Chapter 8
VR Surgery: Interactive Virtual Reality Application for Training Oral and Maxillofacial Surgeons using Oculus Rift and Leap Motion

Yeshwanth Pulijala, Minhua Ma, and Ashraf Ayoub

Abstract VR Surgery is an immersive virtual reality operating room experience for trainee surgeons in oral and maxillofacial surgery maxillofacial surgery. Using a combination of Oculus Rift head-mounted display, Leap Motion tracking devices, high-resolution stereoscopic 3D videos and 360-degree videos, this application allows a trainee to virtually participate in a surgical procedure and interact with the patient's anatomy. VR Surgery is highly useful for surgical trainees as a visualisation aid and for senior surgeons as a practice-based learning tool. This chapter discusses the need for reforms in the existing surgical training methods and a brief review on simulation, serious games and virtual reality in surgical training. Following this, the principles of design and development of VR Surgery are presented.

Keywords VR Surgery • Oculus Rift • Leap Motion • Orthognathic surgery • Surgical training • Mixed reality • Immersive reality • Virtual reality • 360-degree video

8.1 Introduction

According to a Lancet report released in 2015 (Meara et al. 2015), 5 billion people in the world lack access to safe and affordable surgery. To meet this challenge, an additional 2.2 million surgeons, anaesthetists and obstetricians are needed in the next 15 years, which is unlikely to happen with the current methods of surgical education (Meara et al. 2015).

Y. Pulijala (✉) • M. Ma
School of Art, Design and Architecture, University of Huddersfield, Huddersfield, UK
e-mail: Yeshwanth.Pulijala@hud.ac.uk; m.ma@hud.ac.uk

A. Ayoub
Glasgow Dental School, University of Glasgow, Glasgow, Scotland, UK
e-mail: ashraf.ayoub@gla.ac.uk

M. Ma, A. Oikonomou (eds.), *Serious Games and Edutainment Applications: Volume II*, DOI 10.1007/978-3-319-51645-5_8

Conventionally, surgical residents learn through observation and hands-on participation in the operating room sessions following a structured training programme. This process, termed as Halsted's method of learning (Kerr and O'Leary 1999), has been in practice for more than a century now. Gradual changes in the learning methods led to the introduction of more hands-on approach where surgical trainees assist and perform parts of the procedure under the guidance of an experienced surgeon (Reznick 1993). In addition to these sessions, trainees undergo rigorous practice in surgical skill labs to improve their manual skills including hand-eye coordination. In spite of all these training methods, four out of every ten novice surgeons are not confident in performing a major procedure (Rodriguez-Paz et al. 2009, Geoffrion et al. 2013). Further, overcrowded operating rooms, reduced training hours and poor visibility of surgical site are multiplying the intensity of their problem. The VR Surgery project was designed to meet this need in surgical training by providing cognitive training for maxillofacial surgeons.

This chapter explains the VR Surgery project and its role in enhancing surgical education. It is divided into three parts: the first part elaborates on the existing methods of surgical training and need for their transformation; the second part reviews the application of simulation, serious games and virtual reality (VR) techniques for surgical training purposes; and the third part outlines the design and development process and challenges encountered in the VR Surgery project. It is then followed by a discussion on the current state of immersive experiences available for surgical training.

8.1.1 Surgical Training and Its Challenges

Surgical training comprises of two major aspects, namely, technical skills and non-technical skills (Yule et al. 2006). Technical skills are those manual skills required to perform the surgery, which are learned traditionally through mentoring and hands-on practice (Satava et al. 2003). The majority of the existing surgical training suites focus more on the technical skills (Wingfield et al. 2014). However, studies concerning major mishaps in operating room have found that the underlying causes for the errors are poor non-technical skills of the surgeons (Bogner 1994; Fletcher et al. 2004, Dedy et al. 2016). Non-technical skills include interpersonal communication, cognitive skills and diagnostic and decision-making skills, amongst others. Lack of proper cognitive skill training beforehand was found to cause major mishaps in the operating room (Wingfield et al. 2014). Some researchers (Aggarwal et al. 2004, Hull et al. 2012) have highlighted the potential application of non-technical skills training in future simulations. A study on teaching in operation theatres by Roberts et al. (2012) suggested that even though the technical skills can be mastered in skill laboratories and virtual simulations, teaching within operating room remains the cornerstone for surgical education. Lyon (2004) reported that 'operation theatre provides a sensory perceptual experience' to help students develop a 'clinical memory' of the procedure. Students get to observe the involved pathology, touch and understand its spatial location and visualise the surgery at a greater detail. However, restricted resident training hours severely affected teaching within the operation theatre (Kapralos et al. 2014; Royal college of surgeons 2014). The reduction in training hours also reduced the interaction between the trainer and the trainee affecting their teamwork and communication skills (Hartle et al. 2014). Further, less working hours has increased pressure on faculty to hike their productivity (AAMC 2010), negatively affecting the teaching within the operation theatre (Kapralos et al. 2014). A solution for this problem as suggested by Roberts et al. (2012) is for surgeons to identify alternative innovative methods of training.

