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The use of virtual reality and augmented reality in oral and maxillofacial surgery: a narrative review

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Objective. The purpose of this article is to review the current uses of virtual reality (VR) and augmented reality (AR) in oral and maxillofacial surgery. We discuss the use of VR/AR in educational training, surgical planning, advances in hardware and software, and the implementation of VR/AR in this field.

Study Design. A retrospective comprehensive review search of PubMed, Web of Science, Embase, and Cochrane Library was conducted. The search resulted in finding 313 English articles in the last 10 years.

Results. A total of 38 articles were selected after a meticulous review of the aims, objectives, and methodology by 2 independent reviewers.

Conclusions. Virtual reality/AR technology offers significant potential in various aspects, including student education, resident evaluation, surgical planning, and overall surgical implementation. However, its widespread adoption in practice is hindered by factors such as the need for further research, cost concerns, unfamiliarity among current educators, and the necessity for technological improvement. Furthermore, residency programs hold a unique position to influence the future of oral and maxillofacial surgery. As VR/AR has demonstrated substantial benefits in resident education and other applications, residency programs have much to gain by integrating these emerging technologies into their curricula. (Oral Surg Oral Med Oral Pathol Oral Radiol 2024;137:12−18)

Virtual reality (VR) and augmented reality (AR), the creation of reality-like environments with technology, is becoming a more common and widespread tool in everyday life. Developments in VR and AR are changing the way people entertain themselves and interact with their surroundings, and they are also making their way into the medical field. Virtual reality consists of a headset that features a high-resolution display coordinated to both eyes, creating an isolated "reality" and a handheld interface used by the user to interact with reality. Augmented reality, like VR, uses a headset to project images in front of the user's eyes but is unique in that it overlays those images on real objects and augments or enhances them. This innovative and deeply interactive technology has opened the doors of creativity to allow a surgeon to interact with virtual media in a way traditional computers have never allowed.[1] Although virtual surgical planning technology has allowed preparing specific steps in surgery with preformed custom guides and prostheses, it previously was not applied interactively during surgery. Augmented reality has the potential to allow overlaying virtual planning or imaging onto reality during surgery and would allow the surgeon access to additional information without looking away from the surgical field.[2]

Developments in VR and AR are being applied to oral and maxillofacial surgery (OMS) to plan surgeries, teach patients, educate residents, and aid in performing surgeries.[3] Oral and maxillofacial surgery has relied on conventional stone and plaster models for surgical planning. Surgeries are planned and simulated, and surgical stents can be fabricated to aid in surgery and improve predictability and outcomes. With increasing capabilities and a proven track record, virtual surgical planning has quickly become a new standard, taking place in most residency programs and private OMS

Statement of Clinical Relevance

Virtual and augmented reality developments are being applied to oral and maxillofacial surgery to plan surgeries, teach patients, educate residents, and aid in performing surgeries. With increasing capabilities and a proven track record, virtual surgical planning has quickly become a new standard, taking place in most residency programs and private oral and maxillofacial surgery practices worldwide. In a more involved and adaptive application of technology, advances in virtual and augmented reality have begun to bring surgical planning closer to the hands and practice of oral and maxillofacial surgeons.

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practices worldwide. In a more involved and adaptive application of technology, virtual and augmented reality advances have begun to bring surgical planning closer to the hands and practice of oral and maxillofacial surgeons.[4]

This article aims to comprehensively review the various uses and developments of VR and AR technology in different aspects of OMS and present the current breakthroughs and innovations in this novel field.

MATERIALS AND METHODS

A comprehensive search of PubMed, Web of Science, Embase, and Cochrane Library was conducted using the following parameters: ((“Virtual Reality”) OR (“Augmented Reality”)) AND ((“Oral Surgery”) OR (“Oral and Maxillofacial Surgery”)). The search found 313 English articles in the last 10 years, which were evaluated by title for duplicates, title, and content to exclude irrelevant articles.

RESULTS

A total of 38 relevant articles were selected after a meticulous review of the aims, objectives, and methodology by 2 independent reviewers.

