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Virtual reality in preoperative imaging in maxillofacial surgery: implementation of "the next level"?

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Abstract

Not only are current imaging techniques - cone-beam computed tomography (CT), CT, and magnetic resonance imaging (MRI) - becoming more precise in capturing data, but the illustration and interpretation of the acquired images is no longer limited to conventional display screens or projectors. The so-called "virtual reality" (VR) glasses have the potential to engage the viewer in a 3-dimensional space, and ultimately to enable evaluation of the reconstructed anatomical structures from a new perspective. For the first time in the field of oral and maxillofacial surgery (OMFS), a 3-dimensional imaging dataset (cone-beam CT, CT, and MRI) can be evaluated by using VR glasses. A medical student, an OMFS resident, and an OMFS consultant rated the preoperative usability of VR glasses to improve the operative understanding of three cases: a deeply impacted wisdom tooth, a fracture of the lower jaw, and an oncological resection. VR glasses seem to help to simplify operations and give the surgeon a good preoperative overview of the intraoperative findings, particularly in the evaluation of impacted teeth and hard tissue structures. In addition, VR glasses seem to be a promising innovation to help in the training of surgical residents and to teach students. However, the more experienced the surgeon, the smaller is the additional value of VR glasses. Preoperative examination using VR glasses can aid better understanding and planning of the surgical site in the future, and is an innovative piece of advanced technology for displaying CT, cone-beam CT, and MRI anatomical data.

Keywords: VR; Virtual Reality; Preoperative Planning; CT; MRI

Introduction

In 1895 Wilhelm Röentgen discovered the presence of "x-rays", and realised their potential benefit for medical use. The first radiograph of the human body was a record of a hand, followed by one of a chest. Eventually, 3-dimensional imaging was developed, including computed tomography (CT) in the early 1970s.[1] Technological advancements have continued in various imaging applications. Higher resolution, lower exposure to radiation, and alternative techniques, such as cone-beam CT have so far provided promising results.[2] Another widely-used method of imaging is magnetic resonance imaging (MRI), which also delivers 3-dimensional data and has undergone rapid technological advances, particularly in terms of resolution.[3,4]

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Despite the exponential technical development in imaging systems and their potential to capture images, devices for visualisation and interpretation of acquired images have been lagging behind in terms of development. In clinical practice, radiologists and surgeons typically evaluate the 3-dimensional data on 2-dimensional screens in three different layers (axial, coronal, and sagittal). The existing visualisation tools being used in the public entertainment industry, which has provided a vast array of products and services based on advanced imaging technology (such as 3-dimensional films, augmented reality (AR) games, and virtual reality (VR)), are much more technically advanced than those available in the medical field.

There are published reports of the introduction of an AR/VR technique in student education and for enhanced visualisation in training courses during surgical residency. The use of those has shown promising results in teaching and surgical training, and will be further explored in the discussion.[5] VR is superior to simple 3-dimensional visualisations on 2-dimensional screens because it gives the opportunity to "walk" into the 3-dimensional dataset in a virtual room, which adds a new dimension to the visualisation of the image, and provides a unique immersive experience in fully visualised and simulated space. The interaction in VR with the visualised data can also be controlled directly with tactile hand controllers, which add additional interactive physical exposure to the multidimensional virtual images. Functions such as zooming, translating, and rotating the volume dataset from CT or MRI images enable the examiner to orient, enlarge, and elucidate data as required. If they were used in a clinical setting, physicians could view and evaluate 3-dimensional data sets from arbitrary angles, which are unique to VR applications.

However, these techniques are not yet practical for daily clinical use for three reasons. First, there is a high demand for graphical and computational power that can calculate 90 stereo image pairs/second. This high frame rate is needed for VR, so that the user does not experience "motion sickness" while interacting with the virtual scene. Secondly, the data set is required to be seen not only on one pair of VR glasses, but on several viewers. A broad range of clinicians must be able to view the information. This limitation makes the technology available only to a few centres that are interested in advanced technology and medical research. Finally, in many software programs only previously edited imaging datasets can be loaded for the AR/VR devices, which sometimes makes the technique impractical for daily clinical use. The question is, therefore: when will the next level of displaying technique be practical for routine clinical practice?

To solve this problem, we need a new imaging system with an algorithm to display all sorts of 3-dimensional datasets simultaneously. Doubtless, AR and VR are superior to regular 3-dimensional screens in terms of visualisation and an interactive 3-dimensional experience. AR in particular requires more computable power by far, and so remains difficult to implement in daily practice. We therefore decided to focus our work on a VR imaging system that may be more practical.

