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Review Article

Trailblazing Techniques In Maxillofacial Implants: A Detailed Layer –By-Layer Exploration

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ABSTRACT:
Innovative, cutting-edge patient-specific implants are becoming increasingly essential in the field of maxillofacial reconstruction due to their ability to address complex anatomical challenges with unprecedented precision. These advanced implants, tailored to individual patient needs, represent a significant leap forward from traditional methods, offering improved outcomes in both functionality and aesthetics. The integration of digital technologies, such as 3D scanning and printing, allows for the creation of highly customized prosthetics and implants that better match the patient's unique anatomical structures. This approach not only enhances surgical accuracy but also reduces operative time and recovery periods. Given the pressing need for advanced solutions in reconstructive surgery, the adoption of these state-of-the-art implants is of critical urgency. Their development and implementation are pivotal in advancing patient care, underscoring the necessity for continued innovation in this rapidly evolving field.
Key words: Patient-specific implants, Custom made implants, Advanced Technology, Reconstruction, Medical Devices

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INTRODUCTION

Maxillofacial defects can result from many causes, including trauma, congenital malformations, or cancer. Rehabilitation of residual facial defects is challenging due to the complexity of the anatomy and affects the patient's cosmetic and functional outcomes.[1] The use of allografts and autografts is often associated with resorption, infection, and migration. Recent advancements in maxillofacial reconstruction leverage digital technology, innovative materials, refined surgical techniques, and customized patient-specific solutions to enhance both the precision and effectiveness of treatment.[2] The use of technologies such as digital 3D scanning and printing has transformed the field of maxillofacial prosthetics, making it more efficient, effective, and productive.[3] The technology can be used to create an accurate model of a patient’s face, which can then be used to design and manufacture custom products.[4] Digital scanning and 3D printing technology are also increasingly making it possible to create custom prosthetics for patients.[5] Advances in custom prosthetic technology have made it possible to create prosthetics that are tailored to the specific needs of patients. This can include prosthetics designed to match the patient’s skin tone and texture, as well as prosthetics designed to fit the patient’s facial features.[6] Patient-Specific Implants (PSI) are custom medical devices designed to meet the specific needs of individual patients.[7] PSI is designed to use advanced techniques such as computed tomography (CT) or magnetic resonance imaging (MRI) to create 3D models of the body.[8] This allows implants to be customized to the specific needs of the patient. Custom implants are used in a variety of maxillofacial prosthetic applications, including cranial, orbital, auricular, and nasal defects in patients.[9] These implants have proven to be very effective, providing improved function and aesthetics for patients with a variety of facial defects, including cancer, trauma, and congenital anomalies.[10] Another important benefit of custom implants is their ability to reduce surgical time and improve patient outcomes.[11] Because implants are customized to the patient's anatomy, surgery is generally less invasive, resulting in fewer traumas and a faster recovery time.[12] As a result, using PSI for palatal reconstruction has several advantages over traditional reconstruction methods. PSI can improve patient's quality of life by leading to improved health outcomes, such as speech and digestion, as well as improved cosmetic outcomes. Its main disadvantage is its high cost.[13] Technological evolution and manufacturing techniques have advanced PSI from its initial use in treating oral and maxillofacial defects to a more evolved and refined application.