Research Paper
Virtual Reality

An innovative virtual reality training tool for orthognathic surgery

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Abstract

Virtual reality (VR) surgery using Oculus Rift and Leap Motion devices is a multi-sensory, holistic surgical training experience. A multimedia combination including 360° videos, three-dimensional interaction, and stereoscopic videos in VR has been developed to enable trainees to experience a realistic surgery environment. The innovation allows trainees to interact with the individual components of the maxillofacial anatomy and apply surgical instruments while watching close-up stereoscopic three-dimensional videos of the surgery. In this study, a novel training tool for Le Fort I osteotomy based on immersive virtual reality (iVR) was developed and validated. Seven consultant oral and maxillofacial surgeons evaluated the application for face and content validity. Using a structured assessment process, the surgeons commented on the content of the developed training tool, its realism and usability, and the applicability of VR surgery for orthognathic surgical training. The results confirmed the clinical applicability of VR for delivering training in orthognathic surgery. Modifications were suggested to improve the user experience and interactions with the surgical instruments. This training tool is ready for testing with surgical trainees.

Key words: 3D; virtual reality; Oculus Rift; Leap Motion; surgery

~~Introduction~~There has been an upsurge in advancements in surgical training methods and tools in the last century[1]. Training in surgery requires broad clinical exposure and adequate supervision[2–7]. A lack of training facilities may compromise the quality of care delivered to patients[8,9].

This article reports on innovative research in which a virtual reality (VR) and immersive virtual reality (iVR) experience in the field of orthognathic surgery (mainly Le Fort I maxillary osteotomy) was designed, validated, and evaluated. The objective of this study was to test the validity and usefulness of VR surgery for surgical training. The primary objective was to explore the validity of VR as a valid training tool for Le Fort I osteotomy. The secondary objective was to test the usability of VR surgery, with regard to its possible inclusion in the current surgical training curriculum, using a panel of expert surgeons.

Materials and methods

Development of VR surgery

VR surgery is a holistic learning application that provides an uninterrupted close-up surgical training experience[10]. The Oculus Rift Development Kit 2 (DK2) VR headset and a Leap Motion controller were used in the application. The three essential elements used to develop the VR surgery experience were a 360° recording of an operating room, close-up stereoscopic visualization of surgery, and three-dimensional (3D) interaction.

To create a 360° operating room, spherical videos and computer-generated 3D models of an operating room were used. Six GoPro Hero cameras recorded the operating room from all angles. By ‘stitching’ the individual videos from each of these cameras together[11], a spherical video was created, as shown in Fig. 1. The 360° video creates a sense of presence in the operating room when watched on a head-mounted display, such as an Oculus Rift headset. It can also be viewed on a desktop with a 360° video viewer[12].

Fig. 1 360° video of the operating room.

alt-text: Fig. 1

The Le Fort I osteotomy display was subdivided into four sections: soft tissue reflection, osteotomy of the maxilla, bone fixation, and suturing. Each section showed a sequence of stereoscopic 3D videos representing different steps of surgery. These videos were recorded using a Sony 3D camera (HXR-NX3D1E; Sony, London, UK) and arranged in a sequence following the human factors methodology of the cognitive task analysis technique[13]. Further, 3D models of the head and neck anatomy and 3D surgical instruments were achieved using modelling software and 3D photogrammetry techniques. The users were able to choose the surgical instruments and manipulate the tool for the applications at various anatomical sites in order to achieve the desired surgical movements.

A Leap Motion sensor, which tracks the movements of the hands to provide a multi-sensory interactive learning experience, was included in the application[14]. Natural user interfaces were designed to show a menu that allows the user to select different parts of the application. A facility that allows the user to zoom the size of the content using specific gestures, pause a specific part of the surgery, and interact with the anatomy and surgical instruments, was added, as shown in Fig. 2. Additionally, a computer-generated model of the operating room was included to allow the trainees to navigate and interact with 3D models of the patient's data. Data from cone beam computed tomography (CBCT) scans, stereophotogrammetry, and the soft tissue prediction planning were used in the application, as shown in Fig. 3. A quiz scene was also added to test user knowledge on the subject. The developed application was designed to lend itself to the inclusion of other surgical procedures.

