International Journal of Biomedical and Clinical Research
2025 Volume 4, Issue 3
DOI: 10.59657/2997-6103.brs.25.080

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Artificial Intelligence in Maxillofacial Prosthodontics: A Paradigm Shift in Precision Rehabilitation

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Abstract

Artificial Intelligence (AI) has revolutionized healthcare, including dentistry, by enhancing precision, speed, and predictive capabilities. In the specialized field of maxillofacial prosthodontics, where the reconstruction of facial and oral defects demands highly customized solutions, AI holds transformative potential. This narrative review explores the current applications, recent advances, and future prospects of AI in maxillofacial prosthodontics. Key areas of integration include automated 3D imaging, design and fabrication of prostheses using AI-enhanced CAD/CAM systems, virtual surgical planning, and outcome prediction. The review also discusses literature-supported benefits such as reduced human error, faster rehabilitation, and improved aesthetics. Despite its advantages, ethical and technical limitations remain. Understanding the intersection of AI and maxillofacial prosthodontics will be essential for the evolution of personalized patient care.

Keywords: artificial intelligence; maxillofacial prosthodontics; 3D printing; virtual planning; deep learning; facial prosthesis; CAD/CAM

Introduction

Maxillofacial prosthodontics is a specialized branch of dentistry focused on restoring facial and cranial defects caused by trauma, cancer, congenital anomalies, or surgical resections. Historically, the process of designing and fabricating facial prostheses has been manual, time-consuming, and skill-dependent. However, the incorporation of Artificial Intelligence (AI) - including machine learning (ML), deep learning, and neural networks - is streamlining this process with unprecedented precision and efficiency.

AI can analyse large datasets, recognize complex patterns, and automate clinical decisions. Its application in medical fields like radiology and oncology is well established [1]. In maxillofacial prosthodontics, AI is increasingly used in image recognition, virtual design, 3D reconstruction, and surgical simulation, leading to more personalized and accurate prosthetic outcomes [2].

Discussion

Review of Literature and Current Applications

AI in Imaging and Diagnosis: AI algorithms have demonstrated high accuracy in processing radiographs, CT scans, and MRIs to identify anatomical landmarks and pathological changes [3]. For instance, Convolutional Neural Networks (CNNs) have been successfully employed to automate tumor detection, aiding in prosthodontic planning after oncologic surgeries [4].

Virtual Surgical Planning (VSP) and Simulation: The use of AI in VSP allows clinicians to simulate surgical resections and reconstructive procedures in a virtual environment. AI tools can suggest optimal osteotomy lines and predict post-operative facial symmetry [5]. This is especially useful in maxillofacial surgery involving resection of tumors or trauma cases.

AI in Designing and Fabricating Facial Prostheses: AI-integrated CAD/CAM systems can design patient-specific facial prostheses based on 3D data derived from digital impressions or CBCT scans [6]. Machine learning models optimize the selection of materials, margin fitting, and aesthetic matching. These systems significantly reduce manual errors and production time.

3D Bioprinting and AI Integration: AI aids in generating print paths, layer-by-layer consistency, and material customization in 3D bioprinting of facial structures. Studies have shown improved anatomical accuracy and retention in AI-assisted prosthetic models compared to conventional ones [7].

Predictive Outcomes and Patient-Specific Customization: Predictive AI algorithms analyze patient data to forecast prosthesis performance, durability, and patient satisfaction levels. For example, Support Vector Machines (SVMs) have been used to predict soft tissue adaptation and psychological acceptance of prostheses [8].

AI in Training and Education: AI-based virtual reality (VR) platforms are being developed for training postgraduate students in maxillofacial prosthodontics. These platforms simulate real-time surgical environments, helping students understand complex anatomical variations [9].

Challenges and Limitations

Despite promising results, AI in maxillofacial prosthodontics faces several challenges:

Data Limitations: AI models require large, annotated datasets, which are limited in maxillofacial domains due to the rarity and variability of cases.

Cost and Accessibility: High costs of AI-integrated tools and lack of infrastructure limit widespread adoption, especially in developing countries.

Ethical Concerns: Data privacy, informed consent, and reliance on automated systems over clinical judgment are areas of concern.

Technical Limitations: Mislabeling of data or overfitting can lead to erroneous outcomes, necessitating rigorous validation and clinician oversight.

Conclusion

AI represents a paradigm shift in maxillofacial prosthodontics by enhancing diagnostic accuracy, surgical planning, prosthetic design, and educational methodologies. Its ability to process complex datasets and deliver personalized care is transforming patient rehabilitation. However, integration should be approached cautiously, ensuring ethical, technical, and clinical validation. Future research must focus on large-scale clinical trials, multi-center data sharing, and interdisciplinary collaboration to fully harness AI's potential in maxillofacial rehabilitation.

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Cite this article: Sikri A, Sikri J. (2025). Artificial Intelligence in Maxillofacial Prosthodontics: A Paradigm Shift in Precision Rehabilitation, *International Journal of Biomedical and Clinical Research*, BioRes Scientia Publishers. 4(3):1-2. DOI: 10.59657/2997-6103.brs.25.080

Article History: **Received:** June 16, 2025 | **Accepted:** August 08, 2025 | **Published:** August 15, 2025