Design of a Simulation-Based Curriculum to Train Orthopaedic Residents for Disasters in the Operating Room

ABSTRACT

BACKGROUND Surgical simulation has been a useful tool in addressing the concern about decreasing case volumes and autonomy of orthopaedic residents with the new work-hour restrictions in training. However there remains a concern that rare, stressful scenarios such as massive intra-operative hemorrhage can be overlooked by this approach. The goal of our study was to develop a curriculum that would prepare senior orthopaedic residents to address rare but real "orthopaedic disasters" in the operating room.

METHODS We designed an educational course that included a cadaver-based anatomical session and a simulation-based skills session, all with the goal of management of intraoperative orthopaedic emergencies such as vascular injuries leading to massive unexpected intraoperative blood loss, loss of the airway, and acute hemo/pneumothorax. All of the graduating residents participated in the course. After participation in the disaster course, an electronic survey (SurveyMonkey, Palo Alto, CA) was circulated to all participants to gather feedback.

RESULTS Every one of the participating residents recommended continuing the course on an annual basis, and many felt that it was one of the most valuable courses during residency. To summarize the overall effectiveness of the course, we asked each participant the following question: "Assuming you are the attending orthopaedic surgeon in the room, please rate your level of confidence with managing unexpected large volume blood loss in the OR." In answering this question, the proportion of those responding "confident" increased from 9% prior to the course to 45% after the course. Similarly, the proportion of those responding "somewhat confident" decreased from 54% prior to the course to 9% after the course.

CONCLUSION An educational course that includes a cadaver-based anatomical session and simulation-based skills session is effective in training orthopaedic residents in dealing with intraoperative disaster scenarios and can be implemented in other training programs.

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There is a wide-spread perception that current orthopaedic residents are not performing the same volume of procedures, nor operating with the same level of autonomy and confidence as previous cohorts did during training.[1] Duty-hour regulations and more stringent requirements for supervision in the operating room have eroded the opportunity to acquire sufficient operative experience. The American Board of Orthopaedic Surgery, and the Residency Review Committee, Accreditation Council for Graduate Medical Education (ACGME) have recognized this shift and in an effort to make trainees' exposure to

surgery more efficient have offered solutions such as Milestones to make training more systematic. Surgical simulation has been vital in this approach, augmenting case volume and allowing residents to practice skills in a controlled and repetitive fashion.[2-4] However there remains a concern that rare, stressful scenarios such as massive intra-operative hemorrhage can be overlooked by this approach. The paucity of available training or simulation for rare, high stress scenarios is not unique to orthopaedic surgery.[5,6] Taking an approach already popular with military surgeons, other specialties have started to identify the importance of training residents for these uncommon events and are developing models, by which residents are able to practice and objectively evaluate their skills.[7,8] The goal of our study was to develop a curriculum, both simulation- and anatomy-based, that would prepare senior level orthopaedic residents to address rare but real "orthopaedic disasters" in the operating room.

METHODS

We designed an educational course that included a cadaver-based anatomical session and simulation-based skills session. These components are both essential as emergency events require both familiarity with regional anatomy to achieve adequate exposure, in addition to skills necessary to control and manage the acute event. This advanced course was specifically designed for our residency program's 12 Post Graduate Year (PGY)-5 residents. Given the large number of cadavers provided we expanded the anatomical session to include other senior residents in our program.

The Disaster Anatomy session took place at a Smith & Nephew facility in Andover, MA, and was supported by an in-kind grant from the Smith & Nephew foundation. The session began with an introductory lecture from a vascular surgeon detailing an approach to gain proximal control of blood vessels in the upper and lower limbs. The curriculum was built around five cadaver stations. Each station had one fresh frozen cadaver and three or four residents assigned to that table for a total of 20 resident participants **(Figure 1)**. We designed five different modules for the morning session to manage orthopaedic emergencies: vascular injury during proximal humerus fixation or clavicle fixation, vascular injury during femoral fixation, compartment syndrome in the upper limb, compartment syndrome in the lower limb, and the bleeding pelvis. Each faculty member selected had specific expertise

FIGURE 1 Cadaver station

Chief residents performing external fixation of femur and tibia during the cadaveric anatomy session. Two residents were paired with a senior faculty member as described in the text.

