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ADAPTIVE PROSTHODONTICS AND NEURAL ADAPTATION: BRIDGING BRAIN AND BITE IN ORAL REHABILITATION

* Pavithra B, **Vivek V Nair, ***Harshakumar K, ****R Ravichandran

* Postgraduate Student, ** Professor, ***Vice Principal, Professor, Head of the Department, **** Professor, Department of Prosthodontics and Crown & Bridge, Govt. Dental College, Thiruvananthapuram. Corresponding author: Dr Pavithra B Email: pavithraboobalan97@gmail.com

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Abstract

Neuroplastic Prosthodontics is an emerging concept that highlights the role of dental interventions in inducing neuroplastic changes to optimize oral sensorimotor function. Traditional prosthetic treatments often fail to fully restore neurosensory integration, leading to impaired mastication, speech, and oral motor control. This issue is further compounded by aging-related declines in masticatory efficiency, neuromuscular coordination, and sensory feedback. Recent research utilizing functional imaging and transcranial magnetic stimulation (TMS) has demonstrated cortical adaptations in response to prosthetic use, suggesting that structured oral motor training can enhance prosthetic adaptation and overall function. Moreover, the link between masticatory efficiency and cognitive health underscores the broader implications of oral rehabilitation. Given the increasing prevalence of edentulism among aging populations, integrating neuroplasticity-driven strategies in prosthodontics is essential for improving long-term patient outcomes. This review explores the neurophysiological mechanisms underlying jaw sensorimotor control, the impact of aging on oral function, and the potential for training-induced neuroplasticity to enhance prosthetic rehabilitation. Future research should focus on refining prosthetic designs, developing targeted oral motor training protocols, and further investigating the interplay between prosthetic rehabilitation and cortical plasticity. By bridging the gap between traditional prosthodontics and neurosensory adaptation, Neuroplastic Prosthodontics presents a promising approach to enhancing both oral function and overall neurological health.

Keywords: neuroplastic prosthodontics, oral sensorimotor function, training-induced neuroplasticity, functional rehabilitation.

Introduction

Prosthodontic rehabilitation plays a vital role in restoring oral function and esthetics following tooth loss, directly influencing a patient's quality of life. The extent of impairment experienced is not solely determined by functional deficits but also by an individual's ability to adapt to the altered oral environment. According to Avivi-Arber (2025)[1], successful prosthodontic treatment depends not only on mechanical restoration but also on neurosensory adaptation, involving sensorimotor integration and cognitive processing shaped by past experiences and expectations. Orofacial sensorimotor function is governed by complex neural circuits, with the dentition serving as a critical sensory organ due to its high tactile sensitivity. Since many orofacial muscles lack intrinsic proprioceptors, proprioceptive input from the periodontal ligament is essential for accurate jaw position and movement perception. Following tooth loss and prosthetic rehabilitation, patients often experience diminished sensory feedback, affecting oral perception and increasing the risk of prosthetic complications, particularly in older adults with age-related sensory decline.

The emerging concept of Neuroplastic Prosthodontics highlights the role of dental interventions in inducing neuroplastic changes within the nervous system. Prompt replacement of missing teeth is crucial for preserving neural connections, facilitating adaptation to prosthetic restorations, and optimizing sensory-motor control for mastication and speech. Given the importance of oral function in overall health and well-being, the present review aims to emphasize the significance of maintaining optimal chewing function in the aging population. Furthermore, it provides a concise summary of experimental evidence supporting training-induced neuroplasticity as a method to enhance oral motor performance and improve adaptation to prosthetic rehabilitation. By integrating neuroplastic principles into prosthodontic care, rehabilitation strategies can be refined to promote better functional outcomes and long-term patient adaptation.

Effects of Aging on Masticatory Function

The global population is aging at an unprecedented rate. In 2006, nearly half a billion people worldwide were aged 65 years and older, and by 2030, this number is projected to reach approximately one billion, equating to one in every eight individuals.[2] This demographic shift presents significant challenges in healthcare, including the management of age-related declines in masticatory function. Aging is often accompanied by a progressive reduction in muscle mass (sarcopenia), leading to frailty and increased morbidity. While jaw muscles are more resilient than other skeletal muscles, studies have shown a significant decline in their cross-sectional area and density with age. Additionally, aging affects the sensorimotor control of jaw function, impairing mastication, particularly in the "middle old" and "very old" subgroups.[3] These neuromuscular deficits, compounded by systemic conditions, further deteriorate oral function and overall health.