To get the best experience of VR imaging, it should allow the following conditions: real time import of data; DICOM data sets used as general standard; CT, MRI, and cone-beam CT data sets that are importable; it should have a moderate demand for graphical and computational power; hardware should be affordable; control should be intuitive; and there should be no loss of graphic quality.

In this paper we present a clinical application of software for the use of VR in preoperative planning, which addresses these points. It was developed by Aachen University of Applied Sciences and, to our knowledge, it is the first real-time volume rendering in VR to be used for surgical planning without the need for long-lasting modifications of the dataset before use.

Material and methods

For the evaluation of the clinical usability, an oromaxillofacial surgery consultant with 17 years' experience, an oromaxillofacial surgical resident (3rd year), a consultant radiologist with 23 years' experience, and a medical student in the last year of training, underwent VR examination of three typical oromaxillofacial surgical cases: removal of wisdom teeth, fracture of the lower jaw, and an oral squamous cell carcinoma (SCC) in which only the soft tissue of the anterior floor of the mouth was affected.

A standard evaluation by the observation using a regular PC monitor was made after the VR examination to prevent potential damage to the patient or create an ethical conflict. Each of the examiners answered a questionnaire that addressed the potential use and benefits for preoperative planning with VR technology. The imaging dataset used was the conventional DICOM set taken from CT/cone-beam CT scans taken during the patients' admission to hospital. We were able to display the dataset in VR without previous modification or segmentation.

HTC Vive™ (HTC, High Tech Computer Corporation) VR glasses were used, including two controllers. Two basis stations from the HTC Vive™ system were placed in a 2.5×2.5 m room to match the position of the headset and the controller. The VR computer workstation was equipped with a powerful graphic card from NVidia, similar to a GTX1080ti. The software was developed by Professor Scholl and her team (MedicVR; University of Applied Sciences, Aachen). Standardised DICOM datasets can be loaded and visualised using the direct volume rendering algorithm. Direct volume rendering in real time is done with an OpenGL visualisation pipeline and uses the 3584 parallel processor units to calculate the needed 90 stereo image pairs/second. No additional VR software was used.

Table 1
Rating of the clinical usability of the virtual reality (VR) device for different cases. The longer the examiner has been in practice, the less the benefit that is obtained by VR examination in addition to conventional methods. The rating scale was from 1 (very poor) to 10 (excellent).

Variable	OMFS consultant	OMFS resident	Consultant radiologist	Student (OMFS rotation)
Impacted wisdom teeth:				
Help for planning operation/displaying the condition compared with conventional methods	6	7	5	10
Improvement in operative orientation	5	4	Not assessable	9
Potential for clinical use	7	8	8	10
Mandibular fracture:				
Help for planning operation/displaying the condition compared with conventional methods	7	7	6	10
Improvement in operative orientation	7	9	Not assessable	10
Potential for clinical use	7	10	8	10
Oral squamous cell carcinoma:				
Help for planning operation/displaying the condition compared with conventional methods	4	7	2	9
Improvement in operative orientation	4	7	Not assessable	5
Potential for clinical use	5	8	5	9

Table 2
Rating of the software and hardware by the examiners was "satisfactory". The rating scale was from 1 (very poor) to 10 (excellent).

Variable	OMFS consultant	OMFS resident	Consultant radiologist	Student (OMFS rotation)
Resolution of imaging data	8	7	9	8
Intuitive control and examination of images	6	8	8	7
Providing 3-dimensional idea of surgical/anatomical site	10	10	7	9

Results

The first case inspected was the patient with impacted wisdom teeth in the upper and lower jaws. The 3-dimensional anatomical relations with other crucial structures, in particular the inferior alveolar nerve (more precisely to the mandibular canal), was evaluated in the lower jaw. In the upper jaw, the wisdom teeth were relocated to the hard palate. The proximity of the crown of the wisdom teeth to the distal molar could be evaluated accurately, and all examiners reported that it provided them with an additional benefit over examination of a traditional image (Table 1 and video 1).

In the case of the fracture of the lower jaw, the angulation of the fragment segments could be evaluated with the help of VR examination with an additional benefit, particularly for the less experienced examiners (student and resident). In addition, the 3-dimensional positioning of the fragment, particularly in terms of rotation and angulation and the relation to the neighbouring structures, was displayed clearly with satisfactory resolution, and helped in the preoperative orientation and planning of the operation (Table 1 and video 2).

