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Rationale and feasibility assessment of an institution-based virtual reality hub in orthopaedic surgical training: an Australian pilot study

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Abstract

Background: Virtual reality (VR) has been established as a valuable tool outside of medicine but there has been limited uptake in orthopaedics despite being a specialty heavily dependent on psychomotor skills. The purpose of this study was to assess the feasibility of setting up an on-site virtual reality surgical training hub for an orthopaedic surgery unit. A secondary objective was to document encountered hurdles to assist other institutions with a similar process.

Methods: The study explored the logistical and organizational considerations in the process of creating a virtual reality training area. This included: review of location, set up management, funding arrangements, set up time, research opportunities and training time. Set up and completion times were recorded during a separate trial of 24 participants ranging from medical students to senior consultant orthopaedic surgeons.

Results: A VR training area was successfully established over a period of 3 months. A dedicated area for training where the equipment remains permanently was designated to facilitate ease of use. Average set up took 7.5 min to turn the computer on and 25 min for the participants to start the module. Issues identified during set up were recorded.

Conclusions: The study demonstrated that it is possible to set up a dedicated area for virtual reality surgical training within a hospital unit. A dedicated lockable area is the most feasible method of establishing such a space and reduces the requirement to recalibrate and transfer equipment around the hospital.

Introduction

Virtual Reality (VR) training has been established as the standard in competency-based training for military and airline pilots in the aeronautical industry.[1] The advancing technology of VR allows it to be easily applicable to surgical training. Prior to VR, the only options for surgical trainees were live patients or cadaver models which are expensive, non-portable and limited. Recently, there has been a paradigm shift in the adoption of simulation training from traditional cadaveric models.[2,3]

In the United States, VR training forms a part of surgical training and is delivered via institutions such as the Arthroscopy Association of North America (AANA). In 2017, a French national reform mandated that all surgical residents should have access to VR training simulations that must be used prior to arthroscopy on patients. In the Australian ophthalmic training program, VR training is already embedded in the form of virtual cataract surgery.[4] A review of the literature yielded only two randomized control trials which demonstrated a correlation between the use of VR training in total hip arthroplasty and technical skills development.[5,6]

The impetus for VR is the shift from the apprenticeship model of training where trainees practice novel skills under supervision on real patients. Though outdated, this model has been the gold-standard in practical surgical training. This model has implications including patient safety if trainees are not skilled enough to minimize complications, costs of trainees completing procedures and decreasing theatre efficiency. Furthermore, the complexity of trainee learning is increasing while working hours and patient exposure is decreasing. Modern trainees are expected to learn increasingly complex tasks with less time and practice.

Despite the increasing accessibility of VR, its adoption in orthopaedic surgery, particularly in Australia, has lagged relative to other surgical disciplines where it has been proven to be an effective learning tool.[7–12] Contributing factors include an initial lack of evidence for the translational benefit of VR practice and scarce technical knowledge of applying it.[13] In addition, costs can be cumbersome and public funding for staff to assist with such programs is lacking.

A further vision of the Austin VR training hub is developing the 'Hardidge–Balakumar Continuum' on a four-level hierarchy of training:

(1) How to do a procedure
(2) How to do a procedure via a different approach
(3) How to do a procedure in a surgeon-specific way
(4) How to manage complications

Due to the dearth of research, we sought to assess the feasibility of a dedicated in-hospital VR training hub in an Australian public tertiary teaching hospital. We hypothesised that it would be feasible to set up such a lab in an Australian institution. The secondary aim was to document the process of establishing such a VR and provide a reference for others considering similar programs in other hospitals.

Methods

The study was instigated by the Orthopaedic Department at Austin Health, Melbourne. All procedures performed were in accordance with the ethical standards of the Austin Health Office for Research and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The first VR module trialled was a direct anterior approach total hip arthroplasty as it was less familiar for the orthopaedic trainees. Fundamental Surgery version 1.1.0.0 (FundamentalVR, London, England) was chosen as the surgical VR software. This was due to the high-fidelity haptic feedback that would allow better immersion. Other currently available modules from the company include spinal pedicle screw placement or facetectomy, posterior approach to total hip replacement and total knee replacement. The accompanying hardware included a HP1440 spatial computing VR headset (Hewlett-Packard, Palo Alto, USA), Alienware Area-51 m laptop (Dell, Round Rock, USA) running Windows 10 (Microsoft, Redmond, USA) and two Geomagic Touch™ (3D Systems, Rock Hill, USA) haptic units set up as per recommendation by Fundamental Surgery (see Fig. 1(c)). The entire software and hardware package was donated by one of the senior authors (JB) to the department. The commercial recommended retail price of this set up is outlined in Table S1.