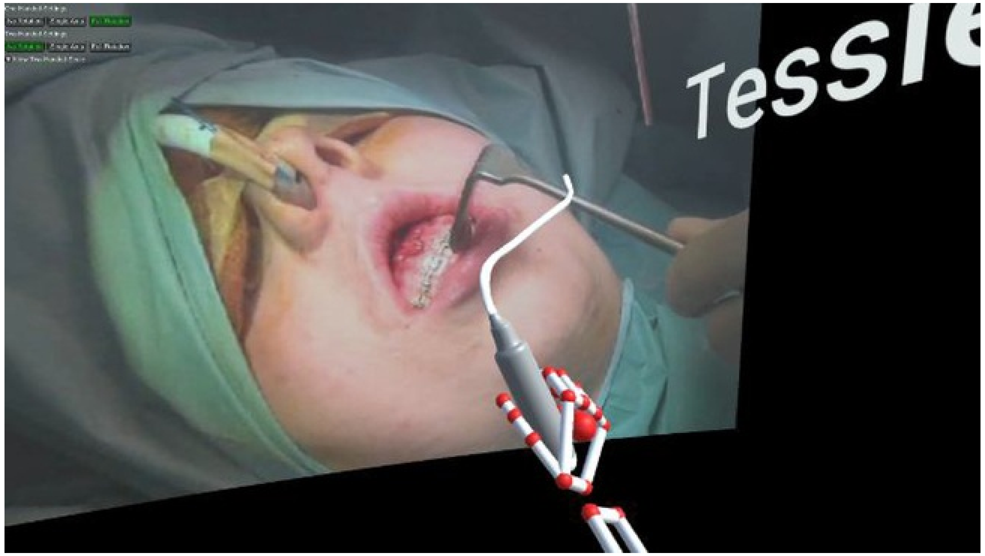

Fig. 2 Interaction with the instruments while watching the stereoscopic 3D videos of surgery.

alt-text: Fig. 2

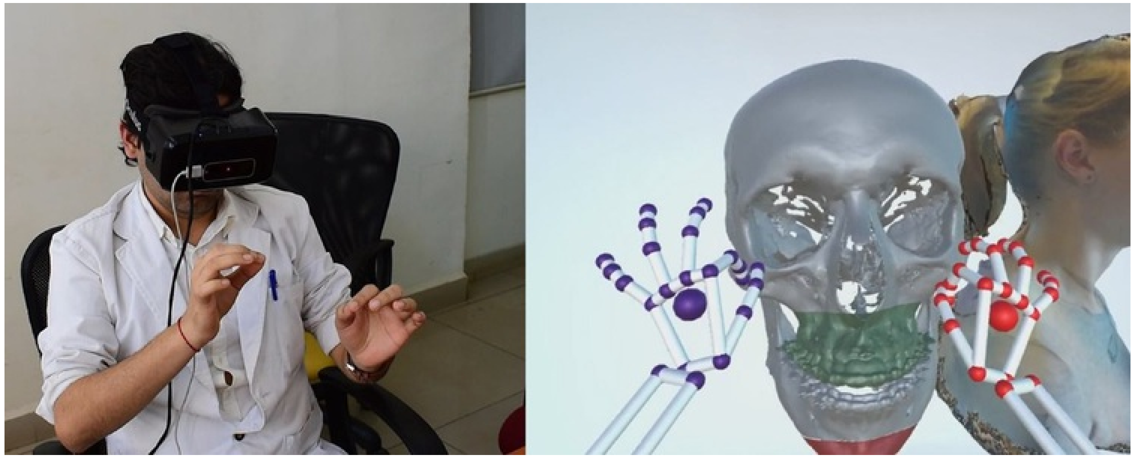

Fig. 3 3D interaction with the patient's CBCT data.

alt-text: Fig. 3

Evaluation of the developed VR surgery

Expert oral and maxillofacial surgeons in various National Health Service (NHS) authorities across the UK tested the validity of the VR surgery for its content and functionality, and the usability of the application. This study was designed based on previous research on face and content validity for VR surgical simulators[15]. Ethics approval was obtained for this study from the School of Art, Design and Architecture Ethics and Integrity Committee, Huddersfield University.

Nine consultant surgeons volunteered to participate in the validation process. Following instructions on safety measures before use of the Oculus Rift headset, all participants were asked if they suffered from any psychiatric disorders (including attention deficit hyperactivity disorder or epilepsy), or if they were on any antipsychotic drugs. Any previous history of motion sickness or seizures was considered an exclusion criterion. The implementation of the study followed the sequence as shown in Fig. 4.