In the patient with the oral SCC of the floor of the mouth, enhancement by contrast helped to ascertain the extent of the tumour. Conversely, the surrounding soft tissues were not easily discriminated, because their radioilluminescent properties were quite similar to each other (Table 1; video 3).

The overall rating of the technical hardware and the software programming was good, although the intuitive control might be improved (Table 2). The VR technique was rated as a promising tool by all the examiners, particularly in the evaluation of its diagnostic application. The primary benefit over traditional 3-dimensional viewing was that the intraoperative orientation was improved (Table 1).

In the clinical evaluation, two aspects became evident. First, the more experienced the examiners, the less they benefitted from VR for 3-dimensional visualisation (the two consultants). Secondly, the younger the examiner, the better the handling of the VR glasses (OMFS resident/student) (Table 2).

The evaluators noted that appropriate visualisation of some structures seemed to be challenging because there is as yet no defined window for soft or hard tissue, and the illumination needs to be manually adjusted. In general, high-density structures (such as bones and teeth) were easier to examine because there was better contrast with neighbouring structures and less variation in the voxel brightness. In the evaluation of soft-tissue structures, the high proximity of voxel brightness between soft-tissue structures such as glandular tissue, muscle tissue, or connective tissue, decreased the diagnostic abilities. Nonetheless, with the use of contrast agents, not only was the course of the vessels highlighted, but also the contrast between malignant tissue and physiological tissue became more obvious.

The ability to cut sections is a promising tool, as it allows the examiner to use conventional examining perspectives in addition to VR examination (video 4). A potential advantage is the use of an infinite number of angles, whereas conventional examination is limited to three angles (coronal, axial, and sagittal).

Considering the hardware costs, a visulisation workstation (€3500) with graphic card from Nvidia GTX1080ti (€950) and a HTC Vive system (€600) are required, for a total amount of €5050 (US$5894).

Discussion

VR is a popular technique that is being tested in many areas of medicine and healthcare. Patients have been provided with VR glasses to allow them to experience clinical conditions and visualise procedures to help them improve their general medical knowledge, increase their cognitive status, and decrease symptoms of chronic pain.[6] Garcia-Betances et al described the potential of VR in the treatment and care of patients with Alzheimer's disease, although further improvement in terms of costs and availability are necessary.[7] Cacau et al claimed improved postoperative rehabilitation with the use of VR compared with a control group with conventional physiotherapy in patients having cardiac surgery.[8] Patients who have had a stroke or brain injury also seem to significantly benefit from the use of VR.[9–11]

The improved diagnostic and therapeutic opportunities delivered by VR would not only benefit patients, but could also be used in various educational opportunities for residents and students. A Cochrane review from 2013 addressed the potential use of VR in the educational training of surgical residents. In 2015, other Cochrane reviews addressed teaching ENT residents, and also used the technology for training in endoscopy. These studies claim a potential saving of cost and operating time by training less-experienced physicians to do procedures efficiently with the help of VR, although a larger number of cases are certainly needed for further evaluation.[12–14] Våpenstad et al described a potential benefit in VR laparoscopy training with a haptic feedback, which allows a more realistic simulation of the operation and has been found to be more appealing to students in training.[15]

In general, the introduction of AR/VR into student life is promising, because traditional resources (such as human cadavers) and personal teaching time might be reduced.[16] However, an increased use of VR in teaching leads to a generation of medical students who are used to it, which potentially leads to more widespread clinical implementation of VR as a standard examination tool. There is therefore a need to implement a practical algorithm that not only allows the use of VR as a training tool after complex handling of the 3-dimensional data, but also delivers the option of an instant, in-depth, anatomical examination that would otherwise be impossible to conduct using conventional diagnostic tools.

