Simulation in shoulder surgery

Henry B Colaço¹ and Duncan Tennent²

Abstract

Simulation is a rapidly developing field in medical education. There is a growing need for trainee surgeons to acquire surgical skills in a cost-effective learning environment to improve patient safety and compensate for a reduction in training time and operative experience. Although simulation is not a replacement for traditional models of surgical training, and robust assessment metrics need to be validated before widespread use for accreditation, it is a useful adjunct that may ultimately lead to improving surgical outcomes for our patients.

Keywords

arthroscopy, education, shoulder, simulation, virtual reality

Is there a need for simulation in shoulder surgery?

Arthroscopy is an integral and common part of shoulder surgery, with over 112,000 arthroscopic procedures in total carried out per year in the UK.¹ Although the number of diagnostic arthroscopies is declining, the indications for therapeutic procedures and available techniques are expanding. Despite the increase in demand and indications, orthopaedic trainees' hands-on exposure to arthroscopy in the operating theatre is reducing, which presents a challenge to achieving proficiency in a wider range of arthroscopic surgical skills. Proficiency in shoulder arthroscopy requires the stepwise learning of a range of psychomotor skills, efficiency, and the ability to interpret a two-dimensional image on a screen as a three-dimensional environment.²

The traditional apprenticeship model of orthopaedic training is not sustainable with a reduction in training time and the Shape of Training Review.³ The European Working Time Directive limits UK trainees to 48 hours per week,⁴ and the Accreditation Council for Graduate Medical Education introduced the 80-hour working week for orthopaedic residents in the USA in 2002.⁵ Recently, there has been an increased focus on patient safety, patient experience and quality of care, including outcomes. This has led to a more consultant-delivered service and reduced the number of operative training opportunities available to trainees. There has always been a conflict between training and service provision

but, in a sustainable model of healthcare, one cannot exist without the other.

The involvement of trainees in the operating theatre comes at a financial cost. A study by Farnworth et al.⁶ in 2001 estimated a \$661.85 increase in the cost per ACL reconstruction as a result of longer operating times when performed by a trainee. A recent study by Ang et al.⁷ in the UK of operating theatre inefficiency in 2015 estimated the total running and staffing costs of an orthopaedic operating theatre to be £24.77/min. A 4-year study of surgical trainees across specialties by Bridges et al.⁸ in 1999 found that on average operations with trainee involvement took 12.64 minutes longer, which added up to a total of 11,184 minutes per trainee over the study period. Using the recent cost estimates, the increased operating time due to trainee involvement equates to over £69,000 per surgical trainee each year.

Reduction in training time has prompted the incorporation of other methods to supplement operating theatre experience. Although there has not been a paradigm shift in orthopaedic surgical skills training, there has been a move towards more focused, competency based assessment, with respect to both selection into higher surgical training programmes and yearly

¹Royal Free London NHS Foundation Trust, London, UK

²St George's Hospitals NHS Foundation Trust, London, UK

Corresponding author:

Henry B. Colaço, Royal Free London NHS Foundation Trust, London, UK
Email: henrycolaco@nhs.net

assessment of trainees with the use of Orthopaedic Competence Assessment Project (OCAP) and Intercollegiate Surgical Curriculum Programme website work based assessments (WBA) for the Annual Review of Competency Progression. WBAs are designed to standardize and record feedback and reflective learning, in an attempt to impose structure on the *ad hoc* nature of training opportunities in the traditional apprenticeship model of orthopaedic training.⁹

Simulation can be used to provide a controlled, reproducible, low-stakes environment where arthroscopic skills can be learned in a stepwise fashion. Initial acquisition of a surgical skill requires the development of the necessary psychomotor skills, many of which are specific to arthroscopic and some other forms of minimally invasive surgery. This requires a level of expert faculty input to direct novice arthroscopists, which can be reduced as experience is gained. Simulation has successfully been incorporated into general surgery training, and shown to improve trainees confidence in the operating theatre,¹⁰ as well as decreasing operative times and surgical errors.¹¹ Given the evidence that junior trainees have a higher incidence of chondral damage early in the learning curve of arthroscopic surgery, simulation may come to play an increasingly important role in reducing costs and errors, and improving efficiency and outcomes.¹²

Background

Simulation can be defined as a model that imitates a real-life scenario, and can be used to learn and develop skills, which can then be applied in the actual setting. It has been used in aviation since the First World War, and sophisticated flight simulators are used extensively in the aviation industry for both novice and experienced pilots. In the context of medical education, simulation has been defined 'any technology or process that recreates a contextual background in a way that allows a learner to experience mistakes and receive feedback in a safe environment'.¹³ Medical simulation began in the field of anaesthesia, and will be familiar to orthopaedic surgeons through AO (AO Foundation, Davos, Switzerland) who have run courses for over 50 years, and the Advanced Trauma and Life Support (ATLS) course (American College of Surgeons), which was introduced in 1980.

