

Neuroprosthodontics: Integrating Neural Principles with Modern Prosthodontic Rehabilitation -A Review

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Abstract—Neuroprosthodontics is an emerging interdisciplinary field that applies neuroscientific principles, neuroengineering and intelligent technologies to prosthodontic rehabilitation. By recognizing the oral–facial system as an integrated sensorimotor network, neuroprosthodontics aims to restore not only static form and masticatory function but also sensory feedback, motor control and cortical representation. This review synthesizes current knowledge on neuroplastic changes following prosthetic rehabilitation, sensory integration (osseoperception), brain–computer interface (BCI) and sensorized prostheses, and the role of artificial intelligence (AI) in personalized prosthesis design. Clinical implications, technical challenges, ethical considerations and future research directions are discussed. Recent developments in AI, implantable sensors, and bidirectional neural interfaces present opportunities to create adaptive, bio-intelligent dental prostheses that improve embodiment, comfort, and function.

Index Terms—neuroprosthodontics, sensory integration, motor control, cortical representation, bidirectional neural interfaces.

I. INTRODUCTION

Prosthodontics traditionally focuses on the restoration of dental form and occlusion to reestablish mastication, aesthetics and speech. However, the oral cavity is more than a mechanical apparatus; it is a highly innervated and richly represented region in the brain. The term neuroprosthodontics has been proposed to describe prosthodontic practice that intentionally engages neural mechanisms — neuroplasticity, somatosensory feedback and sensorimotor integration — to optimize rehabilitation outcomes. Recent technological advances (miniaturized sensors, AI, BCIs and novel materials)

have accelerated progress toward prostheses that do more than replace teeth: they interact with the nervous system to restore perception and motor control. ⁽¹⁾

II. REVIEW OF LITERATURE

NEUROBIOLOGY AND NEUROPLASTICITY RELEVANT TO PROSTHODONTICS

The oral cavity's sensory input (periodontal mechanoreceptors, mucosal receptors, proprioceptors of the masticatory system) is essential for fine motor control of chewing, speech and swallowing. Dental loss and prosthetic rehabilitation change peripheral afferent signals and can lead to cortical reorganization. Neuroplasticity underlies both adaptation (successful prosthesis use) and maladaptation (persistent discomfort, altered chewing patterns). Studies indicate that gradual exposure to a prosthesis, sensorimotor training and appropriately designed sensory feedback can shape central representations and improve function and patient satisfaction. ⁽²⁾

Clinical implication: Prosthetic planning should consider staged sensory re-education and exercises to harness beneficial neuroplastic changes.

OSSEOPERCEPTION AND SENSORY FEEDBACK IN IMPLANT PROSTHODONTICS

Osseoperception describes the phenomenon whereby dental implant–supported prostheses transmit mechanical stimuli to bone and peri-implant tissues that are interpreted centrally, enabling tactile discrimination and improved bite control compared with conventional dentures. Research shows measurable somatosensory responses and alterations in cortical activity following implant placement. Enhancing osseoperceptive input (through implant design, surface interfaces, and adjunctive sensors) may

improve prosthesis embodiment and masticatory precision. ⁽³⁾

SENSORIZED PROSTHESES AND BIDIRECTIONAL INTERFACES

Emergent prostheses incorporate pressure, strain and inertial sensors to monitor occlusal forces and feeding behavior in real time. Such sensorized devices can provide feedback to the patient (haptic or auditory cues) and to clinicians for remote monitoring and adjustment. The integration of sensors with algorithms enables closed-loop control — e.g., a denture that modulates occlusal damping to reduce tissue trauma during function. Early prototypes demonstrate feasibility; translation to routine clinical appliances will require robust miniaturization, biocompatibility and reliable power solutions. ⁽⁴⁾

BRAIN-COMPUTER INTERFACES (BCIS) AND NEUROPROSTHETIC CONCEPTS

BCIs and neuroprosthetic technologies have shown success in restoring limb control and speech in neurological patients. Translating BCI concepts to orofacial rehabilitation remains nascent but promising. Applications could include:

- Restoring volitional control for complex orofacial movements in patients with neuromuscular disorders.
- Providing top-down modulation to neuroadaptive prostheses to improve chewing patterns.
- Using cortical or peripheral neural signals to operate adaptive prosthetic features (e.g., prosthesis stiffness, sensory amplification).

Clinical and ethical challenges include invasiveness, signal stability, and long-term integration. Lessons from limb neuroprosthetics emphasize the need for bidirectional interfaces that deliver both motor intent decoding and sensory feedback to improve embodiment. ⁽⁵⁾

CLINICAL APPLICATIONS AND TRANSLATIONAL EXAMPLES

Potential and emerging applications of neuroprosthetics include:

- Complete dentures with sensor-driven occlusal adjustment to decrease mucosal trauma and accelerate adaptation.
- Implant frameworks designed for optimized osseoperception, with surface engineering to maximize mechanoreceptor stimulation.