Education and Simulation Through AR and VR

Many of the articles first exploring the use of VR/AR in OMS were focused on its uses in education. Because this technology allows learners to demonstrate understanding and practice surgical techniques without any patient risk, it could be used to allow residents to learn faster. Simulators are more cost-effective than animal and cadaver models and lend themselves to repeatability and periodic routine training.[5,6] More importantly, VR/AR simulators offer the potential to measure objective, quantitative outcomes for immediate feedback or evaluation using data collected from haptic devices. Some measurements include time taken, number of errors, number of strokes, and needle insertion angle.[7]

These advances in education through technology are thought to be a more actively engaging form of education than traditional teaching methods. Although most articles on VR/AR in OMS are focused on education, most institutions do not appear to have implemented their use in the regular teaching of residents. The low use of VR in teaching may be due to various reasons. Maliha et al.[8] suggested a lack of scientific and validated study designs reported in simulation literature as one potential cause of underuse.[8] A lack of user-friendliness in VR/AR systems has also been cited as a potential deterrent.[5,6,9] The greatest challenge of implementing VR/AR, however, appears to be technological limitations. Systems must be able to accurately simulate surgery features such as elasticity of blood vessels, hardness of bone, or drill angular velocity.[10,11] This ability requires advanced collision detection algorithms that demand high computer processing power. Current technology is inadequate, and moving forward, the challenge will be balancing computational speed with real-time simulation.[9]

The current state of technology varies widely in which features are available, but advances in haptic technology, and graphics can improve the user experience when immersed in VR/AR. The haptic component of VR/AR has been studied specifically due to the tactile nature of surgery and the reliance on sensory feedback to properly perform surgery, and will be elaborated on further in the paper.

A study comparing residents receiving a conventional demonstration vs VR found that residents who were taught via VR had increased self-confidence and performance and were happy to use the technology overall.[12] As AR/VR technologies advance and more accurately simulate the operating room experience, they have the potential to become an integral tool in the supplemental training of residents.

Innovative Trends in Implant Dentistry Training

Virtual reality has been widely used in implant dentistry and implant training. Implant surgical planning systems with 3-dimensional (3D) arrays are the current standard of practice.[13,14] However, current systems bind these 3D arrays into 2-dimensional displays and computer navigational tools, including mouse and keyboards, even though the navigational data are readily available in 3D statistics.[15] Therefore, VR holds significant advantages over the visualization of 3D objects on conventional computer screens. It allows for interaction with the implant surgical planning so the operator can rotate, enhance, and view their implant placement procedure meticulously and proceed with the actual surgery with more understanding and visualization.[15] Rantamaa et al.[16] evaluated a novel VR system in which implants were placed in a virtual model with either virtual or no virtual handles. Participants reported better results with implants with no virtual handles than with implants with virtual handles. They noted the advantages of the handles for fine-tuning the placement but reported usability issues with virtual handles. Overall, both methods were evaluated as useful, and the VR environment was valued for the virtual implant planning procedure.

Navigation in Training Novice Dental Practitioners

Dental educators training novice practitioners and dental students are constantly seeking the best modalities to implement new and more effective approaches in dental education, specifically in implant dentistry.[17] Casap et al.[18] evaluated the benefits of using a VR navigation system to teach implant drilling to final-year dental students. They concluded that despite the improved performance of the VR navigation system, the added value of training in dental implantation surgery with virtual reality navigation was minimal compared with conventional methods.

Haptic, Physical, and Web-Simulators in OMS Training

Haptic feedback in VR has been widely studied in other fields of surgery, specifically laparoscopic surgery.[19-21] Looking through the current literature and the availability of haptic and physical simulators in maxillofacial surgery, a dearth of evidence is evident. In a systematic review by Maliha et al.,[5] they aimed to identify all digital and mannequin maxillofacial simulators available for OMS training and education. They also aimed to highlight the benefits of each modality and assess the available evidence supporting them. They reviewed 22 papers, of which 10 studied virtual reality haptic-based simulators, 6 studied Web-based simulators, and 6 studied physical model simulators for a variety of maxillofacial procedures, including dental skills, orbital floor repair, Le Fort I osteotomy, vertical ramus osteotomy, bilateral sagittal split ramus osteotomy, sinus surgery, biopsy, genioplasty, cleft lip repair, and bone grafting. They concluded that although these modalities seem beneficial to the maxillofacial surgery trainee, simulation in education in this field is underused mainly due to the significant dearth of scientific evidence and scarcity of high-quality literature.

