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# The role of simulation in developing surgical skills

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**Abstract** Surgical training has followed the master-apprentice model for centuries but is currently undergoing a paradigm shift. The traditional model is inefficient with no guarantee of case mix, quality, or quantity. There is a growing focus on competency-based medical education in response to restrictions on doctors' working hours and the traditional mantra of "see one, do one, teach one" is being increasingly questioned. The medical profession is subject to more scrutiny than ever before and is facing mounting financial, clinical, and political pressures. Simulation may be a means of addressing these challenges. It provides a way for trainees to practice technical tasks in a protected environment without putting patients at risk and helps to shorten the learning curve. The evidence for simulation-based training in orthopedic surgery using synthetic models, cadavers, and virtual reality simulators is constantly developing, though further work is needed to ensure the transfer of skills to the operating theatre.

**Keywords** Arthroscopy · Assessment · Boot camp · Cadaver · Competency · Education · Feedback · Patient safety · Phantom · Proficiency · Psychomotor · Simulation · Skills · Surgical training · Task performance · Training · Virtual reality

## Introduction

Postgraduate surgical training is facing significant challenges following the advent of limitations on working hours. In the United States the Accreditation Council for Graduate Medical Education (ACGME) initially adopted the "80-hour working week" in 2003 and subsequently imposed further restrictions commencing in 2011 [1, 2]. Medical training in Europe has also seen major reductions in the number of hours worked by surgical trainees as a result of the European Working Time Directive (EWTD) incrementally reducing the maximum amount of hours worked down to an average of 48 h a week since 2009 [3].

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## Challenges to training

Surgical trainees now have less dedicated operating time than their predecessors and so must reach the same level of competency within a shorter overall training period [4]. This is on a background of increasing focus on patient safety and rising medico-legal compensation payments resulting in trainees being permitted fewer operating opportunities [5•]. There are also further financial pressures and it has been calculated that it costs $53 million a year in the US to teach trainees in the operating theatre [6]. Surgeons are under greater scrutiny through the measuring of outcome measures, coupled with increasing patient expectations, and as a result senior surgeons may be more reluctant to let trainees gain experience on difficult cases. The heightened need for senior supervision has also limited the use of parallel lists [7].

With fewer operations available for trainees and increasing time constraints in place there is an imperative for more efficient and time-effective methods of surgical training.

## The role of simulation in surgical training

William J. Mayo stated, "There is no excuse for the for the surgeon to learn on the patient" [8]. The Food and Drug Administration (FDA) has supported the role of simulation for over a decade now, stating that simulation should be an important part of training and credentialing surgeons in carotid artery stenting [9]. Similarly, the role of simulation-based training has been emphasized in the US by the

Residency Review Committee and the American College of Surgeons (ACS) [10].

Simulator training is well established in high-risk industries such as aviation and motorsport where a variety of variables and scenarios can be accurately portrayed. Simulation has been evaluated and incorporated into training in a variety of surgical specialties as a means of effective training in a controlled environment without compromising patient safety.

Much work has been done on the use of simulation in laparoscopic surgery where skills learnt using simulators have been shown to transfer into the operating theatre to improve performance metrics [11]. Virtual reality (VR) simulation has also been shown to shorten the learning curve on real laparoscopic procedures and to significantly reduce errors in live surgery [12–15]. This 'crossover' benefit of simulation has been proven repeatedly in laparoscopic surgery where it has been shown to improve patient outcomes [16•, 17•, 18]. Consequently, the American Board of Surgery now requires individuals to have successfully completed the American Gastrointestinal and Endoscopic Surgeons (SAGES) Fundamentals of Laparoscopic Surgery (FLS) program in order to be board certified in general surgery [19, 20].

## Simulation in orthopedics

The orthopedic community has been training using artificial bones, joints, and cadavers for decades, with VR simulators becoming available more recently. A significant amount of orthopedic surgical procedures involve open surgery with complex anatomical and patient positioning factors that are not easily amenable to simulation, but there are a large amount of procedures that can be simulated. Arthroscopic and fluoroscopic procedures better lend themselves to simulation, with the conversion of 3-dimensions to a 2-dimensional screen easier replicated. As computer-processing power has rapidly developed, the quality of graphics has facilitated realistic representations of such procedures, though these simulators can be costly.

## Synthetic models

Synthetic (phantom) models are artificial, physical models that can be used to represent the bones and joints of the body at relatively low cost. Synthetic bones can be used for familiarization with fracture fixation techniques and implants, without the ethical or storage issues associated with cadavers. The lack of soft tissues, however, lowers the fidelity and they have poor discriminative abilities between individuals of different experience levels (construct validity) [21].

