High-fidelity virtual reality simulation training in enhancing competency assessment in orthopaedic training

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Abstract

Surgical competence is the ability to successfully apply academic knowledge, clinical skills and professional behaviour to inpatient care. Along with ensuring patient safety, the ability to communicate effectively, collaborative teamwork and probity, and achieving satisfactory competencies form the fundamental principles of good medical practice. Current strategies to develop surgical competencies include a range of formative and summative assessments. The cancellation of traditional face-to-face meetings and training opportunities during the COVID-19 pandemic had a profound impact on the delivery of medical education and opportunities to achieve surgical competencies. Simulation learning has been used since before the pandemic to deliver surgical training across all grades and specialities, including orthopaedic surgery. Simulation-based training provides a safe, controlled environment to develop skill acquisition. Simulated surgery using virtual reality has evolved following developments in software and hardware. This article explores the role of high-fidelity virtual reality simulation to assess competencies in orthopaedic training in the post-COVID-19 era, and examines whether simulation could be used within the curriculum to augment and improve training.

Key words: Clinical competence; Orthopaedic procedures; Orthopaedics; Patient care; Simulation training; Technology

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Introduction

Achievement of surgical competence, appropriate surgical standards, professionalism and education are key pillars of career progression towards practicing as a consultant surgeon. Assessment of competencies is essential to determine when a trainee is fit to practice safely. Demonstrating surgical competencies is necessary for basic core (CT1–CT2) and specialty surgical training (ST3–ST8). Traditionally these core components of a competency-based curriculum are evaluated via workplace-based assessments, leading to a successful outcome at the annual review of competence progression. From August 2023, the surgical training curriculum changed to an outcome-based skills- and patient-focused framework, replacing the traditional competency-based intercollegiate surgical curriculum programme training assessment. However, the new surgical curriculum still requires the attainment of surgical competencies to progress through the 'phases of training' (Beard, 2008; Lund, 2020).

The COVID-19 pandemic resulted in the cancellation of traditional 'face to face' in-person meetings, clinical examination assessments and subspecialty summative assessments (Kogan et al, 2020), which created challenges for surgical training and trainee exposure. Throughout the pandemic, elective operations were cancelled and many trainees were redeployed to other clinical areas. Orthopaedic trainees were not immune to this restructure (Iyengar et al, 2020), with Bodansky et al (2021) suggesting a 43% reduction in training opportunities, while 22.7% of orthopaedic trainees were redeployed during the first wave of the pandemic (Kogan et al, 2020). In the post-pandemic era, elective surgical waiting lists have grown exponentially and there is pressure on all services to reduce these. Thus, although elective operating has returned, training opportunities are still limited because of the increased pressure on the health service (Iyengar et al, 2022).

Before the pandemic, there had already been a shift away from the traditional concept of 'see one, do one, teach one' and the Halstedian model of apprenticeship, because of

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increasing awareness of patient safety (Rodriguez-Paz et al, 2009; Kokkotis et al, 2020). The introduction of the European Working Time Directive was already limiting trainee operating time (Akhtar et al, 2015; Morgan et al, 2017). Increasing scrutiny of limited training opportunities has meant that training in surgical competencies has had to develop to ensure patient safety, minimise error and reduce cost.

What is simulation-based training?

Simulation is used to facilitate the learning and acquisition of clinical and non-technical skills, without putting the patient at risk (Kalun et al, 2018). In orthopaedic practice, simulation-based surgical skills training can address concerns about patient safety and improve competency in technically challenging procedures, providing a safe and controlled environment to acquire skills. Trainees can experience and interact with mock scenarios based on real-life situations. Simulation requires the use of interactive models, and advances in telecommunication technology and computer programs have made it possible to develop skill stations that can be applied at all levels of professional development (Atesok et al, 2017; Khajuria and Mathew, 2021).

Virtual reality and its application to simulation in orthopaedic surgery

Virtual reality is an innovative technology that can teach surgeons operative procedures and help determine their level of competence before they operate on patients (Cao and Cerfolio, 2019). The first medical virtual reality simulator was developed three decades ago (Satava, 1993), and subsequent developments in software and hardware allow for more advanced high-fidelity simulation training.