Haptic Simulator for OMS

In surgical simulations, an operator usually interacts with a haptic device while viewing visual effects on a computer screen or head-mounted display (HMD). Real-time movement, interaction, and deformation with visually realistic interfaces are critical for enhancing the trainee's experience. Visual rendering, therefore, is an essential component in virtual-realistic surgery simulations, with acceptable bandwidths ranging between 20 and 60 Hz.[22]

Most virtual-realistic surgery simulators use the OpenGL library (Open Graphics Library, Khronos Group) or DirectX Graphic library (Direct eXtension, Microsoft) for virtual rendering. H3D API, developed by SenseGraphics, is a high-level API of the scene graph that uses HAPI for haptics, OpenGL for graphics, and the X3D XML-based file format to represent the scene.[23]

Advancements in virtual reality devices enable more complex and vivid rendering for surgical simulations. Graphic workstations with CPUs and GPUs are the foundation for visual rendering, and graphic display devices are crucial. Some oral and maxillofacial surgery (OMFS) simulators use computer screens for visual rendering, whereas others adopt HMDs or VR glasses to provide an immersive experience. Various commercially available devices have been used in surgical simulations, including Display 300 (SenseGraphics, Sweden), 3D Vision 2 wireless glasses (NVIDIA, US), Oculus Rift (Oculus VR), and HMZ-T1. These devices help create vivid 3D virtual scenes for maxillofacial surgery training and other applications, such as dental and dental implant surgery.[24]

In surgical simulators, not only is the graphical rendering of animation important but also the recreation of actual haptic sensations of deformable tissues for the operator. Haptic rendering is more complex than visual rendering due to its higher refresh rate (300-1000 Hz), and it is composed of object modeling, collision detection, and force response. Haptic devices have rapidly evolved from 1 degree of freedom (DoF) to 7DoF, with desktop-scale and point-interaction devices like Geomagic's Phantom, Force Dimension's Omega 6, and Haption's Virtuose 6D preferred for surgical simulations.[25]

The position and orientation of the haptic device's end manipulator are directly reflected onto virtual tools, generating haptic force upon a collision between virtual objects and tools. Improving haptic device stability involves limiting feedback force within a safe range by determining the properties of virtual springs and dampers.

Real-time collision detection requires efficient algorithms to handle the speed necessary for simulations. Space decomposition and hierarchical bounding volumes are commonly employed in surgery simulations, with current algorithms mainly based on hierarchical bounding volumes, such as k-DOPs, AABB, OBB, and Sphere-Bounding Box.[26] Upon collision detection, force response is triggered. Haptic rendering, which computes interactions between virtual tools and objects, is a critical algorithmic problem. Standard methods implemented in haptic APIs for 3DoF haptic rendering include the God-object method and Virtual proxy method, both simulating the penetration of virtual tools into objects using penalty approaches. These methods continue evolving, with the CHAI3D virtual "finger-proxy" algorithm as an example.[27]

VR Training for Endoscope-Assisted Submandibular Gland Resection

Endoscope-assisted surgery has become increasingly popular due to its minimally invasive nature, resulting in shorter hospital recovery times and improved patient satisfaction regarding esthetic outcomes. Miki et al.[28] discussed developing and evaluating a VR training system for endoscope-assisted soft tissue surgery, specifically for removing the submandibular gland in the oral and maxillofacial region. Existing training methods for endoscope-assisted soft tissue surgery include phantom training and animal training, both of which have limitations in terms of simulating the elasticity of soft tissues or being cost-effective and readily accessible. The authors aimed to create a VR training system that can reproduce soft tissue characteristics and simulate physiologic deformation in response to external forces.

The developed VR system includes the submandibular gland, vessels, and layered connective tissue, allowing trainees to practice basic skills for endoscope-assisted surgery in the oral and maxillofacial region. This study demonstrated the potential utility of the developed training system for novice oral surgeons because it can simulate various operative steps and facilitate the removal of the submandibular gland.

In conclusion, developing a VR training system for endoscope-assisted removal of the submandibular gland offers a valuable tool for trainees to gain proficiency in soft tissue surgery in the oral and maxillofacial region. This innovative approach overcomes the limitations of traditional training methods and can potentially improve surgical outcomes and patient satisfaction.

Virtual Surgical Planning

Surgical planning is one of the clear uses for VR/AR in OMS. As a profession, we have already made leaps and bounds into incorporating computer-aided planning into our surgeries, ranging from dental implants to orthognathic surgery. Virtual reality/AR has the potential to be the next step forward in advancing our ability to plan and prepare for surgery. With VR with haptic feedback, the anatomic landmarks can reportedly be placed quicker and more accurately than conventional cephalometry. Conventional radiographic cephalometry is a standard diagnostic and surgical planning tool in oral and maxillofacial surgery. However, current computer-assisted cephalometric systems, particularly those using 3D methods, are often impractical and unintuitive due to the difficulties and time-consuming nature of the landmarking process.

