How Does Cadaveric Simulation Influence Learning in Orthopedic Residents?

Hannah K. James, MBChB (Hons), MRCS, MMedEd,[*,†]
Giles T.R. Pattison, MBBS FRCSEd (Tr&Orth) FHEA MSc FFSTEd,[†]
Damian R. Griffin, MBM BCH (Oxon) MA MPhil (Cantab) FRCS (Tr&Orth),[*,†] and Joanne D. Fisher, PhD[*]

[*]Clinical Trials Unit, Warwick Medical School, Coventry, United Kingdom; and [†]Department of Trauma and Orthopaedic Surgery, University Hospitals Coventry and Warwickshire, Coventry, United Kingdom

OBJECTIVE: The objectives of this study were to understand how cadaveric simulation impacts learning in orthopedic residents, why it is a useful training tool, and how skills learnt in the simulated environment translate into the workplace.

DESIGN: This is a qualitative research study using in-depth, semistructured interviews with orthopedic residents who underwent an intensive cadaveric simulation training course.

SETTING: The study was conducted at the University Hospital Coventry & Warwickshire, a tertiary care center with integrated cadaveric training laboratory in England, United Kingdom.

PARTICIPANTS: Orthopedic surgery residents in the intervention group of a randomized controlled trial comparing intensive cadaveric simulation training with standard "on the job" training were invited to participate. Eleven of 14 eligible residents were interviewed (PGY 3-6, 8 male and 3 female).

RESULTS: Learning from cadaveric simulation can be broadly categorized into intrinsic, surgeon-driven factors, and extrinsic environmental factors. Intrinsic factors include participant ability to "buy-in" to the simulation exercise, willingness to push one's own learning boundaries in a "safe space" and take out on resident experience and self-reported confidence, with the greatest learning gains seen at around the PGY4 stage in individuals who reported low preintervention operative confidence. Extrinsic factors included; the opportunity to perform operations in their entirety without external pressures or attending "take-over," leading to subjective improvement in participant operative fluency and confidence. The intensive supervision of subspecialist attending surgeons giving real-time performance feedback, tips and tricks, and the opportunity to practice unusual approaches was highly valued by participants, as was paired learning with alternating roles as primary surgeon/assistant and multidisciplinary involvement of scrub-staff and radiographers. Cadaveric simulation added educational value beyond that obtained in low-fidelity simulation training by "stirring into practice" and "becoming through doing." In providing ultrarealistic representation of the space, ritualism, and costuming of the operating theater, cadaveric simulation training also enabled the development of a range of nontechnical skills and sociocultural "nontechnical" lessons of surgery.

CONCLUSIONS: Cadaveric simulation enhances learning in both technical and nontechnical skills in junior orthopedic residents within a single training package. Direct transfer of skills learnt in the simulation training to the real-world operating theater, with consequent patient benefit, was reported. Cadaveric simulation in the UK training system of orthopedics may be of greatest utility at around the PGY 4 stage, at which point operative fluency, independence, and confidence can be rapidly improved in the cadaveric laboratory, to enable the attainment of competence in index trauma operations. (J Surg Ed 77:671−682. © 2019 The Authors. Published by Elsevier Inc. on behalf of Association of Program Directors in Surgery. This is an open access article under the CC BY-NC-ND license.
(http://creativecommons.org/licenses/by-nc-nd/4.0/))

ABBREVIATIONS: PGY, postgraduate year CST, cadaveric simulation training EWTD, European Working Time

Funding: TBC. HJ holds an educational research fellowship with Versus Arthritis (formerly Arthritis Research UK) grant number 20485. Material costs for the course were supported by Industry (DePuy Synthes UK, Leeds, England) and a grant from Health Education England (West Midlands Deanery).

Correspondence: Inquiries to Hannah K. James, Clinical Sciences Research Laboratories. University Hospital Coventry and Warwickshire, Clifford Bridge Road, Coventry, CV2 2DX, United Kingdom; e-mail: H.Smith.1@warwick.ac.uk

 1931-7204/$30.00 https://doi.org/10.1016/j.jsurg.2019.12.006

Directive ORIF, open reduction internal fixation SHO, senior house officer CCT certificate of completion of training

KEY WORDS: high-fidelity simulation, surgical education, orthopedic residency, preparing for practice, cadaveric simulation training

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

INTRODUCTION

The movement to incorporate simulation into postgraduate surgical training is rapidly gaining momentum, in response to perceived threats to the quality of training.[1-6] In the United Kingdom, a 2-year internship, undertaken during postgraduate year (PGY) 1 to 2, is followed by competitive entry into basic surgical training, which begins at PGY3 level. Basic surgical training comprises PGY 3 and 4, at which point a further competitive entry procedure occurs for progression into higher surgical training, which runs from PGY 5 to 10. On completion of higher surgical training, a surgeon is awarded a certificate of completion of training and can begin independent consultant practice at attending-equivalent level.

Surgical training in the United Kingdom is still largely based on the traditional Halstedian master-apprentice model,[7] the success of which relies on an environment of long working hours, volume of exposure,[8] unstructured training progression, and the maintenance of long-term working relationships with senior surgeons to foster constructive mentorship.[9] However, in the current surgical training climate of shift-based work patterns,[10] legally mandated reduced working hours,[11,12] and a move to expediting surgical training,[13,14] new models of training need to be considered to ensure the continued production of appropriately skilled practitioners.

