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Review

Benefits and Limitations of Computer-Assisted Surgery in Maxillofacial Surgery

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Abstract

Computer-assisted surgery (CAS) has revolutionised surgical procedures in both medicine and dentistry. This review explores the benefits and limitations of CAS in maxillofacial surgery. Virtual surgical planning allows for a clear declaration of surgical intentions, avoiding conflicts between resection and reconstruction teams, and enabling communication of preferences and uncertainties. CAD-CAM software facilitates virtual surgery and generates templates and cutting guides for precise implementation in the operating room. CAS has had a significant impact on dental implant placement, enabling accurate positioning and improved outcomes. It also aids in skull base surgery and the removal of foreign bodies. Navigation systems provide real-time tracking and visualisation, ensuring accuracy and safety. However, because of the mandible's movement, there are restrictions, especially in mandibular surgery. Despite these challenges, CAS offers numerous advantages, including increased precision, reduced anaesthesia time, and improved efficiency.

Keywords: *computer-assisted surgery, CAS, maxillofacial surgery, virtual surgical planning, CAD-CAM software*

Introduction

The majority of surgical procedures in both medicine and dentistry have changed as a result of developments in computer-assisted technology during the past few decades. The first navigation system based on an optical sensor was introduced in the early 1990s by Heilbrunn and colleagues (1). Optical tracking, which can be classified into active or passive optical systems, is now used in computer navigation. Within the last 20 years, it has become more common in dentistry and craniomaxillofacial (CMF) surgery. Computer-assisted surgery (CAS) is currently beneficial in dentistry and oral maxillofacial surgery (OMS), including maxillomandibular reconstruction, face trauma, and temporomandibular joint (TMJ) surgery (2). The revolutionary process known as computer-assisted implant surgery (CAIS) has gained popularity for being effective and precise. The use of CAIS protocols simplifies communication between surgical and restorative clinicians, resulting in functional results that take into account the restorative aim and the ideal implant position. For the implantation of implants in either partly or completely edentulous ridges, there are currently two types of CAIS protocols: static CAIS and dynamic CAIS (3). A key component of performing excellent dental surgery is being able to see the patient in three dimensions. CAS enables the physician to collaborate with a design engineer to create numerous virtual designs while simultaneously visualising the patient in the sagittal, coronal, and axial planes on a computer workstation. Today's clinicians can place dental implants, bone grafts, and hardware with greater precision while simultaneously lowering the danger of iatrogenic harm or subpar surgical results by employing computerised technology (2). Dental implants and restorative prostheses have traditionally been created using computer-aided design and fabrication (CAD/CAM). In only one visit, it is possible to produce and deliver digital impressions and restorations. Lowering common mistakes decreases the need for many sessions and increases accuracy. Digital impressions are especially helpful for patients with overactive gag reflexes and restricted mouth openings, which make it challenging to take traditional diagnostic impressions. During orthognathic surgery, dental implant location, size, and degree of movement have all been assessed using preoperative surgical simulations utilising 3D images. Preoperative surgical simulations using 3D models help assess treatment plans and obtain precise representations of the patient's underlying bone structure (4). By reducing intraoperative invasiveness, these most recent technologies aim to increase precision and simplify surgical procedures. The development of navigation-assisted surgery has made oral and maxillofacial surgery more precise (5).

Methodology

This study is based on a comprehensive literature search conducted on June 25, 2023, in the Medline and Cochrane databases, utilizing the medical topic headings (MeSH) and a combination of all available related terms, according to the database. To prevent missing any possible research, a manual search for publications was conducted through Google Scholar, using the reference lists of the previously listed papers as a starting point. We looked for valuable information in papers that discussed the benefits and limitations of computer-assisted surgery in maxillofacial surgery. There were no restrictions on date, language, participant age, or type of publication.

Discussion

Computer-assisted surgery, which was initially used in certain medical fields, has now been adopted in dental specialties as well. This advancement in technology combines volumetric imaging with computer software, allowing for the manipulation of three-dimensional images (6). This innovation has significantly transformed treatment planning and clinical therapy. In particular, dental implant placement procedures have greatly benefited from computer-assisted surgery protocols, as the precise positioning of implants in three dimensions is crucial for their success and to avoid any damage to nearby vital structures. Initially, dental implants were primarily used to restore fully edentulous ridges, and the position of the implant was

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determined during the surgery after assessing the quantity and quality of bone. However, as implant therapy expanded to partially edentulous ridges, additional factors related to restoration became important in determining the ideal implant position. This shift towards a more restorative-driven approach to implant placement was necessary to achieve favorable aesthetic and functional outcomes, especially in the aesthetic zone.