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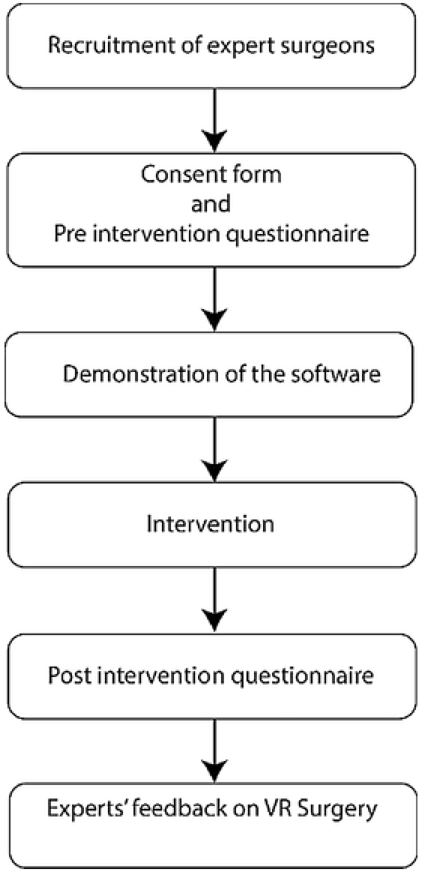

Fig. 4 Flow diagram for the validity study.

alt-text: Fig. 4

Two separate questionnaires were used to check the validity of VR surgery: a pre-intervention questionnaire to understand the training needs and a post-intervention feedback questionnaire to comment on the efficacy, usability, and acceptability of the system. The questions were developed based on previous face and content validity tests and working with expert surgeons in oral and maxillofacial surgery[16].

Questions specific to Le Fort I osteotomy, including technical challenges and the common human errors, were asked. Specific questions regarding the types of educational methods currently used to deliver training were included. The user's expectations regarding how the new technology could influence their satisfaction levels in improving non-surgical skills were considered[17,18]. The questionnaire also explored the consultants' previous experience of using head-mounted surgical displays to determine whether they were familiar with the technology. Questions regarding awareness and certification for the non-technical skills for surgeons (NOTSS) were asked.

Following a structured session of demonstrating the innovative technology and allowing the participants to experience its facilities, a post-intervention questionnaire on the content, usability, and application of the developed tool in training was conducted. A five-point Likert rating scale was used to rate the quality of the videos and the 3D models of the instruments and anatomy. The following scoring elements were used: 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree (neutral), 4 = agree, 5 = strongly agree. Space for additional open comments was provided, and the participants were encouraged to make use of it. Additional suggestions regarding future developments needed in the application were taken from the surgeons. The participants commented on the quality of the videos and 3D models of the instruments and anatomy. The experts rated the comfort of using the headset and the accuracy and appropriateness of hand tracking based on the system usability scale of Bangor et al.[19].

The last section of the questionnaire focused on the potential applications of the VR surgery in training surgical trainees. Their opinions on the use of the VR surgery for training, benefits of its use for multiple procedures, and acceptability for inclusion in the curriculum were questioned. In line with current studies, participants were asked if they considered VR surgery an effective adjunct to current training methods[20]. The effectiveness of VR surgery with regard to self-confidence and knowledge of trainees was also investigated. A question regarding the inclusion of non-technical skills was added to the feedback. Both the pre- and post-intervention questionnaires are available in the.

IBM SPSS Statistics for Windows, version 22.0 (IBM Corp., Armonk, NY, USA) was used for the data analysis. Descriptive statistics showed the frequencies and mean values, and the type of data was ordinal.

Results

Seven of the nine expert surgeons completed the questionnaires. The mean age of the participants was 41.8 years. All of the participants were male and they had a mean surgical experience of 15.5 years. None of the consultants had previous experience in using a head-mounted display for training. The consultants suggested that learning in the operating room is the best form of training, and four of them mentioned that educational videos are currently used as an adjunctive method of training. All of the surgeons reported bone cuts as the most difficult step while training novices in Le Fort I osteotomy in their questionnaire answers.

With regard to the validity of the content of the surgical video clips within the application, the mean score was 4.28, showing strong agreement. The mean score for the benefits of the various components of the application was 4.46. The responses to the individual questions on the quality of the content are shown in Fig. 5. Overall, the mean scores for the content of the application showed agreement with the validity of the developed innovation.