Simulation offers a potential solution to some of these challenges by enabling rapid skill acquisition and progression to competency,[3] within a safe, structured, and controlled environment remote from patients. Other safety-critical professions, most notably aviation,[15] have long used simulation at early career stages to enable trainee pilots to achieve, and demonstrate, competency in the necessary skills before being allowed to take the controls of a real aeroplane. The logical extension of this argument is consideration of why, in surgical training, it is still considered acceptable to allow trainee surgeons to perform their first attempt at a whole operation on a real live patient, with the inherent risks of making mistakes as an inevitable part of learning, with potentially harmful patient consequences. The steep part of the learning curve, from novice to competent (Fig. 1) could be moved away from the patient to the simulator, and only once a trainee has achieved a defined level of competence will he or she be permitted to begin operating on real patients.

Cadaveric simulation (i.e., using deceased, preserved, or fresh donated human bodies) is a potentially promising modality for training as it offers what is arguably the most realistic representation of human anatomy,[16] with realistic tissue handling characteristics and haptic "touch-real" feedback,[17] which cannot be easily replicated by other means.[18]

There is a drive to embed cadaveric simulation in surgical training in the United Kingdom, as part of widespread government-led efforts to modernize and improve efficiency of training. There has been considerable investment in facilities and expansion of provision of cadaveric simulation in recent years.

The literature on the qualitative impact of simulation training for surgeons is limited, and more widely, surgical simulation research is generally undertaken from a quantitative, reductionist perspective.[19] This is because the measures of effectiveness and efficiency of training relate primarily to the mastery of technical skills and confidence gains, including "downstream translational effects on patient outcomes and patient care practices."[19] A criticism of restricting simulation-based research to purely outcome and effectiveness-based studies is that our understanding of the benefits of simulation-based education remains unidimensional, and that where rich contextualized detail of its impact is missing from the evidence base, explanation of phenomena that could be used to improve the educational value of future simulation training activity is not possible.

The primary objective of this study is to seek a rich understanding of the experiences of surgeons undertaking cadaveric simulation training (CST). The secondary objectives are to describe learner perspectives of the value of CST as a training tool, and to understand how skills learnt in a simulated environment are translated into the workplace from the perspective of the lived experience of the participants.

METHODS

Setting and Participants

This qualitative research study was carried out at the University Hospital Coventry & Warwickshire, a large tertiary care center in the West Midlands of England, United Kingdom. Within the hospital, there is a leading surgical training suite, hosting an active program of regional, national, and international cadaveric training courses. Ethical approval was granted for this research

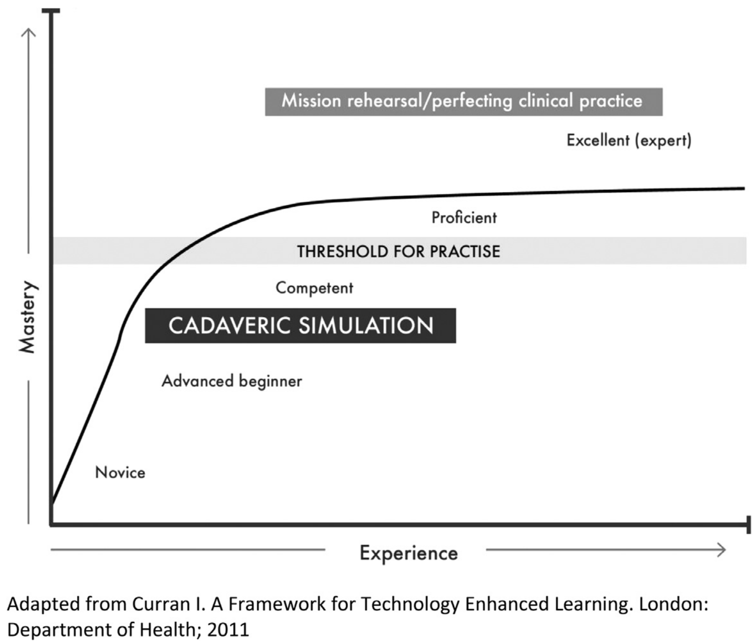

FIGURE 1. Schematic learning curve with Dreyfus stages
Adapted from ref. [3].

(Biomedical and Scientific Research Ethical Committee REGO-2014-718). This study was embedded within a randomized controlled trial comparing the impact of an intensive CST course on objectively measured real-world operative performance versus no additional training beyond the current standard "on the job" training.

Trial participants were a cohort of PGY3-6 orthopedic residents, and those in the intervention group ($n = 14$) were invited by e-mail to participate in the qualitative arm of the study. First and second e-mail reminders were sent to initial nonresponders. Eleven participants were subsequently interviewed. Of the 3 trial participants who were not interviewed, 1 declined to be interviewed, 1 had emigrated abroad into a nonclinical job role, and 1 participant did not respond to attempts at contact.

The mean age of participants was 28 years (range 26-31), 8 participants were male and 3 female. There was 1 in PGY3, 5 in PGY 4, and 5 in PGY5. Four participants had previously experienced CST in any capacity, and 7 were CST-naïve.

All interviews were conducted 6 months after completion of the CST intervention.

The CAD:TRAUMA Cadaveric Training Course

As part of the randomized trial, participants underwent an intensive, 2-day CST course. Eight waist-to-toe tip fresh-frozen cadavers were set-up supine on operating tables and 2 identical circuits of 4 stations were run in parallel. Participants were paired, each pair worked on 1 cadaver performing 1 operation (as first surgeon and assistant) under the supervision of attending faculty, before rotating to the next station after a predetermined time. Over the 2 days, each participant acted as both first surgeon and assistant to their partner for the 4 procedures, and hence each participant was exposed to 8 procedures in their entirety; 4 as first surgeon and 4 as assistant. The 4 procedures were (1) dynamic hip screw fixation, (2) cemented hemiarthroplasty for fractured neck of femur, (3) plate and screw fixation for fractured ankle (open reduction internal fixation—"ORIF"), and (4) 4-compartment lower limb fasciotomy.