- Hybrid systems combining intraoral sensors with smartphone apps for dietary monitoring and remote follow-up.

- Rehabilitative protocols for stroke or cranial nerve palsy patients using prosthetic and neuromodulatory therapy to restore oral function.

Case reports and pilot studies indicate improvements in bite force control, patient-reported comfort, and functional outcomes when prosthetic care is coupled with sensor feedback and guided training.

CHALLENGES: TECHNICAL, BIOLOGICAL AND REGULATORY

Key barriers to wide adoption include:

- Sensor durability and hygiene: intraoral environment is corrosive, wet and biomechanically demanding.
- Power and connectivity: long-term powering of intraoral electronics without frequent interventions is nontrivial.
- Signal reliability: neural signals are variable; robust decoding models are required.
- Interdisciplinary collaboration gaps: dental clinics need streamlined pathways to work with engineers and neuroscientists.
- Regulatory and ethical hurdles: implantable electronics and BCIs raise safety, privacy, consent and long-term safety concerns. ⁽⁴⁾

III. DISCUSSION

Neuroprosthetics represents an evolving intersection of prosthodontics, neuroscience, and bioengineering, bridging the gap between mechanical replacement and neurofunctional restoration. The integration of neural interfaces into prosthetic systems has transformed traditional rehabilitation approaches by introducing communication pathways between the nervous system and artificial devices. This shift from purely mechanical function toward neurophysiological harmony aims to restore not only mastication and phonetics but also sensory feedback, proprioception, and emotional satisfaction—dimensions that define holistic oral rehabilitation. ⁽⁶⁾ Recent advances in brain-computer interfaces (BCIs) and neuro-sensor technologies have opened new avenues for achieving closed-loop control of prosthetic devices. These systems translate neural signals into functional commands, allowing patients to

control prosthetic components with near-natural precision. In parallel, electro tactile and vibrotactile feedback systems provide artificial sensory cues that improve the patient's sense of embodiment and spatial awareness. These developments indicate a paradigm shift toward prostheses that behave as extensions of the nervous system rather than as external replacements.

The neurocognitive aspects of prosthodontics are equally crucial. Functional MRI and neuroimaging studies have shown cortical reorganization following tooth loss and prosthetic rehabilitation, suggesting significant neuroplastic adaptation. ⁽⁷⁾ Such findings underscore the brain's ability to remap sensory and motor regions in response to prosthetic integration. Understanding these neural mechanisms offers new clinical insights into patient adaptation, comfort, and satisfaction, highlighting the need for neuro-based evaluation criteria alongside conventional mechanical and esthetic assessments ⁽⁸⁾.

Artificial intelligence (AI) further strengthens this interdisciplinary framework. Machine learning algorithms facilitate the analysis of neural data, optimization of prosthesis design, and customization of sensory feedback systems. AI-driven prosthodontics not only enhances design precision but also helps predict patient adaptation patterns, reducing rehabilitation time. The convergence of AI, neuro engineering, and digital dentistry thus forms the cornerstone of next-generation prosthodontics, where biological and technological intelligence coexist in restorative harmony. ⁽⁹⁾

IV. SUMMARY

Neuroprosthodontics signifies a transformative evolution in dental rehabilitation—one that moves beyond mechanical reconstruction to functional neurointegration. The ultimate goal is not merely to replace lost structures but to restore the dynamic sensory–motor network that defines oral function and human experience. As neural interface technologies mature, prosthodontic devices will increasingly replicate the bidirectional flow of information between brain and prosthesis, achieving a level of realism once thought unattainable. ⁽¹⁰⁾

Future research must focus on refining biocompatible neural interfaces, enhancing long-term signal stability, and ensuring ethical and safe integration of

neuroprosthetic systems in clinical dentistry. Collaborative research among prosthodontists, neuroscientists, engineers, and computer scientists will be vital to translate laboratory innovations into patient-centered applications. Additionally, regulatory frameworks and educational reforms are needed to prepare clinicians for this neuro-technological era. In the coming decade, the fusion of AI-assisted design, neural feedback loops, and personalized digital fabrication is expected to produce prostheses that communicate, adapt, and learn in synchrony with their users. Neuroprosthodontics thus represents not only a scientific advancement but also a redefinition of rehabilitation—where technology aligns with human neurobiology to restore function, confidence, and identity. ⁽¹¹⁾

V. CONCLUSION

Neuroprosthodontics offers a paradigm shift: treating oral rehabilitation not merely as mechanical replacement but as restoration of sensorimotor function and cortical representation. Advances in neuroengineering, AI, materials science and sensor technology make it possible to design prostheses that interact with the nervous system, promote beneficial neuroplasticity, and deliver measurable functional gains. Realizing this vision will require rigorous clinical trials, attention to safety and ethics, and sustained interdisciplinary collaboration.

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