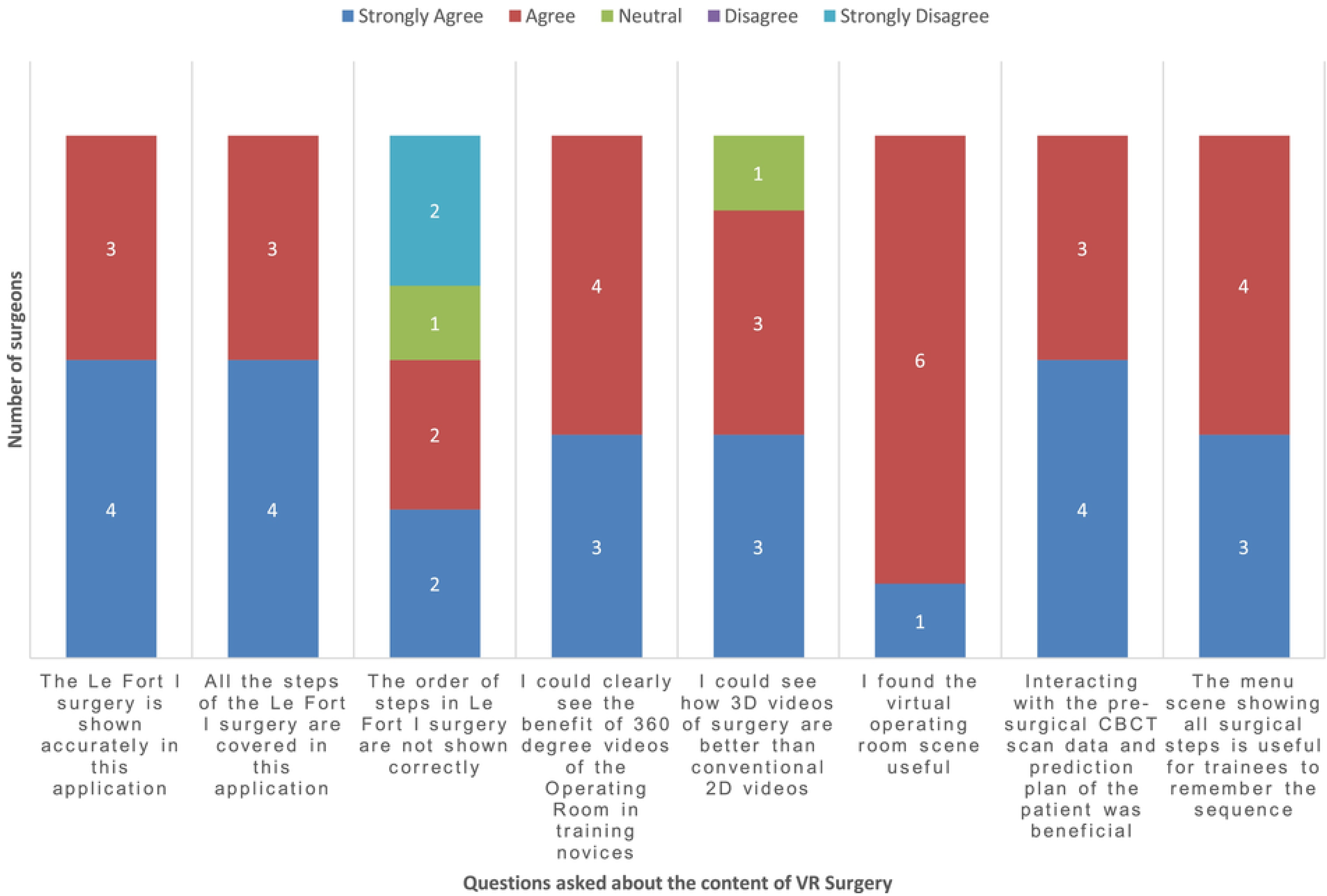

Fig. 5 Responses to the questions regarding the content of VR surgery.

alt-text: Fig. 5

The mean score for the appearance, use, and realism of the developed training tool was 3.92 out of 5. The questions regarding the anatomy in the application scored 4.53, showing strong agreement with the face and content validity. The responses to the individual questions on the quality of the anatomy are shown in Fig. 6.