FIGURE 2 Simulated operating room

A bleeding thigh tumor was presented to residents.

in the module they were assigned. Each module was scheduled for 45 minutes and instructors rotated through each table. Following the formal morning session, participants had the opportunity to independently practice the lessons learned from the modules.

The Disaster Skills session was held in one of our affiliated hospitals' medical simulation center. Introductory lectures focused on strategies for achieving acute hemostasis delivered by a vascular surgeon. The skills curriculum again focused on five modules: emergent airway and chest tube placement, vessel repair, deep vessel control and ligation, multiple vessel exposure and ligation and a simulated disaster in the operating room. The OR scenario involved volunteers from departments of anesthesia and nursing assuming the roles of anesthesia, scrub technician, and circulating nurse and took place in a simulated operating room **(Figure 2)**. The simulation involved a bleeding thigh tumor **(Figure 3)** with plan for resection by an operative team lead by one of the chief residents. The extent of "tumor" bleeding and the changes in vital signs were controlled by simulation staff, and the scenario was monitored and debriefed by a senior orthopaedic staff. The remaining skills modules utilized specific models to teach the desired goals **(Figure 4).** As residents rotated through each module, there was opportunity for skills teaching from circulating faculty. A lunchtime lecture focused on concerns outside of the operating room, including pre-operative preparation, delivering difficult news, and appropriate documentation after unexpected events.

After participation in the disaster course, an electronic survey (SurveyMonkey, Palo Alto, CA) was circulated to all participants to gather feedback.

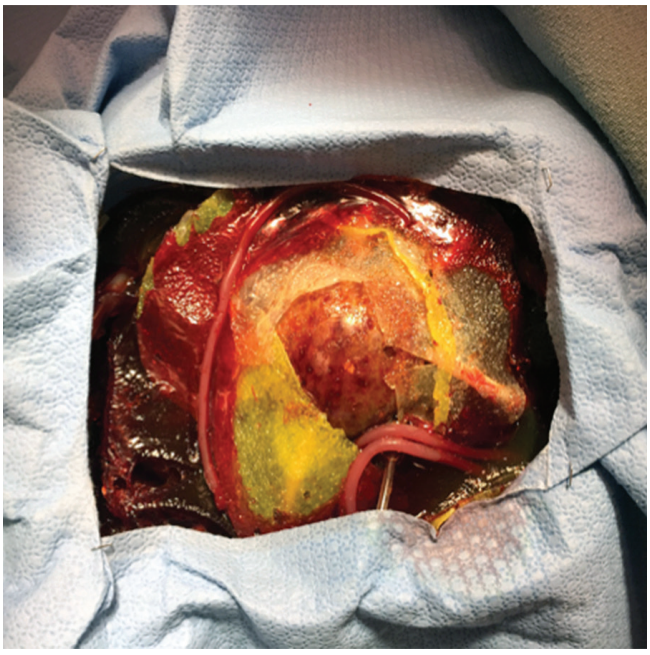
RESULTS

All of the 12 graduating residents participated in the course. The cadaver session was also attended by seven additional residents from post-graduate years 3 and 4. Of the respondents whose post-graduation fellowship plans were known, five planned to pursue fellowship in adult reconstruction, two in spine, two in pediatric orthopaedics, two in hand and upper extremity and one in sports medicine. All participants responded to the survey questions.