8.2 Innovation in Surgical Training Methods

Efforts to find suitable adjunctive to conventional training methods led surgeons to use simulation, serious games and virtual reality for training novice surgeons, just like flight simulators for pilots (Jackson and Gibbin 2006). The following is a brief review of advances in surgical training methods.

8.2.1 Surgical Simulation

Simulation provides surgeons with a safe and repeatable environment for practising their skills without causing any damage to the patient (Issenberg et al. 1999). Multiple studies (Evgeniou and Loizou 2012; Kapralos et al. 2014) have confirmed the positive implications of virtual reality and simulation for surgical training purposes including skill transfer (Sturm et al. 2008) and improvement in training efficiency (Gurusamy et al. 2008). They also help in shortening the learning curve of surgeons (Patel et al. 2006). Based on the technology used and the complexity of skills trained, the classification of simulators was made by researchers (Torkington et al. 2000). Simulators used in surgical training varied from physical simulators to computer-based virtual reality simulators (Sutherland et al. 2006). Physical simulators include cadavers, animal models and inanimate plastic models, foam suturing pads and box trainers for laparoscopic surgeons (Huynh-Thu et al. 2011; Vitish-Sharma et al. 2011). However, while physical models suffered from a lack of realism, cadaveric dissections suffered from a lack of their availability, legal restrictions and ethical concerns limiting their usage. These factors pushed researchers more towards technology-based surgical simulations including serious games and virtual reality experiences (Sarker and Patel 2007). Moreover, virtual reality-based simulators were found to be more effective in training surgeons than physical simulators (Orzech et al. 2012). However, lack of out of hour's access and reduced availability to trainees in the first 3 years of surgical training also highlight a major need to be met in developing future surgical simulators. In addition to these challenges, the high cost of production and investment in developing realistic surgical simulations prevents a worldwide acceptance of these simulators.

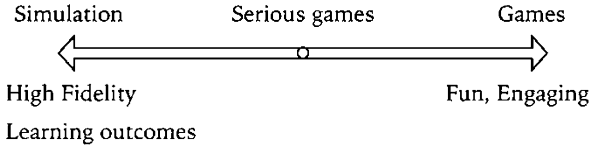

Fig. 8.1 Differences between simulations and games (Graafland et al. 2012)

8.2.2 *Serious Games for Surgical Training*

Unlike simulations and games, serious games provide measurable learning outcomes in a fun and engaging manner (Graafland et al. 2012) as shown in Fig. 8.1. A detailed systemic review on the application of serious games in surgical training by Graafland et al. (2012) showed the gamification of surgical education for decision-making, teamwork and cognition. Issenberg et al. (2005) detailed the essential aspects of simulations which can improve learning in medicine are feedback, ability to practice repeatedly and introduction into the curriculum. Serious games with competitive elements including challenge-driven practice and incentives-driven scoring techniques were found to play a major role in surgical training (de Wit-Zuurendonk and Oei 2011).

Challenge-driven serious games can be applied where repeated practice is necessary to gain expertise, such as decision-making skills. Intraoperative decision-making, one of the essential skills for surgical trainees, can be learned through this technique (Michael and Chen 2005) as serious games provide an opportunity for deliberate practice till a level of expertise is reached. Another application of gaming element for decision-making is seen in a mobile app, Touch Surgery (Surgery 2015). This application trains the cognitive skills of surgeons through cognitive task analysis method (Wingfield et al. 2014) and tests decision-making skills. In addition to the above-mentioned aspects, feedback in learning, intrinsic scoring and multiplayer performance in serious games help the trainees to practice their teamwork skills. When such serious games are applied in a clinical environment (Kneebone 2009), they will reinforce the communication and teamwork skills necessary to practice in real-life emergencies. However, serious games suffered from a lack of fidelity, high investment involved and low immersion of users when not displayed on virtual reality devices.

8.2.3 *Immersive Virtual Reality in Surgical Training*

Immersive virtual reality experiences provide a sense of ‘presence’ to the user. They require the user to wear a head-mounted display or goggles to engage visual senses, headphones to engage auditory senses and occasionally gloves to engage tactile sense. The first immersive experience was created using a mechanical device called the Sensorama. Rapid advances in technology and research led to the introduction of commercially available high-quality immersive virtual reality devices including Oculus Rift (Te 2015), HTC Vive (2015), Gear VR (Samsung 2015) and Google Cardboard (Google 2015). Amongst these devices, Gear VR and Google Cardboard create a portable virtual reality environment as they work with smartphones.