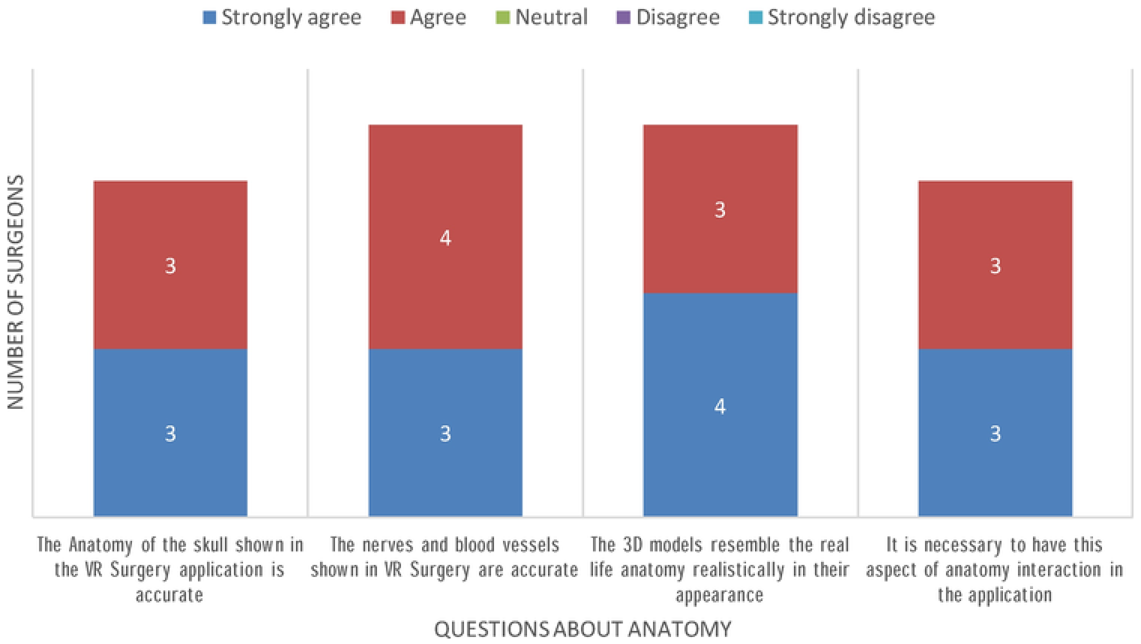

Fig. 6 Responses to the questions regarding the quality of the anatomy in the application.

alt-text: Fig. 6

When asked about the applicability of VR surgery to the current curriculum, the experts rated the application with a mean value of 4.53. Figure 7 shows the responses to the individual questions on the applicability of the developed VR surgery for surgical training. In contrast to the previous research, three surgeons commented that VR surgery represents a necessary addition and not an adjunct to current training methods.