The use of simulation for surgical skills acquisition in orthopaedics has lagged behind other fields of surgery, although arthroscopic surgery lends itself well to this training method. The first arthroscopic knee simulators were developed in the early 1990s, although fidelity and face validity was limited by cost and computer processing power available at the time.¹⁴ Advances in technology have allowed the development of

increasingly realistic high fidelity virtual reality (VR) arthroscopic simulators, although there has been little impact on non-arthroscopic simulators. As a result, most of the present review will focus on arthroscopic simulation.

Arthroscopic simulation

The nature of arthroscopy lends itself well to simulation; the use of a camera, arthroscope and screen, and working in a confined pre-determined space with a limited field of view. Experts can assess performance on recorded video, which can reduce bias by allowing for blinding. The ability to record internal and external objective metrics differs between types of simulators, and is yet to be standardized.

Surgical skill acquisition requires deliberate practice, which is known to reduce morbidity and improve outcomes in surgery.¹⁵ 'Deliberate practice' is not simply repetition, but rather a focused process that requires immediate, formative feedback, and can be enhanced by progressive assessment of specific competencies.¹⁶

The magic number of 10,000 hours of deliberate practice to achieve expert level that was observed in a cohort of young violinists is not attainable by trainees in arthroscopic surgery, although it is clear that time to achieve expertise in performing a specific procedure depends on time spent on deliberate practice.^{17,18} There is also evidence of the benefit of periodic practice over 'crammed' practice as demonstrated by Moulton et al.¹⁹ in a randomized controlled trial of orthopaedic trainees performing a simulated drilling task.

The potential applications of arthroscopic simulators in the future include assessing basic psychomotor skills and identifying surgeons of the future, providing a learning environment for surgical skill acquisition, and assessment of competencies for progression in training or certification.²⁰ Alvand et al.²⁰ found that, although specific training on bench model arthroscopic simulators could improve the arthroscopic performance of medical students, some individuals were unable to achieve competence despite focused training, which may have implications for selection into orthopaedic training programmes. There is evidence that, although practice can improve performance on arthroscopic simulators, a greater improvement can be achieved by additional structured training that requires set competencies to be achieved in order to progress.¹⁶

Simulator design

Simulators designs include inexpensive portable 'box' trainers, bench-based shoulder models with real arthroscopic equipment, 'expensive' high-fidelity VR simulators and fresh-frozen cadavers. Although low-tech

simulators exhibit low physical fidelity, the lower cost means that there is the potential for wider accessibility for trainees to perform periodic practice. Low-tech simulators have been validated in the field of laparoscopic surgery, although the design differs from arthroscopic simulators because the focus is on bimanual operating with a fixed camera, and a less restricted field of view.²¹

Physical trainers

There are differing levels of sophistication of non-anatomical 'box' trainers. The Fundamentals of Arthroscopic Surgery Training (FAST) Arthroscopy Training Workstation (Sawbones®; Pacific Research Laboratories, Inc., Vashon Island, WA, USA) was developed by a collaborative effort involving the Arthroscopy Association of North America (AANA), American Academy of Orthopaedic Surgeons (AAOS) and the American Board of Orthopaedic Surgery (ABOS) (Figure 1). The modular design allows basic arthroscopic skills to be developed sequentially, and was introduced in 2011, accompanied by a basic skills curriculum,²² which is currently being trialled in the UK. Lower cost portable options that use a 0° USB-powered scope include the ArthroBox® (Arthrex, Naples, FL, USA) and the validated shoulderbox trainer (St George's Shoulder Unit, London, UK), which can be assembled by trainees for under £50²³ (Figure 2).

More anatomical 'phantom' bench models (e.g. Alex III Shoulder Professor, Sawbones®; Pacific Research Laboratories, Inc.) allow users to gain familiarity with

manipulating an arthroscope, camera and light lead around a simulated glenohumeral joint but not fluid management (Figure 3). They also allow for practice of triangulation and rehearsal of specific procedures. However, there are additional costs involved because, although the shoulder models themselves are relatively inexpensive, once components have been instrumented and used to practice knot tying or implant insertion, they must be replaced. Additional costs are incurred by the purchase, maintenance and storage of arthroscopic stacks and instruments.