Applications of Oculus Rift in medical education started with anatomy applications (Carson 2015), whereas their role in surgical education began with MOVEO Foundation (Rousseau 2014). The first immersive surgical experience was recorded using a head-mounted Dual Hero GoPro camera rig to provide a first-person perspective of the surgical process. Immersive technologies are ideal for surgeons to experience real-life scenarios, which are not faced frequently in their regular practice (Moorthy et al. 2006). A realistic simulation of operating room on these devices can cut down the costs spent in training surgeons (Bridges and Diamond, ASIT 2015). Oculus Rift-based experiences create the possibility of situated learning (Lave and Wenger 1991) and support the idea of contextualised learning (Kneebone et al. 2004; Kneebone 2009), where surgeons can learn within a clinical environment, such as operating room Paige et al. (2009). Recently, a 360-degree experience of surgery on a head-mounted display was demonstrated by a UK-based colorectal surgeon, Shafi (Quinn 2016), where a surgery to resect cancer was viewed by trainees all over the world. Applications like these show how global inequalities in surgical training can be solved with virtual reality. However, the existing and developing VR surgical training applications suggest the need for more evidence on their impact on surgical training, which the VR Surgery project is aiming to provide.

8.3 VR Surgery

VR Surgery provides an immersive learning experience for surgical trainees through pre-recorded stereoscopic 3D videos of surgery and interactive models of patient's anatomy using an Oculus Rift headset. The surgical procedure demonstrated in this application is Le Fort 1 surgery, a type of maxillofacial surgery, performed to correct lower midface deformities (Miloro et al. 2004). This section discusses the equipment used and the design of VR Surgery application.

8.3.1 Hardware and Software

Oculus Rift head-mounted display is selected due to its availability, cost and efficiency at the time of research. It is also compatible with motion tracking devices such as Leap Motion and Unity3D game engine, which allow development of VR applications. Additionally, strong online support communities of Oculus Rift were useful in building this app.

Fig. 8.2 Six GoPro cameras in freedom 360 setup (Go Pro 2014)

Leap Motion is a motion tracking device which tracks the position of the bones in the hand. This device was chosen for its ubiquity in use, low cost and ease of use with Oculus Rift and Unity3D application. Moreover, it was only the hands that needed to be tracked for this application, and Leap Motion fulfilled the task appropriately.

GoPro 360-degree cameras were used to capture the operating room in 360 degrees as they are small in size, can capture 1080pHD videos and render an easy to edit output. Six GoPro cameras were arranged in a setup as shown in Fig. 8.2 to record the entire operating room in 360 degrees.

Sony 3D stereoscopic cameras were chosen to record the surgery in a close-up stereoscopic manner due to their high quality, low cost and ease of availability.

Unity3D game engine is used to integrate all the components of the application and create a VR application on Oculus Rift due to its cross-platform compatibility and robust functionality. Other softwares used for building the application include Autodesk 123D for 3D scanning, Autodesk Maya for modelling and animation, GarageBand for editing audio and iMovie, Final Cut Pro, Adobe After Effects, Adobe Premiere, GoPro video manager and AutoStitch for editing video and post-production.

8.3.2 Design of VR Surgery

The immersive experience in VR Surgery was designed following multiple steps as shown in Fig. 8.3.

We discuss three components of VR Surgery design elements, i.e. content design, application design and user feedback.

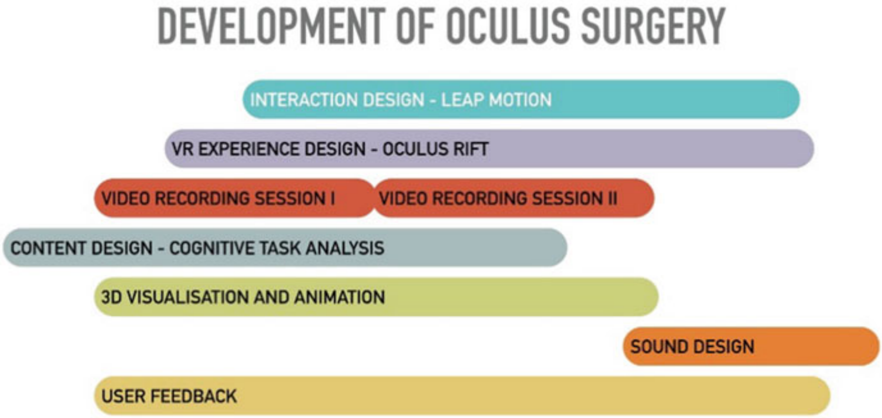

Fig. 8.3 Design elements of VR Surgery

8.3.2.1 Content Design

Maxillofacial surgery involves the surgical procedures of the face and jaws. Orthognathic surgery is one of the types of jaw surgery, which is very complex in nature involving the movement of jaws to correct facial deformities. Due to the level of complexity and lack of innovative training tools, Le Fort procedure (Miloro et al. 2004), a form of orthognathic surgery, was chosen for VR Surgery. Le Fort 1 procedure or horizontal maxillary osteotomy involves the fracture line or osteotomy at the base of the upper jaw above the tooth apices. The surgery was divided into a sequence of logical steps, following cognitive task analysis technique. Cognitive task analysis (CTA) creates a logical sequence of knowledge so that decision-making and other cognitive skills can be learned in a structured approach (Li 2005). Multimedia methods applying cognitive task analysis were found to enhance learning (Luker et al. 2008; Clark et al. 2012; Wingfield et al. 2014). Based on these findings, we split the content in VR Surgery into four steps:

1. Preoperative preparation
2. Soft tissue incision and exposure
3. Bone cuts, disimpaction and mobilisation
4. Bone fixation and suturing

8.3.2.2 Application Design

The application was designed to work in a *see one, simulate* one *and teach one* approach for surgical trainees (Vozenilek et al. 2004). Out of all the three, more focus was laid on the visual experience as it plays a major role in providing a sense of immersion (Huynh-Thu et al. 2011).

Fig. 8.4 Surgical environment for Le Fort 1 surgery

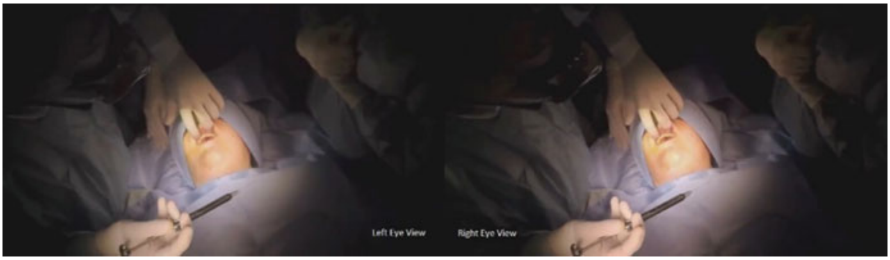

Fig. 8.5 3D video of operating room

See One

Understanding an intricate surgical procedure by watching it over a surgeon's shoulder in a crowded operating room is a challenge (Reid 2007). During maxillofacial surgery procedures, it gets even more challenging to the trainees as there are always up to four hands covering the patient's face as shown in Fig. 8.4. A stereoscopic 3D video was used as shown in Fig. 8.5 to provide a detailed view of the surgical process. This 3D video provides depth perception and realistic view of the surgical procedure (Wagner et al. 2012). On the other hand, the context was found to play an equally important part in addressing the level of immersion (Kneebone et al. 2004). When the context of simulation closely resembles a real-life model, such as an operating room environment, learning was found to be better. To create such an experience, 360-degree video of operating room was introduced in the application.

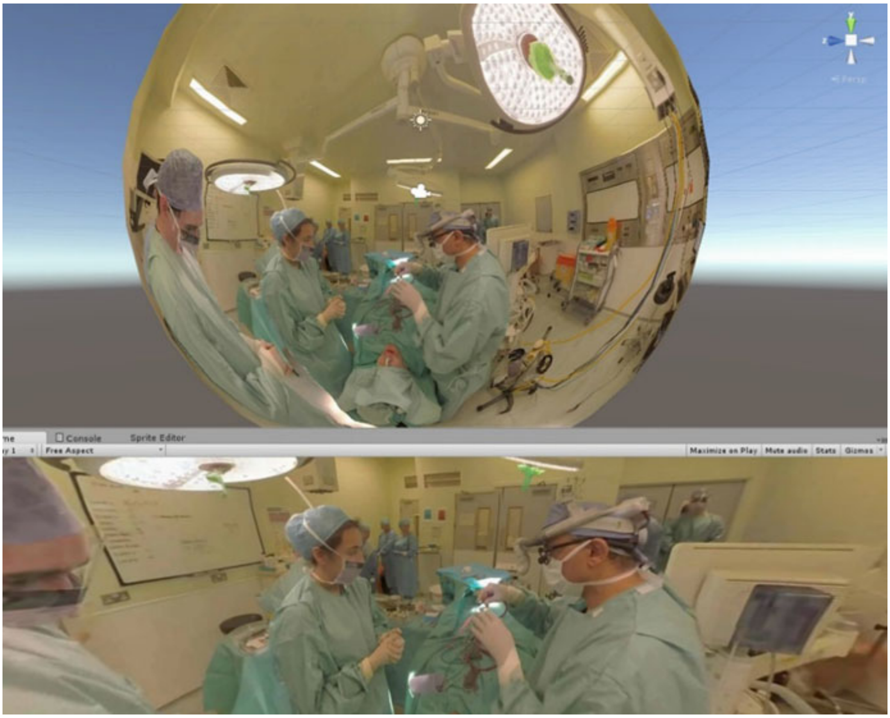

Fig. 8.6 360-degree video of operating room

Six GoPro cameras were used along with a Hero 360-degree setup as discussed earlier. A consultant VR specialist collaborated with our team to capture the surgery in 360 degrees and 3D stereoscopic views (Miller 2015). Individual camera settings and white balance were standardised to run the cameras in unison. To enable error-free video stitching at later stages, motion synchronisation (Kolor 2015) of the cameras was done by rotating the rig to and fro. Natural challenges of sterility, blood-filled field and distance from the surgical field inherent in every video recording within an operating room environment Pallace (2014) were negotiated by proper positioning of the cameras. The resultant 360-degree video was placed on the inner walls of a sphere to provide the user with the context of operating room as shown in Fig. 8.6.