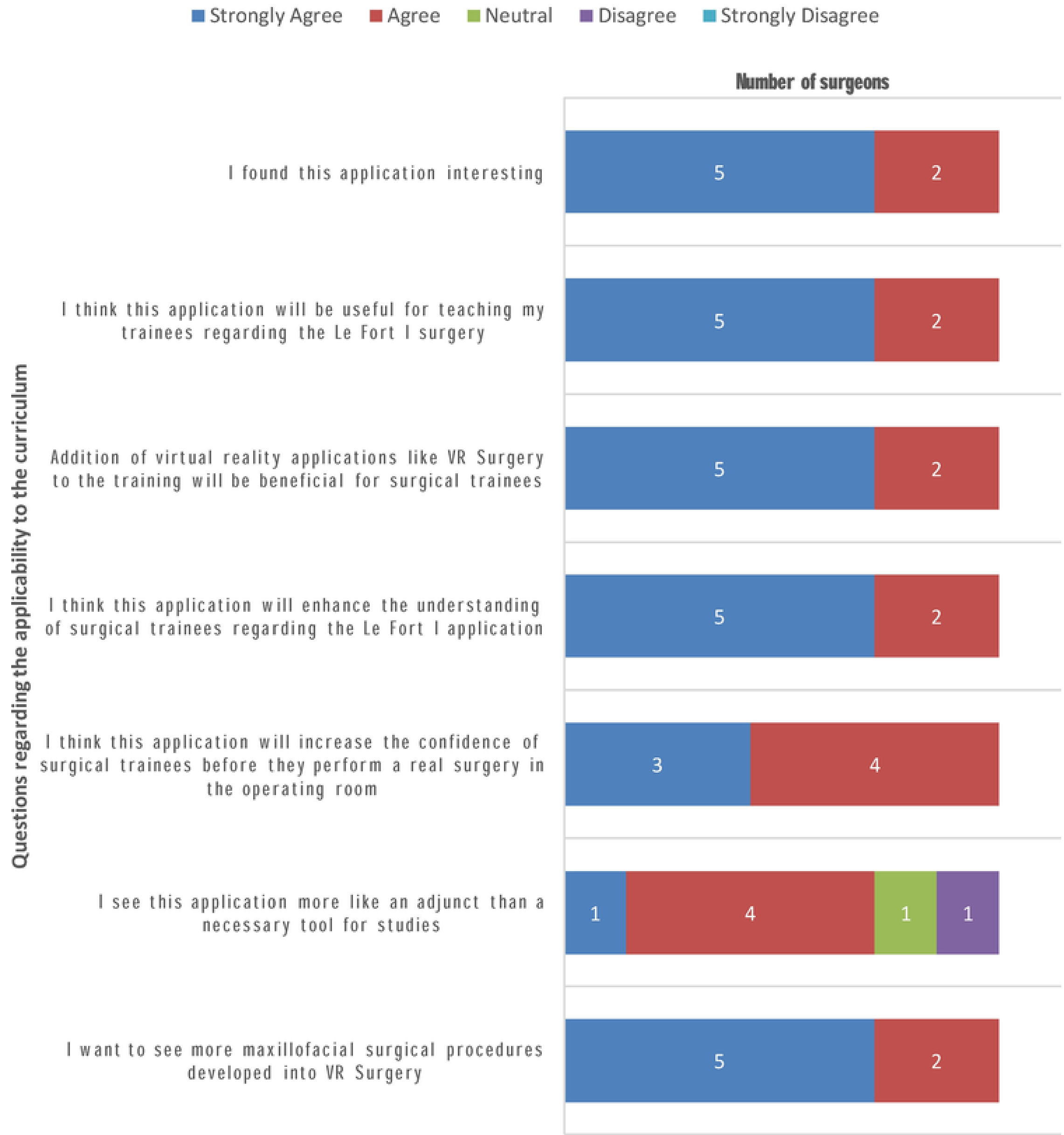

Fig. 7 Responses to the questions regarding the applicability of VR surgery to the curriculum.

alt-text: Fig. 7

The mean score for the various questions regarding the ease of use and hand tracking was 4.05. The responses to the individual questions on the usability of the VR surgery are shown in Fig. 8. Overall, the surgeons ranked VR surgery as a valid training tool, as shown in Fig. 9.

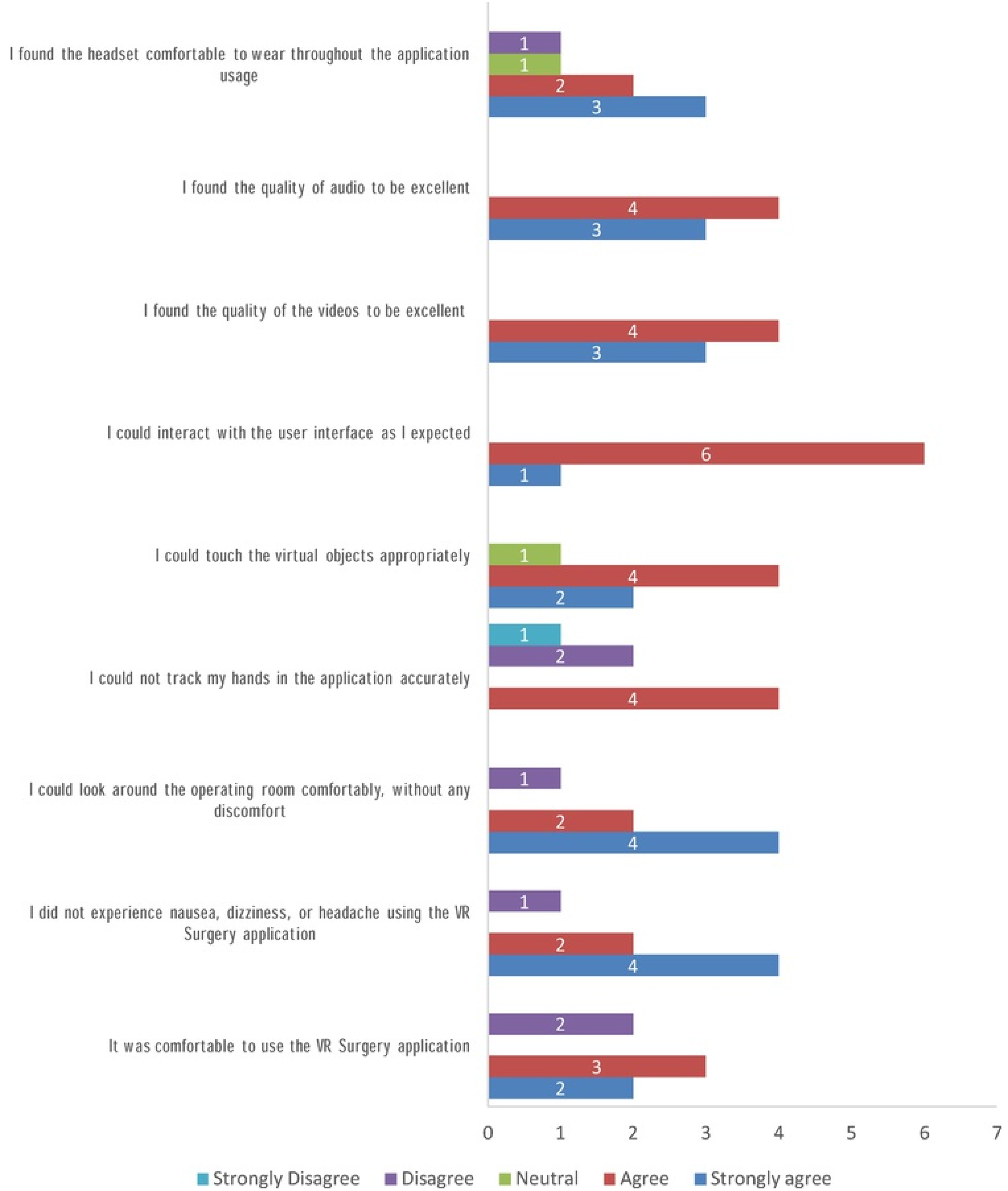

Fig. 8 Responses to the questions regarding usability.

