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REVIEW ARTICLE

Relationship between dental occlusion and brain activity: A narrative review

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KEYWORDS

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Abstract *Objectives:* Occlusal function stimulates different areas of the cerebral cortex. The purpose of this narrative review was to identify the relationship between occlusion and brain activity so as to provide theoretical support to enable future studies on the subject.

Study selection, data, and sources: Relevant case-control studies, clinical trials, and systematic reviews available in English were retrieved from the following databases: MEDLINE, PubMed, ScienceDirect, Wiley Online Library, and Biblioteca Virtual en Salud (BVS). Of the 53 articles obtained, 12 were included.

Conclusion: The sensorimotor cortex is affected by changes in occlusion. It is speculated that occlusion could play an important role in the development of diseases, from anxiety and stress to Alzheimer's disease and senile dementia. Further investigations into the interactions between occlusion and brain function are needed to elucidate the parts of the brain that are affected when occlusion is disturbed and to determine whether brain function is altered.

Clinical significance: Dentists must consider that alterations in the occlusal pattern during mastication can lead to changes in the activation of different brain regions related to memory, learning, anticipatory pain, and anxiety. This suggests that mastication maintains the integrity of certain brain areas and that it may be a key factor in the onset of neurodegenerative diseases.

Abbreviations: *BVS*, *Biblioteca Virtual en Salud*; *CPG*, *central masticatory pattern generator*; CNS, *central nervous system*; AOD, *artificial occlusal disharmony*; oxyHb, *oxyhemoglobin*; TMD, *temporomandibular disorders*.

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Contents

1. Introduction

Little is known about the relationship between the stomatognathic system and brain activity. Non-invasive neuroimaging methods have revealed that mastication activates various areas of the somatosensory, supplementary motor, and insular cortices. (Barreto, 1999; Bermúdez Nur, 2016; Guerrero et al., 2013; Ohkubo et al., 2013).

Cognitive memory impairment can be caused by various factors, some of which are clearly understood, such as normal aging, whereas others remain unclear, such as the influence of masticatory function. Studies suggest that alterations in oxygen transport to the prefrontal cortex caused by dental absence, poorly adapted prostheses, or decreased bite force are risk factors for Alzheimer's disease, senile dementia, anxiety, and stress. (Aguirre-Siancas, 2014; Barreto, 1999; Bermúdez Nur, 2016; Dammann et al., 2020; Guerrero et al., 2013; Miyamoto et al., 2005; Ohkubo et al., 2013; Ono et al., 2010).

Accordingly, these findings suggest that alterations in brain function may be triggered by structural changes in the stomatognathic system. Consequently, dental treatment could potentially improve mental health. The objective of this article was to examine these important relationships and the reciprocal disorders evident in stomatognathic and nervous system pathologies.

2. Materials and methods

2.1. Search strategy and methodological design

An electronic search was performed in MEDLINE via PubMed, Science Direct, Wiley Online Library, and BVS. A highly sensitive search strategy was developed to identify studies of interest using the following keywords: "occlusal splints", "brain activity", and "brain function". Additionally, "AND" and "OR" were used as Boolean operators. The following search formula was constructed for each of the databases using MeSH terms: ("occlusal splint") AND ("brain activity" OR "brain function").

2.2. Inclusion and exclusion criteria

Studies conducted in healthy humans older than 18 years, irrespective of sex, with or without complete natural dentition and use of maxillary or mandibular occlusal splints were assessed. We included articles written in English for which the full text was available, irrespective of the year of publication. Studies that reported inclusion and exclusion criteria, measurement methods, evaluation criteria of brain activity, and respective results were considered. The search was limited to case-control studies, clinical trials, and systematic reviews, excluding finite element studies.