[14] Beginning in the 1980s, 3-dimensional images were created from computed tomography scans.[15] 3D models are not suitable for pre-planning. To create this model, 3D image archives were used on a computer-aided milling machine to cut polystyrene foam or polyurethane blocks to final standards, supplied by Dow Chemical Company, Midland, MI, USA.[16] Early patient implantation has also been developed using this technology. However, the manufacturing process has limitations in the production of anatomical data.[17] With the emergence of advanced manufacturing techniques such as stereolithography, multiplanar and fused deposition modeling 3D, selective laser melting, selective laser sintering, and electron beam melting, this technology is being scaled up to eternity.[18] They allow the production of complex structural components regardless of the format to be associated with the preparation model and have therefore proven important for the reconstruction of precise implants in affected individuals.[19] In advanced manufacturing processes, prosthetics are made from layers of materials and digitally controlled tools.[20] Orofacial PSI addresses both cosmetic and therapeutic needs, offering solutions for congenital facial syndromes associated with skeletal dysplasia and challenging facial deformities, as demonstrated in various clinical applications and case studies.[21] The most common surgeries include osteotomy, bone grafting, and grafting to improve the face.[22] The outcomes of this surgery can vary and are influenced by factors such as graft viability, accuracy of bone repositioning, and healing. PSIs can be designed to provide essential imaging and treatment for facial deformities; several studies have examined their use in treating severe facial abnormalities.[23] Implants, whether male or female, are employed to address jaw atrophy in elderly patients. Modified subperiosteal implants made from titanium using direct metal laser sintering technology have been developed. Evaluation results indicate that the subperiosteal implant's health is rated highly, with an average score of 7 out of 10 and a 100% survival rate after 300 tests over 65 days.[24] Dr. Jules Poukens and his team in Belgium pioneered the creation of the first complete lower jaw set using synthetic materials.[25] Creating facial defects remains a challenging task for many surgeons due to the area's complexity, which impacts the aesthetic and structural integrity of the facial frame. Traditional prefabricated materials or autografts often face issues such as resorption, infection, and migration.[26] As technology advances, PSIs are set to transform maxillofacial reconstruction and enhance the quality of life for patients with various facial deformities.[27] Despite these advancements, it is crucial to recognize that PSIs may not be suitable for all patients or every type of maxillofacial defect. The choice to use PSI should involve a multidisciplinary team of maxillofacial prosthetists, radiologists, surgeons, and engineers.[28] Dental implants are recognized for their safety and comfort, with estimates suggesting that at least 10% of individuals will require dental implants at some point.[29] The fabrication, construction, and repair of facial defects are tasks for skilled practitioners. Correcting three-dimensional (3D) facial morphology requires custom shaping and contouring of both autografts and synthetic implants, adapting to the original bone structure, and reconstructing facial anatomy. Inadequate implant preparation can be detrimental. Nevertheless, advancements in computer-aided design/computer-aided manufacturing now enable the creation of PSIs with remarkable precision and provide guidance for correcting and enhancing contours and shapes.[30] Recent technological advancements have led to the development of computerized systems for PSIs to perform medical procedures.[31] This article discusses our focus on PSI management, treatment strategies, and patient satisfaction metrics. Due to the complexity of this field, achieving optimal function and aesthetics can be challenging.[32]