Cadaver dissection session

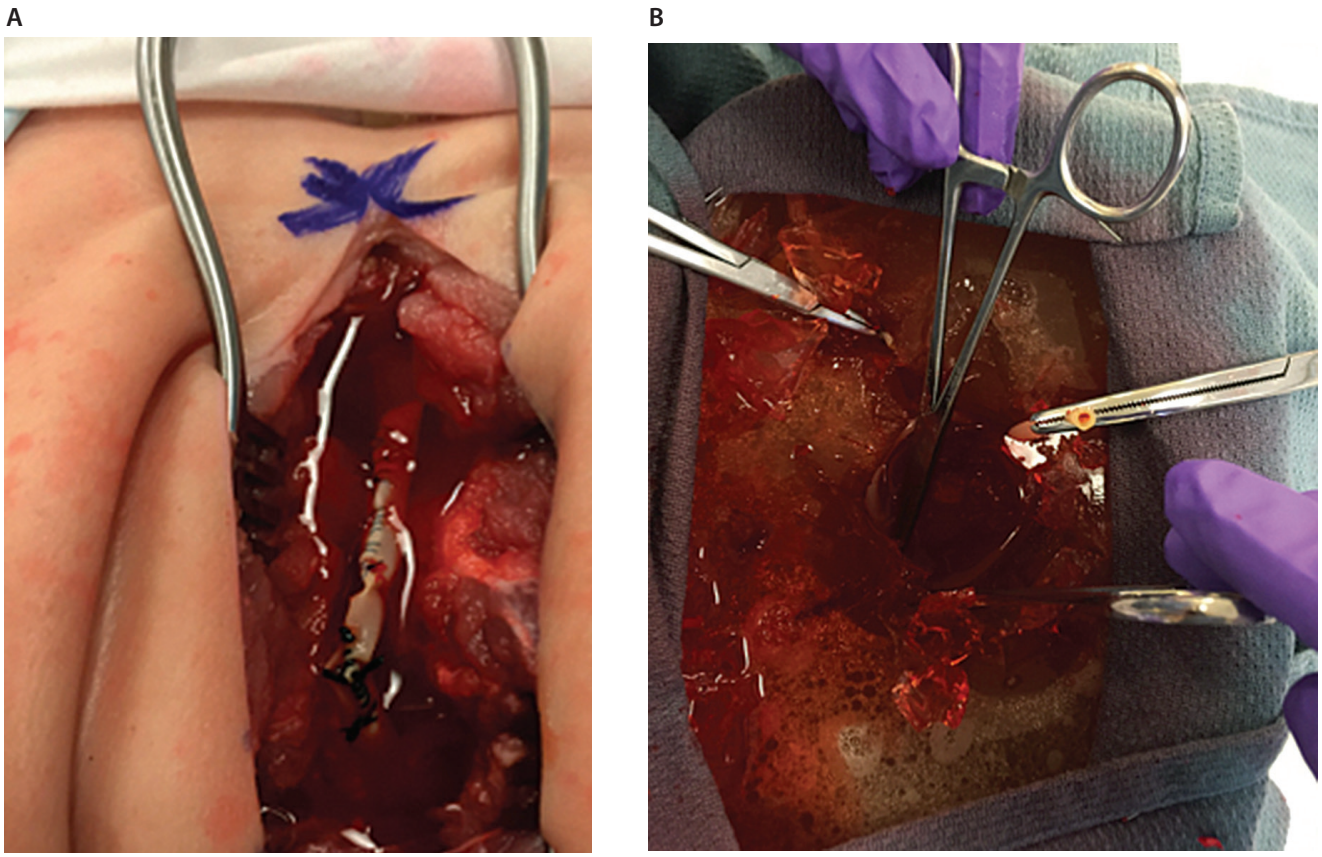
The response to the cadaver dissection session was overwhelmingly positive A majority of participants reported that the session allowed for exploration of vascular anatomy that is important and relevant to an orthopaedic surgeon, and that the session facilitated learning of anatomic vascu-

FIGURE 3 Bleeding thigh tumor model



The tumor was simulated with a pluot while large gauge IV tubing was run through the gelatin simulating vessels providing blood supply to the tumor.

FIGURE 4 Skill Module



(A) Large vessel repair simulation. A penrose drain was run through a piece of pork belly (described in text) and lacerated longitudinally requiring repair. Seen is dissection through skin, fat and muscle to the simulated vessel with the the 6-0 prolene repair. (B) Completed dissection with removal of the thigh tumor which took place in the simulated operating room. Control of all feeding vessels has been maintained and the tumor successfully removed.

lar dissection proximally and distally enough to gain control **(Table 1)**. Similarly, the majority of the participating residents felt adequately challenged by each station to provoke learning **(Table 1)**.