Simulate One

To be able to touch and interact with objects in the application fulfils the second essential element of VR experience interactivity. Leap Motion device is used to establish interactivity in the app by attaching it to the Oculus Rift (Leap 2015). The

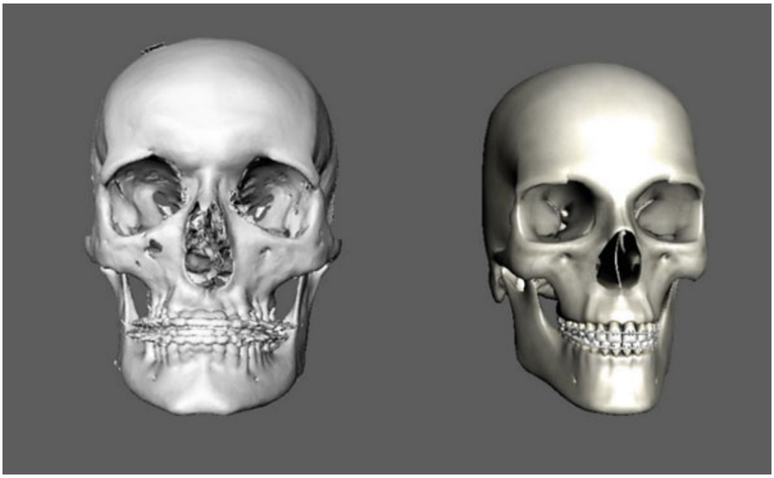

Fig. 8.7 3D surface model generated from CT scanned data (*left*) and 3D model of skull modelled in Autodesk Maya (*right*)

user can place his hand in front of the Oculus and touch to interact with the objects in the virtual world. 3D CT scan data and dental casts were scanned and modelled using 123D Catch and Autodesk Maya to show the pre-surgical plan as in Fig. 8.7. Interactive models of skull anatomy and animations of surgery were used for tasks and questions. The users can zoom in and touch the annotated 3D models of the skull while also isolating one or a group of structures to inspect anatomic relationship between them. The trainees can also control the animations of the surgical process while interacting with the model. As the platform was designed to work with an integrated Oculus-Leap Motion, the best practices in interface design are followed for a satisfactory user experience design (Leap Motion 2015).

Teach One

The third aspect of this application is the element of teaching. VR Surgery follows the Kolb's learning model in providing an appropriate learning experience for the surgical trainees as shown in Fig. 8.8 (Kolb et al. 2001).

Knowledge about the surgical procedure, pre-surgical plan, instruments and relevant anatomy were presented in the form of 3D videos and interactions. These represent the concrete experience aspect. A feedback on performance through questions and tasks helps trainees to reflect on their knowledge. This reflective observance is guided through scores and notifications. Abstract conceptualization aspect is represented by the steps to improve the performance of trainees, such as revising their knowledge regarding anatomy and instruments by interacting with the

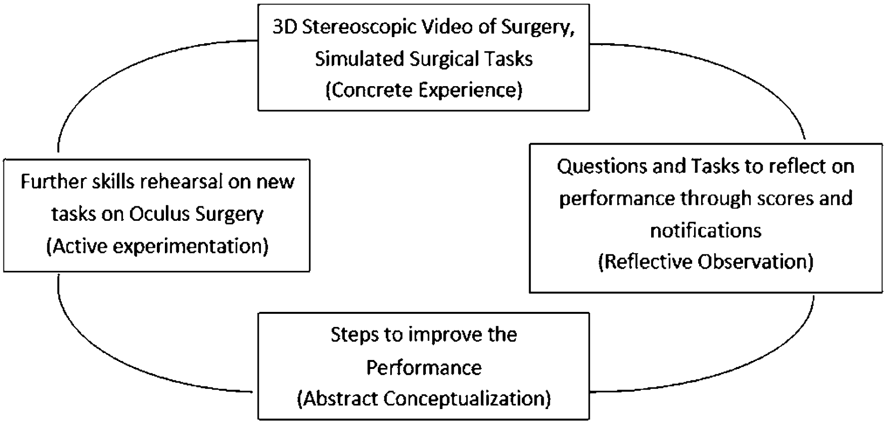

Fig. 8.8 The *teach one* approach in VR Surgery

3D models. Following this, a trainee can return to the application and answer a set of new questions and take up the tasks regarding the surgical procedure, representing active experimentation phase.