alt-text: Fig. 8

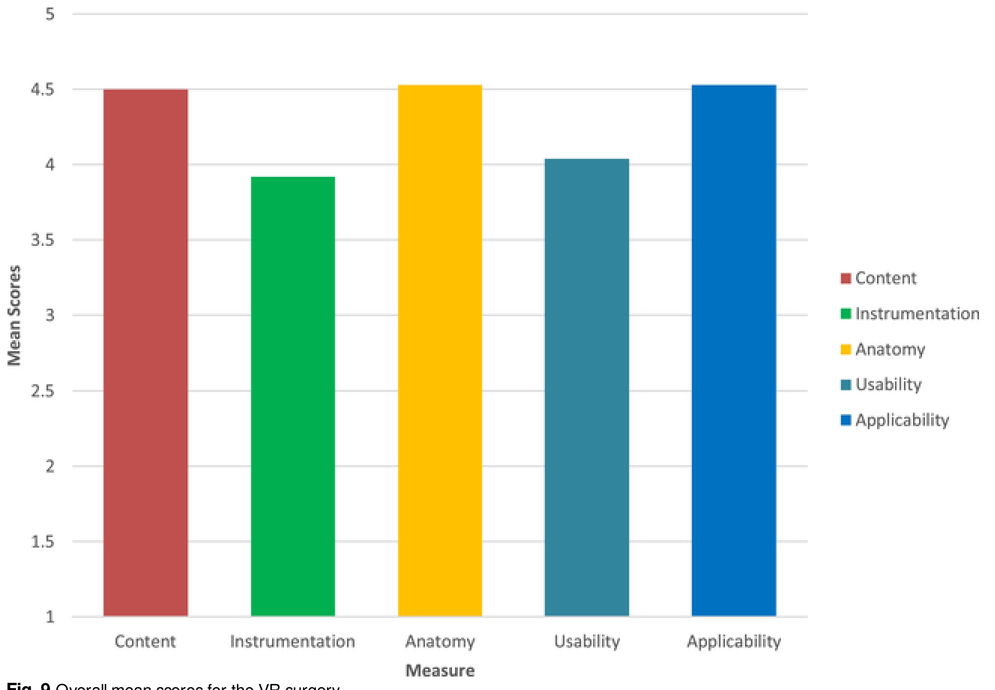

Fig. 9 Overall mean scores for the VR surgery.

alt-text: Fig. 9

Discussion

The results showed agreement among the experts regarding the face and content validity of VR surgery. The experts found VR surgery easy to use, following a short learning curve of about an hour before getting used to the sensitivity of head tracking and interaction. To further shorten the learning curve, a tutorial was introduced, which gives a hands-on demonstration before use of the application.

The surgeons felt that the advantage of VR surgery lies in its interactivity. They suggested that the addition of haptic force feedback and realistic interaction with 3D models of instruments would enhance the experience. The ability to pause the surgery and take part in it virtually was also recommended. The interactive 3D anatomy and instruments were the most appreciated features in the application, alongside the 360° video of the operating room. The addition of multiple levels of complexity for basic, intermediate, and advanced levels of training was also suggested.

The surgeons commented on the reduced quality of the stereoscopic 3D videos on the Oculus Rift DK2 headset. This was due to the screen door effect[21], where the user perceives a grid of fine lines due to the space between the pixels on a low-resolution screen. This effect is more pronounced when a low-resolution LCD screen is placed only inches away from the eyes. Currently available VR headsets have improved their resolutions considerably.

A key strength of this study is the combining of technology (VR, motion detection), cognitive science, and surgical knowledge to create an evidence-based immersive surgical training experience. The use of natural hand gestures in combination with a 360° VR experience to learn a complex surgery is the core functionality. The validation studies of this research add more value to the work. This research paves the way for potential applications of iVR experiences for other surgical procedures, including the removal of impacted teeth, raising a flap, and cancer resection.

Technological limitations of this research include the lack of haptic force feedback. The availability of suitable technology and time constraints in developing a realistic haptic force feedback prevented this from being implemented. However, future research on VR surgery aims to include haptic feedback in the application. This will be considered the next phase of the current research programme. The need for expensive headsets and high-specification computers makes desktop VR applications unaffordable for individual surgical trainees. The development of a low-cost version using Google Daydream or Google Cardboard will be key to addressing this issue[22]. In this study, the validation of VR surgery was limited to face and content validity tests. Due to the early stage of development of the system and time constraints, objective validity tests including concurrent, construct, and external validity were not performed.