These procedures were chosen as they are curriculum-defined "index" procedures in which competency is expected to be achieved for progression from PGY4 to PGY5 in orthopedic residency (which within the UK system represents a significant transition, with a considerable increase in operative and decision-making responsibility from PGY4 level as a "Senior House Officer"/"SHO" to PGY5 level and onward as a "Specialist Registrar"). Great effort was made to authentically recreate the operating theater environment to ensure the highest possible environmental fidelity of the simulation; each cadaver was fully draped and participants wore surgical scrubs, masks, gloves, hats, and gowns. Each station had operating theater lights in use and fully stocked instrument trays with an array of implants (and cement for the hemiarthroplasty station). Scrub nurses and radiographers participated as ancillary faculty, and there were 2 radiographers with "mini-C" arm x-ray machines to check intra/postoperative implant position. The pre-procedure preparation that would be undertaken as routine in real-life surgery, such as patient positioning, skin preparation, draping, and incision site marking were also carried out before each case. The participants were expected to "scrub up" for each case and to respect the sterile operative field as they would in real life. The result was 8 highly realistic, equipped and staffed operating theaters running in tandem within the surgical training suite.

The consumable costs of the course were funded by a research grant, and used commercially procured fresh-frozen human cadaveric material (Science Care ltd, Phoenix, Arizona) and industry donated implants and instruments (DePuY Synthes, Raynham, MA). The approximate cost of the course was $2500/delegate. The attending faculty generously donated their "continuing professional development" time to the course, so there was no extra faculty cost incurred.

Data Collection

Interviews took place 6 months after conclusion of the CST intervention. This was felt to be the optimum post-training interval, with an important balance to be struck between there being enough time to return to clinical rotations after the course, to give participants the opportunity to reflect on the impact of the training and potential influence on their real-world practice, while still being in recent enough memory to be accurately recalled.

The majority of interviews (8 of 11) were face-to-face, 3 interviews were conducted by telephone at the request of the participants. All reasonable efforts were made to accommodate the participants busy working schedules and their preferences for location/interview modality. All interviews were conducted by HJ (orthopedic resident undertaking doctoral research) and recorded using a digital voice recorder. All interviews took place in a location familiar to the participants, and the interviewer was known to all participants as acquaintance and peer. Previous work has shown that matching the major social characteristics of the interviewer and interviewee is an important determining factor in the effectiveness of the interview.[20] Great care was taken to avoid imposing implicit interviewer biases on the participants, or steering the interview based on them, and to remain as objective and neutral as possible. The duality of the participant-interviewer peer relationship was managed mindfully and all participants were assured of confidentiality and gave their permission for the interview to be recorded and analyzed for research purposes. A prepiloted topic guide was used to structure the discussion (Appendix 1).

Data Analysis

An experiential thematic analysis approach was used for analysis, with a critical realist and postpositivist ontological and epistemological stance, respectively. This approach enabled complete focus on the participants own framing around issues, and their own terms of reference, allowing a fuller multifaceted understanding of the issues around the use of CST, in an exploratory and flexible manner that embraces the complexity of human experiences and perspectives. The analysis approach was structured around Braun & Clark's checklist of criteria for "good thematic analysis."[21]

The digital audio recordings were transcribed to a high level of orthographic detail and were rechecked against the original tapes to ensure accuracy. An initial process of reading and familiarization with the transcripts was followed by the start of the coding process and searching for themes. A complete coding strategy to identify "anything and everything" of interest within the entire dataset was used, generating a mixture of semantic and latent codes, in a recursive process over many weeks involving multiple revisions, until the entire dataset was completely coded. NVivo qualitative data analysis software version 11.4.3[22] was used to collate relevant extracts for each theme. Once coding was felt to be complete, patterns were searched for within the coded data, from which to build themes. Themes generated during the analysis process were checked against each other and repeatedly referenced back to the original data set, to ensure they each had distinct scope and purpose, were faithful to the data, and that together they would provide a coherent and meaningful overview of key concepts in the data that addressed the research question.

RESULTS

Two key themes were evident: first, "factors driving learning from cadaveric simulation training," which can be subdivided into intrinsic surgeon-driven factors, and external environmental factors (Table 1), and second, "added value of cadaveric simulation" (Table 2). This was the unifying concept of a cluster of findings relating to how cadaveric simulation can add value to training beyond that of other simulation modalities.

Intrinsic, Surgeon-Driven Factors

Self-perception of operative confidence influenced learning following CST. Those with low self-reported confidence in their operative skill appeared to make the greatest gains following the CST intervention

> *"for me before I started the course, hemiarthroplasty was my Everest and I think after that course I*

TABLE 1. Summary of the Factors Driving Learning in Cadaveric Simulation

Intrinsic, Surgeon-Driven Factors	Extrinsic, Environmental Factors
Self-perception of skill level • Least confident participants appeared to make the most gains Willingness to "buy-in" to the simulation • Suspension of disbelief • Staying in "character" Pushing boundaries • Move out of comfort zone • Not ask for help as often • Safe space to make mistakes Timing of delivery • Participant at correct stage of training for maximal benefit—early/mid-PGY4 • Do CST just before start of trauma rotation	Paired learning • Practice assisting • Learn from colleague Multidisciplinary simulation • Experience being scrub nurse • Alternative perspectives Perform operations in their entirety • Fluency • Momentum Intensive consultant supervision • One-to-one • Real time feedback • Superspecialized • Tips/tricks • Unusual approaches Becoming through doing • Nontechnical skills • Highly realistic space, time and costuming • Sociocultural, "unspoken" lessons of surgery • Stirring to practice

was much more confident in approaching it" (Participant 12)