A summary of key features in various scenes of VR Surgery and the purpose behind their use is shown in Table 8.1.

8.3.2.3 User Feedback

Throughout the application design, feedback on usability, design and content were gathered from surgical trainees in maxillofacial surgery, supervisors and colleagues. This helped the system to be robust and comfortable for usage, especially in viewing content in 3D and in designing Leap Motion-based interactions. An image of the users testing VR Surgery can be seen in Fig. 8.9.

8.4 Discussion

Surgical education needs major reforms to face emerging challenges including reduced training hours and decreasing number of surgical faculty. Simulation promises to be adjunctive to existing training methods. However, high costs, lack of access and limited availability of high-end simulators prevent trainees from taking full advantage of these systems. The introduction of Oculus Rift- and HTC Vive-like devices brought high-quality surgical simulations into common man's reach with some barriers to cross. These head-mounted VR devices require high specification software and hardware for a satisfactory virtual reality experience (VR 2016). However, high specification computers are not easily available in university teaching

Table 8.1 Scene design of the VR Surgery

Scene	Purpose
1. 3D stereoscopic video	Orthognathic surgery involves the movement of the bones in a 3D space. As 3D stereoscopic videos enhance the depth perception, they were chosen over conventional 2D videos. These videos allow surgical trainees to watch the procedures in great detail
2. 3D interactions	3D interactions help the user in understanding the surgical procedure from different perspectives. This involves:
	1. 3D animations of the surgery
	2. 3D anatomy
	3. Interaction with instruments
	4. Interaction with patient's data
3. 360-degree video of surgery	Operating room environment, the sounds and teamwork are essential cues in surgical training. To create a realistic learning environment and to create a sense of 'presence', 360-degree videos were used
4. Virtual operating room	During training, there are various elements other than the surgery itself, including 3D data, surgical instruments, negotiating the terms of the operating room and understanding the interpersonal relations. The virtual operating room scene allows the user to walk around the operating room environment and experience the ambiance
5. Quiz	While watching a surgical procedure, trainees are asked questions about the anatomy of the patient, surgical procedure, potential complications and instruments used. This helps them to connect various elements and reinforce the knowledge with the experience. Real-time feedback will improve their learning
6. Instruments	Le Fort 1 surgery uses a wide variety of instruments. As surgical trainees need to know the instruments and their order of usage, this scene is a very useful learning tool
7. Anatomy	Learning the surgical anatomy is an essential cognitive skill before any procedure. Users can touch and learn different aspects of skull anatomy. Scenes showing potential complications of orthognathic surgery are also introduced in VR Surgery
8. Instructions	VR environments and devices like Oculus Rift need instructions to understand how different elements work in the application. This scene guides a trainee on:
	1. How to walk/move in a 3D environment
	2. How to interact with instruments
	3. How to interact with various elements in the quiz scene
9. Pre-surgical planning	Before the surgical procedure, understanding why the surgery needs to be done using the CT scan data of the patient is essential. This scene allows the trainees to interact with the patient's CT scan data and also dental scans

hospitals and NHS (Serjeant 2016). In addition to that, an investment in VR hardware such as Oculus Rift or HTC Vive pushes the users to look into cheaper solutions of experiencing immersive VR, e.g. Google Cardboard (Google 2015). Despite all the advances, a lack of awareness of innovative VR technologies can be the reason for the trainees to not experience this mode of training. But once

Fig. 8.9 Users interacting with VR Surgery

the challenges are met, VR Surgery like applications provide an alternative way of learning and can reduce the time taken in training surgeons in operating rooms (Vinden et al. 2016). The future work of the VR Surgery project is to validate and evaluate its impact on training surgeons through rigorous validity experiments. Until then, immersive VR simulations can only be adjunctive methods of training, not a substitute of conventional training as suggested by Sutherland, Middleton et al. (Sutherland et al. 2006).

Acknowledgements We would like to thank Mr. Edward Miller, a virtual reality consultant from Business Tours UK, who helped in capturing the 360-degree videos at Glasgow Dental Hospital for the VR Surgery project.

References

AAMC: Physician shortages to worsen without increases in residency training. Available at: https://www.aamc.org/download/150584/data/physician_shortages_factsheet.pdf (2010). Accessed 18 Apr 2016