Figure 2. Shoulder Box trainer (St George's Shoulder Unit).

Figure 1. Fundamentals of Arthroscopic Surgery Training (FAST) Arthroscopy Training Workstation (Sawbones®; Pacific Research Laboratories, Inc.).

Figure 3. Alex II Professor shoulder model (Sawbones®; Pacific Research Laboratories, Inc.).

Cadaveric models have been used as the most realistic representation of the clinical setting, although there are concerns regarding standardization and variations in preparation, anatomy and pathology. The supply of cadaveric limbs is limited, and the cost of purchasing, preparing and storing cadaveric material is high. There are also significant additional costs for laboratory space and equipment, staff, and experienced faculty. However, this model does allow some experience of fluid and soft tissue management (albeit without bleeding), in addition to camera management, triangulation and other skills. The cadaveric model has also been used as a surrogate for real-life arthroscopy in studies of transfer validity of skill acquisition on simulators.^{24,25} However, although there is evidence of learning curve with repetition of tasks in cadaveric models, there is no direct evidence in open orthopaedic surgery that demonstrates improved performance in the operating theatre.^{26,27}

The fidelity of a simulator is the degree of precision or accuracy with which the real-life scenario is reproduced. One of the main aims of VR simulators is high physical fidelity, but psychological fidelity must also be considered when designing a simulator and a specific task.¹⁵ Psychological fidelity has been defined as 'the degree that a simulation produces the sensory and cognitive processes within the trainee as they might occur in operational theaters'.¹⁵ These parameters are more difficult to define and reproduce; they are more often used in anaesthetic or ATLS simulation, where an intelligent mannequin will respond to treatment. Stress of unexpected steps in the operating theatre that can be replicated in VR simulators include loss of view as a result of bleeding, which must be located and controlled before proceeding. The effect of intra-operative stressors has not yet been investigated in the setting of arthroscopic simulation.

Virtual reality

VR simulators involve a large capital expenditure, as well as annual service contracts, but have several advantages, including the ability to automatically record assessment metrics, such as task completion time, accuracy, probe path length and collisions, and force transduction as a surrogate marker for chondral damage.²⁸

There are two different categories of high fidelity VR simulator; those that have active haptic feedback (e.g. ArthroMentor, Symbionix Ltd, Airport City, Israel) (Figure 4) and those that have passive haptic feedback (e.g. Virtamed ArthroS, Virtamed AG, Zurich, Switzerland) (Figure 5). Both types of VR simulator have advantages and drawbacks. Active haptic feedback systems can provide artificial mechanical

Figure 4. Active haptic feedback VR Simulator (ArthroMentor, Symbionix Ltd).

resistance to mimic the presence of physical structures within the joint. They can provide instant tactile cues to the user to complement visual and proprioceptive feedback, and be used to record the amount of force applied to chondral surfaces and other structures.²⁸ The main disadvantage is that the arthroscope and instrument remain tethered to the simulation model via rigid articulated arms, which does not replicate the feel of arthroscopy in a clinical setting.

By contrast, passive haptic feedback systems rely on 'mixed' reality, where a phantom shoulder model with physical, palpable intra-articular components can be probed and palpated with an instrument, although the screen displays a virtual environment, which is closely calibrated to the physical structures. This allows the arthroscope and instrument(s) to not be tethered by articulated arms, creating a more realistic feel, although the passive haptic feedback is limited to the physical structures within the phantom shoulder, which cannot be altered to reflect pathology, and relies on accurate calibration. Apart from quantifying probe and arthroscope collisions with chondral surfaces, actual force transduction data cannot be recorded.

Figure 5. (a) Passive haptic feedback VR Simulator (Virtamed ArthroS, Virtamed AG). (b) Close-up of passive haptic feedback VR Simulator (Virtamed ArthroS, Virtamed AG).