"I'm just much more happy and confident [having done the CST course] that I'll be competent to do it [the operation]" (Participant 1)

The ability to "buy into" the simulation exercise and behave as if operating on a live patient was important for optimal learning and the ability to do this successfully varied between individuals. One participant had previously struggled with "suspension of disbelief" in the low-fidelity setting and appreciated the value of the high fidelity of the CST in achieving an immersive experience

"so in a [low-fidelity simulation setting] workshop, it is much easier to slip into not quite doing it properly, such as a soft tissue guide, because there isn't soft tissue to worry about...suddenly the whole illusion breaks down" (participant 8)

TABLE 2. Summary of the "Added Value" of Cadaveric Simulation. Superiority of CST as compared other simulation modalities

Anatomical fidelity
- Soft-tissue envelope
- Neurovascular hazards
- Tissue tension
- Haptic feedback

"Dress rehearsal" for real surgery
- Whole learning, enabling direct skill transfer to the operating theater
- Can build on and refine foundational skills learnt in low-fidelity simulation
- Becoming through doing, "stirring into practice"

Offers solutions to some of the barriers to learning in the operating theater
- No time pressure
- No pressure from anesthetist/other theater staff
- No risk to patients

An ability to push one's own learning boundaries within the safety of a simulation exercise enabled learners to gain maximal benefit from the CST intervention. For example, whereas in real life, an inexperienced trainee often seeks reassurance from the trainer before progressing through each stage of the operation, in the simulation exercise, the trainee can move beyond their comfort zone under careful-guided supervision more confidently and improve their operative fluency without the risk of causing patient harm.

Within this sense of safety, and yet investment in the environmental fidelity of the simulation, participants reported valuing the opportunity to have the time to perform the operation in its entirety, without the usual time pressures of the operating theater

"so that [the CST intervention] was a great place to just do a procedure and not be cut there, cut there, cut there, just crack on, do it and it doesn't matter if you get it wrong" (Participant 3)

> *"in an environment that wasn't time pressured or, no external pressures, the anesthetist or something like that or an unwell patient...was very helpful indeed and from a learning point of view I think I learnt more in the cases I did there [the CST intervention] than the vast majority of cases that I do in theatre" (Participant 7)*

> *"I got to the end and I thought 'Ah I haven't actually asked for help' as supposed to in a real situation...I will be constantly looking for reassurance that the guide wire is in the right place, that you know, everything was, everything was right...and almost asking permission before going onto the next step" (Participant 6).*

Correctly timing the delivery of the CST intervention within training was perceived to be a crucial intrinsic, learner-dependent factor to its success. Most of the participants felt that delivery of the course in its original format was best suited to the beginning or middle of PGY4. This was because at the start of PGY4 level, within the UK training system, the participants did not have much independent operative experience. Most participants reported encountering significant practical and logistical difficulties accessing the operating theater to receive conventional training, and yet competence in these index procedures was expected to be achieved to progress on to PGY5 (Specialist Registrar) level—thus, a paradox exists between the demands of the curriculum and the realities of the daily working environment these doctors find themselves in. This was a consistent finding across participants at PGY4 level who felt the course was appropriately timed for their stage of training, and participants at PGY5 level at the time of the intervention felt the course would have been of greater benefit to them a year earlier.

> *"I felt that the level I went into it at the beginning of PGY 4 was perfect because you, you've had a bit of time in trauma theatre, but maybe not as much independence as the senior trainees...and then getting a lot of confidence from having seen the four index procedures [on the CST course] (Participant 16)*

> *"middle of PGY 4 [would be ideal], those procedures are, apart from the fasciotomies, I think they are all essentials for becoming a registrar [PGY 5]" (Participant 2)*

Timing of delivery with respect to the commencement of a trauma rotation was also raised, with the course being more useful if it were delivered before the placement begins (as compared to 6 weeks in, as it was in this study), and that there was a perceived risk of learned skill attrition if the course was delivered too early.

> *"If I had it just before [trauma rotation] that would be even better...you need to be doing it relatively fresh, within four to six weeks" (Participant 3)*

Extrinsic, Environmental Factors

Participants were paired during the CST training intervention, and while one was operating as "first" surgeon, their partner was assisting or acting as scrub nurse if no assistant was required. The paired-learning nature of the CST intervention was perceived as valuable, as there was the opportunity to learn from the experience of a colleague partner

> *"I think having...two participants working together was very useful because you see one [procedure], your colleague doing it and then you do it yourself, you can kind of learn from each other and even if you do make any pitfalls you can kind of learn from that experience, and think what you would have done differently and so I think learning from each other is a really good thing" (Participant 15)*

> *"It was nice to learn from your partner aswell, so if you saw a case that, for example, you weren't particularly sure about then the next day you had opportunity to do it" (Participant 16)*

The multidisciplinary environment of the CST intervention was perceived as valuable and enhanced learning, both in terms of enabling dialog about their performance between allied health professionals (scrub staff and radiographers) and through the opportunity to assume the role of scrub nurse. This gave participants an insight into the role the scrub nurses play in ensuring the smooth progress of an operation, and furthermore to improve their own knowledge of the sequence of steps in a procedure, as the scrub nurse is required to anticipate the next stage of a procedure and have the correct instruments to hand

> *"Actually what I found very helpful was being a scrub nurse and watching and anticipating and giving them the next thing and the next thing" (Participant 8)*

> *"I liked the way that we had the theatre staff come in aswell, it was really good to get their opinions on things...I think that was very good" (Participant 10)*