2.3. Information processing

Study review and data extraction were carried out by two independent reviewers. The search resulted in 26 articles obtained from MEDLINE via PubMed; 13, from ScienceDirect; 9, from Wiley Online Library; and 5, from BVS. From the total of 53 articles, eight were repeated (six duplicates and two triplicates). Following evaluation of the title and abstract and application of our inclusion and exclusion criteria, 12 articles were included in this review (Table 1).

3. Literature review

3.1. Dental occlusion and brain activity

The communication bridge between teeth and brain functions is through mechanoreceptors in the periodontal ligament that play an important role in the tactile function of natural teeth. Neurogenesis of occlusion and mastication can be explained through a mixed theory comprising a generating center and its sensory feedback. The former is a neural network called "central masticatory pattern generator" (CPG), located in a region ranging from the middle pontine to the upper bulbar of the brainstem. This CPG causes mastication due to mandibular and lingual movements and perioral muscle action, which are modulated by sensory information provided during mastication itself and by higher order sensory areas

Table 1 Selected papers.

DATABASES	TITLE	AUTHOR, YEAR	JOURNAL	TYPE OF STUDY
PubMed BVS	Regional brain activity during jaw clenching with natural teeth and with occlusal splints: a preliminary fMRI study.	Ariji et al., 2016	*CRANIO: The Journal of Craniomandibular & Sleep Practice.*	Case-control
PubMed BVS ScienceDirect	Functional magnetic resonance imaging of brain activity during chewing and occlusion by natural teeth and occlusal splints.	Kordass et al., 2007	*Annals of Anatomy*	Clinical trial
PubMed	The Cerebral Representation of Temporomandibular Joint Occlusion and Its Alternation by Occlusal Splints.	Lotze et al., 2012	*Human Brain Mapping Wiley Periodicals, Inc.*	Clinical trial
PubMed ScienceDirect	Effects of jaw clenching while wearing an occlusal splint on awareness of tiredness, bite force, and EEG power spectrum.	Narita et al., 2009	*Journal of Prosthodontic Research*	Clinical trial
PubMed	Effects of Occlusal Disharmony on Working Memory Performance and Prefrontal Cortex Activity Induced by Working Memory Tasks Measured by NIRS.	Sakatani et al., 2013	*Oxygen Transport to Tissue XXXIV, Advances in Experimental Medicine and Biology*	Clinical trial
PubMed ScienceDirect	Spontaneous neural activity alterations in temporomandibular disorders: A cross sectional and longitudinal resting state functional magnetic resonance imaging study.	He et al., 2014	*Neuroscience*	Clinical trial
PubMed	Association of decrease in insula fMRI activation with changes in trait anxiety in patients with craniomandibular disorder	Dammann et al., 2020	*Behavioural Brain Research*	Clinical trial
PubMed	Successful therapy for temporomandibular pain alters anterior insula and cerebellar representations of occlusion.	Lickteig et al., 2013	*Cephalalgia*	Clinical trial
PubMed	Changes in cortical activation in craniomandibular disorders during splint therapy. A single subject fMRI study.	Lickteig et al., 2012	*Annals of Anatomy*	Clinical trial
PubMed	Effects of Mandibular Retrusive Deviation on Prefrontal Cortex Activation: A Functional Near Infrared Spectroscopy Study	Otsuka et al., 2015	*BioMed Research International*	Case-control
PubMed BVS	Shortened Dental Arch and Cerebral Regional Blood Volume: An Experimental Pilot Study with Optical Topography.	Miyamoto et al., 2009	*The Journal of Craniomandibular Practice*	Clinical trial
PubMed BVS Wiley Online Library	Interactions between occlusion and human brain function activities.	Ohkubo et al., 2013	*Journal of Oral Rehabilitation Revisión sistemática*	Systematic review

BVS: Biblioteca virtual en Salud; fMRI: functional magnetic resonance imaging; EEG: electroencephalogram; NIRS: near-infrared spectroscopy.

