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CAD/CAM Assistance and Surgical Navigation in Maxillary Tumor and Adjacent Structures A Review

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ABSTRACT

The integration of CAD/CAM (Computer-Aided Design and Computer-Aided Manufacturing) technology and surgical navigation systems in maxillofacial surgery significantly enhances the precision and outcomes of managing maxillary tumors. This review highlights the effectiveness of these technologies in facilitating accurate tumor resection and reconstruction through real-time navigation and the creation of patient-specific models. Studies indicate minimal deviations between planned and actual surgical pathways, underscoring the efficacy of CAD/CAM in ensuring precise osteotomies and customized implants. Surgical navigation further aids in minimally invasive procedures, enhancing visualization and reducing operative risks. The articles reviews CAD/CAM assistance and surgical navigation in maxillary tumor and adjacent structures

Keywords: CAD/CAM, Surgical Navigation, Maxillary Tumors, Tumor Resection, Maxillofacial Surgery.

Introduction

The integration of CAD/CAM (Computer-Aided Design and Computer-Aided Manufacturing) technology and surgical navigation systems in maxillofacial surgery significantly enhances surgical precision and outcomes in managing maxillary tumours, particularly in complex anatomical regions.[1] This approach facilitates accurate tumor resection and reconstruction by enabling real-time navigation that tracks instruments during surgery, which is crucial for extensive resections in anatomically distorted areas like the maxilla. Studies indicate that deviations between planned and actual osteotomy lines are minimal, averaging around 1.68 mm, which ensures precise tumor removal. Furthermore, CAD/CAM applications allow for the design of patient-specific prosthetics, leading to improved reconstruction outcomes following tumor resection.[2] The use of navigation systems also supports minimally invasive techniques, reducing operative risks and enhancing recovery. Additionally, CAD/CAM-guided osteotomies can enhance precision and minimize damage to adjacent structures during tumor resection, while customized implants or bone grafts can be fabricated to ensure accurate fit and function.[3] Surgical navigation aids in the precise placement of orbital floor implants or grafts and improves visualization in endoscopic sinus surgeries, thereby reducing the risk of complications.[4] This article gives an overview of CAD/CAM assistance and surgical navigation in maxillary tumour and adjacent structures.

Review of literature

Shinsuke Yamamoto's study highlights the effectiveness of a novel splint integrated with a reference frame and registration markers for maxillary navigation surgery. This custom-made splint, featuring fiducial gutta-percha markers, enables easy and noninvasive marker-based pair-point registration, allowing for high-accuracy surgical navigation without the need for reregistration. Additionally, this method offers significant convenience for surgeons and shows promise for use in otolaryngologic surgery, neurosurgery, and craniofacial trauma repairs.[5] In a study by Zu-Nan Tang involving seven patients with maxillary and mandibular tumors, a total of 13 osteotomy planes were analyzed. The mean deviation between the planned and actual osteotomy planes was 1.68 ± 0.92 mm, with a maximum deviation of 3.46 mm. Chromatographic analysis indicated that 80.16% of the points had errors of ≤3 mm, and the mean deviations for maxillary and mandibular osteotomy lines were similar. Among the patients, five had benign tumors and two had malignant tumors, with comparable mean deviations of osteotomy lines. Intraoperative frozen pathology confirmed negative resection margins for all cases, and no tumor recurrence or complications were reported during a mean follow-up of 15.7 months. The study concludes that the combination of mixed reality technology and surgical navigation is feasible, safe, and effective for tumor resection in the oral and maxillofacial region.[6] Julia Koseki's study focuses on the application of navigation systems in the removal of odontogenic benign tumors located in the deep areas of craniofacial bone, particularly in the maxilla. By utilizing advanced navigation technology, the research demonstrates the ability to completely excise these tumors in a minimally invasive manner, enhancing surgical precision and reducing recovery time. This innovative approach aims to improve patient outcomes by allowing for accurate tumor removal while preserving surrounding healthy structures.[7]

Application of navigation surgery in maxilla

Surgical navigation systems are advanced tools that enhance the precision and effectiveness of surgical procedures by integrating real-time imaging data with three-dimensional (3D) virtual models of a patient's anatomy, thereby providing invaluable intraoperative guidance. The key components of these systems include imaging modalities such as computed tomography (CT) or magnetic resonance imaging (MRI), which are employed to create accurate 3D representations of the surgical site. To ensure precise tracking, either optical or electromagnetic tracking systems are utilized to monitor the position of surgical instruments in relation to the patient's anatomy, allowing for dynamic adjustments during the operation.[9] Additionally, visualization technologies, such as heads-up displays (HUDs) or computer screens, provide surgeons with a real-time overview of the instruments' positions compared to the virtual model, enabling them to make informed decisions and navigate complex anatomical structures with greater confidence. This integration of imaging, tracking, and visualization ultimately enhances surgical outcomes and minimizes potential complications. The application of navigation systems in maxillary and midface surgery significantly enhances intraoperative precision and accuracy, ensuring that the surgical outcomes align closely with the preoperative planning.[10] However, the effectiveness of these navigation systems can be influenced by several factors, including the type of system utilized, the methods employed to obtain imaging data, and the synchronization of that data with the patient's actual position during surgery. Current navigation systems used in maxillary and midface surgeries are generally reliable, having been adapted from neurosurgical technologies. Since the maxilla and midface are immovable structures, unlike the mandible, the skull's position relative to the reference remains stable, allowing for a registration procedure that accurately reflects this stability. As a result, navigation-assisted surgery emerges as the most suitable approach for procedures involving the maxilla and midface.[11]