> *"...your interaction with your team, having that one on one feedback as well as you were doing the process [was beneficial to learning]" (Participant 16)*

One of the key extrinsic features of CST that drive learning is the opportunity to perform operations in their entirety as first surgeon, and in an intensive way; that is, several successive operations in a short overall period of time. This would not typically be encountered in the real-life operating theater environment, because of the service demands placed upon trainee surgeons to process admissions, medically manage inpatients, and deal with administration. The participants valued this opportunity and felt that it enabled them to progress their skills more quickly than usual

> *"[CST] gives you an opportunity to do a lot of operations in a short period of time as first surgeon" (Participant 6)*

> *"I think [the CST course] was the first time I had ever done a hemiarthroplasty entirely on my own" (Participant 12)*

Another key feature driving learning was the intensive nature of the supervision during the CST intervention. Each operation was supervised by a consultant/attending, who provided real-time feedback and guidance, and were given the scope to challenge participants as they judged appropriate. Having intensive supervision also helped the learners maintain the fidelity of the simulation, as the faculty helped maintain the illusion that they were in the "real" operating theater through their nonverbal cues and behaviors

> *"it keeps you switched on and stops you lapsing, so [you aren't] doing the 'oh in real life' I would have done this', that's really helpful" (Participant 8)*

> *"to have high quality teachers one-on-one was fantastic...[the CST course was] an excellent way of learning, having the consultant [attending] stood over your shoulder which is something you might not have in the actual theatre itself" (Participant 3)*

> *"[amongst] the things I found most helpful [about the CST] was you were getting one-on-one consultant level teaching" (Participant 7)*

The US convention faculty were allocated stations according to their subspecialist interests, and their expertise was highly valued by the participants

> *"having an ankle surgeon [specialist] at the ankle station was good, because ankles can always be a bit fiddly and people have certain tips and tricks, it was very helpful" (Participant 15)*

> *"I think it [the CST intervention] was really well thought out" (Participant 10)*

There was recognition that simulating the complexities of the real-life operating theater was extremely difficult, and that CST was the best available simulation modality to try and achieve this replication

> *"its very hard to simulate training in orthopaedics...certainly cadaveric training is probably the only way you're going to be able to do that" (Participant 2)*

Some aspects of the CST intervention compromised the fidelity of the training experience, in particular, the specimens moved around during the hemiarthroplasty procedure (normally the patients' body weight and positioning aids prevent this in real life). Waist-to-toe-tip specimens were used rather than whole cadavers, and so these obviously weighed less than a whole body. This also negatively affected the realism of relocating the hip once the implant was in position for similar reasons.

> *"for the hemiarthroplasty they [the cadavers] were just moving around a little bit and it wasn't as realistic as you had in theatres" (Participant 16)*

> *"having just the one leg for hemiarthroplasty made setting up quite difficult and when you tried to relocate the hip" (Participant 10)*

The Added Value of Cadaveric Simulation

With cadaveric simulation being so much more expensive to deliver[16] than other lower fidelity, inorganic types of simulation, it needs to bring additional benefits that these cheaper alternatives do not, to justify the cost. Participants were asked if there were features of the CST which were particularly useful to them in developing their skills as surgeons-in-training, and whether they felt CST offered value beyond that of other simulation modalities.

Anatomical Fidelity

Anatomical fidelity, the presence of a soft-tissue envelope and neurovascular structures as seen in life, were reported by participants as features peculiar to CST that could not be found elsewhere. Intuitively, deceased human bodies offer the most realistic representation of living anatomy, which is extremely difficult, if not impossible, to replicate by other means. Where visual representation of anatomy can be achieved by use of sophisticated computer and virtual reality programming, the haptic, tactile feedback and "tissue tension" experienced in cadaveric simulation is unparalleled.

> *"tissue tension is something that is quite unique to the cadavers really" (Participant 8)*

"technical skills, in going through [dissecting] various layers, you can't simulate [that] with dry bone" (Participant 7)

"life-like I suppose, with tactile feedback" (Participant 1)

"I think in terms of how high fidelity it was compared with what you normally do [in real life], it was very close" (Participant 16)

The presence of a soft-tissue envelope made the educational experience much more valuable for participants as they had to navigate the neurovascular hazards as they would in real life, and they could not "cheat" by obtaining direct visualization of the bone, as is possible in low-fidelity benchtop models such as sawbones. They were therefore more invested in the authenticity of the simulation experience, which became immersive, and led to other cognitive benefits.

Within the immersiveness of the experience, participants "bought into" the realism and began to behave as they would in the operating theater. This investment in the simulation exercise revealed another important area of the added value of CST—consequence and patient safety. Participants, while immersed in the realism of the training experience, knew that there were no real consequences to their making a mistake, and there was no risk to patient safety. In treating the exercise as a "full dress rehearsal" for real-life operating, the participants felt confident to push their own boundaries and progressed their learning as a result.

"it doesn't matter if you get it wrong" (Participant 3)

"I think its good for the trainee, because they go through all the steps [in CST], they make sure they feel happy and confident, they've gone through the motions, and they can consolidate that on a cadaver first...and its good for patients because they get someone [a surgeon], they're not practicing on a real person" (Participant 15).

Skills learnt in the CST intervention were directly transferred to the operating theater, as result of this "dress rehearsal" opportunity. There was no need for the participants to aggregate or embellish their learning before taking it to the operating theater, the learning from CST was whole, or complete.

For example, 1 participant described how a week after attending the CST course, they had been on-call over the weekend and been asked to perform a lower limb fasciotomy. The participant describes how there was no-one available to supervise them performing the procedure, but having completed the procedure on the cadaver during the CST course the previous week, they felt confident of the surgical landmarks and hazards, in a way that reading about the techniques in a textbook would not have achieved.