Simulation center exercises

Similar to the cadaver dissection session, the simulation exercises were also well-received by the participating residents. Every one of the survey respondents strongly agreed that the simulation session featured skills that are important for orthopaedic surgeons to be comfortable performing. Two-thirds of survey respondents strongly agreed that the simulation exercises featured skills that were not clearly addressed in traditional orthopaedic residency training **(Table 2)**.

When asked whether each simulation station provided enough challenge to provoke learning, the response indicated less uniform agreement **(Table 2)**. Comments from respondents on this question indicated that the simulated vessels were often "too easy to identify" and "not deep enough," and that the time allocated to each station could be shortened.

Overall course evaluation

Every one of the participating residents recommended continuing the course on an annual basis, and many felt that it was one of the most valuable courses during residency.

To summarize the effectiveness of the course, we asked each participant the following question: "Assuming you are the attending orthopaedic surgeon in the room, please rate your level of confidence with managing unexpected large volume blood loss in the OR." In answering this question, the proportion of those responding "confident" increased from 9% prior to the course to 45% after the course. Similarly, the proportion of those responding "somewhat confi-

TABLE 1 Participant survey results – Cadaver anatomy session

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
The cadaver session allowed for exploration of vascular anatomy that is important and relevant to an orthopaedic surgeon	88.2%	11.8%	0.0%	0.0%	0.0%
The cadaver session was helpful in learning how to expose a vessel proximally and distally enough to gain control	82.3%	17.7%	0.0%	0.0%	0.0%
The cadaver session provided an appropriate balance between instruction and practice	82.3%	11.8%	5.9%	0.0%	0.0%
Each station in the cadaver session provided enough challenge to provoke learning	82.3%	17.7%	0.0%	0.0%	0.0%
Instruction provided by faculty was clear, detailed and imparted key learning points	82.3%	17.7%	0.0%	0.0%	0.0%

TABLE 2 Participant survey results – Simulation session

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
The simulation session featured skills that are not clearly addressed in traditional orthopaedic residency training	66.6%	25.0%	8.4%	0.0%	0.0%
The simulation session featured skills that are important for orthopaedic surgeons to be comfortable performing	100.0%	0.0%	0.0%	0.0%	0.0%
The simulation skills session provided an appropriate balance between instruction and practice	75.0%	25.0%	0.0%	0.0%	0.0%
Each station at the simulation center provided enough challenge to provoke learning	50.0%	41.6%	8.4%	0.0%	0.0%
Instruction provided by faculty at the Stratus skills lab was clear, detailed and imparted key learning points	75.0%	25.0%	0.0%	0.0%	0.0%
The OR scenario was effective in simulating significant intraoperative bleeding	66.6%	16.7%	16.7%	0.0%	0.0%