Aggarwal, R., et al.: The simulated operating theatre: Comprehensive training for surgical teams. Qual. Saf. Health Care. **13**(suppl 1), i27–i32 (2004)
ASIT: Cost of surgical training. Retrieved April 18, 2016, from http://www.asit.org/news/costofsurgicaltraining (2015)
Bogner, M.S.E.: Human Error in Medicine. Lawrence Erlbaum Associates, Inc, Hillsdale (1994)
Bridges, M., Diamond, D.L.: The financial impact of teaching surgical residents in the operating room. (0002–9610 (Print))
Carson, E.: Digital cadavers: How virtual reality and augmented reality can change anatomy class. Available at: http://www.techrepublic.com/article/digital-cadavers-how-virtual-reality-and-augmented-reality-can-change-anatomy-class/ (2015). Accessed 17 April 2016
Clark, R.E., et al.: The use of cognitive task analysis to improve instructional descriptions of procedures. J. Surg. Res. **173**(1), e37–e42 (2012)
de Wit-Zuurendonk, L.D., Oei, S.G.: Serious gaming in women's health care. BJOG: An Int. J. Obstet. Gynaecol. **118**(s3), 17–21 (2011)
Dedy, N.J., et al.: Structured training to improve nontechnical performance of junior surgical residents in the operating room: A randomized controlled trial. Ann. Surg. **263**(1), 43–49 (2016)
Evgeniou, E., Loizou, P.: Simulation-based surgical education – Evgeniou – 2012 – ANZ journal of surgery – Wiley online library. ANZ. J. Surg. **83**(9), 619–623 (2012)
Fletcher, G., et al.: Rating non-technical skills: developing a behavioural marker system for use in anaesthesia. Cogn. Tech. Work. **6**(3), 165–171 (2004)
Geoffrion, R., et al.: Validating a self-confidence scale for surgical trainees. J. Obstet. Gynaecol. Can. **35**(4), 355–361 (2013)
Go Pro, H.: 360Heros® announces release of time saving file manager 360CamMan™ software (2014)
Google: Google cardboard (2015)
Graafland, M., et al.: Systematic review of serious games for medical education and surgical skills training. Br. J. Surg. **99**(10), 1322–1330 (2012)
Gurusamy, K., et al.: Systematic review of randomized controlled trials on the effectiveness of virtual reality training for laparoscopic surgery. Br. J. Surg. **95**(9), 1088–1097 (2008)
Hartle, A., et al.: Can doctors be trained in a 48 hour working week? 2015 (2014)
HTC (2015) HTC Vive hardware. Available at: https://www.vive.com/us/product/ Accessed 25 Jan 2017
Hull, L., et al.: The impact of nontechnical skills on technical performance in surgery: A systematic review. J. Am. Coll. Surg. **214**(2), 214–230 (2012)
Huynh-Thu, Q., et al.: The importance of visual attention in improving the 3D-TV viewing experience: Overview and new perspectives. IEEE Trans. Broadcast. **57**(2), 421–431 (2011)
Issenberg, B.S., et al.: Simulation technology for health care professional skills training and assessment. JAMA. **282**(9), 861–866 (1999)
Issenberg, B.S., et al.: Features and uses of high-fidelity medical simulations that lead to effective learning: A BEME systematic review*. Med. Teach. **27**(1), 10–28 (2005)
Jackson, C., Gibbin, K.: Per ardua … 'Training tomorrow's surgeons using inter alia lessons from aviation. J. R. Soc. Med. **99**(11), 554–558 (2006)
Kapralos, B., et al.: An overview of virtual simulation and serious gaming for surgical education and training. Springer Science + Business Media (2014)
Kerr, B., O'Leary, J.P.: The training of the surgeon: Dr. Halsted's greatest legacy. Am. Surg. **65**(11), 1101–1102 (1999)
Kneebone, R.L.: Practice, rehearsal, and performance. JAMA. **302**(12), (2009)
Kneebone, R., et al.: Simulation and clinical practice: strengthening the relationship. Med. Educ. **38**(10), 1095–1102 (2004)
Kolb, D.A., et al.: Experiential learning theory: Previous research and new directions. Perspect. Think Learn Cogn. Style. **1**, 227–247 (2001)