Clinical significance

Computer-assisted surgery has a wide range of therapeutic uses that are feasible. After more than ten years of practice, the majority of surgeons came to the opinion that navigation systems are useful and beneficial for use in oral and maxillofacial surgery (7).

Clinical use in maxillofacial trauma surgery

It has an important effect on enhancing facial aesthetics and the proper functioning of the eyes (8-10). Orbito-zygomatic midfacial fractures are frequently seen in oral and maxillofacial trauma cases. The treatment of these fractures depends on the level of bone stability and displacement. However, correcting the functional and aesthetic deformities caused by poorly treated midfacial fractures remains a complex and challenging task for oral-maxillofacial surgeons. Orbital or complicated midfacial fractures have been treated using CAS (7). This method allows for accurate preoperative preparation and precise orbital reconstruction. Conventional methods involve creating a custom-made model for preparation, which can be expensive and time-consuming. However, emergency surgery using surgical navigation can deliver a precisely fitting plate and allow for assessment of orbital floor restoration and plate location. In emergency maxillofacial surgery, the use of surgical navigation permits more precise orbital reconstruction, making it an important tool for treating complicated midfacial orbito-zygomatic fractures.

Clinical uses for skull base surgery

A detailed study of the anatomical features in the area is required for treatment of severe degenerative temporomandibular joint (TMJ) problems or tumours of the skull base. Precise 3D operative planning is crucial, particularly in determining the extent of tumour resection and ensuring an adequate margin. Due to the restricted amount of space available for manoeuvring, special care must be taken to prevent harming the structures inside the middle cranial fossa. Depending on the location, invasion, and size of the tumour, a surgical method for removal must be chosen (11). This innovation reduces the dangers involved with surgery while enhancing its quality. The navigation technology also makes it possible to outline anatomical features prior to surgery, protecting crucial markers during reconstructive surgeries. During malignancy surgery, navigation techniques reduce the need to remove important tissues and provide precise imaging of the connections between lesions at the base of the skull. Overall, the use of a navigation system by oral and maxillofacial surgeons during surgeries on the skull base or the temporomandibular joint offers them more confidence, allowing them to adopt a more radical approach and cutting the procedure's time in half (7).

Clinical uses for orthognathic surgery

Using navigation during orthognathic surgery has several advantages, including the chance to examine the surgical strategy and the ability to avoid important structures. For optimal outcomes, it is essential to have a thorough understanding of the anatomy and positional correlations of each patient. The need for precise anatomical information in orthognathic surgery is demonstrated by patient variances in the mandibular thickness, marrow space, and length, as well as the course of the inferior alveolar nerve (12, 13). Using a navigation system during orthognathic surgery allows for accurate, real-time evaluation of tool placement. This requires planning the placement of several instruments during a vertical ramus osteotomy, including oscillating cuts and pterygoid osteotomes in relation to the lingual nerve and sigmoid notch and pterygoid osteotomes in the pterygomaxillary fissure. The navigation system also assists in avoiding the inferior alveolar nerve during a blind

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inferior border osteotomy. 3D planning software allows for the upload and use of preoperative computer-assisted surgical plans, which overlay planning files from the Digital Imaging and Communications in Medicine with navigated CT images. This enhances the accuracy of putting the maxillary and mandibular segments in their ideal placements as compared to conventional surgical planning. Because it allows for accurate localization of the osteotomy sites, the location of the distractor's screw holes, and a suitable orientation of the distraction device, navigation is very beneficial in distraction osteogenesis surgeries (14). In orthognathic operations, navigation surgery facilitates the examination of numerous anatomical locations. The degree of surgical change may be clearly specified for surgeons utilising computer-assisted surgical simulation at certain anatomical areas, such as the anterior nasal spine, A/B points, and pogonion. During surgery, navigation enables medical professionals to more accurately locate and confirm the positions of important anatomical landmarks, ensuring the right bone changes are made (15, 16).

Clinical uses for removing foreign bodies.

Because of their closeness to important structures and the difficulty in reaching them, foreign bodies in the craniomaxillofacial area can be difficult and dangerous to remove (17). Removing deep, irregular foreign bodies in situations of severe trauma, such as gunshot and bomb injuries, offers significant challenges because of potential modifications to or harm to normal anatomy. To guarantee the safe removal of the foreign object, its position must be accurately identified. Preoperative CT scanning and 3D image reconstruction are valuable techniques for accurately identifying the foreign body and providing a great picture of the surrounding anatomy, including significant blood vessels. Even with prior information, intraoperative foreign body detection might be difficult. There have been a number of documented approaches for intraoperative localization, including the stereotactic use of two venipuncture needles. In this method, two reference needles are arranged such that they radiographically meet at the foreign body. Then, one of the needles is used to bluntly dissect the foreign body to locate its tip (18). It could be challenging to get intraoperative standard radiography pictures in emergencies due to the length of time required for imaging. Additionally, it could be difficult to see slight positional changes on plain radiographs. C-arm digital fluoroscopy has been employed in rapid radiography, but like plain films, it only generates two-dimensional images and lacks accurate placement in three dimensions. The tiny size of the mouth cavity and the challenge of placing the ultrasound equipment precisely have limited the use of intraoperative ultrasound imaging to find foreign substances (19).

