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Patient-Specific Dental Implants Following Jaw Resection: A Review

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Abstract

Patient-specific dental implants (PSI) have emerged as a transformative solution for post-resection maxillofacial rehabilitation, providing customized reconstruction tailored to the patient's unique bone defect following tumor resection, trauma, or osteoradionecrosis. These implants overcome the limitations of conventional grafting by minimizing donor-site morbidity, reducing surgical time, and offering precise anatomical fit for improved functional and aesthetic outcomes. Advanced imaging, virtual surgical planning, and CAD/CAM or 3D printing technologies facilitate accurate design and fabrication, enabling immediate or early prosthetic rehabilitation. Clinical studies demonstrate enhanced mastication, speech, swallowing, and facial symmetry, alongside high implant survival rates and minimal complications. Despite advantages, challenges include high cost, technical complexity, and limited long-term data. Emerging innovations, such as bioactive and porous surfaces, integration with growth factors or stem cells, and AI-driven planning, further enhance osseointegration and personalized treatment. PSDIs represent a reliable, patient-centered approach for restoring both function and aesthetics in complex maxillofacial reconstructions.

Keywords: Patient-specific implants, Maxillofacial reconstruction, CAD/CAM, Osseointegration, Jaw resection

Introduction

Patient-specific dental implants (PSI) are custom-designed implants tailored to precisely fit a patient's unique maxillofacial defect following tumor resection, trauma, or osteoradionecrosis, offering a safe and effective alternative for dental rehabilitation while avoiding the prolonged treatment time and donor-site morbidity associated with conventional grafting.[1] Indications for these implants commonly include malignant or benign jaw tumors, such as squamous cell carcinoma, ameloblastoma, or keratocystic odontogenic tumors, which often necessitate segmental or hemi-mandibulectomy or maxillectomy to achieve tumor-free margins, as well as severe osteoradionecrosis resulting from radiation-induced bone necrosis, and complex traumatic defects involving nonviable bone segments.[2] Post-resection rehabilitation poses multiple challenges, including profound bone loss that disrupts mandibular continuity, altered skeletal anatomy complicating implant placement, occlusal changes affecting bite force distribution and mastication, and esthetic deficits such as facial asymmetry and loss of chin or lip projection that impact quality of life.[3] Conventional approaches, including autogenous grafts, carry risks of donor-site morbidity and graft failure, while allogenic grafts may induce immune reactions or infection, and standard titanium plates or meshes

often lack precise conformity, leading to soft tissue complications and suboptimal implant stability. Patient-specific implants address these limitations by utilizing advanced imaging such as CT or 3D scans combined with CAD/CAM software to design implants that replicate the patient's anatomical defect, which are then fabricated using 3D printing or milling in biocompatible materials like titanium.[4] These implants allow accurate surgical placement guided by virtual surgical planning, provide improved load distribution, reduce operative time, and facilitate soft tissue management, while often incorporating prosthetic attachment points for immediate or early dental rehabilitation. Clinical outcomes consistently demonstrate primary and long-term implant stability, restoration of occlusal function, and improved aesthetic results, with minor complications such as mucositis or framework exposure rarely compromising implant success.[5] This article details on Patient-Specific Dental Implants Following Jaw Resection.

Review of Literature on Patient-Specific Implants

Patient-specific implants have been widely recognized for their precision in maxillofacial reconstruction, offering improved aesthetic and functional outcomes compared to conventional approaches, particularly in maintaining mandibular continuity after resection (Stoor et al., 2017).[6] Studies in irradiated oral cancer patients indicate that PSIs contribute to satisfactory oral health-related quality of life (OHRQoL), enabling successful dental rehabilitation with minimal functional impairments (Jehn et al., 2023).[7] In vitro investigations have further demonstrated that these implants provide enhanced stability and resistance to physiological forces, supporting their durability under functional load (Telschow et al., 2019).[8] Despite these advantages, certain challenges remain. Incomplete osseous union has been reported as a notable concern in PSI reconstructions, with higher rates compared to conventional methods. Risk factors include the type of osteosynthesis used and the application of adjuvant radiotherapy (Knitschke et al., 2022).[9] Postoperative complications such as mucosal perforation or infection, although infrequent, may necessitate implant removal (Stoor et al., 2017).[6] Long-term outcomes, however, are generally favorable. When combined with fibula-free flaps, PSIs show high implant survival rates with minimal complications such as infection or mobility, demonstrating their reliability for extended rehabilitation (Zavattero et al., 2021).[10] Moreover, integrating PSIs with autologous bone grafts has been suggested to reduce fracture risk and enhance long-term functional outcomes, making hybrid approaches preferable to purely alloplastic reconstructions (Telschow et al., 2019).[8]