Set up requirements for each use involved connecting a power supply to units, turning them on then connecting the haptics and headset to the laptop. Opening the gaming program Steam (Steam, Bellevue, USA) as well as the Fundamental Surgery program on the laptop was required for use of the VR headset. Four separate power points were required to connect the laptop and haptic arms. The VR headset and haptic arms then needed to be calibrated if moved from a previous location. Eventually the haptic arm and desk configuration was formalized (see Fig. 1) to a specific set up arrangement. Participants were able to self-guide through the steps of the procedure as directed by the program and a laminated set-up instruction sheet.

A dedicated space was established in the same building as our major theatre complex for the permanent storage of equipment. Access to the equipment was protected by a numeric code and trainee surgeons were recommended to immediately use it prior to performing an anterior hip replacement procedure. In addition, appointments were made with the authors of this article for their initial induction and supervised usage.

The users of the VR training hub had their set up duration timed under supervision. However, set up was only directed by written instructions to simulate future self-service. Participants were asked to independently unpack and set up the equipment and start Fundamental Surgery on the PC. The time for the participant to complete setup up until module start was recorded. Issues that participants experienced were also noted. The participants covered a range of experience levels including medical students, junior medical officers, orthopaedic trainees (residents) and consultants.

Results

The initial set up location was in an operating theatre with the equipment stored in a portable suitcase on a mobile trolley that would be assembled prior to use. The aim was to set it up in the operating theatre for use immediately prior to surgical procedures to refresh skills. This process proved to be cumbersome due to limited theatre space and accessibility to the VR setup was not equal between hospital sites and trainees. In addition, the set-up time was long due to the need to recalibrate the system with every use in a new location which was not practical. It was decided that further in-theatre use with the current hardware was not practical.

This led to the development of a dedicated location for training which involved deciding firstly on a location based on the following requirements. A lockable entry with a numeric code for ease of access by multiple different trainees. Proximity to theatres for accessibility prior to procedures. Desk space that would allow for permanent set-up of hardware to avoid replicating set-up time and calibration for every use. Additional physical space for future expansion of the VR hub. Once established this proved more useful, obviated the need for transport of bulky equipment between theatres and reduced set up times.

The hardware was initially transported in a softshell case but due to concerns regarding fragility, in particular of the haptic arms, a custom foam lined suitcase was obtained from a photography store which offered better equipment protection, compartmentalisation and lockability (Fig. 2). The mean set up time duration was recorded over six separate sessions by five different people, taking a mean of 7.5 min for the computer to be turned on (range 6–9 min) and a total of 25 min (range 15–40) to be ready to start the module.

Issues identified during set up and use were noted during our pilot phase and are summarized below:

- Recalibration of haptic arms and VR headset with each use
- Accuracy of calibration occasionally lead to abnormal head positions
- 'Ghosting'– getting stuck in a virtual solid object with surgical instruments
- Wearer fatigue from the headset related to head positioning
- Limited range of motion of haptic arms not accurately reflecting anatomic movement of users' hand and wrist