Synthetic joints can be used for arthroscopic procedures by combining them with cameras and arthroscopic stack systems. They facilitate safe practice of procedures such as diagnostic knee, shoulder, and hip arthroscopy as well as therapeutic tasks such as meniscal debridement, meniscal, and labral repair, and ACL reconstruction. These simple models cost considerably less than cadaveric and VR simulator training and allow trainees to hone their visualization, triangulation, and feedback skills [22]. These models have replaceable inserts to allow reuse and do not have the logistical problems associated with cadavers. Face validity (resemblance to reality) and construct validity have been demonstrated for synthetic models for knee arthroscopy [23, 24], and a learning effect has been shown for meniscal repair [25•].

Knee arthroscopy skills learnt on synthetic models have shown crossover with improved proficiency in individuals performing diagnostic knee arthroscopy in cadaveric models [26•].

A study from Oxford has demonstrated the transfer of skills learnt in a skills laboratory to the operating room [27•]. In this study, 20 junior orthopedic trainees were split into 2 groups, with 1 group assigned to 3 sessions of performing simulated arthroscopies under supervision using a phantom model and a control group who received no simulator training. All 20 were subsequently assessed performing a diagnostic knee arthroscopy in the operating room under supervision, using a checklist and a global rating scale. Motion analysis demonstrated that the simulator-trained group all made significant improvements in the objective measures of time taken, economy of movement, and number of hand movements. The simulator-trained group also performed arthroscopy in the operating room significantly better than the control group. This confirms that simulation training with a phantom model can improve real-life surgical performance.

## Animal models

These have a lower initial cost than the synthetic bones and joints and have been shown to have a higher fidelity for certain procedures, particularly trauma tasks such as the plating of fractured bones where the presence of the soft tissues enhances the realism [21]. The cost benefit, however, is offset by the necessary increased equipment and preparation requirements.

## Cadaveric training

Cadaveric training has been an essential part of surgical training for decades and has been considered the best substitute for actual live surgery [28]. It is commonly used for arthroscopic and arthroplasty training as it can facilitate experience of skin incisions, approaches, and portal placement. It allows tactile feedback and limb manipulation while creating an awareness of anatomical structures and their positioning. The majority of joint replacements and more complex arthroscopic procedures cannot be adequately simulated by any other means at present, and it is here that the use of cadavers remains the gold standard. Because of the nature of the more complex tasks, cadaveric training on the whole is predominantly used for senior trainees and independent surgeons.

Simulators are not readily available for certain challenging surgical tasks such as pedicle screw placement. A study found that focused didactic and cadaveric laboratory training resulted in a significant increase in accuracy rate amongst novice orthopedic residents [29]. It concluded that a cadaver-based training module resembling the clinical setting could be used to teach complex surgical skills.

There are limitations to cadaveric training, however. The specimens are not readily available, involve ethical restrictions, are resource-intensive as special facilities are required to store and preserve, and can be expensive [30]. The quality and handing of tissues varies differs from the live limb and is dependent on the embalming regimen used [31]. Feedback on performance is not readily available, and the number of times a cadaver can be used is limited [32].

## Virtual reality simulation

Percutaneous and minimal access trauma surgery is amenable to simulation-based training and, in addition, also negates issues of radiation exposure. Studies on simulation-based training in trauma surgery are limited with only a handful papers in the literature. Studies from New Zealand have demonstrated the face and construct validity of a basic PC based VR system using a computer mouse and keystrokes to place a dynamic hip screw [33, 34]. Froelich et al. took this 1 step further by using a VR simulator with haptic feedback from a stylus representing the drill and simulated fluoroscopic images [35•]. Using this equipment they were able to prove construct validity, suggesting the simulator's discriminatory value.

Similar PC-based simulation has been used for percutaneous sacroiliac screw insertion and found substantial differences with individuals having undergone simulation training taking significantly fewer x-rays, as they had become familiarized with movements in 3-dimensions being represented on a 2-dimensional screen [36].

Physical, haptic VR simulators have been developed to address the deficiencies of cadavers and phantoms. Once setup, they can be used repeatedly, maintained and updated remotely, and have no consumable parts or ethical constraints. They are compact and do not take up a significant amount of space, nor do they place learners at risk. After a short period of training, trainees can undertake self-directed learning at their own pace and at a time of their choice to achieve personal goals without the need for a senior surgeon to be present [37].

Feedback is one area where VR simulators excel and immediate visual feedback of multiple performance metrics highlights their educational potential. Trainees can closely monitor their performance through metrics that are proven to correlate with actual surgical proficiency and, thus, provide valuable feedback [22, 38]. It has been shown that the performance of basic arthroscopic tasks by residents and attending surgeons on a VR simulator is strongly correlated with similar tasks during cadaveric arthroscopy [39•]. Furthermore, it has been shown that performance on a VR arthroscopy simulator correlates with clinical experience and that as residents progress through their training and gain greater surgical experience, their performance on the simulator improves [40•]. A recent study has shown that training on a VR shoulder arthroscopy simulator results in significant improvements in arthroscopy time on a cadaveric model [41•]. A longitudinal study by Gomoll et al. retested 10 trainees 3 years after initial training on a shoulder simulator [42]. They had proceeded with their orthopedic training and had gained moderate experience, performing an average of 60 shoulder arthroscopies in the interim. All trainees were found to have significantly improved their performance in all parameters on the simulator with this further surgical experience. These results suggest that the skills required for in-vivo arthroscopy are indeed the same skills used on the VR simulator.