Patient-Specific Implant Design and Fabrication

Patient-specific implant design and fabrication involve a comprehensive workflow that integrates advanced imaging, careful material selection, and precise engineering to create implants tailored to the patient's unique anatomical and functional needs. High-resolution CT or Cone Beam CT (CBCT) scans provide detailed three-dimensional anatomical data of the jaw and defect region, while 3D surface scanning and digital impressions capture the soft tissue and dental morphology necessary for accurate prosthetic integration.[11] Virtual Surgical Planning (VSP) software enables simulation of jaw resection and precise implant positioning, allowing preoperative iteration of design features such as screw placement, load distribution, and prosthetic alignment to achieve optimal functional and esthetic outcomes, and facilitates the creation of patient-specific surgical cutting guides for intraoperative accuracy. Implant materials commonly include titanium and titanium alloys (e.g., Ti6Al4V) for their strength, biocompatibility, and osseointegration potential, with alternatives such as PEEK or bioceramics used in specific scenarios.[12] Manufacturing is performed via subtractive CAD/CAM milling or additive techniques like Electron Beam Melting (EBM) or Direct Metal Laser Sintering (DMLS), enabling the fabrication of complex geometries and porous structures that promote bone ingrowth. Key design considerations include precise adaptation to residual bone to ensure stability, optimized load distribution to prevent stress concentrations, strategic screw placement avoiding vital structures, and incorporation of prosthetic attachments to restore occlusion and functional alignment. Additionally, porosity or lattice designs may be incorporated to reduce implant weight and enhance osseointegration.[13]

Clinical Applications of Patient-Specific Implants

Patient-specific implants have demonstrated significant utility in reconstructing mandibular and maxillary defects resulting from tumors, trauma, or osteoradionecrosis. In mandibular reconstruction, custom titanium implants precisely restore mandibular continuity, facial contour, and occlusion, with long-term follow-up showing favorable bone integration, minimal complications, durable functional load-bearing, and high patient satisfaction. These implants can also accommodate conventional dental implants, enabling comprehensive prosthetic rehabilitation and restoration of functional occlusion.[14] Maxillary and zygomatic reconstruction similarly benefits from the precise anatomical fit of patient-specific implants, effectively replacing lost bone without donor-site morbidity and enhancing facial esthetics, particularly in complex three-dimensional defects of the midface. Implantation may be performed immediately during reconstructive surgery to allow early prosthetic rehabilitation and reduce overall treatment time, or delayed in cases with healing concerns, infection, or soft tissue complications; combining pre-planned dental implant placement with PSI can help minimize multiple surgeries.[15] For prosthetic rehabilitation, PSIs support both fixed and removable implant-retained solutions, with fixed prostheses providing superior masticatory efficiency and patient satisfaction when bone support and implant stability are adequate, while removable options may be preferable when soft tissue management or hygiene considerations are prioritized. Overall, patient-specific implants offer a versatile and precise approach for restoring both function and esthetics in complex maxillofacial reconstructions.[16]

Outcomes of Patient-Specific Implants

Patient-specific implants demonstrate significant improvements in both functional and aesthetic outcomes following jaw reconstruction. Functionally, mastication efficiency increases markedly, with objective assessments showing up to a threefold improvement compared to preoperative status, alongside enhanced dietary intake, oral competence, and chewing ability; early implant-supported prostheses further facilitate the recovery of swallowing and speech.[17] Restoration of mandibular or maxillary continuity and occlusion improves articulation and oral airflow control, while patients often report reduced dependence on feeding aids, particularly in immediate implant protocols. Aesthetically, PSIs accurately reconstruct bony contours, restoring facial symmetry and providing critical soft tissue support for lips and cheeks, thereby re-establishing normal facial profiles and preventing collapse or asymmetry; patient satisfaction scores consistently reflect high levels of contentment with postoperative appearance, contributing to improved quality of life and social reintegration.[3] Implant survival is favorable, with high osseointegration rates, especially when rough or mesh-type surface designs are employed, and long-term follow-up shows minimal loosening or fractures. Complications such as infection or implant exposure are infrequent and typically associated with prior radiation or compromised soft tissue, while prosthetic failures are rare when implants are designed with appropriate load distribution and prosthetic integration.[11] Minor issues, including mucositis or framework exposure, can generally be managed successfully without compromising implant survival.[18]

Advantages and Limitations of Patient-Specific Dental Implants

Patient-specific implants offer substantial advantages over conventional reconstruction methods by providing a precise, customized fit to the patient's unique bone anatomy, minimizing intraoperative adjustments, reducing surgical time and trauma, and optimizing load distribution to enhance implant stability and longevity. These implants facilitate improved functional outcomes, including mastication, speech, and occlusion, while restoring facial contours with superior esthetic results. Compared to autogenous bone grafts, PSDIs eliminate donor-site morbidity, and their tailored design reduces the risk of implant exposure relative to standard plates. The integration of CAD/CAM and 3D printing technologies allows highly accurate fabrication, accelerating postoperative healing and enabling early prosthetic rehabilitation. Nevertheless, PSDIs are associated with high costs due to advanced imaging, design software, manufacturing, and surgical implementation, which can limit accessibility.[19] The requirement for sophisticated digital infrastructure, trained multidisciplinary teams, and experienced surgical and prosthodontic personnel makes the workflow resource-intensive. Additionally, long-term clinical data remain limited, and potential technical errors in imaging, virtual planning, or manufacturing may result in implant misfit or failure, highlighting the importance of strict quality control. Overall, while patient-specific

implants represent a significant advancement in personalized maxillofacial reconstruction, their adoption necessitates careful consideration of cost, technical demands, and evolving evidence.[20]

Conclusion

Patient-specific implants represent a significant advancement in post-resection rehabilitation, offering superior functional and aesthetic outcomes compared to conventional methods. Emerging innovations, including bioactive and porous implant surfaces, integration with growth factors or stem cells, and AI-driven planning and predictive modeling, hold promise for further enhancing osseointegration, bone regeneration, and personalized treatment outcomes.

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