Several factors contribute to compromised mastication in older adults, including reduced antagonistic teeth, altered saliva quality, and impaired neuromuscular coordination of the tongue and jaw muscles. The decline in oral sensory perception diminishes chewing efficiency, affecting food processing and intake. Research suggests that jaw muscle activity in older adults is less precisely adapted to food texture, increasing the risk of nutritional deficiencies. Impaired chewing function has been reported in 2.5% to 40% of institutionalized elderly individuals and has been directly linked to a higher risk of mortality.[4] Furthermore, poor dentition—resulting from edentulism, chronic periodontal disease, or inadequate oral hygiene—remains a key determinant of dietary choices. Despite improvements in tooth retention, maintaining oral health in aging populations remains a challenge. Many elderly individuals unconsciously adapt by avoiding hard or fibrous foods such as raw vegetables, fruits, and meats, often opting for soft or pureed alternatives. While these modifications may not be perceived as restrictive, they frequently lead to inadequate protein and fiber intake, further exacerbating health risks associated with aging.

Impacts of aging on oral sensorimotor abilities

Aging-Related Changes in Jaw Sensorimotor Functions

Aging significantly affects jaw sensorimotor control, leading to impairments in mastication, swallowing, and speech, particularly in individuals with extensive tooth loss or neurological disorders such as Parkinson's disease, dementia, and stroke. These changes are primarily due to increased chewing cycle duration, reduced muscle strength, diminished tactile sensitivity, and impaired coordination of oropharyngeal muscles. Such sensorimotor declines not only affect nutritional intake but also elevate the risk of aspiration pneumonia, a major cause of mortality in older populations. Additionally, aging-related speech alterations, including slower articulation, reduced accuracy, and greater variability in jaw and lip movements, further highlight the decline in neuromuscular control.[5]

Structural and Functional Changes in Orofacial Muscles with Aging

Structural and functional changes in jaw and orofacial muscles are evident with aging. Factors such as temporomandibular joint degeneration, tooth wear, hormonal fluctuations, and altered nutrition contribute to muscle atrophy and neuromuscular inefficiency (Holtrop et al., 2014). While jaw muscles exhibit greater resilience compared to limb muscles, degenerative changes in nerve terminals, reduced conduction velocity of motor neurons, and atrophy of muscle fibers collectively impair masticatory function[5]. Despite these alterations, evidence suggests that jaw muscles retain a degree of regenerative capacity, possibly explaining their relative resistance to severe atrophy compared to limb muscles.[6]

Neural Adaptations and Sensorimotor Control in the Elderly

Aging also induces neurophysiological changes in central nervous system regions responsible for jaw function. Reduced connectivity between sensorimotor and cerebellar regions, along with alterations in cortical motor pathways, negatively affects masticatory coordination[7]. Functional imaging studies reveal that older adults exhibit compensatory neuroplasticity, involving the recruitment of additional cortical areas beyond traditional motor regions to sustain masticatory control[8]. While this may reflect an adaptive response to aging-related neurodegeneration, it may also indicate inefficiencies in sensorimotor execution. Additionally, approximately 20% of elderly individuals are estimated to be "orally disabled" due to extensive tooth loss, leading to reduced bite force, impaired mastication, and even cognitive decline[5]. Given the increasing proportion of older adults globally, these sensorimotor impairments are expected to present significant public health challenges. Despite age-related neuromuscular decline, research suggests that sensorimotor training—such as targeted masticatory exercises—may enhance neuroplasticity and improve oral rehabilitation outcomes[8]. Similar to the benefits of physical exercise in maintaining motor function in aging limbs, structured oral sensorimotor training could help older adults adapt to intraoral changes, including prosthetic use, thereby enhancing masticatory efficiency and overall oral health[7].