As commercially available VR and augmented reality experiences are increasingly used for surgical training[23], a framework to build effective iVR solutions is needed. This research attempted to address that challenge by using a three-step process of build, evaluate, and iterate with expert surgeons and trainees. Further, for global application of these emerging technologies, they should be made more affordable so that they can be extended to low- and middle-income countries (LMIC) with maximum need. Once the challenges are met, applications like VR surgery will provide an alternative way of learning and could reduce the time taken to train surgeons in the operating room[24]. Moreover, the ability to experience surgery remotely will change the way surgeons learn in many ways.

The main limitation of this study is that fact the technology developed was evaluated by expert surgeons. It is the authors' intention to recruit trainees in order to assess this innovation further.

In conclusion, the VR-based training instrument developed has a satisfactory level of validity and so can be tested among surgical trainees in oral and maxillofacial surgery to augment their non-surgical expertise and increase their knowledge on orthognathic surgery.

Funding

None.

Competing interests

None.

Ethical approval

Approval to conduct the study was obtained from the School of Art, Design and Architecture Ethics and Integrity Committee, Huddersfield University, UK.

Patient consent

Not applicable.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ijom.2018.01.005.

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Appendix A. Supplementary data

The following is Supplementary data to this article:

Multimedia Component 1

Queries and Answers

Query: The author names have been tagged as given names and surnames (surnames are highlighted in teal color). Please confirm if they have been identified correctly.
Answer: Yes

Query: “Your article is registered as a regular item and is being processed for inclusion in a regular issue of the journal. If this is NOT correct and your article belongs to a Special Issue/Collection please contact j.faur@elsevier.com immediately prior to returning your corrections.”
Answer: This is correct

Query: “Both the pre- and post-intervention questionnaires are available *in the*.” This sentence remains incomplete. Please amend (“…in the *Supplementary Material*”?) or delete.
Answer: Please delete this statement.

Query: “In contrast to *the previous research*, three surgeons commented that VR surgery represents a necessary addition and not an adjunct to current training methods.” What previous research? Should this read: “In

contrast to the results of the pre-intervention questionnaire…"? Or other?
Answer: Please delete 'in contrast to the previous research" It should read: "Three surgeons commented that VR surgery represents a necessary addition and not an adjunct to current training methods."

Query: Sentence "The development of a low-cost version using *Google Daydream, Google Cardboard*[22], will be key to addressing this issue" in the revision has been changed to "The development of a low-cost version using *Google Daydream or Google Cardboard* will be key to addressing this issue[22]." Is this correct?
Answer: The development of a low-cost version of VR Surgery for devices such as Google Daydream and Google Cardboard, will be key to addressing this issue.

Query: Please note that file named "Pulijala 1475891_Validity Study.docx" has been treated as Supplementary material, please check and correct if necessary.
Answer: Thats fine.

Query: One or more sponsor names and the sponsor country identifier may have been edited to a standard format that enables better searching and identification of your article. Please check and correct if necessary.
Answer: Thats fine.

Query: Ref. 7: 'Br J Oral Maxillofac Surg' has been changed to 'Br J Surg'. Please confirm that this is correct.
Answer: Yes, 'Br J Surg' is correct.

Query: Author name 'Mehta' was changed to 'Ehta' in the revision; however the name is given as Mehta on the title page of the article (http://ijettjournal.org/volume-13/number-4/IJETT-V13P237.pdf), so has been left as 'Mehta'. Please confirm that this is correct.
Answer: Mehta is correct. Thank you

Query: Fig. 5: the third statement is "The order of steps in Le Fort I surgery are *not* shown correctly" This is the only 'negative' statement in the list. Disagreement would be positive. Is this statement correct?
Answer: "Yes, that is the only negative statement. Disagreement to it will be positive." However, we found that only 3 surgeons realised it as a negative statement within the options.

Query: Fig. 6: first and fourth statements have only six responses and not seven. Is this correct?
Answer: A new attachment is made to correct the changes in Fig. 6

Query: Fig. 7: the second statement is "I see this application more like an adjunct than a necessary tool for studies" This is the only 'negative' statement in the list. Disagreement would be positive. Is this statement correct?
Answer: Yes, this is a negative statement and the disagreement would be positive.

Query: Fig. 8: the sixth statement is "I could not track my hands in the application accurately" This is the only 'negative' statement in the list. Disagreement would be positive. Is this statement correct?
Answer: Yes, this is a negative statement and the disagreement would be positive.