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Virtual and Augmented Reality in Oral and Maxillofacial Surgery: Current Trends and Future Aspect

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Background: The oral and cranio-maxillofacial region houses various delicate, complex and vital structures imperative for sustaining an individual's survival. Therefore, in order to provide the best possible outcome—both functionally and aesthetically, surgery in this area demands a high level of precision. In order to achieve this finesse last few decades have witnessed the birth of various innovative tools and concepts. Interactive visual guided surgical interventions is one such field of active research and upgrade, the latest addition to this being the introduction of virtual and augmented reality in the surgical domain.

Conclusion: This literature review provides an insight in the current employment and future scope of this rapidly evolving technology in the field of oral and maxillofacial surgery.

Keywords: Oral & maxillofacial surgery; augmented reality; virtual reality; surgical navigation.

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1. INTRODUCTION

Oral and cranio-maxillofacial surgery is a specialty that deals with the diagnosis and treatment of conditions affecting the mouth, face, jaws, head, and neck region. Due to the fact that this surgical specialty is frequently associated with intricate surgical procedures involving delicate and important anatomical components, it has a significant potential for image- guided technology. Thus, the fact that oral and cranio-maxillofacial surgery (OCMS) was one of the first specialties to be explored in terms of medical-Augment reality (AR), (which was introduced in 1995 by Wagner et al. [1]), should come as no surprise. Since then, AR has found its application in maxillofacial implantology, orthognathic surgeries, oncology, and trauma cases [2,3]. Virtual reality (VR) can be understood as the art and science of introducing a virtually created environment that offers a predictable, secure, and customizable interface for the evaluation of various anatomical regions in order to aid in the examination, diagnosis and ultimately the required treatment planning [4]. This artificially created interface can also be put to use in surgical training and understanding. Thus, VR constitutes a 3D-generated world which can be easily explored and interacted with by a person. Contrarily, augmented reality uses a complex registration procedure to create an integrated image that augments the virtual scene with the actual one by fusing virtual reality with a 3D real environment that is unique to each patient [5,4]. The integrated image is thus superimposed on the real environment. According to Azuma [6], for an interface to be considered as an AR, it should be incorporated with the following attributes [1]: (1) combination of real and virtual elements, (2) interaction in real-time, and (3) 3D registration. The fact that distinguishes virtual reality from augmented is that, VR entirely engrosses users into an artificial world without being subjected to any awareness of the real world whereas the technique of AR enhances the sense of reality by instantaneously superimposing virtual images over the actual scene. All these advanced technologies broadly fall under the umberella, of Mixed reality, which in addition to these also contains telepresence.

AR technology makes use of a combination of devices such as display units, certain input devices, tracking, and computer [7]. There are 3 main types of displays used in the fabrication of AR: Head-mounted devices (HMD), hand-held displays, and spatial displays (video/optical see-through) [5,7]. These days some AR systems are utilizing contact lenses and newer innovations like virtual retina displays (wherein the display is scanned directly onto the viewer's retina) [7]. Presently, various types of input devices are available and tracking devices comprise of digital cameras and other optical sensors, wireless sensors, accelerometers, global positioning system (GPS), etc.

Currently, in the field of surgery, the navigation data/output is displayed on one or more monitors positioned around the surgical site, which is a demanding process as a whole owing to space limitations and line-of-sight restrictions. The operator is therefore compelled to divide his focus between the patient and the navigation display while synchronizing the employment of surgical instruments simultaneously. In order to address the aforementioned issues, augmented reality (AR) has recently been implemented in maxillofacial surgery. Using AR, real and virtual pictures are combined into a unified scenario, enabling direct viewing of the patient imaging overlaid to the surgical field thus, subtly improving the impression of the surrounding environment [5]. This allows, the operator to visualize the displayed images and the surgical field simultaneously at once thus, negating the need to divert the attention from the operative field.

2. DISCUSSION

A number of elements must be incorporated in order to fabricate a successful augmented reality system [3,7]. The first component is a scanning device in the form of a camera or a sensor, for capturing the real-life scenario and objects. A second important constituent is a computer unit; which processes the captured images and motion, analyzes its location, and finally adds up depth to the captured images; thereby converting them into three dimensional entities. The third element is, a display system to showcase the virtual and 3D objects in the real world. Finally, a tracking device is used to register and actively track the user during the entire process in order to achieve real-time visualization [8]. The two primary categories of registration procedures are marker-free registration, which uses lasers to scan the surface of the skin, and marker-based registration, which uses anatomical landmarks, bone screws, and skin adhesive markers [9,10]. The tracking systems are utilized to follow the patient, the instruments, and the operator's movements, and the virtual objects may be observed from different perspectives [8-11]. Two methods are employed for tracking: a) The Fiducially Markers: based on anatomical landmarks identified by X-rays, and b) Surface Matching: which relies on position sensors that are attached to both the patient and the device being used. [11].