Jaw sensorimotor function and its regulation

Jaw sensorimotor functions are governed by a sophisticated integration of muscular coordination, neural regulation, and sensory feedback, ensuring the precise execution of both voluntary and reflexive movements. The jaw musculature is classified into jaw-closing muscles (e.g., masseter, temporalis, and medial pterygoid), jaw-opening muscles (e.g., anterior digastric), and the lateral pterygoid, which differentially contributes to both opening and closing movements. These muscles facilitate not only vertical jaw movements but also horizontal actions such as lateral excursion, protrusion, and retrusion, enabled by their complex multi-compartmental structure that allows for selective motor unit activation. Unlike limb movements, jaw movements often necessitate bilateral muscle activation and are centrally regulated by higher brain centers, with continuous modulation through orofacial sensory inputs. Reflexive jaw movements, such as the jaw-closing and jaw-opening reflexes, operate through specialized brainstem circuits that process afferent signals from muscle spindles and orofacial receptors, playing a critical role in protective and regulatory functions such as bite force modulation. While functions like swallowing are innately established at birth, mastication and speech develop postnatally through the progressive maturation of central nervous system (CNS) pathways and sensory adaptation. The eruption of teeth introduces additional sensory input from periodontal receptors, further refining masticatory control and neuromuscular coordination. Speech, a highly specialized and uniquely human function, emerges as a learned behavior that necessitates intricate synchronization of sensory and motor pathways to coordinate the activity of the jaw, tongue, and facial muscles.[9] However, aging-related neurophysiological changes, muscle degeneration, and alterations in orofacial tissues compromise these sensorimotor functions, leading to diminished mastication efficiency, impaired swallowing, and speech difficulties, all of which have profound implications for the oral and systemic health of the elderly population.[5]

The regulation of jaw sensorimotor function involves a sophisticated integration of muscular coordination, neural control, and sensory feedback. Jaw movements such as mastication, swallowing, and speech rely on the precise activation of jaw-closing muscles (masseter, temporalis, medial pterygoid), jaw-opening muscles (anterior digastric), and the lateral pterygoid, which contributes to both opening and closing actions. Unlike limb movements, jaw function necessitates bilateral muscle coordination and continuous modulation by higher brain centers, ensuring adaptive control of force and movement.[5] Sensory inputs from periodontal mechanoreceptors, orofacial muscles, and temporomandibular joint receptors provide critical feedback for regulating bite force, food manipulation, and oral stereognosis. The loss of natural dentition significantly disrupts this feedback loop, leading to impaired mastication efficiency, reduced force control, and compromised oral sensorimotor integration. While implant-supported prostheses improve oral function by enhancing tactile perception (osseoperception), they do not fully replicate the sensorimotor capabilities of natural teeth, resulting in challenges in force modulation and adaptive responses during mastication and speech.[10]

Neural control of jaw function is mediated by key brain regions, including the primary motor cortex

(M1), somatosensory cortex (S1), thalamus, and cerebellum, which collectively process and execute motor commands. Functional imaging studies indicate that masticatory activity enhances cortical activation in these areas, yet edentulous individuals exhibit diminished neural engagement compared to dentate individuals. However, implant-supported prostheses users demonstrate increased M1 and S1 activation, suggesting compensatory sensory inputs from peri-implant tissues that enhance oral motor function.[11] The regulation of jaw function relies on a dynamic interplay between feedback and feedforward mechanisms—where real-time sensory feedback adjusts muscle activity, and pre-programmed motor patterns anticipate sensory input.[12] This is particularly evident in speech production, where jaw stability and precise positioning are essential for articulation. Although auditory feedback plays a vital role, somatosensory input is equally critical in maintaining accurate speech patterns despite external disturbances. A deeper understanding of these regulatory mechanisms is essential for advancing clinical interventions, optimizing prosthetic designs, and enhancing rehabilitative strategies for individuals with compromised oral sensorimotor function.