Kolor: Autopano video – practical synchronization – Autopano. Available at: http://www.kolor.com/wiki-en/action/view/Autopano_Video_-_Practical_synchronization?action=view&title=Autopano_Video_-_Practical_synchronization#MOTION_SYNCHRONIZATION (2015). Accessed 12 April 2016
Lave, J., Wenger, E.: Situated Learning: Legitimate Peripheral Participation. Cambridge University Press, Cambridge (1991)
Leap, M.: Leap Motion controller (2015)
Leap Motion: VR best practices guidelines. Available at: https://developer.leapmotion.com/assets/Leap%20Motion%20VR%20Best%20Practices%20Guidelines.pdf (2015). Accessed 17 April 2016
Li, P.: Cognitive task analysis. OCLC Syst. Serv.: Int. Digit. Libr. Perspect. **21**(3), 252–256 (2005)
Luker, K.R., et al.: The use of a cognitive task analysis–based multimedia program to teach surgical decision making in flexor tendon repair. Am. J. Surg. **195**(1), 11–15 (2008)
Lyon, P.: A model of teaching and learning in the operating theatre. Med. Educ. **38**(12), 1278–1287 (2004)
Meara, J.G., et al.: Global surgery 2030: Evidence and solutions for achieving health, welfare, and economic development. Lancet. **386**(9993), 569–624 (2015)
Michael, D.R., Chen, S.L.: Serious Games: Games That Educate, Train, and Inform. Muska & Lipman/Premier-Trade, New York (2005)
Miller, E.R.: Creating 360 degree videos for surgical education. Available at: http://www.medicalrealities.com/creating-360-video-content-for-surgical-education/ (2015). Accessed 12 April 2016
Miloro, M., et al.: Peterson's Principles of Oral and Maxillofacial Surgery, vol. 1. PMPH-USA, Shelton (2004)
Moorthy, K., et al.: Surgical crisis management skills training and assessment: A stimulation-based approach to enhancing operating room performance. Ann. Surg. **244**(1), 139 (2006)
Orzech, N., et al.: A comparison of 2 ex vivo training curricula for advanced laparoscopic skills: a randomized controlled trial. Ann. Surg. **255**(5), 833–839 (2012)
Paige, J.T., et al.: High-fidelity, simulation-based, interdisciplinary operating room team training at the point of care. Surgery. **145**(2), 138–146 (2009)
Pallace, N.: BioCommunications association. Available at: http://www.bca.org/resources/tips/surgical_photography_tips.html (2014). Accessed 12 April 2016
Patel, A.D., et al.: Learning curves and reliability measures for virtual reality simulation in the performance assessment of carotid angiography. J. Am. Coll. Cardiol. **47**(9), 1796–1802 (2006)
Quinn, B.: UK cancer surgery to be live-streamed via virtual reality technology. Available at: http://www.theguardian.com/society/2016/mar/25/uk-cancer-surgery-live-streamed-virtual-reality (2016). Accessed 6 April 2016
Reid, W.M.: Teaching and learning in operating theatres. Available at: http://www.faculty.londondeanery.ac.uk/e-learning/explore-further/teaching_and_learning_in_operating_theatres.pdf (2007). Accessed 16 April 2016
Reznick, R.K.: Teaching and testing technical skills. Am. J. Surg. **165**(3), 358–361 (1993)
Roberts, N.K., et al.: Capturing the teachable moment: A grounded theory study of verbal teaching interactions in the operating room. Surgery. **151**(5), 643–650 (2012)
Rodriguez-Paz, J., et al.: Beyond "see one, do one, teach one": toward a different training paradigm. Qual. Saf. Health Care. **18**(1), 63–68 (2009)
Rousseau, R.: Virtual surgery gets real. Available at: https://medium.com/@Goetz/virtual-surgery-gets-real-221beeac65ea#.o2lwpyixa (2014). Accessed 17 April 2016
Royal College of Surgeons: Taskforce report on the impact of the European Working Time Directive — The Royal College of Surgeons of England 2015 (2014)
Samsung: Samsung Gear VR 2015 (2015)
Sarker, S., Patel, B.: Simulation and surgical training. Int. J. Clin. Pract. **61**(12), 2120–2125 (2007)

Satava, R.M., et al.: Surgical competence and surgical proficiency: Definitions, taxonomy, and metrics. J. Am. Coll. Surg. **196**(6), 933–937 (2003)
Serjeant, J.: The NHS technology lag cannot go on (2016)
Sturm, L.P., et al.: A systematic review of skills transfer after surgical simulation training. Ann. Surg. **248**(2), 166–179 (2008)
Surgery, T.: Home | touch surgery surgical simulator | the virtual surgery App (2015)
Sutherland, L.M., et al.: Surgical simulation. Ann. Surg. **243**(3), 291–300 (2006)
Te, Z.: Oculus Rift vs. Morpheus vs. Vive VR. 2015 (2015)
Torkington, J., et al.: The role of simulation in surgical training. Ann. R. Coll. Surg. Engl. **82**(2), 88 (2000)
Vinden, C., et al.: Teaching Surgery Takes Time: the impact of surgical education on time in the operating room. Can. J. Surg. **59**(2), 87–92 (2016)
Vitish-Sharma, P., et al.: Acquisition of fundamental laparoscopic skills: Is a box really as good as a virtual reality trainer? Int. J. Surg. **9**(8), 659–661 (2011)
Vozenilek, J., et al.: See one, do one, teach one: advanced technology in medical education. Acad. Emerg. Med. **11**(11), 1149–1154 (2004)
Vr, O.: Oculus-ready PCs (2016)
Wagner, O., et al.: Three-dimensional vision enhances task performance independently of the surgical method. Surg. Endosc. **26**(10), 2961–2968 (2012)
Wingfield, L.R., et al.: Cognitive task analysis: Bringing olymbic athlete style training to surgical education. Surg. Innov. 2015. **22**(4), 406–417 (2014)
Yule, S., et al.: Non-technical skills for surgeons in the operating room: A review of the literature. Surgery. **139**(2), 140–149 (2006)