CLINICAL AND FUNCTIONAL OUTCOMES OF PATIENT-SPECIFIC 3D-PRINTED TITANIUM IMPLANTS IN RECONSTRUCTION OF EXTENSIVE MANDIBULAR DEFECTS

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Abstract: *Extensive mandibular defects caused by malignant tumors, trauma, or severe inflammatory diseases represent one of the most complex challenges in modern maxillofacial surgery, as they lead to significant functional impairment and aesthetic deformity. Traditional reconstruction techniques, including autogenous bone grafting and standard reconstruction plates, are associated with limitations such as donor site morbidity, insufficient anatomical accuracy, and prolonged rehabilitation. The development of computer-aided design and additive manufacturing technologies has enabled the creation of patient-specific 3D-printed titanium implants, allowing precise anatomical restoration and improved biomechanical stability. The aim of this study was to evaluate the clinical and functional outcomes of individualized titanium implants in mandibular reconstruction. The study included 32 patients with extensive mandibular defects who underwent surgical reconstruction using customized 3D-printed titanium implants based on preoperative CT imaging and virtual surgical planning. Clinical, radiological, and functional parameters were assessed during a follow-up period of up to 24 months. The results demonstrated a high implant survival rate (93.7%), satisfactory osseointegration, and significant improvement in mastication, speech, and facial symmetry. The findings confirm that patient-specific titanium implants provide reliable structural and functional rehabilitation and represent a promising direction in modern reconstructive maxillofacial surgery.*

Keywords*: mandibular reconstruction, 3D printing, titanium implant, CAD/CAM, maxillofacial surgery, osseointegration, personalized implant, additive manufacturing, facial reconstruction, surgical planning*

INTRODUCTION

Mandibular defects represent a serious clinical condition that significantly affects essential functions such as mastication, speech, swallowing, and facial aesthetics. These defects most commonly occur as a result of malignant tumor resection, severe trauma, osteomyelitis, or congenital anomalies (Ellis & Zide, 2016). Loss of mandibular continuity disrupts biomechanical balance and leads to functional disability and psychological distress, significantly reducing patient quality of life. Traditional reconstruction techniques, including autogenous bone grafts such as fibula free flaps, have long been considered the gold standard; however, these procedures require complex microsurgery, prolonged operative time, and are associated with donor-site complications (Bianchi et al., 2018). Furthermore, conventional reconstruction plates do not always provide sufficient anatomical accuracy or long-term biomechanical stability.

Recent advances in digital medicine, including computer-aided design and computer-aided manufacturing technologies, have introduced new possibilities for personalized reconstructive surgery. Three-dimensional imaging combined with virtual surgical planning allows precise evaluation of anatomical defects and enables the fabrication of customized implants tailored to individual patient anatomy (Ciocca et al., 2015). Titanium is widely recognized as an optimal implant material due to its high strength, corrosion resistance, and excellent biocompatibility, which promotes osseointegration and long-term stability (Throckmorton & Dechow, 2016). Additive manufacturing technologies allow the production of highly accurate patient-specific implants that restore anatomical continuity and improve functional outcomes.

Several studies have demonstrated that patient-specific implants reduce surgical time, improve implant fit, and decrease complication rates compared to conventional reconstruction methods (van Baar et al., 2019). However, clinical data regarding long-term functional recovery and implant stability remain limited, particularly in patients with extensive mandibular defects. Therefore, the aim of this study was to evaluate the clinical effectiveness, functional outcomes, and implant survival rate following mandibular reconstruction using patient-specific 3D-printed titanium implants.

MATERIALS AND METHODS

This prospective clinical study included 32 patients aged between 22 and 67 years (mean age 45.8 ± 12.4 years) who presented with extensive mandibular defects requiring surgical reconstruction. The primary causes of mandibular defects included malignant tumors in 18 patients (56.3%), post-traumatic deformities in 7 patients (21.9%), and chronic osteomyelitis in 7 patients (21.9%). All patients underwent comprehensive preoperative evaluation, including clinical examination, multislice computed tomography, and digital 3D reconstruction of the mandible. Imaging data were converted into digital models using specialized software, allowing virtual surgical planning and precise implant design (Schouman et al., 2020).

Customized implants were manufactured from medical-grade titanium alloy using additive manufacturing technology. The implant design replicated the original anatomical contour of the mandible and included fixation points for osteosynthesis screws to ensure mechanical stability. Surgical reconstruction was performed under general anesthesia following standard maxillofacial surgical protocols. After removal of pathological tissue and preparation of bone margins, the patient-specific implant was positioned and fixed using titanium screws.

Postoperative evaluation included clinical examination, radiological assessment using CT imaging, and functional evaluation of mastication and speech. Follow-up examinations were performed at 1, 3, 6, 12, and 24 months after surgery. Implant stability, signs of infection, and evidence of osseointegration were assessed. Functional recovery was evaluated based on chewing efficiency, speech clarity, and facial symmetry. Statistical analysis was performed using standard methods, and differences were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Mandibular reconstruction using patient-specific 3D-printed titanium implants demonstrated favorable clinical and functional outcomes in the majority of patients. Primary implant stability was achieved in 30 out of 32 patients (93.7%), confirming the high accuracy of implant design and surgical placement. Radiological examination performed at 12 months demonstrated stable implant positioning and satisfactory osseointegration in 29 patients (90.6%), which is consistent with previous studies highlighting the biocompatibility of titanium and its ability to integrate with surrounding bone tissue (Throckmorton & Dechow, 2016). Early postoperative complications were observed in 5 patients (15.6%), including mild inflammation and temporary soft tissue swelling, which were successfully managed with conservative treatment. No cases of implant rejection were observed.