Utility in mandibular procedures

There are various methods for using navigation systems in the mandible right now. The mandible can be fixed with a dynamic reference frame, allowing for continuous monitoring of mandibular mobility throughout the operation. With this strategy, the mandible may be monitored and navigated in real time while being operated on (20). There are multiple approaches for utilizing navigation systems in mandibular surgery. One method involves directly tracking the mandible using a sensor frame and fiducial markers attached to the teeth or mandible. This allows for accurate navigation of the mandible during surgery. However, the fixation of reference points using this approach requires a specialised and time-consuming procedure. Another strategy involves maintaining an immobile intercuspal position to ensure intraoperative mandibular synchronization. A third method includes utilising an occlusion splint to hold the jaw against the maxilla in a fixed or repeatable posture. This technique lessens the relative mobility of the jaw, but it may also decrease precision due to possible issues with the mandible's artificial fixation.

Computer-Assisted Implant Surgery (CAIS)

Due to recent technical developments in CBCT, intraoral scanning, and computer-aided design and manufacture (CAD/CAM) technologies, CAIS has grown in popularity quickly. CAIS streamlines the interaction between the restorative and surgical

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teams in planning and placing dental implants for the reconstruction of partial to fully edentulous ridges. The objectives of CAIS are to plan minimally invasive treatment with predictable clinical outcomes while minimising intraoperative complications, post-operative discomfort, and overall treatment time. CAIS is categorised into two systems: static computer-assisted implant surgery (sCAIS), which features the use of an individually fabricated surgical guide, and dynamic computer-assisted implant surgery (dCAIS), which features the use of a computer-aided navigation system (21).

To facilitate the accurate transfer of the planned implant position to the surgical site, various surgical guides were introduced. With the integration of computer-assisted technology, dental implant surgery has evolved into a recognized treatment modality, offering improved precision and outcomes.

Benefits

Virtual surgical planning offers numerous advantages for surgical procedures. By using virtual planning, surgical intentions are declared, minimising potential conflicts between resection and reconstruction teams. Preferences such as recipient vessel choice or soft tissue requirements can be communicated effectively. Additionally, if there is uncertainty regarding the resection or reconstruction, it can be noted and accounted for in virtual surgery. CAD-CAM software enables surgeons to perform virtual surgery and generate templates and cutting guides, facilitating the precise and efficient implementation of the surgical plan in the operating room. The use of advanced software and manufacturing tools enhances the education of caregivers, aids in explaining the procedure's complexity to patients, and allows different services to provide input on the procedure before it takes place. Ultimately, this approach can lead to more precise surgeries, shorter anaesthesia times for patients, and increased efficiency in the surgical process (22).

Limitations

Although navigation systems provide advantages in midfacial surgical procedures, they also have certain drawbacks. Compared to the immobile maxillary/midfacial region, the mandible's motion makes it harder to synchronise locations with previously obtained pictures, making navigation systems for the mandibular region more challenging to utilise. Despite these challenges, using a navigation system for the mandibular region may still be beneficial in accurately identifying foreign objects and offering the surgeon intraoperative aid. Although locating the location of the mandible requires more preoperative preparation, thorough planning can shorten the surgery's length and improve the procedure's safety and dependability (7).

Conclusion

CAS has revolutionised surgical procedures in maxillofacial surgery, offering numerous benefits and some limitations. The use of virtual surgical planning and CAD-CAM software allows for clear declaration of surgical intentions, effective communication between teams, and precise implementation in the operating room. CAS has significantly impacted dental implant placement, orthognathic surgery, skull base surgery, and the removal of foreign bodies, enabling accurate positioning and improved outcomes. Navigation systems provide real-time tracking and visualisation, ensuring accuracy and safety. However, limitations exist, particularly in mandibular surgery, due to the mandible's mobility. Despite these challenges, CAS offers advantages such as increased precision, reduced anaesthesia time, and improved efficiency. Future developments in navigation system design are expected to improve their applicability.

Disclosure

Conflict of interest

There is no conflict of interest.

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Ethical consideration

Non applicable

Data availability

Data that support the findings of this study are embedded within the manuscript.

Author contribution

All authors contributed to conceptualizing, data drafting, collection, and final writing of the manuscript.

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