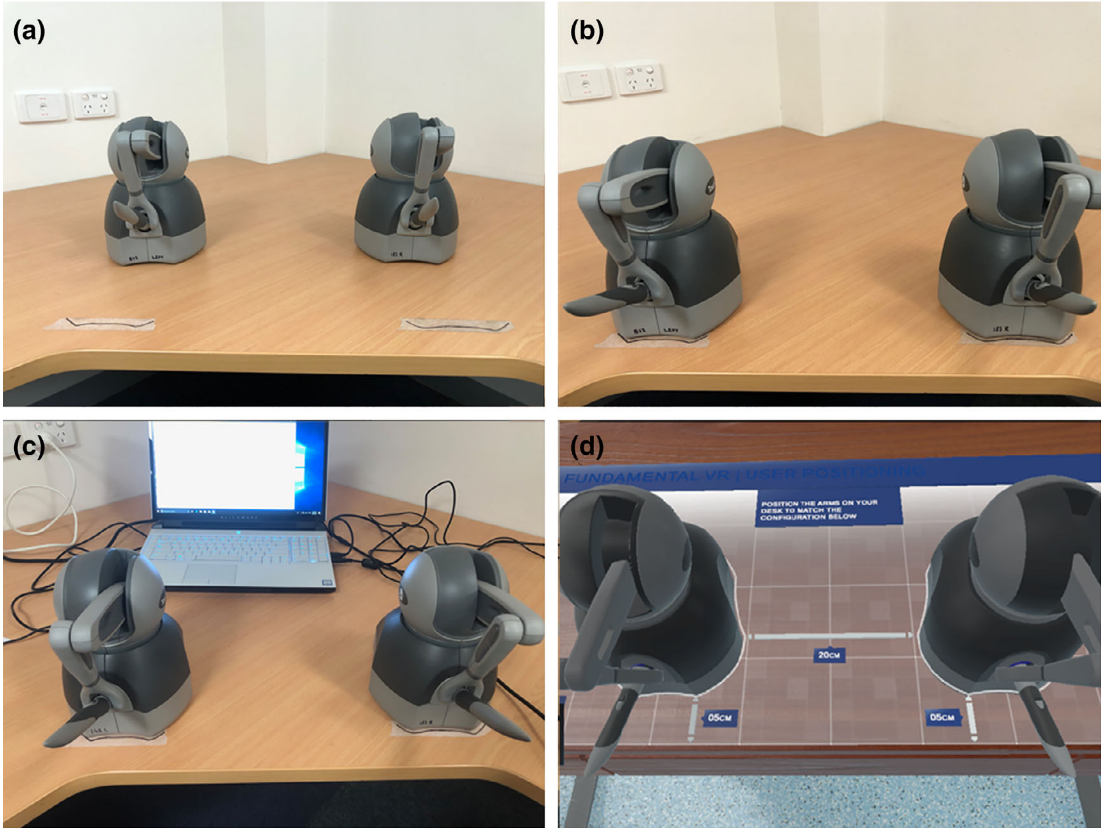

Fig. 1. (a) labels on desk for rapid placement of haptic arms (b) haptic arms placed in recommended distance apart (c) fully set up hardware (d) visual output through VR headset to the user.

Fig. 2. (a) custom protective case (b) equipment packaged in foam lined case.

- Breakage of a haptic arm hardware due to movement beyond device range
- Multiple power points required
- Heavy suitcase

In relation to the Hardidge–Balakumar training continuum, current technology easily allows for first and second level training. Customisation of surgical steps was explored aimed at re-creating a particular surgeon's workflow. Currently there is a compromise between software fidelity and customisability. The system used here has high fidelity, however, a request for surgical step customisation required significant cost and time outlays for development. Conversely, the vibration-based (less haptic) systems are simpler to customize and may prove more useful for the third and fourth levels of VR training where the surgeon already has acquired the haptic skills and the focus is towards learning a particular process or complication management.

Discussion

With the paucity of VR adoption in orthopaedic surgical training nationally, this study describes some of the feasibility issues and set up logistics regarding its use in a department-owned context. To the authors' knowledge, this is the first establishment of a virtual reality training hub in Australia.

As orthopaedic surgery is a discipline that is heavily dependent on technical motor skills, the clinical significance of this technology is the ability to perform VR simulations prior to patient exposure. This would allow for the development of the 'pretrained novice'.[14,15] In this setting, trainees would have pre-developed many psychomotor skills and spatial judgements via exposure to a virtual simulation. This has the potential to improve patient safety, theatre efficiency, reduce skill decay between operative events and accelerate the learning curve for trainees. Consequently, the technology holds strong promise in reducing adverse events intra-operatively as was found in a randomized control trial comparing VR and traditional teaching methods.[5] The use of VR simulations has largely been directed towards arthroscopic rather than open procedures.[16] As a result, there is minimal literature to demonstrate the efficacy of training in open procedures.