Furthermore, the lack of established 3D cephalometry norms and standards necessitates the development of new landmark selection methods. A study by Medellín-Castillo et al.[11] introduced and evaluated a novel haptic-enabled landmarking approach to address the limitations of existing 2D and 3D cephalometry methods. The feasibility and performance of this new system were assessed through 21 dental surgeons (7 novices, 7 semi-experts, and 7 experts) performing a series of case studies using haptic-enabled 2D, 2.5D, and 3D digital cephalometric analyses.

Results demonstrated that 3D cephalometry significantly reduced landmarking errors and variability compared with 2D methods. The haptic-enabled 3D digital cephalometric approach, which provides a sense of touch, was found to be more intuitive, effective at reducing errors, and efficient in terms of task completion times compared with conventional methods. It was suggested that this novel approach could potentially improve the cephalometric analysis process in oral and maxillofacial surgery.

The use of VR/AR has been shown to be quite essential in facial transplantation planning to ensure soft tissue compatibility with the recipient. In facial transplantation, the accurate matching of donors and recipients is crucial for successful outcomes. The Fernandez-Alvarez et al.[29] study aimed to validate a virtual reality software, AYRA (The manufacturere is VirSSPA, Spain), for recording anthropometric measurements to enhance donor-recipient matching in the pre-operative planning process for facial allograft harvesting.

The researchers compared conventional analog measurements with digital measurements obtained from 3D reconstructions produced using AYRA software on 5 cryopreserved human heads. Intra-class correlation coefficients were calculated for each pair of measurements to assess the correlation between the 2 methods.

The results demonstrated a substantial or almost perfect correlation (intra-class correlation coefficients >0.6) between the 2 methods for all pairs of variables, except for 2 measurements in bone tissue. These findings suggest that virtual reality software such as AYRA can effectively record anthropometric measurements and provide a useful tool for characterizing potential donor faces. This digital approach can potentially improve pre-operative planning, ensuring better anatomic compatibility between donor allografts and recipient defects and ultimately leading to more successful facial transplantation procedures.

Orbitozygomatic Maxillary Complex Fractures

Virtual reality navigation has been successfully implemented for orthognathic surgeries in numerous studies.[30,31] Yu et al.[32] undertook an overview of the indication and the implementation of computer-assisted navigation in oral and maxillofacial on 104 cases, which included 37 orbitozygomatic maxillary complex fractures, 9 mandibular hypertrophies, 27 unilateral temporomandibular joint ankylosis, 29 craniofacial fibrous dysplasia, 3 bone tumors, and 2 foreign bodies cases. Osteotomy lines, the amount of resection, the anticipated position of bony segments, and the reconstruction morphology were determined and portrayed by pre-operative simulation with superimposing and mirroring procedures. They concluded that all surgical procedures were performed successfully with the guidance of a computer-assisted real-time navigation system; therefore, it can greatly improve the accuracy of maxillofacial surgery, reduce perioperative risk and morbidity, and accurately restore facial symmetry. It seems that the ability to conduct pre-operative planning, surgical simulations, and postoperative predictions through computer-assisted navigation offers significant benefits in enhancing the precision of maxillofacial surgery. This approach minimizes operative risks and postoperative complications while promoting the restoration of facial symmetry. As such, computer-assisted navigation is considered a valuable technique for these potentially complex procedures.

Surgical Implementation

This is the field that stands to improve the most in the field of VR/AR. It will take the effort of oral and maxillofacial surgeons all over to be actively engaged in advancing and using this technology for it to achieve its full potential in our field. As surgeons, we will need to work with data scientists, study and improve existing software/hardware, and facilitate its development if we want it to be used.[10]

A study by Pulijala et al.[12] evaluated the impact of an immersive VR (iVR) surgical training application, specifically focused on the Le Fort I osteotomy maxillofacial surgical technique, on residents' self-confidence and knowledge. A multisite, single-blind, parallel, randomized controlled trial was conducted involving 95 novice surgical residents with limited experience in Le Fort I osteotomy. Participants were divided into a study group using the iVR application with Oculus Rift and Leap Motion devices and a control group using a standard PowerPoint presentation on a laptop. The primary outcome measures were trainee confidence self-assessment scores and objective cognitive skill assessments. The results of this study revealed that the study group participants exhibited significantly higher self-confidence levels than the control group. First-year novices demonstrated the most substantial improvement in confidence compared with second- and third-year residents. It can be concluded that iVR experiences enhance the knowledge and self-confidence of surgical residents, suggesting the potential for these technologies to improve surgical training outcomes.