According to our preliminary results, we think that a preoperative 3-dimensional evaluation of the surgical site does improve the overall performance of the operation, particularly in terms of assessing the relations with vital neighbouring structures. Nonetheless, several further improvements have to be implemented. The windows for reconstruction of both hard and soft tissue require more datasets to implement standard buttons, similar to the already existing options in conventional data examination. The ease of use of the VR examination technique was promising for all our testers and provided a good experience for all participants in the study. All our users were able to find their way in the VR. Certainly, a larger study population of both patients and examiners is needed to decide the role of VR in preoperative planning in OMFS. So far to our knowledge only Arikatla et al have described the use of VR in OMFS and applied it for virtual surgical simulation using segmentation options, which surely provides an additional promising application.[17]

We conclude that five of seven of our proposed criteria for VR (real time data import, the use of DICOM datasets, moderate demand for graphical and computational power, affordable hardware, and intuitive control) were sufficiently fulfilled. We used only cone-beam CT and CT data sets; MRI datasets should be further evaluated. The graphical quality was good, but the correct illumination and contrast level of the various anatomical soft-tissue structures remain challenging.

Virtual reality is a promising tool in the preoperative planning of OMFS operations. Evaluation of more patients and further improvement in the software are needed before the technique can be implemented in daily clinical practice.

Conflict of interest

We have no conflicts of interest.

Ethics statement/confirmation of patients' permission

Ethics approval was not required. We obtained the patients' permission for publication.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.bjoms.2019.02.014.

References

1. Hounsfield GN. Computerized transverse axial scanning (tomography).Part 1. Description of system. *Br J Radiol* 1973;**46**:1016–22.
2. Hans MG, Palomo JM, Valiathan M. History of imaging in orthodontics from Broadbent to cone-beam computed tomography. *Am J Orthod Dentofacial Orthop* 2015;**148**:914–21.
3. Scatliff JH, Morris PJ. From Roentgen to magnetic resonance imaging: the history of medical imaging. *N C Med J* 2014;**75**:111–3.
4. Tanenbaum LN. Clinical 3T MR imaging: mastering the challenges. *Magn Reson Imaging Clin N Am* 2006;**14**:1–15.
5. Kim Y, Kim H, Kim YO. Virtual reality and augmented reality in plastic surgery: a review. *Arch Plast Surg* 2017;**44**:179–87.

6. Solca M, Ronchi R, Bello-Ruiz J, et al. Heartbeat-enhanced immersive virtual reality to treat complex regional pain syndrome. *Neurology* 2018;**91**:e479–89.
7. Garcia-Betances RI, Arredondo Waldmeyer MT, Fico G, et al. A succinct overview of virtual reality technology use in Alzheimer's disease. *Front Aging Neurosci* 2015;**7**:80. Erratum: *Front Aging Neurosci* 2015; 7:235.
8. Cacau Lde A, Oliveira GU, Maynard LG, et al. The use of the virtual reality as intervention tool in the postoperative of cardiac surgery. *Rev Bras Cir Cardiovasc* 2013;**28**:281–9.
9. Kim WS, Cho S, Park SH, et al. A low cost kinect-based virtual rehabilitation system for inpatient rehabilitation of the upper limb in patients with subacute stroke: a randomized, double-blind, sham-controlled pilot trial. *Med (Baltimore)* 2018;**97**:e11173.
10. Faria AL, Cameirao MS, Couras JF, et al. Combined cognitive-motor rehabilitation in virtual reality improves motor outcomes in chronic stroke - a pilot study. *Front Psychol* 2018;**9**:854.
11. Zanier ER, Zoerle T, Di Lernia D, et al. Virtual reality for traumatic brain injury. *Front Neurol* 2018;**9**:345.
12. Nagendran M, Gurusamy KS, Aggarwal R, et al. Virtual reality training for surgical trainees in laparoscopic surgery. *Cochrane Database Syst Rev* 2013. CD006575.
13. Piromchai P, Avery A, Laopaiboon M, et al. Virtual reality training for improving the skills needed for performing surgery of the ear, nose or throat. *Cochrane Database Syst Rev* 2015. CD010198.
14. Walsh CM, Sherlock ME, Ling SC, Carnahan H. Virtual reality simulation training for health professions trainees in gastrointestinal endoscopy. *Cochrane Database Syst Rev* 2012. CD008237. Update: *Cochrane Database Syst* Rev 2018; CD008237.
15. Vapenstad C, Hofstad EF, Lango T, et al. Perceiving haptic feedback in virtual reality simulators. *Surg Endosc* 2013;**27**:2391–7.
16. Moro C, Stromberga Z, Raikos A, et al. The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anat Sci Educ* 2017;**10**:549–59.
17. Arikatla VS, Tyagi M, Enquobahrie A, et al. High fidelity virtual reality orthognathic surgery simulator. *Proc SPIE Int Soc Opt Eng* 2018;**10576**.