This article examines the possible role of high-fidelity virtual reality simulation training to assess competences in orthopaedic surgery. It explores challenges to implementation and strategies for integrating virtual reality-based orthopaedic surgical simulation training into an established training programme.

Current orthopaedic training programme, practice of simulation and advances in training

Training entry requirements and assessments

Applications for orthopaedic speciality training in the UK include self-assessment. For example, applicants must demonstrate the number of completed dynamic hip screw procedures that have been undertaken, with the highest scores awarded to those who have completed 12 or more of these procedures. Similarly, core surgical procedures, which form the basis of the procedure-based assessments, must be validated by their supervisors and evidence gathered from appropriate procedures (Hainsworth and Beaumont, 2021). Supporting information is collected from the integrated electronic logbook for the intercollegiate surgical curriculum.

Throughout specialist registrar training, at annual review of competence progression and before being awarded the certificate of completion of training, an orthopaedic trainee is expected to show a broad understanding of trauma and elective surgery across all domains (foot and ankle, knee, hip, spine, hand, elbow, and shoulder).

Current practice in simulation training

Sir Liam Donaldson (2008) stated that ‘simulation based training should be fully integrated and funded within training programmes for clinicians at all stages’. Deemed safe and risk free, it is supported by the General Medical Council when conducted in a secure controlled environment. Morgan et al’s (2017) systematic review found that there were fewer validated commercially available high-fidelity simulators for orthopaedics than other surgical specialties.

Surgical simulators can include synthetic bench top, animal or human cadavers or computer-assisted virtual reality. Orthopaedic simulation largely focuses on technical skill acquisition, skill development, decision making and surgical technique. Not only is similarity of the tissue important, but also the ability to manipulate and shape bone for simulated fracture repair and joint reconstruction. Early simulation design centred around synthetic bone, which could be used to practice joint fixation, drilling and manipulation, and this is still used commercially to demonstrate new devices (Marchand and Sciadini, 2020).

The introduction and uptake of minimally invasive arthroscopic surgery led to a surge in use of simulation (Braman, 2019). This was partly in response to the well-documented steep learning curve associated with minimally invasive surgery, following research identifying that simulation training can translate into improved operative outcomes (Seymour et al, 2002; Grantcharov et al, 2004). Morgan et al (2017) highlighted that 62% of the articles in their systematic review discussed arthroscopy simulators, with knee and hip arthroscopy models developed by Sawbones (Pacific Research Laboratories, Washington USA) being most described.

High vs low fidelity simulation training

Several studies have investigated the effect of different forms of simulation training on skill acquisition, but an in-depth analysis of these is beyond the scope of this article. However, the difference between high and low fidelity simulation appears to be of minimal importance for novice trainees, as they first need to acquire basic skills. This can be replicated with abstract exercises such as using laparoscopic box trainers (ie placing hoops on pegs). Munz et al (2004) compared a group of medical students who received virtual laparoscopic simulation and traditional box training with a control group who received no training, and found significant improvement for those who received simulation training. Higher fidelity simulation may be more beneficial for the expert trainee who is developing complex skills. Sidhu et al (2007) looked at outcomes of anastomoses in groups trained on plastic tubes as opposed to a cadaveric brachial artery, and found that the group trained on the high-fidelity brachial artery model was far superior.

Advances in software and hardware have led to the development of increasingly realistic virtual reality environments. These allow high-fidelity simulation to extend training beyond tasks and recreate a complete surgical procedure or part of one, providing an alternative to physical simulators. They create a patient-free, unhurried, controlled environment for acquiring skills and understanding procedures.

Simulation in orthopaedic surgery outside the institution

High-fidelity virtual reality models are usually computer or headset based. Virtual reality simulators have the advantage of providing instantaneous unique performance metrics, such as the accuracy or positioning of the instrument. These simulators include a visio-haptic element allowing for specific feedback to mimic human tissue by adapting to the type of tissue for that specific operation (bone, soft tissue) (Ruikar et al, 2018). They have been developed to simulate specific elements of orthopaedic surgery, with a focus on arthroscopy, drilling, screw and plate fixation, or specific operations such as total knee or hip replacement and even amputation (Vankipuram et al, 2010).