Location and access

After a brief trial of in-theatre usage as discussed, a decision was made to have a dedicated room close to theatre to calibrate and set up the VR system as it proved to be too time and space consuming to set-up prior to surgery. The markings on the desk with the accurate haptic arm positioning and labelling of the arms as right and left was particularly helpful. Having a coded access to the equipment removed the inconvenience of a physical key to be shared amongst different users.

Clear and open communication with building and departmental managers was essential to obtain hospital 'real estate' which took several months. Despite the challenges, it was worth the effort to have a dedicated space and avoid frequently transporting heavy equipment. There are also plans to expand this area with other VR and arthroscopy simulation which is possible with the dedicated space acquired. The space was obtained one level above the operating theatres for proximity.

Set-up and equipment

An average set up time of 25 min was long for first time users, but improved with subsequent use to 15 min. Shorter durations will make more frequent usage and use prior to cases more feasible. Set up in theatre took more than 40 min and was abandoned. If funding was available, it would be ideal to employ a facilitator to remove the requirement for users to perform set up.

Further plans are in place to obtain an OssoVR (Osso VR Inc., Palo Alto, USA) system, which is more realistic with more degrees of freedom with regards to hand position. However, this has a significant drawback of inferior haptic feedback. Our impression is that learning how to do procedures, such as joint replacement, will best be achieved with a haptic system. For example, the tactile feedback is important when broaching and cup impaction. OssoVR may be better for learning particular surgeon's workflows or dealing with intra-operative complications. We are also trialling arthroscopic simulators such as ArthroBox (Arthrex, Naples, USA) as well as planning a trial using the ArthoS system (VirtaMed, Schlieren, Switzerland) system in the future.

Costs

The recommended retail price of all the equipment has been outlined in Table S1. There are also ongoing costs to consider such as the subscription to Fundamental Surgery. If a particular hospital chooses, there are also the costs of adding additional modules. The current cost of a one-year subscription for one module is 11,500 AUD and 23,000 AUD for three modules a year. However, there is no additional costs for updates to already purchased modules. For the first year, the total software and hardware cost would be 24,000 AUD for one module (Table S1). Furthermore, the potential costs of acquiring a dedicated room or area for equipment to be set up permanently. These costs would depend on the local hospital.

Additionally, there are sunk costs associated with the hardware package as there are equipment purchases that cannot be reclaimed. For example, the breakage of one of the haptic arms requiring replacement. The replacement was received under warranty during the study, however, would incur an additional 4000 AUD per breakage if this occurred outside this warranty period. It is not difficult to foresee numerous breakages during repeated use by VR novices where multiple repairs would be costly. Furthermore, this would decrease available VR time and learning opportunities for trainees.

Given the interest in utilizing VR technology in surgical training, multiple VR systems and software companies have focused development in this area. The perimeter of this space is expanding rapidly with many innovations and improvements made in a short period of time. Though software updates may be less expensive, there will also be a necessity to update equipment with the latest developments as older technology falls behind. Establishing an up-to-date VR training facility would require ongoing funding to keep up with these advancements.

Other considerations with funding include the investment in a larger area. If a particular hospital chooses to pursue the creation of a VR hub, as is the case at Austin Health, a larger dedicated room would be a good investment for future expansion.

When considering all the initial and ongoing costs previously discussed, it is evident that this could be an outstanding barrier for utilization by some hospitals.

Research

Research will be aimed at *utility* from this point onwards to assess how effective VR training will be at improving surgical efficiency and skill acquisition. Current projects are investigating the same software and which level of training is most appropriate for this training intervention.

Issues

Recalibration of the haptic arm and VR headset was the major reported issue by participants of the study. Participants found that prior to attempting the training module, the haptic arms would not register on the VR platform, requiring recalibration. Furthermore, participants would find that the VR headset would be incorrectly orientated in virtual space thus requiring recalibration.