Face and construct validity have been repeatedly proven for various knee and shoulder arthroscopy VR simulators [23, 24, 30, 39•, 43–47] though there were mixed results for a rudimentary VR trauma simulator [48]. The training effect has also been well proven for both knee and shoulder VR simulators, with multiple studies showing that such training can improve simulator performance [30, 43, 49–51].

## Boot camps

Whilst the evidence supporting the role of simulation in developing surgical skills continues to grow, it has not been clear how best to incorporate it into routine orthopedic training.

The use of simulation as part of an intensive surgical skills program can be an effective way for junior orthopedic trainees to quickly attain the basic technical skills specific to orthopedic surgery, without putting learners or patients at risk. Similar boot camps have been used to demonstrate significant improvements in, and retention of, general cognitive and procedural skills [52–54]. There are nontechnical benefits of such an approach too. Trainees have found boot camps to be useful and relevant, with faculty and nursing staff reporting improvements in patient assessment, team-working, effective communication, self-confidence, and more respectful patient care [55].

The simulation methods discussed earlier have been combined to create an orthopedic "boot camp", an intensive 1 month laboratory-based skills course to teach core technical skills to new residents starting orthopedic surgical training. They were trained using didactic lectures, synthetic bones, and cadaver dissection with a focus on aseptic technique, application of casts and splints, and familiarization with basic surgical instruments [5•]. Residents who passed through the boot camp scored significantly better on checklists and global rating scores at performing core procedural tasks when compared with peers undergoing traditional training.

A follow-up study demonstrated that the skills learned in the orthopedic boot camp at the onset of residency had excellent retention rates after 6 months and allowed junior residents to perform at the same level as senior residents for specific tasks [56•]. It, therefore, appears that providing junior trainees with an early focus on technical skills may allow them to maximize any further learning opportunities.

Further work evaluating this orthopedic boot camp has assessed how the basic surgical skills have been acquired and found that a directed, student-regulated approach further improved skills above and beyond the improvements seen with traditional instructor-led learning methods [57]. This method allows trainees to progress at their own pace and have senior input for feedback and clarification as and when needed.

## Future developments?

It is clear that the role of simulation in orthopedic surgical training will continue to expand. Over the next decade, it may become used for selection of trainees into training programs or identifying those trainees that require extra support. Innate arthroscopic skills vary markedly between individuals and this has been demonstrated in medical students. Differing learning curves exist and some students have been found unable to achieve competence in basic arthroscopic tasks despite sustained practice [58, 59•]. Trainees may have to pass an objective examination tool such as the Arthroscopic Surgery Skill Evaluation Tool (ASSET) before being allowed to operate on patients [60•, 61•].

Simulation may also be used to establish proficiency levels as has been done in general surgery, where the simulator scores of experienced laparoscopists have been used to set targets for trainees and established surgeons [62].

Similarly, with increasing subspecialization the frequency with which a surgeon does an operation may become an issue. Certainly, minimum numbers of cases have been suggested for knee arthroscopy and ACL reconstructions [63–65] and simulation may come to play a role in revalidation and recertification. In order to be board certified in general surgery, individuals have to successfully complete the Fundamentals of Laparoscopic Surgery (FLS) program. The Fundamentals of Arthroscopic Surgery Training (FAST) is a collaborative effort between the Arthroscopy Association of North America (AANA), the American Academy of Orthopedic Surgeons (AAOS), and the American Board of Orthopedic Surgery (ABOS) [66]. This is currently being developed to teach arthroscopic skills in a step-wise manner, and it is possible that completing this may become a requirement for board certification in the near future.

## Conclusions

Ericsson has stated that it takes 10,000 hours of sustained, deliberate practice to achieve mastery of a technical skill [67]. It is evident that this amount of time cannot be attained during routine clinical training. There is a growing mandate for a more time-efficient and effective method of training surgeons without putting patients at risk. Simulation offers a safe environment, in which to augment psychomotor skills in a controlled manner without posing a risk to patients or to learners. The use of simulation as part of an intensive surgical skills program can be an effective way for junior orthopedic trainees to quickly attain the basic technical skills specific to orthopedic surgery. Simulation-based training can cause a 'right-shift' along the learning curve for more efficient training with real-world improvements [14, 15, 68].

Further work is needed on the simulation of more complex arthroscopic and open procedures as it is currently aimed at more basic psychomotor skills and there is a paucity of evidence for the role of simulation in orthopedic trauma surgery.

There is growing evidence for simulation to be formally integrated into the orthopedic curriculum. It should, however, be placed in the context of traditional training methods and regarded as a means rather than an end in itself.

### Compliance with Ethics Guidelines

**Conflict of Interest** K. S. N. Akhtar, N. J. Standfield, and C. M. Gupte declare that they have no conflict of interest.

**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

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