Functional oral rehabilitation

Aging populations, particularly in industrialized nations, increasingly depend on dental prostheses for mastication and oral function after tooth loss. While modern oral rehabilitation techniques successfully restore dental anatomy and aesthetics, they often fail to fully recover natural sensorimotor function. Research indicates that prosthetic rehabilitation alone does not guarantee improved masticatory efficiency or successful adaptation to new oral conditions. Many prosthesis users struggle with chewing hard or fibrous foods due to impaired jaw muscle coordination and reduced force regulation, leading to compromised food control during mastication. Additionally, the lack of standardized clinical assessment methods makes it difficult to quantify these deficits across studies. Given these challenges, oral rehabilitation strategies should move beyond mechanical restoration to incorporate sensorimotor integration, optimizing both function and patient adaptation.[13]

Emerging evidence links masticatory function with cognitive health, suggesting that impaired chewing efficiency may contribute to neurodegenerative disorders such as Alzheimer's and Parkinson's disease. Studies indicate that difficulty chewing hard foods is associated with an increased risk of cognitive decline, while maintaining masticatory function supports better cognitive performance.[14] Functional MRI studies show that chewing activates key brain regions, including the sensorimotor cortex and supplementary motor areas, enhancing cerebral blood flow and sustaining neuronal activity.[11] However, aging-related attenuation of chewing-induced neural activation underscores the need for targeted rehabilitation strategies. Although the exact causal mechanisms remain unclear, animal studies suggest that reduced masticatory activity negatively impacts neuroplasticity, synaptic connectivity, and cholinergic neurotransmission, affecting memory and learning.[15] These findings emphasize the importance of functional oral rehabilitation strategies that not only restore mastication but also promote cognitive well-being in aging populations.

Training-Induced Neuroplasticity in oral motor function

Recent research has explored our ability to enhance oral motor performance through repetitive practice of various motor tasks. These studies primarily focus on behavioral learning and skill acquisition in well-coordinated oral motor activities, ranging from simple tasks like tongue protrusion and clenching to more complex tongue training exercises and controlled biting with precision. Training-induced adaptations have been assessed at both behavioral and neurophysiological levels by evaluating performance improvements and examining changes in motor-evoked potentials (MEPs) and cortical representations using transcranial magnetic stimulation (TMS) and functional imaging techniques such as fMRI.[16] These findings suggest that training may enhance cortical plasticity by facilitating corticomotor pathways specific to the trained muscle groups. Additionally, training-related adaptations may occur in other brain structures, including the brainstem, thalamus, and hippocampus.[17]

While the facilitation of corticomotor pathways in response to training is not definitive proof of neuroplasticity, it strongly suggests cortical reorganization. However, TMS has certain limitations; for instance, fMRI studies on novel tongue training have shown activation beyond the primary motor cortex. Consequently, the precise cortical and subcortical regions involved in neuroplastic adaptations remain unclear. Repeated practice is typically associated with enhanced performance and increased representation of the trained muscles within the primary motor cortex. These somatosensory representations are dynamic and remodel during learning and in response to altered sensory input, as observed in rodent studies.[18] Cortical neuroplasticity has also been linked to changes in the stomatognathic system, such as tooth loss, intraoral pain, or nerve injury. Research suggests that primary motor cortex reorganization occurs following peripheral nerve injuries, while human studies demonstrate that altering peripheral sensory input from orofacial structures affects cortical excitability.[19] These findings highlight the importance of understanding training-induced cortical plasticity, as it may have implications for rehabilitation strategies aimed at improving oral motor function.

Neuroplastic Changes and Cortical Adaptations in Tongue Motor Training

Transcranial magnetic stimulation (TMS) studies have demonstrated that tongue motor training induces neuroplastic changes in the corticomotor pathways, as evidenced by alterations in motor-evoked potentials (MEPs) recorded from electrodes on the dorsolateral surface of the tongue. Early research established a link between behavioral learning and cortical adaptations during novel tongue training, with various studies exploring different training paradigms, including tongue protrusion, tongue lift movements, and task complexity variations. Training durations ranged from brief 15-minute sessions to extended protocols lasting up to an hour daily for a week.[20] Additionally, factors such as visual observational conditions and transcranial direct current stimulation (tDCS) have been examined for their influence on motor performance. Findings suggest that training enhances behavioral performance in both healthy individuals and patients with brain injuries, leading to increased cortical representation of the tongue muscles. These adaptations, assessed through changes in motor thresholds and MEP amplitudes, demonstrate a significant expansion of cortical areas associated with tongue motor responses.[13]