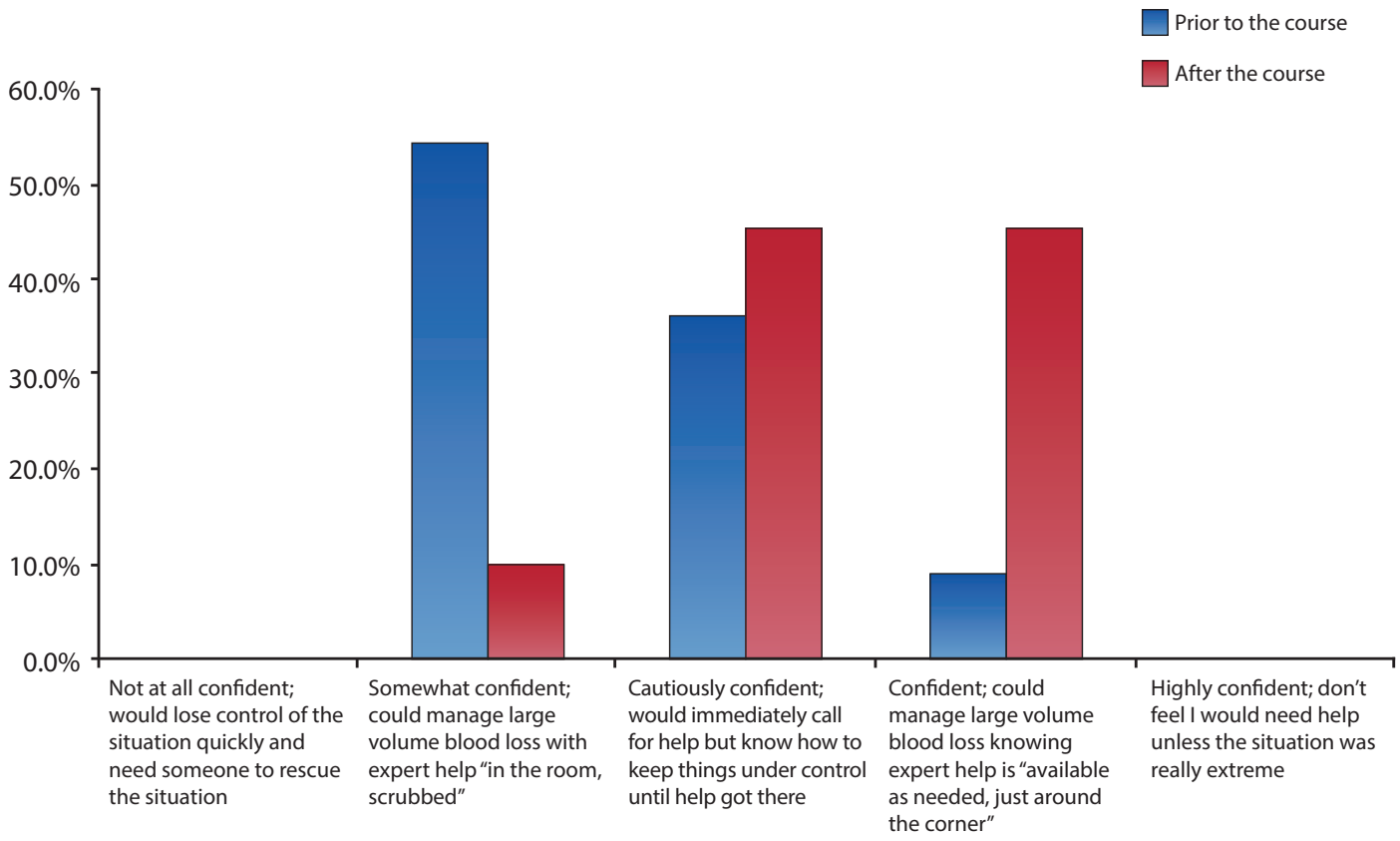
dent" decreased from 54% prior to the course to 9% after the course **(Figure 5)**.

DISCUSSION

The concern regarding resident preparedness for responding to major incidents, and the paucity of available training and simulation targeting rare and high stress scenarios in surgical specialties has been an evolving topic of discussion in surgical training. The rapid expansion and evolution of orthopaedic techniques, work-hour restrictions and a changing healthcare environment have decreased learning opportunities in the operating room, thus requiring residents to acquire more complex skills in less time.[9] Unlike aviation training, where the utilization of in-flight simulation exercise had an early role and thus has evolved to include more sophisticated technology,[10] surgical specialties including orthopaedics have only recently embarked on utilizing simulation-based teaching in traditional curricula. While surgical simulation is evolving to become a part of residency training, there is still a dearth of evidence on the most effective use of simulation in orthopaedics, its role in existing residency training curricula and the need for high fidelity models that facilitate the teaching of basic skills. Additionally, while the role of simulation in training for common procedures is now accepted, the field of orthopaedic simulation has not yet expanded to include management of uncommon or high stress intraoperative scenarios.[5,6] This course sought to develop high fidelity models that adequately simulate difficult operative scenarios, and allow for objective assessment and evaluation of resident skills in managing difficult cases.

