporating decision making between operative and nonoperative management strategies, management of the trauma patient with deterioration following initial management plan, or the role of the tertiary survey. These factors are of particular importance as trauma care is becoming an integral part of an increasing number of care provision centers and there may be a prevalent lack of previous exposure to trauma scenarios.

This review identified few articles describing CRM training in the UK. A national survey of 1130 UK surgical trainees found that only 466 (41.2%) of respondents had access to a skills simulator facility and of those with access, only 111 (16.3%) had protected access away from clinical duties.[19] However, this survey was focused on technical surgical skills simulation and it likely that the prevalence of CRM training utilizing simulation is

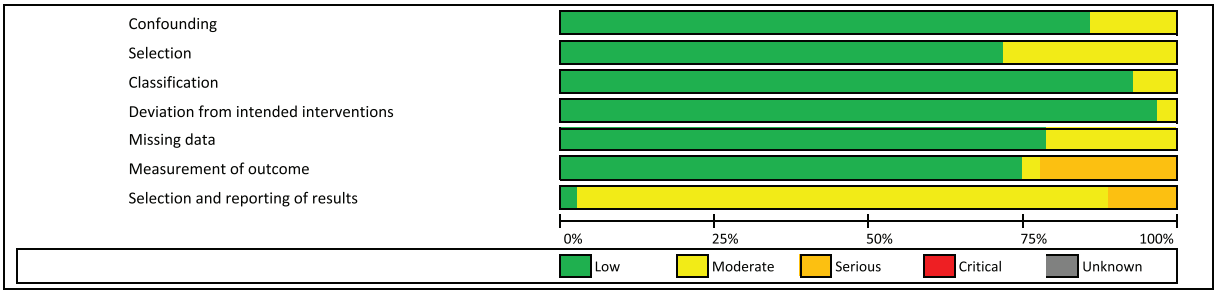

FIGURE 2. Overall risk of bias for nonrandomized control trials determined by ROBINS-1.

substantially lower within the UK. Due to the highly specialized skills required of trauma personnel, this review suggests that future CRM training, and particularly training within the UK, should be shifted towards in situ scenarios or high-fidelity simulative experiences in order to truly influence behavioral change in trauma teams.

None of the 29 articles included in this systematic review were able to measure or demonstrate significant objective clinically persistent impact to the clinical trauma patient population, particularly in mortality and morbidity. This is likely due to the complexity of clinical care in trauma patients, with clinical outcomes being dependent on an immeasurable number of factors which would be difficult to attribute to a single training program. Clinical care outcomes were significantly improved in a proportion of USA-based CRM training which used "perfect task completion" and "time to, for example, imaging, airway management' outcomes. These parameters can be impacted by multiple factors beyond the scope of CRM training such as team familiarity and resource availability, however, indicate that CRM training could have a substantial impact on patient care not currently captured. Previous studies have suggested the use of process measures such as introducing evidence-based procedures, checklists, and quality assessments create significant benefit to trauma patient care, and therefore an evidence-based approach to CRM training could also influence the same parameters.[1-3] Only USA-based courses were able to demonstrate behavioral change in their trauma personnel by undertaking longitudinal studies and by utilizing in situ hospital-based training and outcome assessments. In addition to this, UK-based CRM training included in this systematic review recruited a limited number of healthcare professionals whilst USA-based CRM training had a predominance of multidisciplinary participants. It is recognized that there is a strong collaboration between military trauma research and civilian healthcare in the USA, and this may explain the higher output of USA led published CRM training reports and optimization of CRM through multidisciplinary inclusion.[20] For effective future training, longitudinal multidisciplinary team training should be undertaken promoting communication over multiple departments and coordination of staff and resources from clinical to administrative levels.

The training reports identified in this review were open to study design limitations, especially pertaining to the none-validated implementation methods and outcome measures. In the USA standardized and validated methods were utilized more frequently when compared to the UK, but a much wider range of methods existed. Within the courses reviewed there were a range of participants recruited, ranging from multidisciplinary students who may have had less trauma experience or responsibility to military participants eager to gain experience in high intensity simulation. It is presumable that the trauma personnel recruited in the course reviewed are highly motivated groups of people. Those from military groups or high-level trauma centers are likely to engage with courses in a way which maximizes impact, which may drastically differ from civilian participants of a mandatory course. All of the studies reporting pre- and postcourse outcomes in this review were single centered. Future work should be undertaken to implement multi-centered or multinational training in order to ensure rigorous implementation and assessment of curriculum and to create large studies for validation of previously successful training methods.

This systematic review included only a small number of training courses from the UK which limits the lessons which can be learned through this review. However, by using key components of established USA-based training programs an evidence-based approach can be applied to future UK-based CRM training with the publication of insightful training results. The lack of standardized structure, components, and outcomes of CRM has led to difficulties in the widespread adoption of CRM in trauma personnel and this may be more prevalent in the UK. CRM is an intensive method of training which requires extensive economic, staff, and time resources however has the potential benefit of improving behavioral changes which influence patient outcomes. Reviewing only articles that fully reported training outcomes in trauma-based personnel investigating human factors skills has limited the conclusions to be gained from comparison of USA and UK trauma training, however, validity can be gained by comparing this review to previous literature that align with the broad findings of this study.[1-3]

CONCLUSIONS

This systematic review found CRM training to have an overwhelmingly positive impact on confidence, preparedness, and teamwork in trauma personnel. Whereas UK-based CRM training predominantly focused on limited participants undertaking training in specific tasks without evidence of behavioral change, USA-based training was more likely to focus on behavior outcomes and nontechnical skills utilizing multidisciplinary teams with high-fidelity in-situ training. Further evidence and consensus are needed in CRM training with the aim of producing replicable content, consistent outcome measurements, and collaboration across the 2 countries in order to further develop trauma training in healthcare systems. CRM has the potential to significantly improve participant satisfaction in training, participant learning, participant teamwork behaviors, and most importantly clinical care outcomes in the management of the trauma patient population.

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