DISCUSSION

Traditional prefabricated materials or autografts often face issues such as resorption, infection, and migration. Technological innovations have introduced PSIs designed with modern computing to enhance performance and reduce discomfort. However, a significant drawback of PSIs is their high cost. Maxillofacial reconstruction is complex and requires precise solutions to address patient needs while ensuring functionality and appearance.[33] Autologous grafts are typically preferred due to their biological compatibility, though they may affect the donor site. Technological advances in PSI, including additive manufacturing and 3D printing, are revolutionizing the field by enabling the customization of implants to fit each patient's unique anatomy. These implants are created using advanced techniques such as CT scans, which are converted into 3D models using software like Slicer 3D.[34] PSI production utilizes various methods, including fused filament fabrication and direct metal laser sintering.[35] For example, studies have shown that fused filament fabrication can effectively create PSI with materials such as Ti-6Al-4V, enhancing the accuracy and quality of jaw and facial reconstructions. Despite the substantial advantages of PSI, its high expense remains a primary drawback.[36] Ongoing advancements in manufacturing technology and materials are expected to reduce costs and enhance efficiency, making PSIs more viable for a broader range of patients. The aesthetic and emotional significance of the chin and face presents notable challenges. Technological advancements in manufacturing and 3D imaging have enabled the creation of PSIs to address jaw and facial deformities, enhancing both health and aesthetic results.[37] Computer-generated PSIs offer superior precision, improved fitting, increased stability, better outcomes, and enhanced facial contours. In specific studies, Polyether ether ketone and titanium implants have shown promising results.[38] Polyether ether ketone is known for its excellent biocompatibility, adjustability, and mechanical properties, making it effective for general reconstructive surgery.[39] Titanium is preferred for specific cases, such as orbital implants. Dividing large areas into smaller segments can help manage complex reconstructions more effectively.[40] For complex reconstructions involving the mandibular angle, positioning the implant near the lower mandible or midcortex can be beneficial.[41] In one study the final design was based on the mid-level of the nasal bones required additional adjustment during surgery. Despite this, none of the patients experienced complications related to PSI reconstruction. With a 0% infection rate and no issues in wound healing, these findings align with literature indicating that infection rates after maxillofacial PSI reconstruction range from 7.7% to 14.3%. During an average follow-up period of 9.4 months, no postoperative infections were observed.[42] While PSI's high cost is a significant drawback, its advantages—such as precision and improved patient outcomes—justifies its use.[43] PSI effectively manages complex post-traumatic facial defects, and the orbital wall and floor are particularly suitable for deformable facial bones. Proper surgical techniques are essential to avoid complications such as vision loss. Materials for PSI include metals, polymers, and ceramics, utilizing additive manufacturing technologies.[44] These materials are categorized as absorbable, such as Poly-D, L-Lactic Acid and Poly (lactic-co-glycolic acid), and non-resorbable, such as Titanium and Polyether ether ketone. Metal implants, including Titanium, are preferred for their strength and compatibility with human bone, although they may not match bone's elastic modulus, potentially leading to stress-related issues.[45] Additional technologies for titanium implants include physical vapor deposition or electrochemical methods to modify the surface at a site containing bioactive material.[46] Among ceramics, iron oxides, calcium phosphates, and glass ceramics are frequently used. The materials used are less toxic and compatible with body tissues. However, decreased toughness and ductility coupled with increased elastic modulus and brittleness make them unsuitable for load-bearing applications. With recent advances in technology and materials, polyetheretherketone has emerged as a promising heterogeneous implant material that can be used as an alternative to creating PSI.[47] Polyether ether ketone is a semi-crystalline linear polycyclic aromatic thermoplastic that belongs to a group of linear aromatic polymers with ether and ketone bonds and is known for its flexibility and resistance to environmental changes.[48] Osseointegration of Polyether ether ketone is based on properties such as surface composition, strength of force, surface roughness, and topography that can be modified to create a rough or smooth surface using fused filament fabrication technology.[49] Many studies have investigated the use of Polyether ether ketone and other materials in producing bone-based implants, highlighting various challenges associated with Polyether ether ketone artifacts.[50] Alonso Rodriguez et al. and Rosenthal et al. reported a study of 65 cases showing an infection rate of 7.7%.[51] Poly Methyl acrylate (PMMA) Computer-Aided Design and Computer-Aided Manufacturing implants were applied to 21 patients with extensive cranial deformities. The reported complication rate, including soft tissue and implant complications, was 23.8%, while the infection rate in 65 patients reported by Rosenthal et al. was 7.7%.[52] Gerbino et al. presented the results of a clinical study on 13 patients, stating that the shape and fit of the implants used in each case were comparable. Minor modifications were required in 11 cases, and revision in 1 case. Of the 13 implants used for rehabilitation, 11 healed with good aesthetic results and no other complications occurred.[53] Jarvinen also reported that 19 out of 24 patients did not require modifications for patient-specific implants with Polyether ether ketone. He added that only five cases are enough to see or cut the bone to achieve a good fit.[54] Polyethylene, including porous polyethylene and ultra-high molecular weight polyethylene, is used in the treatment of orbital defects and facial growth. Porous polyethylene is durable and easy to model, and tissue can grow through its pores. However, there is a risk of infection. Ultra-High-Molecular-Weight Polyethylene is known for its strong structure and is used to repair the orbital or temporo mandibular joint using

