ORTHOPAEDIC SURGERY

Royal Australasian College of Surgeons

Utility assessment of virtual reality technology in orthopaedic surgical training

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Key words

haptic feedback, orthopaedics, surgical education, virtual reality.

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Accepted for publication 25 April 2023.

doi: 10.1111/ans.18501

Abstract

Background: Virtual reality (VR) has proved to be a useful technology beyond the field of surgery in areas that are highly dependent on consolidating motor tasks. Despite being reliant on these skills, the uptake of VR in orthopaedics has been extremely limited. Therefore, this study's purpose was to help assess the utility of applying this technology in teaching different experience levels of orthopaedic training. Secondary objectives were to assess enjoyability and feasibility to complete modules prior to surgery.

Methods: The study explored which experience level of orthopaedic trainee benefits the most from the proposed haptic VR package. Participants completed a total hip arthroplasty module using the Fundamental Surgery package. Qualitative data was collected in the form of a post completion survey of 24 participants. Quantitative data was collected in the form of module completion time and percentage of skills completed.

Results: 37.5% of participants rated non-training orthopaedic registrars as the experience level that would benefit the most from using VR. 88% of participants would recommend this module to a colleague and found the module very enjoyable (4.2 out of 5). 50% of participants took between 25 and 31.5 min to finish and completed between 80% and 95% of tasks in the module.

Conclusions: The study demonstrated that non-training orthopaedic registrars were most likely to benefit using this particular VR package. Most users found the experience to be enjoyable and would recommend it to a colleague. It was also deemed feasible to complete the module prior to performing an operation.

Introduction

Simulation and virtual reality (VR) platforms have been utilized by the aeronautical industry for decades as a significant component of their competency-based training.[1] Like many practices adopted by medicine from the aviation industry, simulation lends itself well to the field of surgery because it allows technical skill development without harm to patients and theatre efficiency. While the model of apprenticeship training in surgery remains relevant, there has been the development of larger learning curves. This is due to the emergence of technically demanding disciplines such as arthroscopy or minimally invasive approaches, combined with a reduction in operating opportunities for trainees in orthopaedic surgery. A paradigm shift towards use of surgical training simulations is underway.[2,3] Furthermore, when the COVID-19 pandemic introduced the new challenge of limiting face to face teaching, new learning tools had to be implemented to supplement deficient learning opportunities. In this light, the conventional learning model for surgical training of 'see one, do one, teach one' is difficult to justify in the current context where technology exists to support the training of surgeons as an adjunct to traditional techniques.

The novel technology of VR has allowed the development of the 'pretrained novice'. This notion would permit trainees to be exposed to virtual simulations of planned procedures and allow adequate psychomotor skills and spatial judgements to be automated. This means those tasks now occupy significantly fewer attentional resources, allowing the novice to focus more on learning the steps of the operation from their supervising surgeon and the nuances of their approach. Due to orthopaedics being heavily dependent on technical skill, orthopaedic VR simulation holds great potential to positively impact on improving surgical training, exposure to and management of otherwise rare intra-operative complications and simulated management of these complications.

VR in surgical training is not a novel concept. Over two decades ago, Satava proposed early adoption of VR as a training tool.[4] Despite this early vision, VR simulation in orthopaedic surgery has been relatively slow to progress. This contrasts with other surgical disciplines where VR has been adopted and proven to be an effective training tool, particularly in the field of laparoscopic surgery.[5–10] It has been shown that VR intra-operative metrics are both sensitive and specific in measuring skills relevant for laparoscopic surgery.[10]

While the reasons for this delayed acceptance are numerous, the initial paucity of robust scientific evidence to support the use of VR for skills training has been a major contributing factor.[11] Furthermore, a lack of knowledge of how to effectively apply simulation to the field of orthopaedics from a technical perspective have contributed to this. Following directions of VR use in other disciplines, most of the work in the field of VR applied to orthopaedics has been directed towards arthroscopic procedures.[12] To date a range of arthroscopic simulators have been developed with evolving evidence to support their use. Largely these studies have focused on validating the use of a particular VR system but have not measured how the skills translate to clinical performance. This has been partly due to the lack of an easily measurable metric that can be translated to *in vivo* performance. While there are some studies that have examined the effect of simulator training on performance in the operating theatre, they are very few.[13]

With the improvement in technology surrounding VR and haptic systems, there has been the introduction of platforms that provide VR training in open elective and trauma procedures. In the setting of total hip arthroplasty, this is a relatively new and evolving field. Only one article has been published supporting the use of VR in total hip arthroplasty which showed an improvement in technical skills but was limited to the setting of a cadaver model.[14] This was not correlated to performance in a clinical setting. In this light, the Austin orthopaedic unit has made steps towards introduction of a VR training program in hip arthroplasty to improve surgical training in this area.