"I knew where the perforators would be, it all went very smoothly, and its one of those things where if you've never done something before you can read it in a book, but you're not going to be sure of yourself, and I think that once I've done something [on the cadavers] I know I can do it, then I'm just much more happy and confident that I'll be competent to do it...doing that on a specimen rather than a person, in that situation [the fasciotomy] especially because its not something that you see every day, I might not do one for another few years, it's very valuable" (Participant 1).

Another participant described how their supervising attending knew that they had recently successfully completed a fasciotomy procedure during the CST course, and so when a real case was encountered a few weeks later, they were happy to let the resident perform the entire operation on the patient, confident in the knowledge that the resident had previously achieved competence in the simulated environment.

"I definitely used what I learnt [on the course]...it's definitely made a difference to training" (Participant 16)

Real-Time Feedback

Participants valued the real-time feedback and "tips and tricks" that supervising faculty provided during the CST course, and the opportunity to complete workplace-based assessments from their operative performances

"I really liked the one on one consultant [attending] feedback. I thought it was a really nice way of doing things" (Participant 16)

"it's quite hard in day to day training sometimes to get the consultants to sit down and do the forms properly and give you constructive feedback...often they will say 'oh just fill it in and send it to me', but they had to do it properly [during the CST intervention]" (Participant 6)

"people have certain tips and tricks...it was very helpful" (Participant 15)

"for me, the best bit about cadaveric training is getting to do things [approaches] that you don't normally do" (Participant 2)

Timing of Training Delivery

The timing of CST with respect to delivery of other low-fidelity simulation training opportunities was also explored with participants, with a particular emphasis toward understanding whether CST has an adjunctive or replacement role when compared with low-fidelity simulation.

As a prerequisite to completion of PGY4, all UK orthopedic residents must undertake the AO Foundation Basic Principles of Fracture Management Course.[23] This is an interactive course which teaches the basic concepts of stability, physiology of bone healing, and reduction and fixation techniques for simple fractures using low-fidelity, plastic bone simulation. Given the consensus among participants that the CST intervention was best delivered in the middle of the PGY4 year, that is, within the accepted timeframe for AO course completion, it was interesting to explore whether they felt that CST carried most educational benefit when delivered before or after the AO course.

Participants reported that the CST was most beneficial after they had grasped the basic principles of fracture management via the AO course, and that the more sophisticated simulation environment of CST allowed them to build on what they had already learnt in the low-fidelity environment. The AO course is very valuable as a first introduction to the principles and surgical instrumentation, which do not require the expense of CST to impart to surgeons-in-training.

> *"dry bones are really good, I think for basic principles and just getting familiar with technique and equipment. . .and then being able to apply those basic principles [in CST]..if you like, a higher level of simulation" (Participant 7)*

Participants were also asked about their opinions on whether there is a role for embedding CST within the curriculum, making it routinely accessible to surgeons-in-training as part of their formal teaching program. The response was very much in favor of this approach, that CST should be centrally funded and provided free of charge within residency programs, and was a tremendous yet presently underutilized training tool.

> *"Absolutely. Absolutely, I think it's the way forward really" (Participant 15)*

> *"It'd be a big loss if you weren't able to build it into the curriculum" (Participant 16)*

> *"they [the courses] should be delivered in region, for free to your trainees at the appropriate time" (Participant 3)*

> *"I think having cadaveric [simulation] training is an unbelievable privilege for us and really, really useful" (Participant 10)*

> *"I thought it [the CST intervention] was perfect, it was fantastic and I'm so lucky to be part of it" (Participant 12)*

Value of CST in Developing Nontechnical Skills

In Cleland et al,[19] a rapid ethnographic study of 2 surgical boot-camp training courses delivered to early stage-postgraduate surgical trainees was undertaken. The study aimed to understand the sociocultural influences of this intensive training and the wider implications for simulation-based education. The authors found that intensive boot-camp style training (of which CST is a variant) is "as much about social and cultural processes" as it is about "individual, cognitive and acquisitive learning."[19] These findings build on previous work examining how surgeons-in-training "become through doing." Prentice, in an ethnography examining how medical students and junior doctors learn surgical skills in the operating theater, states that in order to gain a full understanding of how a "resident comes to embody the knowledge, skills and values of a surgeon requires understanding how social milieu and guided practice interact."[24] Prentice describes the "guided physical training in the operating room" as embodying the "technical and social lessons of surgery," even where the skills being taught are purely "technical." Her findings reported that technical skill is only "20 percent" of the overall skillset required of a surgeon, with unspoken "tacit" knowledge, clinical judgment, and moral behavior forming a substantial part of what is required of a surgeon, beyond technical proficiency.[24]

Previous qualitative work examining surgical practice has "shown surgical action in detail, but have little to say about how surgical trainees learn to fit themselves into the team, how they take on increasing levels of responsibility and how they develop the moral qualities of a surgeon."[24] Prentice attempts to "unpack the unspoken lessons of surgery" by framing it within Bourdieu's (Bourdieu 1977 cited by Prentice.[24]) discussion of the "symbolically structured environment." According to Bourdieu, the "structures of an environment build particular organizing principles, habits and the ways of being into the minds and bodies of cultural actors" (surgeons in this instance), and the symbolic structured environment (the operating theatre) exerts an anonymous, pervasive, pedagogic action."[24] Prentice elaborates on this with reference to surgical training, that in the operating theater the highly ritualized "space, time and costuming provide structuring effects that make the imitation of a surgeon's actions and attitudes have meaning."[24] This helps create a positive economy in learners by instilling "the social hierarchy of the operating room," a hierarchy that "places surgeons in the centre, and gradually (with increasing experience) moves surgical residents into full participation at the centre of the action."