Computer-Aided Design and Computer-Aided Manufacturing technology to create PSI.[55] It has been reported to be less contaminant compared to Porous Polyethylene and hydroxyapatite has been used as a biocompatible scaffold material for bone engineering. They are osteoconductive and non-absorbable and are widely known for their excellent adhesion to bone and soft tissue.[56] Absorbable materials such as Poly-D, L-Lactic Acid and Poly (lactic-co-glycolic acid) are widely used in pediatric surgery. However, foreign body formation and ruptures have been reported after implantation.[57] Calcium phosphate is also used in the treatment of craniofacial disorders and is known to have good biocompatibility and biodegradation properties. These are likened to stones in the bones and therefore do not cause interference or intervention when performing CT or MRI scans.[58] Calcium phosphate is thought to aid bone growth, although it is weaker than titanium and may contain proteins or antibiotics. The manufacturing process involves imaging, where 2D imaging data from CT/MRI is used as Digital Imaging and Communications in Medicine (DICOM) data.[59] These DICOM files are prepared using software (3D Doctor, MIMICS) to create 3D models of anatomical deformities. This 3D model is then entered into design software and the "3D" model is processed into the final design.[60] Planting is achieved by shaping blocks of material through subtractive manufacturing or by adding and fusing material layer by layer using additive manufacturing.[61] In the early days, the creation of patient-specific implants was done through a manufacturing process in which pieces were cut until the final image was completed. However, it was noted that there was a lot of material waste in the production of the products and that complex anatomical shapes could not be reproduced using computer numerical control. This method employs additive manufacturing, also known as rapid prototyping or 3D printing, to create patient-specific implants.[62] This overcomes the limitations encountered in the production of the products and allows the products to be implanted in specific patients.[63] Additive manufacturing includes techniques such as binder jetting, direct metal laser sintering, electron beam melting, laser engineered net shaping, and fused deposition modeling.[64] Binder Jetting consists of two components: the powder that forms the artificial material and the adhesive that bonds the powder material. Implants made with this method do not require additional support. However, compared to products produced by selective laser melting or electron beam melting manufacturing methods, these products have low material density and roughness due to the inherent porosity of the capital and heat treatment.[65] Additionally, the manufacturing cost increases and is considered another disadvantage. Direct Metal Laser Sintering uses high-power lasers to melt metal layer by layer based on 3D Comuter Aided Design files. It helps reduce manufacturing costs and produce ready-to-use mesh products, but with disadvantages such as size limitations, high energy consumption, and large initial costs.[66] Electron Beam Melting similar to Direct Metal Laser Sintering, it uses an electron beam to melt metal powder layer by layer. Laser Engineered Net Shaping uses steel additives taken directly from a Computer Aided Design- stabilized model and injects changes in alloy parts into a molten metal vat with the aid of an intense, powerful laser beam. After each layer is formed, the molten metal expands rapidly when the laser beam is fired. This process repeats until all parts are produced as given in the 3D Computer Aided Design- version.[67] Fused Deposition Modeling, also known as fused filament manufacturing, involves liquefying polymer at the printer's nozzle and depositing it in layers. The first layer is laid down in a precise pattern, and subsequent layers are added on top as the distance between the printing surface and the extruder is adjusted. The Fused Deposition Modeling method offers benefits such as reduced production costs and faster setup times. The production process is optimized based on factors like material properties, equipment used, and delivery timelines for patient-specific implants. Currently, developing these implants takes several days. However, with advancements in 3D printing technology, production times are expected to decrease, enhancing efficiency. Future developments may incorporate both allogeneic and autologous materials to create personalized dental implants, advancing the field of craniofacial prosthetics.[68]

FUTURE DIRECTIONS

In the future, fat stem cells are poised to play a crucial role in the production of PSIs). Research indicates that anatomically tailored fat stem cell bone grafts can be effectively cultivated and used in Yucatan minipigs to reconstruct the ramus condyle unit. Patient-specific implants have already transformed oral and maxillofacial prosthetics by enabling precise customization to individual needs, although they may not always yield perfect outcomes. These implants significantly enhance reconstruction quality and allow for more accurate treatment planning. Future advancements in 3D printing technology are expected to further refine PSI production, integrating both allogeneic and autologous materials to achieve superior customization. The incorporation of fat stem cells in PSI development may open new avenues for improving implant integration and functionality. As these technologies advance, it is anticipated that production times will shorten, and the overall cost of PSIs will become more affordable.[69]

CONCLUSION

The use of PSI for maxillofacial reconstruction features predictable outcomes, eliminates the usual complications seen in non-custom-made implants, and boasts excellent patient satisfaction with high cost as the main drawback. Patient-specific implants have significantly improved the quality of maxillofacial reconstruction by providing customized solutions that address individual anatomical and functional needs. While challenges such as high cost remain, the advancements in CAD/CAM technologies and material science promise enhanced accuracy, efficiency, and outcomes in the future of PSI applications.

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