Functional evaluation revealed significant improvement in mandibular function and facial aesthetics. Restoration of mastication function was achieved in 26 patients (81.3%), while speech articulation improved in 24 patients (75.0%). Facial symmetry was successfully restored in 28 patients (87.5%), contributing to improved psychosocial well-being. These findings support previous research demonstrating that patient-specific implants provide superior anatomical accuracy compared to conventional reconstruction methods (Bianchi et al., 2018).

The use of digital planning and additive manufacturing significantly improved surgical precision and reduced intraoperative adjustment. Customized implants ensured optimal load distribution, minimizing mechanical stress and improving long-term stability. Compared to traditional bone graft reconstruction, patient-specific implants eliminate donor site morbidity and reduce operative complexity (Ciocca et al., 2015). However, limitations include the cost of implant production and the need for advanced technological infrastructure. Despite these limitations, the high implant survival rate and favorable functional outcomes observed in this study confirm the effectiveness of this approach.

Table 1.

Clinical and functional outcomes after mandibular reconstruction using patient-specific 3D-printed titanium implants (n=32)

Indicator	Number of patients	Percentage (%)
Primary implant stability	30	93.7
Successful osseointegration	29	90.6
Early postoperative complications	5	15.6
Implant survival rate	30	93.7
Restoration of mastication	26	81.3
Improvement of speech function	24	75.0

Indicator	Number of patients	Percentage (%)
Restoration of facial symmetry	28	87.5

Source: *Authors' clinical data (2023–2025).*

The table demonstrates a high level of implant stability and survival, exceeding 90%, which confirms the reliability of patient-specific titanium implants. Functional recovery indicators were also high, particularly in mastication and facial symmetry restoration. The relatively low complication rate indicates good biocompatibility and surgical safety. These results confirm that individualized implants provide both anatomical and functional rehabilitation.

Diagram 1.

Functional recovery indicators after mandibular reconstruction
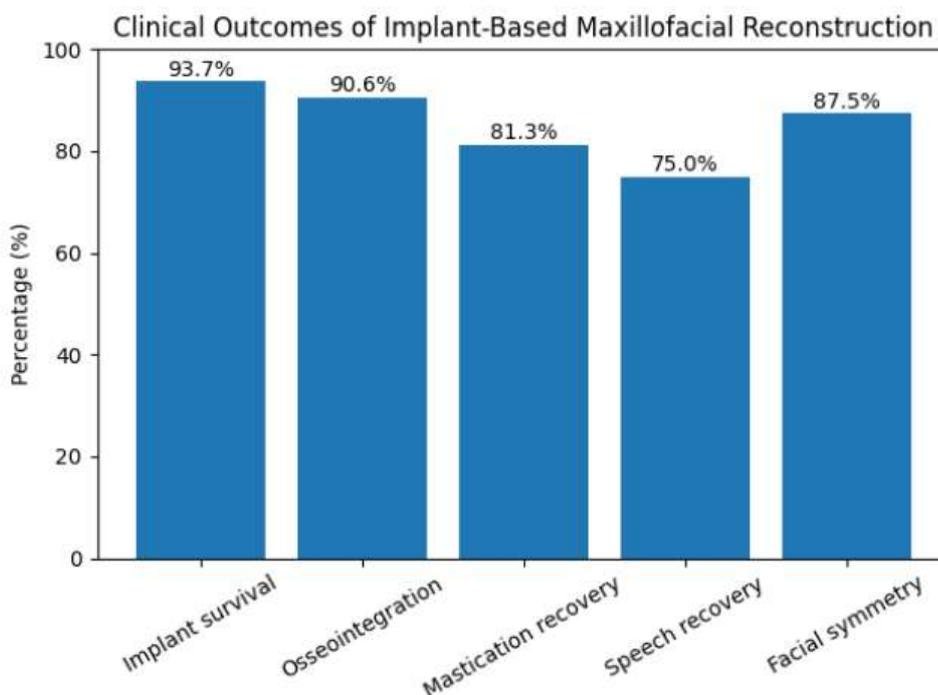
Source: *Authors' clinical study (2023–2025).*

The diagram clearly illustrates that implant survival and osseointegration rates are the highest indicators, confirming strong biological integration of titanium implants. Functional parameters such as mastication and speech also show significant improvement, demonstrating successful rehabilitation. These results support the effectiveness of digital planning and additive manufacturing in modern mandibular reconstruction.

Conclusion

The use of patient-specific 3D-printed titanium implants represent a highly effective method for reconstruction of extensive mandibular defects. This technology allows precise anatomical restoration, ensures high implant stability, and significantly improves functional outcomes, including mastication, speech, and facial symmetry. The high implant survival rate

and low complication rate observed in this study confirm the clinical reliability and safety of customized titanium implants. Digital surgical planning and additive manufacturing technologies play a crucial role in improving surgical accuracy and rehabilitation outcomes. Patient-specific implants eliminate many limitations associated with traditional reconstruction methods and provide improved quality of life for patients with severe mandibular defects. Further long-term studies involving larger patient populations are necessary to evaluate the durability and long-term clinical effectiveness of this innovative reconstructive approach.

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