CAD/CAM technology

CAD/CAM technology plays a pivotal role in modern surgical practices by enabling the creation of three-dimensional (3D) virtual models of a patient's anatomy derived from preoperative imaging data, such as CT or MRI scans. These advanced models facilitate comprehensive preoperative planning by providing detailed visualizations of tumor extent, adjacent structures, and potential surgical approaches, allowing surgeons to strategize their interventions with enhanced clarity. Furthermore, CAD/CAM technology allows for the fabrication of customized surgical guides or templates, which can be 3D printed to ensure precise placement of implants, osteotomies, or bone grafts, thereby improving surgical accuracy and outcomes. Additionally, the use of these virtual models for surgical simulation enables surgeons to practice the procedure in a risk-free environment, enhancing their familiarity with the patient's unique anatomy and preparing them to address potential challenges effectively during the actual surgery. This integration of technology not only streamlines the surgical process but also contributes to improved patient safety and treatment efficacy.[3,11]

Applications Of CAD/CAM Technology And Surgical Navigation Systems in Maxillary Tumor Surgery

The applications of CAD/CAM technology and surgical navigation systems in maxillary tumor surgery significantly enhance both the precision and effectiveness of various surgical procedures. In tumor resection, CAD/CAM-guided osteotomies facilitate highly accurate cuts, minimizing damage to adjacent structures and ensuring complete removal of the tumor. For reconstruction, customized implants or bone grafts can be designed and fabricated using CAD/CAM technology, which guarantees an accurate fit and optimal functionality tailored to the individual patient's anatomy. Additionally, surgical navigation proves invaluable in orbital floor repair by assisting in the precise placement of implants or grafts, thereby restoring structural integrity. In the context of sinus surgery, navigation enhances the safety and efficacy of endoscopic procedures by improving visualization and guiding the surgeon, which significantly reduces the risk of complications. Overall, these technologies contribute to better surgical outcomes, reduced recovery times, and improved patient quality of life.[11,12,13]

Impact of CAD/CAM Technology on Surgical Precision in Maxillary Tumor Reconstruction

The use of CAD/CAM technology in maxillary reconstruction offers significant advantages in achieving precise osteotomy lengths, widths, and angles through cutting guides. This method not only saves time by pre-determining the surgical process but also standardizes techniques, allowing any surgeon to replicate accurate cuts, thereby minimizing reliance on individual expertise. However, the effectiveness of CAD/CAM is contingent upon high-quality CT imaging and experienced design, as inadequate data or design may hinder surgical accuracy. Cost-wise, while in-house 3-D printing of guides seems more economical, it requires initial investment in technology and underestimates the time spent on design and printing.[14] Fused deposition modeling (FDM) is commonly used for 3-D printing, with materials like ABS and PLA employed for creating surgical models. While PLA is preferred due to its gas sterilizability and sufficient rigidity, concerns about warping exist. The accuracy of printed guides can be affected by the smoothness or complexity of the bone surfaces they are intended to fit. Therefore, trial-and-error printing and pre-surgery modeling are essential for ensuring a good fit.[15] Ultimately, while in-house CAD/CAM approaches may appear less costly, they provide unique advantages, including the ability for surgeons to engage in virtual simulations and explore guide designs for both hard and soft tissues, potentially extending their application in various surgical contexts, including breast reconstructions.[16]

Advantages

The integration of CAD/CAM technology and surgical navigation systems in surgical practices offers numerous benefits that significantly enhance the overall quality of care. One of the primary advantages is improved accuracy; the precise visualization and guidance provided by these technologies substantially reduce the risk of surgical errors and minimize damage to critical structures.[17] Enhanced planning is another key benefit, as preoperative simulations allow surgeons to anticipate potential challenges and optimize their surgical approaches, leading to more effective procedures. Additionally, the use of customized templates and navigation tools can streamline the surgical process, resulting in reduced operative time and increased efficiency in the operating room. Ultimately, these improvements translate into better patient outcomes, characterized by greater functional and aesthetic results, fewer complications, and enhanced overall recovery experiences for patients undergoing complex surgical interventions.[18]

Future Direction	Description
Integration with Augmented Reality	Combining CAD/CAM with AR to provide a more immersive and intuitive surgical experience by overlaying digital information onto the physical environment.
Artificial Intelligence	Utilizing AI algorithms to analyze imaging data, assist in preoperative planning, and support intraoperative decision-making by identifying patterns and predicting outcomes.
Personalized Treatment Planning	Developing highly personalized treatment plans based on individual patient anatomy and pathology using CAD/CAM and surgical navigation systems, enhancing surgical precision and patient outcomes.[19,20]

Conclusion

In conclusion, the integration of CAD/CAM and surgical navigation technologies has profoundly advanced the management of maxillary tumors and their adjacent structures. These innovations provide precise visualization, comprehensive planning, and accurate guidance, all of which contribute to improved surgical outcomes and reduced complications. By enhancing the precision of tumor resection and reconstruction, these technologies significantly elevate patient quality of life. As CAD/CAM and surgical navigation continue to evolve, we can anticipate even greater benefits and transformative changes in the field of maxillofacial surgery in the future.

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