The aim of this study was to implement and evaluate a VR training program in total hip arthroplasty. Specifically, we would like to address which level of trainee is the software most suitable. Furthermore, if the fidelity of current VR technology is effective enough to deliver novice teaching. We will utilize the Fundamental Surgery system which is a software platform that takes advantage of readily available virtual reality hardware combined with haptics technology. Secondary objectives are to assess how enjoyable using the technology is and if completion times are feasible for it to be used prior to performing an *in-vivo* surgery.

Methods

The same methodology was used in a prior study we conducted on the feasibility of VR.[15] A direct anterior approach total hip arthroplasty was the first VR module trialled in this study as it was less familiar to the participants. The chosen VR software was Fundamental Surgery version 1.1.0.0 (FundamentalVR, London, England) due to the high-fidelity haptic feedback system. The accompanied hardware package was set up as per recommendation by Fundamental Surgery as depicted in Figure S1. Both the software and hardware packages were donated to use in the study by one of the senior authors (JB).

Participants consisted of a range of experience levels to both orthopaedic training and VR exposure. This population included medical students, junior medical officers, orthopaedic registrars (residents) and consultants. Twenty-four participants were invited to complete the Fundamental Surgery module and asked to anonymously complete a survey immediately after completion. The survey consisted of the following: basic demographic information, multiple choice questions and Likert rating scales. Fundamental Surgery also provided virtual intra-operative metrics that were used to describe user performance.

Quantitative data obtained from the survey was depicted using descriptive statistics (median, Q2, Q3, minimum and maximum). All statistical analysis on quantitative data was performed using Microsoft Excel (Excel 365 for Windows 10, Microsoft Corporation, Washington, USA).

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Formal consent is not required for this type of study and is implied by completing the post-performance survey.

Results

The demographics of the participants are as follows. The mean age of the participants was 30.8 years old with a range of 22–56. Most participants were male (83%) and interns or residents (Fig. 1). The results of the closed questions are as follows. From a scale of 1–5 (1 = most enjoyable and 5 = most enjoyable), it was found that participants rated the VR module enjoyable, at 4.2 out of 5. Furthermore, 88% of participants would recommend VR surgical training to a colleague.

Fundamental Surgery provides virtual intra-operative metrics such as: total duration of module, time spent looking at the surgical field of view, number of X-rays taken, and number of module skills completed. The module allows for an unlimited number of X-rays to be taken to inspect orientation of bone to instruments and the ability to skip skills if too difficult. Only total duration and percentage of completed skills were reported in this study as they were the only relevant parameters to answer the objectives of the study.

Figure 1a shows the distribution duration to complete the VR module for 24 participants was approximately symmetric, with half the participants taking 27 min or more to finish. Typically, participants finished between 25 min (Q1) and 31.5 min (Q3), with half of the participants falling in this interval. The fastest participant finished in 12 min and the slowest took 40 min for completion.

Figure 1b shows the distribution of completed skills (%) was approximately symmetric with half of the participants completing 85% or more (Q1 80% and Q3 95%) of the in-module skills (range, 40%–100%). The participant that completed only 40% of the module was due to the breakage of a haptic arm necessitating cessation.

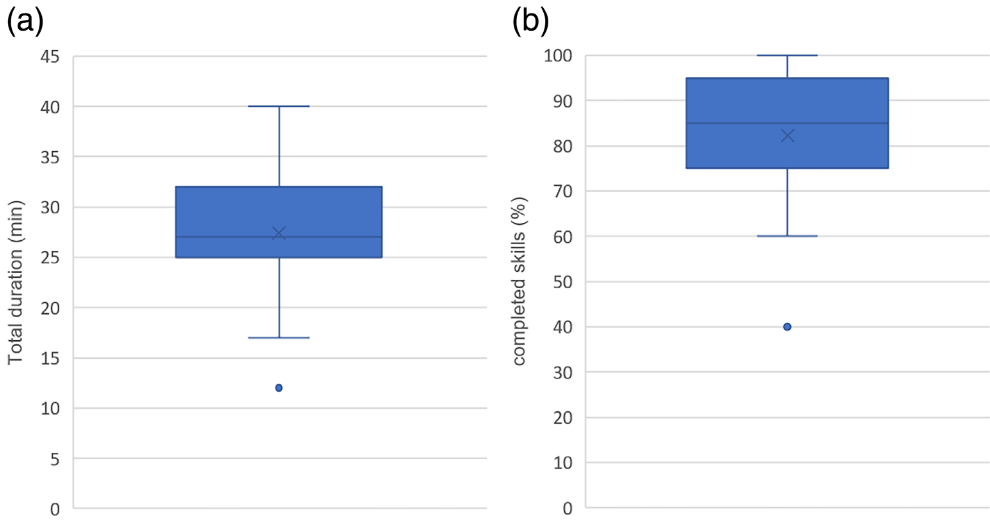

Fig. 1. (a) Distribution of total duration to complete the VR module and (b) the percentage of in-built skills in Fundamental Surgery completed by the participants.