Though there are limitations, the use of augmented reality in the operating room during OMS procedures has been demonstrated. Chen et al.[33] employed AR to view a 3D image of the orbitozygomatic maxillary complex in real-time during surgery and found that despite challenges in implementing its use, it provided a benefit to the surgeon and reduced operating time. Another study by Ann et al.[34] used AR in orthognathic surgery and, although it was necessary to crosscheck the results intra-operatively, found its accuracies comparable to conventional methods.

Free-Hand Orthognathic Surgery

In a study by Kim et al.,[35] researchers developed a novel, simplified workflow for AR-assisted orthognathic surgery using electromagnetic tracking and a skin-attached dynamic reference frame. This approach eliminates the need for optical markers and invasive procedures. Two essential processes for AR-assisted surgery, namely registration between physical and CT image spaces and between physical and AR camera spaces, were performed pre-operatively using a registration body complex and a 3D depth camera. The maxillary bone segment was then superimposed on the patient's real image using a flat-panel display for intra-operative guidance.

The accuracy of this AR-assisted method was evaluated using a Le Fort I surgery simulation on a phantom. The results demonstrated high accuracy and reliability, with minimal mean absolute deviations between simulated and postoperative positions. Furthermore, there were no significant differences in accuracy between the skin-attached dynamic reference tool and the bone-attached reference tool.

Overall, the developed method is promising to improve the precision and convenience of free-hand orthognathic surgery using AR assistance, electromagnetic tracking, and skin-attached dynamic references.

Wearable AR Devices in Maxillary Repositioning

In 2014, Badiali et al.[36] used a stereoscopic video see-through display mounted on the surgeon's head to develop a new strategy for delivering AR information to the surgeon. This head-mounted wearable AR system facilitated a type of augmented surgery in which the digital visual features were adapted to real-time visualization of the field of surgery. Le Fort 1 maxillary repositioning was chosen as the experimental procedure in this in vitro study. Surgical accuracy was then measured with the aid of an optical navigation system, which recorded the coordinates of 3 reference points on the repositioned maxilla. To assess the results, they employed 9 surgeons with different levels of expertise and compared these 3 repositioned reference points with those expected to be achieved in a conventional 3D environment. Despite variations in surgical expertise, they demonstrated no statistically significant difference in errors in different reference point positions among operators. Furthermore, they concluded that this AR implementation modality could be extended for use in other maxillofacial surgical procedures.

Patient Education Using AR and VR

There has been an effort to apply VR/AR technology to alleviate patient discomfort and anxiety associated with surgery. Virtual reality can be used to provide a relaxing pre-operative environment for patients and can also be used intra-operatively for local procedures to reduce stress and anxiety.[37] One study found that pre-surgery exposure to a VR surgical environment did not help reduce children's anxiety before general anesthesia.[7] Other studies found that VR application during surgery was very beneficial in reducing patient anxiety levels during local anesthesia and dental extractions,[6,10,38] with 1 study demonstrating that 92% of patients reported a decrease in anxiety with using VR intra-operatively.[6] It would appear that implementing this technology in OMS clinics could improve patient satisfaction but may require an adjustment of surgeons to incorporate the technology into their practice.

Although VR/AR has great potential, from teaching students, evaluating residents, planning surgeries, and implementing surgeries, it has yet to be widely accepted. These reasons may include a need for additional research, costs required to use VR/AR technology, unfamiliarity with new technology among current teachers, and the need for additional improvement in technology. The question remains: at what point will the profession decide to invest in accepting and advancing the technological advancements that can come with VR/AR? It appears that technology currently has the capability to make improvements to the way we practice but has a long way to go to provide a more fully integrated surgical experience.

Residency programs sit in a particularly influential position in implementing changes in the future of OMS. Given that VR/AR has shown a large benefit for the education of residents along with other implementations, residency programs stand the most to gain by incorporating these new technologies into their practice. Each program is different, but by incorporating both resident and faculty insights into using technology in OMS, programs may be able to bring this technology to the forefront.

DISCLOSURES

None.

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