Recent studies have assessed the validity of a passive haptic VR simulator (Virtamed ArthroS). Stunt et al.²⁹ demonstrated construct validity and the ability to distinguish between novices and experts but not between novices and intermediates or intermediates and experts on the knee arthroscopy module. They did not demonstrate full face validity, with the surgical instruments scoring lowest despite not being tethered to articulated arms. Educational value and user friendliness were perceived as unsatisfactory, primarily as a result of a lack of tactile feedback.²⁹ Rahm et al.³⁰ from the centre involved in the simulator design demonstrated construct validity of the shoulder module when comparing the performance of novices and experts. The shoulder module scored highly on measures of face validity.

To date, there is no evidence demonstrating a benefit of active feedback over passive feedback in VR simulators, and it appears that both avenues will continue to be developed.³¹

Assessment

In any training environment, there is a requirement for assessment of progress. The commonest assessment metric used in validation studies is the time taken for task completion. This is a simple metric that can be recorded across all forms of simulator and in the operating theatre but it is not a measure of accuracy or outcome. Other simple metrics include recording time spent looking at hands for additional feedback when

triangulating. VR simulators can automatically record internal objective data, including accuracy of task completion, probe movements, collisions and chondral damage (which can be quantified in active haptic feedback systems).³²

External metrics include eye tracking and electromagnetic motion analysis, which has been validated using a bench model. Howells et al.³³ recorded task completion time, total path length and number of movements in a study involving 20 surgeons and 15 non-surgeons using an Alex Shoulder Professor bench model (Sawbones®; Pacific Research Laboratories, Inc.) and found a significant difference in performance between senior and junior grades of surgeon, as well as between surgeons and non-surgeons. Howells et al.³³ also identified trends between experience and both task completion time and economy of movement, although neither reached significance.

Objective assessment tools that can be applied in simulator and real-life settings have been developed, including the Objective Structured Assessment of Technical Skills (OSATS) and the Global Rating Scale of Performance. The shoulder Objective Practical Assessment Tool, developed by the British Shoulder & Elbow Society Education Committee, is an objective scoring system for monitoring progress and providing immediate feedback to orthopaedic trainees learning diagnostic shoulder arthroscopy.³⁴ The Imperial Global Arthroscopy Rating Scale is used to measure more generic arthroscopic skills but has also

been validated for use in shoulder arthroscopy using a VR simulator.³⁵ These tools are useful to standardize assessment and minimize observer bias.³⁶

Validation

For any simulation tool to be useful, it must undergo some form of validation. Validation is not a binary concept; some aspects of validation are based on subjective measures and some on more objective measures. Facets that are commonly evaluated in the simulation literature include face, construct, transfer and concurrent validity. Although each of these is discussed only briefly below, they are important elements to be considered when evaluating the use of any training tool. Validation studies should be performed not only for individual simulators, but also for each specific task before they can be used for objective assessment of competency and certification purposes.

Some useful metrics recorded by VR simulators are not transferrable (e.g. probe path length, chondral surface force) because they cannot be applied to other simulation methods and patients. Primary outcome measures should include assessment metrics that can be applied to VR simulators and real patients in the operating theatre, in particular for studies addressing concurrent or transfer validity.

Face validity

Face validity is the degree to which a simulator is able to replicate a real-life clinical scenario; a measure of the realism of the simulated environment. The measures are subjective, and generally acceptable for newer VR simulators.³⁰ Tuijthof et al.³⁷ demonstrated partial construct validity for two brands of arthroscopic VR simulator. Although face validity was satisfactory for the outer appearance and joint anatomy, it was barely satisfactory for the arthroscopic instruments. Interestingly, the perception of usefulness did not differ between levels of arthroscopic experience.³⁷

Construct validity

Construct validity is the measure that the performance of a specific simulated arthroscopic task is related to the level of arthroscopic surgical experience. Several studies have demonstrated construct validity of different simulators.^{28,32,38} Martin et al.³⁹ found that years of training and shoulder arthroscopic experience correlated with task completion time on a VR shoulder simulator (Insight Arthro VR, Immersion, San Jose, CA, USA).

Gomoll et al.⁴⁰ found a close and statistically significant correlation between performance on a VR shoulder simulator (Procedicus, Mentice Corp, Göteborg,

Sweden) and experience level, in terms of task completion time, path length, hook collisions and average probe velocity. In addition, no correlation was found between video gaming experience and performance, which appears to support the content validity of the simulated arthroscopic task.⁴⁰ In a continuation of the same study, 10 orthopaedic trainees from the original cohort of 43 participants were retested after a period of 3 years. During this time, all 10 participants had gained real-life experience of arthroscopy in the operating theatre but no further simulation training. The subjects improved significantly in all four metrics but, with the exception of probe velocity, there were no significant differences between the subjects and a matched cohort from the original study with no previous exposure to arthroscopic simulation.⁴⁰ Despite the small number of participants, this study does raise an interesting idea regarding setting benchmarks for arthroscopic competency for different levels of surgical experience.