Discussion

With the lack of uptake of VR technology in orthopaedic surgery on a national level, this study aims to investigate whether the current technology is appropriate for use in training. Moreover, which level of surgical trainee is most suited for the technology based on the post-use opinion of the participants of this study.

Experience level

From Table 1, it was clear that participants thought that the experience level that would benefit the most from VR technology was the non-training orthopaedic Registrar. The authors attribute this to the notion that non-training orthopaedic trainees have the steepest learning curve in terms of acquiring operative psychomotor skills. Given that these 'procedure naïve' trainees are yet to develop the methodological or motor patterns needed for surgery, it is reasonable to assume that this technology would benefit these trainees the most as a platform to transition from the virtual patient to a real patient. Furthermore, it would allow the practice of management of intra-operative complications without these arising intra-operatively.

In the same vein, the reasoning that a consultant or senior fellow may benefit from the technology is to learn the procedure from another surgeon's workflow. It may not provide the same exponential psychomotor learning as a trainee would, however, would help the surgeon explore operations using a different methodology. Additionally, in the future when the technology is sufficiently advanced, the equipment could be used for practising operations on complex and rare variant anatomy.

Participants thought that medical student would be the demographic to least benefit from use of the technology as seen in Table 1. This notion is reasonable, given that students are most likely trying to master the basic principles of medicine and surgery before advancing onto operative skill later in their career. Despite this, the technology acts as an approximate proxy for what medical students can expect down the line in a career in surgery.

Feasibility

As was discussed in the previous article by the same authors, the total hip arthroplasty module is feasible to complete prior to commencing *in vivo* surgery.[15] This is further reinforced this study where half of the participants were able to complete the module 25–31.5 min (Fig. 1a). In combination with a VR hub, which would be ready and set up for a trainee to use, would limit the amount of total time including setting up, travelling to the VR hub and others. Not only was this a reasonable and short time to complete the module, but users completed a majority of the intra-operative tasks without using the skip function. This is demonstrated in Figure 1b which shows half of the participants completing 80–90% of tasks.

Fidelity

To demonstrate the high fidelity of the system, when impacting the femoral broach with the mallet (held by one haptic arm), the hand holding the haptic arm for the broach is palpably and visibly struck

Table 1 The current level of medical training of the participants as well as their response to the question, 'What is the highest level of expertise you think the current technology is most helpful for training?'

	Current level of training	The highest level of expertise participants think VR is most helpful for training?
Medical student	6	0
Intern/Resident	7	2
Non-training Orthopaedic Registrar	4	9
Training Orthopaedic Registrar	2	7
Fellow/Junior Consultant (within 2 years of obtaining fellowship)	2	1
Senior Consultant	3	5
Total	24	24

by the other hand (virtually) as seen in Figure 2d. The same occurs during acetabular shell placement (Fig. 2b). Contours such as that of the femoral neck are palpated in the haptic environment while drawing a planned cut level with the diathermy (Fig. 2a). In addition, for the anterior hip arthroplasty module, intra-operative radiographs can be obtained for cup reaming and definitive cup placement (Fig. 2c). Despite high fidelity with instrumentation using this system, it is limited to this as there is no means of delivering feedback without the haptic arms. Therefore, the user is not able to experience feedback for steps that do not require the use of instruments, for example, dislocating the hip.

Advantages of the software

To the authors' knowledge, the haptic technology created by Fundamental Surgery is the only virtual reality simulator that provides the operator the element of real-world feedback. This provides a colossal advantage when using the technology in upskilling a profession so highly dependent on psychomotor skills as well as consolidating specific motor tasks through repetition.

As reported on the Likert scale, it was found that participants found that on average that completing the module was enjoyable to very enjoyable (rating 4.2 out of 5). The experience was enjoyable enough that large majority (88%) of the participants would recommend using the technology to a colleague. This majority positive feedback on enjoyability of the technology likely stems from the modules immersion factor and providing both visual and tactile feedback to the user which is very novel to the population of the participants in Australia.

Limitations of software

Fundamental Surgery represents some of the latest technology that utilizes both visual input as well as haptic feedback for the operator. However, there are limitations to the technology. When using the Fundamental Surgery VR system, an error that is evident during use is the presence of ghosting. This is when the haptic arms are placed in an impossible place in virtual space which can lead to virtual tool getting stuck. This was found to be the case in our previous feasibility study with use of the same software and hardware.