Examples of these systems include ArthroSim (ToLTech, Aurora, CO), which is supported by the American Academy of Orthopaedic Surgeons. This is a knee and shoulder high fidelity virtual reality arthroscopy simulator with haptic feedback. It has gone through several validity studies demonstrating high levels of skill acquisition and improved efficiency when performing diagnostic knee arthroscopy (Cannon et al, 2014). Vankipuram et al (2010) developed a visio-haptic drilling simulator using the SYNTHES surgical drill attached to a three degree of freedom sensable phantom haptic desktop device. This provides a realistic drilling experience and has been validated in a small study with six experts, eleven residents and six novices testing the simulator.

In the UK, Imperial College has developed a system to train and assess the placement of a lag screw in the femoral head for fixation of a fracture in a neck of femur fracture. The haptic orthopaedic training simulator used a five degree of freedom virtual reality simulator, giving a three-dimensional view that approximates the viewpoint of surgeons, and uses X-ray images to replicate an intraoperative scenario (Barrow et al, 2013). Fundamental Surgery (UK) have developed The Flight Simulator for Surgeons, accredited by the Royal College of Surgeons and American Association of Orthopaedic Surgeons.

It incorporates haptic virtual reality technology, which gives users access to high fidelity at scale, and has been used in total knee replacement, total hip replacement and several spine procedures. The simulator has been developed to include a multiuser platform where trainers can watch and assess trainees. At a test event at the British Orthopaedic Trainee Association conference, 92.5% of participants agreed that the simulator was a useful tool for training and 85% agreed that it presented a high-quality visual representation of the operation (O'Malley, 2020).

The majority of high-fidelity virtual reality simulators available for orthopaedics train solely for specific skills, with only one providing training on three procedures (Fundamental Surgery). There is scope to have a 'one system fits all' model, to allow training on arthroscopy, individual drilling and fixation as well as full procedural total knee or total hip replacement. If these simulators were adapted for use outside the training setting, these devices could be conveniently incorporated into orthopaedic surgical training, however, rigorous validation studies would need to be undertaken.

Incorporating simulation into training

Despite the advances in simulation, there are significant challenges in incorporating this into surgical training. These include difficulty in ensuring accessibility and providing a designated space, the need to use a validated system and the high cost of simulators. Currently simulation requires a dedicated centre with a faculty who are responsible for the training programme. Although training is mandated by the surgical curriculum in the UK, individual deaneries decide how they provide and fund this. Different budget allowances in each deanery may cause disparities in training if high-fidelity simulators are only accessible in some regions. A national approach should be taken to ensure widespread accessibility.

Milburn et al's (2012) review of simulation training in surgical specialities found 26.6% of orthopaedic trainees had access to simulation, which was considerably lower than the national average of 41.2% in other surgical specialities. This reduced accessibility to training may be a barrier to widespread rollout within a curriculum. There are no more recent data relating to this.

Validity of a training system is critical. A systematic review by Tay et al (2014) highlighted that only one arthroscopic simulator study demonstrated concurrent validity. Morgan et al (2017) found that 38% of studies of simulation systems gave only descriptive results without any form of validation. As simulator training aims to provide skills that can be transferred into the operating room, validation studies with an emphasis on transfer validity are needed to incorporate a virtual reality simulator into orthopaedic surgery. However, if a system is to be used nationally, it must be a well-validated platform that supports skills which are transferable between subspecialties and deaneries.