A recent systematic review found excessive heterogeneity in tasks and assessment metrics to determine internal and transfer validity between simulators.⁴¹ Studies generally demonstrate a difference in performance between experts and novices, although there is little evidence identifying differences between adjacent levels of experience (e.g. year 4 versus year 6 trainees). This lack of discriminatory ability may be a result of several factors in the study design, often including small study populations. Further research is required to develop simulated tasks and assessment metrics that are carefully designed to discriminate between adjacent levels of experience (e.g. novice versus intermediate trainees). This would allow for assessment of skill acquisition and use as part of a formative assessment of a trainee's progress.⁴¹

Content validity

As implied by the name, this domain considers the actual procedure and the steps involved. Content validity can be established by detailed analysis of the contents of proposed test items by a panel of experts. Angelo et al.⁴² deconstructed the steps and potential errors of an arthroscopic Bankart repair using a modified Delphi panel methodology to create validated procedural metrics. These were shown to have construct validity in both bench shoulder simulators and a cadaveric model.^{43,44}

Transfer validity

The terms 'transfer validity' and 'concurrent validity' are used interchangeably: transfer validity is the ability to transfer skills acquired on a simulator to another

simulator or cadaver or patient. The transfer of acquired skills to a patient is also termed ‘concurrent’ validity because it is a measure of how skills acquired on a simulator correlate with skills acquired on real-life patients in the operating theatre. Surgical skills learned on a VR simulator have previously been shown to improve performance in the operating room in laparoscopic surgery.^{45,46} Minimally invasive surgical skills have been shown to be transferrable between laparoscopic and arthroscopic haptic VR simulators, in a randomized controlled trial by Akhtar et al.⁴⁷ They discovered a greater effect on performance in the group trained on a laparoscopic simulator prior to assessment on an arthroscopic simulator than vice versa.⁴⁷

Martin et al.³⁹ compared the performance of 15 trainees and four experienced orthopaedic surgeons performance of an arthroscopic task on a VR shoulder simulator (Insight Arthro VR) with their performance on a cadaveric shoulder model. Task completion time on the VR simulator correlated strongly with time taken on the cadaveric model.³⁹ Henn et al.²⁴ studied 17 arthroscopic-naïve medical students, who completed a baseline diagnostic arthroscopy on a cadaveric model; nine of the students then underwent training on a VR shoulder simulator (Procedicus) before all 17 repeated the cadaveric arthroscopy. They observed a 30% reduction in task completion time in the VR trained group.²⁴

Howells et al.⁴⁸ conducted the only study that explores the transferability of skills learned on a simulator to performance on a patient in the operating room. They randomized 20 junior orthopaedic trainees to undergo arthroscopic simulator training on a knee bench simulator (Sawbones®; Pacific Research Laboratories, Inc.) or no additional training before performing a diagnostic knee arthroscopy in the operating theatre.⁴⁸ Outcome measures included motion analysis, OCAP procedure-based assessment and the OSATS global rating scale. The simulator-trained group significantly outperformed the untrained ‘control’ group. One limitation of the study is that the comparison ‘control’ group received no additional training at all, although it is a well-designed study and remains the only one of its kind. There is currently no direct evidence demonstrating transferability of arthroscopic skills learned and assessed on a VR simulator.

Learning curve and skill retention

Several studies have demonstrated a learning curve in arthroscopic simulator models.⁴⁹ There have been few studies that address the concept of retaining skills learned on a simulator, with conflicting results. In a study by Howells et al.,⁴⁹ six lower limb fellowship-trained orthopaedic surgeons performed an arthroscopic Bankart repair on a bench shoulder model

using real arthroscopic stack and instruments. All demonstrated an improvement over four attempts spread over a few weeks. When the participants repeated the process after a period of 6 months with no further instruction, a similar learning curve was repeated, and no benefit of the initial experience was retained.⁴⁹ By contrast, Jackson et al.⁵⁰ demonstrated retention of arthroscopic skills learned on a simulator after a 6-month interruption. Nineteen trainees with experience of knee arthroscopy, but not meniscal repair, performed 12 meniscal repairs on a bench simulator over a 3-week period and did not display any loss of skill when completing 12 meniscal repairs 6 months later.⁵⁰ It was suggested that the discrepancy compared to previous studies implies that task-specific and surgical-group specific factors may play an important role in learned surgical skill retention.