Neuroplasticity and Cortical Adaptations in Jaw Muscle Training

Transcranial magnetic stimulation (TMS) studies have demonstrated distinct cortical representations of the masseter muscle, with reproducible corticomotor maps that can be influenced by specific motor tasks, such as clenching in different occlusal positions. Similar to tongue training, jaw muscle training has been shown to improve task performance and elicit neuroplastic changes in corticomotor control. However, simple clenching tasks performed for one hour failed to induce detectable neuroplasticity in the masseter muscle, suggesting that either the training was insufficient to trigger cortical excitability changes or that adaptations occurred at subcortical levels not detected by TMS.[21] Notably, increasing task complexity—such as precision biting of a sugar-coated chocolate candy into two halves—resulted in neuroplastic changes in the masseter corticomotor pathways. Animal studies further support the dynamic nature of cortical adaptation in response to novel oral motor tasks and altered oral environments, such as occlusal modifications or tooth extraction. These findings highlight the potential for investigating sensorimotor re-learning and adaptation in patients undergoing oral rehabilitation, providing valuable insights into optimizing functional recovery following dental interventions.[13]

Role of neuroplasticity in prosthodontics

Neuroplasticity plays a fundamental role in prosthodontics by facilitating sensorimotor adaptation in patients undergoing oral rehabilitation due to tooth loss, occlusal modifications, or maxillofacial interventions. The brain's ability to reorganize itself through new neural connections is crucial for restoring masticatory function, occlusal stability, and oral motor control following prosthetic treatment. The placement of complete, partial, or implant-supported dentures induces changes in occlusal and proprioceptive input, triggering cortical reorganization primarily in the motor (M1) and somatosensory (S1) cortices. Functional neuroimaging and transcranial magnetic stimulation (TMS) studies have demonstrated increased activation in key cortical regions, such as the precentral and postcentral gyri, reflecting the brain's adaptive mechanisms in response to altered oral environments. These neuroplastic changes contribute to improved masticatory efficiency, bite force, and oral motor coordination, progressing from conscious cognitive engagement to more automatic control with continued prosthetic use.

The neuroplasticity associated with prosthodontic rehabilitation follows distinct phases of motor learning, beginning with an early fast learning phase and transitioning into a slower, sustained phase that consolidates skill acquisition.[22] Performance improvements can occur within a single session and continue to develop with repeated practice, reinforcing neuromuscular coordination. Once a motor behavior is learned, it can be retained and recalled even after extended periods without practice. However, studies suggest that certain neuroplastic changes, such as corticomotor excitability related to tongue musculature, may be transient, with cortical activity returning to baseline within two weeks after training cessation. This highlights the importance of continuous functional engagement with prosthetic devices to maintain long-term neuromuscular adaptation. In aging populations and individuals with neurodegenerative conditions, prosthodontic interventions may help counteract declining neuroplasticity by recruiting additional brain regions, such as the prefrontal cortex, which could contribute to cognitive resilience.[13] Understanding the interplay between prosthodontic rehabilitation and cortical plasticity is essential for optimizing treatment strategies. Factors such as prosthesis design, occlusal adjustments, and structured adaptation protocols influence the extent of neural reorganization, ensuring effective functional outcomes. Future advancements in prosthodontics should further explore these neural mechanisms to refine rehabilitation approaches, ultimately enhancing both oral function and overall neurological health.

Conclusion

Neuroplastic prosthodontics represents a transformative approach beyond mere anatomical restoration to enhance sensory and motor functions, significantly improving oral health-related quality of life. By harnessing the principles of neuroplasticity, structured training programs and sensory feedback mechanisms can be implemented to optimize masticatory efficiency, particularly in aging populations facing challenges in adapting to new prostheses. Despite advancements in prosthetic design, there remains a critical need for further research into the aging-related changes in orofacial sensorimotor function and the role of neuroplasticity in these adaptive processes. A deeper understanding of the underlying molecular and structural mechanisms will facilitate the development of innovative diagnostic and therapeutic strategies. Ultimately, integrating neuroplastic principles into prosthodontics can lead to enhanced patient adaptation, prevention of sensory-motor dysfunctions, and improved long-term functional recovery, thereby ensuring superior prosthetic outcomes and an enriched quality of life for patients.

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