The value of CST, therefore, goes beyond provision of technical skills training. The ultrahigh environmental fidelity of CST replicates the "symbolic structured environment" of the operating theater and allows the learner to begin to become socialized in the practice of surgery and to "become through doing," learning both technical and nontechnical skills in a highly realistic environment, which itself exerts a "pervasive pedagogic action."

DISCUSSION AND IMPLICATIONS

Context of Findings Within Existing Evidence

Cleland's ethnographic study[19] of a UK-based simulation "boot-camp" for PGY3 residents described 3 broad areas of educational gains following the training; technical (and nontechnical) skills, "cultural capital," which the authors describe as "resources in the form of learning what knowledge, skills, and values were needed to succeed in the surgical training system" and "social capital," in terms of extending their mentoring network.[19] The authors acknowledge finding evidence of a distinction between the explicit and "hidden" curriculum within the boot-camp environment, with the latter adding value to the training by facilitating "enculturation and socialization into surgical training." They state that because this intensive training environment supports "both formal skills learning and informal learning about how to be a surgeon through social and cultural processes," it is important that simulation-based training program developers and researchers "address the social and cultural aspects of learning when planning similar enterprises," as educational interventions do not occur in "social, historical or cultural isolation."[19]

Their conclusion aligns with the findings of Jensen's[25] study of how medical students learn in the operating theater that the phenomena of surgical learning can be perceived as "instances of transformation in and among social practices," that students learn by "participating in the practice of providing high quality care," beyond simply technical skill acquisition in isolation, and the overall aim therefore is to teach "students to be surgeons instead of teaching them to perform surgery."[25]

Our analysis shows that the sociocultural features of CST were valued by participants, it helped with preparing them for the PGY4-5 transition and developing their professional identities and confidence as surgeons, and that the ultrahigh-fidelity nature of the simulation had additional, nuanced "cultural capital" benefits beyond the more obvious remit of developing technical skill acquisition. These benefits are particular to CST, as a consequence of successfully replicating the symbolically structured environment of the operating theater, with its associated "pervasive pedagogic action" in developing both technical and nontechnical "tacit" social skills and knowledge.[24]

Strengths and Limitations

This study has several strengths; it is the first in-depth qualitative study (to our best knowledge) on the role of CST for training surgeons and thus adds to the existing evidence base in this area. We have followed Yardley's "open-ended, flexible" quality principles (Yardley 2000 cited by Braun & Clarke[26]) in conducting this study, which "represent one of the most successful attempts to develop theoretically neutral validity criteria in qualitative research."[26] Commitment and rigor has been demonstrated by a thorough data collection and analysis procedure and by in-depth engagement with the research topic on both a professional and personal level. Transparency and coherence are also central to robust qualitative research practice, and we have endeavored to demonstrate this by presenting a clear analysis that is faithful to the dataset and theoretical framework, and reflexive in acknowledging the role that HJ has had, as both researcher and peer colleague of the participants, in shaping the research.

This study also has several weaknesses. The participants were all from one training region in the United Kingdom (West Midlands) and were individuals who had agreed to take part in the educational trial, and thus might represent a particularly motivated cohort of residents who are interested and engaged in simulation training research.

The interviews were conducted 6 months after the CST intervention and represent the participants' experiences in training at that point in time. Ideally, if resources had permitted, it would have been helpful to have repeated the interviews at a later stage, to further explore the longitudinal nature of the impact of CST, and to also interview the attending faculty involved in delivering the CST, to gain an understanding of their perspectives.

Three of the interviews were conducted over the telephone, which may have shaped the data obtained from these participants, as "virtual" interview methods can mean that information can be lost or misconstrued in the absence of nonverbal cues that occur during the interaction of a face-to-face interview.[20] The telephone interviews were shorter in length than the face-to face interviews, and the data generated is likely to be different than that from a face-to face encounter.

CONCLUSIONS

CST was highly valued by the resident participants in this study. Direct transfer of skills learnt in the cadaveric laboratory to the real operating theater was reported. CST can help offset the issues around accessing conventional training opportunities in the operating theater in the early stages of training, and it may serve to help residents achieve competency in index surgical procedures more quickly, with resultant patient safety benefits.

CST is advantageous over low-fidelity simulation and appears to offer "added value" for several reasons. The ultrahigh anatomical fidelity of cadavera presents an opportunity to practice operations with an unparalleled realism. The intensive consultant supervision with real-time performance feedback and opportunity to perform an operation in its entirety as first surgeon allows leaners to push their own boundaries within the safety of a simulated environment. The multidisciplinary nature of CST allows the learner to experience the perspective of scrub nurse which enhances their knowledge of sequencing of operative steps, teaches anticipatory skills and team working.

CST has an adjunctive role alongside convention surgical training and low-fidelity simulation. The middle of the PGY4 year was reported to be the best time to deliver this training course in the context of this group of participants, and the CST course added most value when delivered after low-fidelity simulation training, to build on the foundational skills already learnt.

CST has value beyond merely acquiring technical skills. Through the ultrahigh environmental fidelity of the simulation, the "pervasive pedagogic action" of the symbolically structured environment of the operating theater can be recreated, enabling surgeons-in-training to gain a myriad of nontechnical skills and become "stirred into practice" by learning the values, behaviors, and tacit knowledge required for surgical practice. CST may therefore be a promising candidate in the drive to reform surgical training within the current climate.

An important direction for future work in this area would be to further explore the role of CST in the acquisition of nontechnical skills. There is also a need to explore the experiences of the attending trainers in delivering CST.