The results collected from the anonymous survey administered following the course demonstrated and confirmed residents' self-identified needs for supplemental training. In the overall course evaluation, every participating resident recommended continuing the course annually, describing as vital to resident education. This mirrors what has been identified in the literature. Resident confidence in managing a high stress operative environment, proxied by the scenario of unexpected large volume blood loss, increased from 9% pre-course to 45% post-course. This was paralleled by a simultaneous decrease from 54% to 9% in those who were initially "somewhat confident" in managing unexpected large volume blood loss in the OR. In the current era of duty-hour regulations and the associated decrease in night, weekend and involvement in urgent surgical cases, the opportunity to build the skills to perform urgent surgical procedures continues to decrease, and thus could be supplemented by simulation exercises.

FIGURE 5 Participants' confidence prior to vs. after the course



At the initiation of course the majority of participants were not comfortable operating in a disaster scenario without an attending surgeon scrubbed in the room. Following the course, a marked increase in participants' confidence was seen with approximately 90% feeling as though they could, at a minimum, control the situation until expert help arrived.

Survey assessment of the respective cadaver dissection and simulation center activities also revealed an opportunity to address an otherwise minimally-covered skill set in the traditional orthopaedic residency curriculum. A majority of the respondents (88.2%) strongly agreed that the sessions allowed for exploration of vascular anatomy that is necessary and relevant to the practice of orthopaedic surgery. A majority of respondents (82.3%) also reported that they were adequately challenged by each exercise at the respective skill stations, with a similar proportion strongly agreeing that sessions were thought-provoking, clear in instruction and balanced in teaching and practice.

In evaluating the simulation center exercises, participants unanimously agreed that the session assessed skills that are important for orthopaedic surgeons to be prepared and equipped to perform. In addition, two-thirds of the participating respondents (66.6%) strongly agreed and 25% agreed that the simulation exercises featured key skills that were not otherwise adequately addressed in a traditional curriculum. Sixty-six percent also strongly agreed that the operative scenario was effective in simulating the management of intraoperative hemorrhage. However, the challenge of creating reproducible models that closely depicted anatomy and adequately tested surgical skill led to varied participant experiences with the level of difficulty posed at each station. In assessing degree of challenge, 50% of participants strongly agreed that the exercises were challenging enough to provoke learning, while 41% agreed and 8.4% were neutral.

The reported survey results and quoted participant responses highlight the value, role and growing utility of simulation in surgical training, and mirror what has been captured in the literature on surgical simulation. The concerns regarding the decline in case volume, deteriorating skills and dwindling autonomy are reflected in the findings of this study as much as they have been in the literature.[1] In an era of reduced resident work hours and an associated decrease in time spent acquiring technical skills and expertise in the operating room,[11,12] the role of simulation education in achieving technical proficiency as well as the capacity to identify, respond and adapt to unexpected or "disaster" scenarios has become pivotal. From the initial volunteered high interest for participation in this course, to the unanimous agreement amongst respondents for continuing the course annually, there is a continuously expanding perception, and ACGME-supported position,

holding that the simulation experience is becoming vital to efficacious resident surgical education.[2-4]

As is the case with any simulated environment, simulation is certainly not a substitute for real clinical context, and its effectiveness in replicating clinical scenarios often relies on the applicability of the model utilized. Thus a limitation in effective use of simulation continues to be centered around building models that test skill in a reproducible manner, and challenge the learner appropriately. While our OR simulator and the cadaver sessions did this job well, the individual models for suture ligation of vessels were lower-fidelity and less challenging. Work remains to be done in creating a model of a deep bleeding vessel that is difficult to see, hard to approach and yet amenable to suture ligation.

This course provides an example of how the accrual of challenging orthopaedic skills in dealing with rare life-threatening bleeding can be gained in a simulated environment. Moving forward, the inclusion of this course in orthopaedic residency training may allow for the deliberate practice of difficult skills under pressure, for team-building efforts in management of operative emergencies, and for developing such skills early in the career of an orthopaedic resident.

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