Another recurring issue was 'ghosting' during the training sessions. Ghosting is defined by Fundamental Surgery as placement of the tool in an impossible position in virtual space. This leads to the characteristic 'ghosting' of the surgical tools such that participants are not able to use them when stuck. It is possible that the tolerances of the Fundamental Surgery were too minimal to sufficiently replicate *in vivo* procedures. It became easier to correct this error once more familiar with the arms.

Wearer fatigue of the VR headset was also a significant issue. Participants described tension-like headaches even after short periods of wearing the headset. This improved with better virtual space arrangements such as altering the desk height. Other limitations involve the limited range of motion of the haptic arms. The technology does not allow a full range of motion through three-dimensional space as an inherent limitation of the haptic arms. One of the more experienced consultants snapped a haptic arm during broaching which was replaced. This was likely the result of either movement beyond what was possible or excessive force.

The fundamental surgery platform utilizes gaze and optic tracking as a metric of performance. There is little data on the validity and translatability of psychomotor and non-technical skills developed with a VR simulator. This is partly due to difficulties in measurement of effect which remains an obstacle in the adoption of VR in surgical training. There has only been one study that has been able to show translation of skills developed from VR to cadaveric models.[6] Nevertheless, other metrics need to be established that can be translated into operative skill such that VR performance can be directly compared to performance in the operating theatre.

The future of VR-based training

Recommendations for future avenues with this technology involve teaching novel and rare procedures to increase baseline knowledge of trainees. This reduces the burden of teaching by senior surgeons where more time can be utilized to address the intricacies of an operation and skill deficiencies rather than the basics. This notion would reduce patient risk and maintain or potentially increase case numbers. The target population would be trainee surgeons and junior doctors who are yet to master the basics of orthopaedic surgery.

Exposure to rare or complex intraoperative complications is an area where VR training eclipses traditional training models. Simulations will provide teaching experience and how to manage otherwise rare adverse complications. This aims to create an ever-increasing library of virtual complications such that surgical trainees may learn from others. Complication management in this setting would increase operator confidence and remove the need for complications to occur intra-operatively before management is learnt. VR assessment of complications could be incorporated into examination for training providers. In the context of consultant learning, these simulations have benefit in practicing on virtual patients with complex variant anatomy. This would use Digital Imaging and Communications in Medicine (DICOM) to create a model that could be readily implemented in VR software such as Fundamental Surgery.

In regard to the Hardidge–Balakumar training continuum, each level of simulation is aimed at a different experience level from student to surgeon. The first level is aimed at teaching medical students and junior doctors how to do an operation. It exposes them to the basic steps and provides the ability to learn specific skills required. The second level is learning how to do a known operation through a different approach. The third level is aimed at trainee surgeons on how to perform a procedure in a surgeon-specific way.

The fourth and final level is complication management, aimed at advanced surgical trainees and consultant surgeons. As major complications are rare events, trainees may not be exposed to certain ones throughout their entire training program. The aims of this level would be to expose, train and then test the surgeon's ability to recognize and address complications and assess their competency in doing so. Rare complications could be shared across the world to upskill others without that particular experience. Each of these steps seek to provide information and skills that can be acquired prior to entering the operating room to increase the yield of the operating experience and to maintain skills.

This pilot study demonstrates that it is possible to set up a dedicated area for virtual reality orthopaedic surgical training within a hospital unit. A dedicated lockable area is the most feasible method of establishing such a space and reduces the requirement to recalibrate and transfer equipment around the hospital. Whilst there is a wealth of potential, VR surgical training is still in its infancy. Despite this, with an evidence base growing that demonstrates translatable skills, its use is anticipated to expand.

Conflict of interest

None declared.

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Author Contributions

Allan Le: Investigation; visualization; writing – original draft; writing – review and editing. **Anuj Krishna:** Investigation; writing – review and editing. **Anton Philip Lambers:** Conceptualization; data curation; investigation; methodology; project administration; supervision; writing – review and editing. **Andrew Hardidge:** Conceptualization; resources; supervision; writing – review and editing. **Jitendra Balakumar:** Conceptualization; resources; writing – review and editing.

Data Availability Statement

The data that support the findings of this study are openly available in Zenodo at http://doi.org/10.5281/zenodo.5673365.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Table S1. Recommended retail prices of required equipment and software.