Furthermore, an intrinsic limitation of using these haptic arms is that they must be connected to a base to deliver physical feedback to the user. This means that the tools in the user's hands can be limited due to this connection which does not reflect a true *in vivo* surgery. The physical attachment between the instrument and can act like a barrier during arm movements and this is not reflected in the visual experience in the software therefore acting like an invisible barrier to the user. Additionally, these arms can be fragile and not much force can be applied through them. This can be a challenge given the need to generate a large amount of force during orthopaedic operations and more operation adverse surgeons may be susceptible to damaging the hardware. By contrast, those who are just learning the motor patterns and skills may not find that the feedback given by the haptic arms are significantly lower force when they start to operate on patients.

Future applications

With the rise of more sophisticated and precise three-dimensional imaging, the possibility of reconciling this with VR technology has great potential. This would enable the creation of a library which can be used as a resource of complicated and variant anatomy

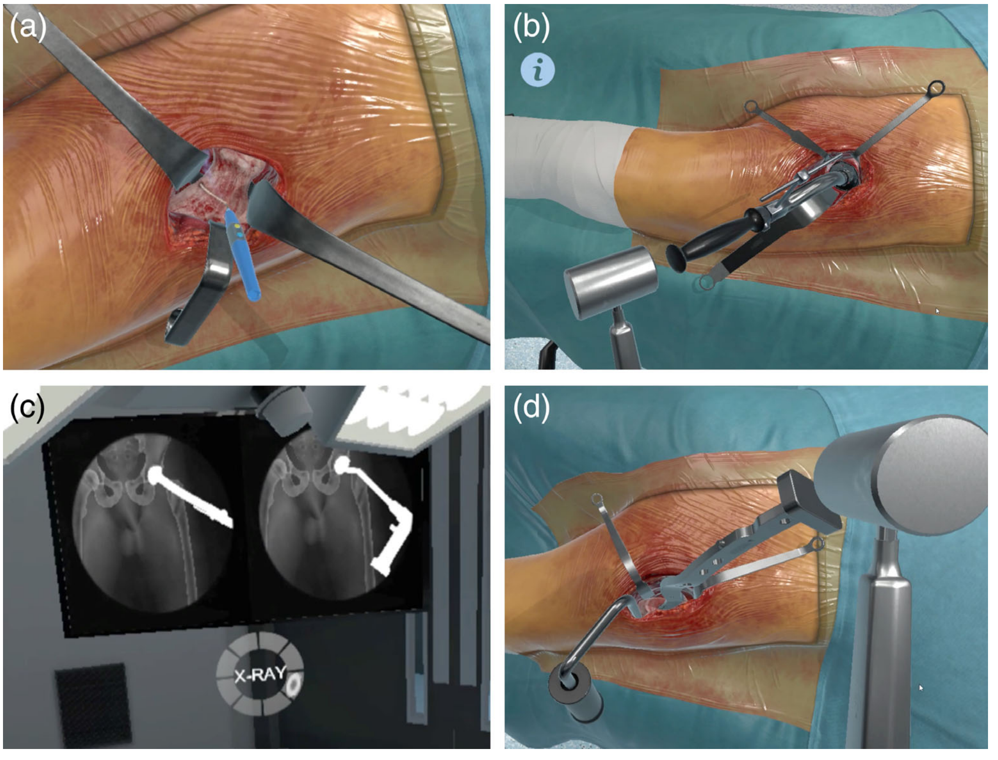

Fig. 2. Showcases the key features of the haptic arm setup and the virtual environment from the perspective of the user. (a) Marking the femoral neck with diathermy, (b) acetabular component insertion, (c) intra-operative radiographs obtained and (d) femoral broaching.

which may help guide junior surgeons in particular with complex patients. The other use case scenario is greatly increasing the individualized care a patient may receive by mapping out their particular anatomy for the surgeon to prime themselves prior to performing an operation.

Furthermore, the focus of this study was on the utility of using VR technology using an instantaneous point in time for assessment. Therefore, future studies on the same topic may explore how psychomotor skills improve over time and how this compares with training with traditional cadaveric models.

Author contributions

Allan Le: Formal analysis; investigation; methodology; writing – original draft; writing – review and editing. **Anton Philip Lambers:** Conceptualization; investigation; methodology; writing – review and editing. **Andrew Fraval:** Writing – original draft. **Andrew Hardidge:** Conceptualization; visualization; writing – review and editing. **Jitendra Balakumar:** Funding acquisition; resources.

Conflict of interest statement

None declared.

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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:

Figure S1. Depicts a participant completing the module and the recommended set up of hardware package as per fundamental surgery guidelines.