Cost–benefit analysis of simulation-based training

The cost benefits of these training models have not been fully studied. Setting up a simulation centre can be very expensive – an American study estimated set up costs over $800 000 with additional annual costs for staff and upkeep of the facility (Hippe et al, 2020). FundamentalVR, a UK-based firm, advised that a high-fidelity haptic simulator can cost in the region of £80 000, although this is considerably less than cadavers, often used in surgical training courses, which cost upwards of £10 000 and can only be used for 4–6 trainees (Wade, 2018). The cost of a simulator must be offset against the potential time saved in training surgeons in the operating room, which has been estimated as a loss of 11 184 minutes operating over a 4-year period when looking at operating theatre efficiency. Thus, by initiating the use of high-fidelity simulators, theatre efficiency may improve by reducing the number of novel surgeons. As with the implementation of a simulator programme for trainees, time may be saved in training basic surgical skills and therefore increase the number of operating cases that can be performed per surgical list (Sasor et al, 2013; Thomas et al, 2014). The potential added morbidity to patients from operations performed by novice surgeons and increased time of operations while training must also be considered. A full assessment and cost–benefit analysis is needed, looking at the cost of the simulation training compared to the potential savings of decreased requirements for intraoperative training.

The future for virtual reality-based simulation orthopaedic training

The impact of the COVID-19 pandemic on orthopaedic trainees is going to be felt for a long time. Despite this, maintaining high standards of training is vital for the development of competent future orthopaedic consultants.

A high-fidelity virtual reality simulator could help training via assessment of competency but identifies the role of in-training virtual reality as a whole. By introducing a simulator programme into the curriculum, trainees should progress from novice to master at a quicker rate and reduce the actual operating time requirement. A model has yet to be developed that addresses all features of orthopaedic surgery. Any simulator that is to be introduced into an already established curriculum must be accessible and transferable, have demonstrable validity and be cost effective (Table 1).

Table 1. Challenges in implementation of virtual reality-based simulation in orthopaedic training and strategies to address them

Challenge	Strategies to support implementation
Planning	Establishment of virtual reality-based simulation orthopaedic training module Feasibility study
Validation of competencies	Standardisation of assessments Validatory studies to compare traditional training modules with virtual reality-based simulation orthopaedic training modules Standard validity tests (face, content, construct, and concurrent validity, consistency) to be proven
Faculty training	Dedicated faculty to enhance and implement processes of virtual reality-based simulation orthopaedic training module University or deanery funding and training opportunities Simulation training skills stations
Trainees support	Practical skills laboratory accessibility Protected time Feedback Establishment of training log Synchronisation with intercollegiate surgical curriculum programme curriculum
Technological assistance	Choosing the right simulator for the task or skill to be learnt 'High fidelity' synchronisation Newer generation of trainees more comfortable with technology Appropriate hardware, software and information technology solutions Support from regional university information technology departments
Evaluation of training	Objective and standard measurement techniques to compare virtual reality-based simulation learning with live operating theatre training skills Feedback assessments Remediation of poor performance
Cost implications	Government, national and deanery funding to support virtual reality-based simulation orthopaedic training module Funding or grant support from technological companies and/or institutions
Integration into intercollegiate surgical curriculum programme curriculum	Will require buy in from all Royal colleges in the UK Standardisation and accessibility of simulators across the country

Key points

- Simulation training is a safe and effective modality for delivering training across a range of surgical expertise and specialities.
- Advances in technology could allow the development of interactive virtual reality models to replicate 'real life' surgical experience, enhance training assessments and achieve competencies.
- Comparative studies between traditional and virtual models of surgical training will be needed to ensure consistency of assessment and confirm validity.

Limitations of virtual reality-based simulation for orthopaedic training

Virtual reality simulation is an evolving, innovative model to develop surgical knowledge, skills and performance in orthopaedic surgical training. It has significant benefits, but quality assurance and validation of this model are needed. Provision of high-fidelity virtual reality training requires financial investment and support from training bodies. Longitudinal studies that compare traditional methods of training with interactive virtual reality models that replicate 'real life' patient experience will be necessary to understand whether and/or how to take this training model forward.

Conclusions

The impact of the COVID-19 pandemic on orthopaedic trainees and their training will be felt for a long time, but despite this, high standards of training must be maintained to develop competent future orthopaedic consultants. This paves the way for the use of virtual reality, both in simulation training to aid the assessment of competencies and for inperson training. There is not yet a simulation model that addresses all features of orthopaedic surgery. Any simulator must be accessible and transferable, have confirmed validity and be cost effective. Adoption and adaptation of home virtual reality could be vital for future training, empowering trainees and ensuring standards are maintained when hands-on training is declining.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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