STUDY DESCRIPTION

This was a qualitative research study using semistructured interviews with PGY3-6 orthopedic residents who had undertaken an intensive CST course to explore the impact the training had on their learning.

REFERENCES

1. Temple J. Time for Training. A Review of the Impact of the European Working Time Directive on the Quality of Training. London: Medical Education England; 2010.
2. Greenaway D. Securing the Future of Excellent Patient Care: Final Report of the Independent Review, London.
3. Curran I. A Framework for Technology Enhanced Learning. London: Department of Health; 2011.
4. Donaldson L. 150 Years of the Annual Report of the Chief Medical Officer. London: Department of Health; 2009.
5. A High Quality Workforce: NHS Next Stage Review. London: Department of Health; 2008.
6. Department of Health Council GM, *The Trainee Doctor*. 2011: London.
7. Reznick RK, MacRae H. Teaching surgical skills—changes in the wind. *N Engl J Med*. 2006;355:2664–2669.
8. Hargreaves DH, Bowditch MG, Griffin DR. On-the-Job Training for Surgeons. London: The Royal Society of Medicine Press; 1997.
9. Walter AJ. Surgical education for the twenty-first century: beyond the apprentice model. *Obstet Gynecol Clin North Am*. 2006;33:233–236. vii.
10. Marron C, Byrnes C, Kirk S. An EWTD-compliant shift rota decreases training opportunities. *Bull R Coll Surg Engl*. 2005;87:246–248.
11. Pickersgill T. The European working time directive for doctors in training. *BMJ*. 2001;323:1266.
12. House J. Calling time on doctors' working hours. *Lancet*. 2009;373:2011–2012.
13. Shape of Training., Report from the UK Shape of Training Steering Group (UKSTSG). 2017: General Medical Council.
14. Royal College of Surgeons of England. Improving Surgical Training—Trainee Prospectus. London: The Royal College of Surgeons; 2018.
15. Mitha AP, Almekhlafi MA, Janjua MJ, Albuquerque FC, McDougall CG. Simulation and augmented reality in endovascular neurosurgery lessons from aviation. *Neurosurgery*. 2013;72(suppl_1):A107–A114.
16. Gilbody J, Prasthofer AW, Ho K, Costa ML. The use and effectiveness of cadaveric workshops in higher

surgical training: a systematic review. *Ann R Coll Surg Engl*. 2011;93:347-356.

17. Carey J, Minneti M, Leland HA, Demetriades D, Talving P. Perfused fresh cadavers: method for application to surgical simulation. *Am J Surg*. 2015;210:179-187.

18. Sugand K, Abrahams P, Khurana A. The anatomy of anatomy: a review for its modernisation. *Anat Sci Educ*. 2010;3:83-93.

19. Cleland J, Walker KG, Gale M, Nicol LG. Simulation-based education: understanding the socio-cultural complexity of a surgical training 'boot camp'. *Med Educ*. 2016;50:829-841.

20. Braun V, Clark C. Successfully collecting qualitative data. Interactive data collection 1: interviews. Successful Qualitative Research—A Practical Guide for Beginners. SAGE Publications; 2013. p. 77-105.

21. Braun V, Clark C. Successfully analysing qualitative data. First analytic steps: familiarisation and data coding. Successful Qualitative Research—A Practical Guide for Beginners. SAGE Publications; 2013. p. 201-222.

22. NVivo Qualitative Data Analysis Software. QSR International Pty Ltd.; 2017 *Version 11*.

23. Available from: https://www.aofoundation.org/Structure/Pages/default.aspx.

24. Prentice R. Drilling surgeons: the social lessons of embodied surgical learning. *Sci Tech Human Val*. 2007;32:534-553.

25. Jensen RD, Seyer-Hansen M, Cristancho SM, Christensen MK. Being a surgeon or doing surgery? A qualitative study of learning in the operating room. *Med Educ*. 2018;52:861-876.

26. Braun V, Clark C. Quality criteria and techniques for qualitative research. Successful Qualitative Research—A Practical Guide for Beginners. SAGE Publications; 2013. p. 277-294.

APPENDIX 1

Interview Topic Guide for CAD:TRAUMA Participants

1. Demographic information about participant

Current post including specialty and hospital

- Stage of training

2. Topics for discussion (not exhaustive)

- Challenges of modern day surgical training
- Experiences of cadaveric simulation as an adjunct to training
- Factors that make good surgeons
- Preparedness for operating in real-life as a junior trainee surgeon

Questions will be framed to encompass four key domains – knowledge, opinion, feeling and experience (1)

Example knowledge questions:

1) Do you know what the European Working Time Directive says about the hours trainee surgeons are allowed to work?
2) Do you know how many index procedure* performances and work-based assessments you need to have logged by CCT**

Example opinion questions:

1) What do you think about modern surgical training in general? In Trauma & Orthopaedic surgery? In your hospital?
2) What do you think about using simulation to augment training? Cadaveric simulation in particular?
3) What do you think makes a good surgeon?

Example feeling questions:

1) What do you feel is the best way to train surgeons?
2) Do you feel that the CST training has benefited? How so?

Example experience questions:

1) Can you tell me about any times that you were not able to get access to the training opportunities you needed in the operating theatre? If yes -Why do you think this happened? If no – How is your training organized to avoid this happening?
2) When you have been doing operations in the recent past, have you felt well prepared?

* Index procedures are the key operations as defined in the curriculum

** Certificate of Completion of Training – the endpoint of surgical training

(1) Lichtman, M. *Qualitative research in education: A user's guide*. 3rd Edition. London: Sage Publications; 2013