The future

Clearly, arthroscopic simulation is no substitute for real-life arthroscopic experience, although it has the potential to prepare junior trainees early in the learning curve, maximize early experience of arthroscopy in the operating theatre, improve efficiency, reduce errors and improve outcomes. There is no consensus regarding the number of arthroscopic procedures required to achieve competency, and no clear definitions of proficiency.

Arthroscopic simulation is part of a much larger move towards simulation and competency-based assessment involving medical training across specialties. Interest in simulation is growing within the orthopaedic community, and it has been introduced into the curriculum for UK orthopaedic trainees. The British Orthopaedic Association has established a Simulation Award for innovation in developing low-cost, freely available equipment, and will host the first free paper session in simulation at the annual congress in 2016. The British Association for Surgery of the Knee and the British Elbow and Shoulder Society have formed Simulation working groups, aiming to explore the possibilities of simulation and facilitate further integration into the curriculum.

Although there has been previous research into the cost implications of orthopaedic training in the operating theatre, there has been no cost-benefit analysis to date of arthroscopic simulation training.^{6,8} Further research is required into the transferability of surgical skills acquired by simulation training to the operating theatre (concurrent validity) to demonstrate the true benefits in terms of reducing cost and errors, as well as improving efficiency and patient outcomes. Criticisms remain regarding the accessibility to arthroscopic simulators, with only 26.6% of UK trainees in a recent survey reporting access to a surgical skills

simulator facility.⁵¹ Until this can be addressed with greater accessibility to VR simulators, or the development and validation of lower-cost models, arthroscopic simulation cannot be fully integrated into the orthopaedic training curriculum or assessments of competency required to determine progress. Cost-benefit evidence in favour of VR simulation might justifiably increase investment by training centres, and thereby improve accessibility to trainees.

ABOS requires passing the Fundamentals of Laparoscopic Surgery program to demonstrate competency in basic skills for certification and recertification in General Surgery.⁵² In the future, a similar program (e.g. FAST) may be used for competency-based assessment in orthopaedics, although further work is required into designing and validating training programs and robust objective assessment tools.

Recently, the focus has been on improving the fidelity of VR simulators to recreate anatomy and pathology, although the success of simulation in orthopaedic training will rely on careful simulator module design, and validation using widely accepted, transferrable metrics. The future is promising, although there is a long way to go before it can be used as an assessment tool for certification of competence, identification of surgeons of the future, competency based selection, progression and possibly accreditation. Flight simulation has been used successfully to develop international standards for pilots in the aviation industry. Future research into arthroscopy simulation could look not only at developing international standards of assessment of skill competency, but also at achieving an internationally agreed standardization of VR simulator design, which would facilitate cross-continent multicentre trials.⁴¹

As mentioned in the Introduction, the majority of the current impetus is for the development of high fidelity arthroscopic VR simulation. There are VR and computer-assisted trauma simulators, although these suffer from a lack of face validity because the techniques do not lend themselves as easily to simulation. There are computer-based and mobile device application simulators: Touch Surgery (Kinosis Ltd, London, UK) is a pan-specialty smartphone-based app that can be used to learn the sequence of steps involved in a surgical procedure.⁵³ Gandhi et al. have developed a simple on-line arthroscopic simulator, which was validated against performance on a VR simulator.⁵⁴ This may prove to be useful to aid junior trainees with cognitive simulation to shorten the learning curve when beginning arthroscopy in the operating theatre.

Conclusions

Achieving proficiency in specific surgical skills is only one facet required to become an orthopaedic surgeon,

and cannot replace complex intra-operative decision-making that can only come from an accumulation of knowledge and surgical experience.

There are currently a limited number of simulators available, ranging from simple 'box' trainers, which are cheap but do not attempt to reproduce the surgical environment, through to sophisticated bench models, which replicate some of the anatomy but not the surgical environment, and, ultimately, VR simulators. These can record a wide range of detailed internal metrics to measure performance, but are expensive and there remains a lack of evidence of the transferability of surgical skills to the operating room. Although simulation is not a replacement for traditional models of surgical training, it is a useful adjunct that may ultimately lead to improving surgical outcomes for our patients.

Declaration of Conflicting Interests

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