First reported in the late 1980s, computer-assisted head and neck procedures have now been integrated into several cranio-maxillofacial subspecialties, as a means of performing precise and minimally invasive procedures. A review conducted in 2019 by Ayoub A. et al. [5] reveals maxillofacial surgery to be the primary area of application of AR based technologies, as compared to any other dental speciality [4]. Maximum studies that have been conducted to date report orthognathic surgeries to be the most active domain of its employment followed by implantology, traumatology, oncology and others. Other than its surgical application augmented reality is being very popularly used as a learning/ teaching tool making visualization of the complex anatomical structures and associated surgical techniques much more easier and understandable [4-7]. These applications have been described in detail in the following paragraphs:

2.1 Orthognathic Surgeries

The most commonly employed application of AR and/ or VR in orthognathic surgeries is in its treatment planning phase [5,7]. Recently, following the improvements in speed and image quality augmented reality is being utilized intra-operatively to visualize the important underlying anatomical structures helping to prevent any surgical mishaps. The desired treatment outcome that was planned during the treatment planning phase is directly superimposed on the patient in the operative setting helping in visualising the amount of osteotomy, advancement, or set back that is required individually [12].

A study in 2018, done by Zhu M. et al. [9], compared the usage of the AR system, and free-hand technique in a Mandibular Angle Osteotomy [7]. The study results showed that AR needed more time than the free-hand technique in the pre-operative phase, but in regard to the procedure time, the AR system proved to be less. This was in consensus with the results obtained by Zinser et al. [13], in the 46 orthognathic surgeries conducted by them it was observed that overall by using the AR system, operating time was found to be approximately sixty minutes longer than the procedures that were performed free-hand, but the technique using AR navigation was noted to be superior to conventional in terms of precision, ease of planning and specific clinical requirements thus, resulting in more predictable and favorable patient outcomes. Han et al in 2019 [14]. incorporated the use of this technology in the ‘synostotic plagiocephaly surgery’ of 7 patients and reported sufficient compliance between the pre-surgical plan and the surgical outcome. It has been further reported in the literature that the usage of AR as a navigational system can potentially reduce the mean positional errors to approximately 0.7 mm [13].

2.2 Dental Implantology

To satisfy the necessary functional and cosmetic requirements in dental implantology, precise placement of dental implants is crucial. To determine the implant size, location, orientation, and vicinity to important structures, substantial use of virtual reality has been made utilising preoperative CBCT [4,5,7]. The operator's freedom to adjust the implant position in order to avoid a weakened bony foundation and anatomical entities that might not have been identified during the presurgical planning phase is one of the key benefits of dynamic navigation. With an overall navigation inaccuracy of 0.35 mm (& a mean angular deviation of $< 4^{o}$), the image guidance implantology technique has been found to be highly accurate. Implant AR-supplemented navigation systems have demonstrated more accurate outcomes and reduced variance as compared to manual processes. Moreover, it decreases the chances of iatrogenic errors such as: sinus perforations, dehiscence, fenestrations, and nerve injury [4,5].

2.3 Oncology

With concern to oncology, the clinician can physically mark the boundaries of the tumor as an overlay making use of the virtual reality programming tools onto the processed radiographic informational indices [9]. Many studies conducted in this regard have elicited the efficacy of virtual planning in mandibular & maxillary reconstructive surgeries. Profeta et al. [15], in their experiment utilized AR for guiding free-hand Single Photon Emission Computed Tomography (SPECT) in sentinel lymph node biopsy of head & neck oncology cases. Scolozzi and Bijlenga in 2017 [16], presented a case report of their case wherein an augmented operating microscope was used for the removal of tumor from the intra-orbital region. In this case in order to achieve a better view of the tumor's deeper extensions a surface rendering of the tumor was overlaid within the microscope. In selected cases of tumor removal followed by reconstruction of the maxillofacial region, Salb et al. [17] estimated the AR-based navigation system error to be around one millimeter.

2.4 Trauma Surgeries

Reduction and fixation of fractures are made easier by thorough intra-operative visualisation of the underlying vital structures thereby, significantly reducing the chances of intra-operative bleeding and post-operative paraesthesia. Also, retrieval of foreign bodies can be accomplished in a more safe and accurate manner by utilizing this image-guided navigation technology.

2.5 Surgical Training

VR in conjugation with the haptic feedback simulation system is being utilized as an important training tool for the surgical and dental trainees in many institutions. This provides the students with the opportunity to prepare themselves by practicing complex surgical procedures and instrument handling in a real-life-like virtual surgical field before they get to work on real patients. Many such training systems are now being introduced in dental colleges to help students grasp complex anatomical aspects by 3D visualisation and simulation. A study done by Pulijala et al. [18] using VR for training students in orthognathic surgery, got the feedback on the system being very reliable and easier to understand [13]. Thus, improving the operative skills among trainees. The inclusion of haptic technology that provides the user with the tactile sensation of the touched structure or object held in hands, has augmented virtual reality and creating more realistic environment for clinical training.

2.6 Drawbacks of AR

1. Longer pre-operative duration.
2. The technical application and accuracy is still in the developing stage with the evolving technologies thus restricting its routine usage in the surgical field which demands a high level of precision.
3. High expenses.
4. The use of HMD devices has been reported to cause vertigo, eye-strain, nausea, blurred vision, and headaches. This augments a thorough evaluation of the potential occurrences of these side effects before the first use.
5. AR cannot be used for emergency treatments, as it requires proper and lengthy pre-operative investigations.

3. CONCLUSION

AR applications have been an area of intense research during the past decade. The increasing interest in the potential that this technology holds has led to its adoption in various aspects and subspecialties of the surgical domain. The present scenario has been limited to pre-operative surgical planning and educational training. Routine usage of this state of the art technology has not been made possible due to its associated exorbitant cost factor and time-consuming learning curve. Furthermore, there is a need for the betterment of the image quality and precision outcomes for surgical procedures. Future research in this domain should be focused on providing direction to these aspects.

CONSENT AND ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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