such as the subcortical motor areas, basal ganglia, and sensorimotor cortex. The latter is sensory feedback, comprising intraoral tactile receptors, elevator muscles, and mechanoreceptors of the periodontal ligament that monitor the activity of the elevator jaw muscles. At the orofacial level, mechanoreceptors fulfill two main functions: they transmit peripheral sensory information for the control of motor functions, and they emit tactile information regarding the texture of food. Alterations in mechanoreceptor stimulation result in a reduction of chewing forces and a lack of control of mandibular movements. The sensory system of the trigeminal ganglion may be a possible path of information from the oral cavity to the central nervous system (CNS). Furthermore, studies have reported that the effects of chewing on the CNS cannot be attributed to a single pathway but rather to multiple complex signals that are not yet fully understood. (Aguirre-Siancas, 2014; Bermúdez Nur, 2016; Ono et al., 2010; Trulsson, 2007).

At the brain level, occlusion and masticatory function of the teeth, lips, and tongue is represented in the postcentral gyrus. Thus, different parts of the cerebral cortex are stimulated by occlusal function and mastication. However, these areas are not exclusive to components of the oral cavity; they also have close relationships with other bodily functions. The strongest activations occur in the somatosensory cortex, bilateral primary motor cortex, secondary motor areas, secondary somatosensory cortex, basal ganglia, thalamus, anterior cerebellar hemispheres, and insula. Furthermore, studies have shown that the representation of mastication in the bilateral primary motor and somatosensory cortices of healthy individuals is lateralized to the dominant hemisphere. (Bermúdez Nur, 2016; Kordass et al., 2007; Ohkubo et al., 2013; Sakatani et al., 2013).

3.2. Effects of occlusal disharmony on brain activity

Chewing improves cognitive performance and is beneficial to memory. Indeed, chewing increases the activation of the somatosensory cortex, supplementary motor area, insular cortex, prefrontal cortex, and hippocampus. Epidemiological research has shown that reduced chewing caused by occlusal disharmony, tooth loss, improper dentures, or decreased bite force may impair cognition, including working memory, and actively manipulate retained information, thus constituting a risk factor for dementia. (Sakatani et al., 2013).

In one study, the mandibular position was altered using a splint, and cerebral blood oxygenation was measured using near-infrared spectroscopy. The results demonstrated that participants with artificial occlusal disharmony (AOD) tended to show an increase in oxyhemoglobin (oxyHb) in the bilateral prefrontal cortex. The participants felt discomfort during AOD, which increased stress on the brain. Short-term physical stress decreased working memory function. This may be due to the activation of the hypothalamic–pituitaryadrenal axis that leads to increase in the levels of glucocorticoid secretion and affects working memory. (Sakatani et al., 2013).

In another study, the authors concluded that increased clenching in a malocclusion model caused increased activation of the prefrontal cortex. They reported a correlation between prefrontal blood flow and the visual analog scale score for discomfort. Therefore, prefrontal cortex activity could impact the perception of unpleasantness. (Otsuka et al., 2015).

Impaired chewing is considered a risk factor for Alzheimer's disease and systemic health, suggesting that mastication plays a key role in senile dementia and stress disorders, which are associated with memory and learning impairments. It is important to focus on the critical role of the hippocampus in memory and learning and on the effects of masticatory function on this brain structure. (Aguirre-Siancas, 2014).

3.3. Effects of dental loss on brain activity

Morphological changes in the hippocampus as well as a decrease in pyramidal cells and cell proliferation in the dentate gyrus have been observed after the loss of molars. These morphological and cellular alterations are similar to age-related changes in the hippocampus. Similarly, a decrease in masticatory function and eating associated with long-term soft diets can suppress learning capacity and memory. Therefore, tooth loss can accelerate the aging process of the hippocampus. (Bermúdez Nur, 2016; Jacobs and Steenberghe, 1994; Ohkubo et al., 2013).

Reducing the dentition, and therefore, the periodontal ligament, can also have an effect on the level of blood volume in the brain and its activity, suggesting that improving occlusion can increase brain blood flow. The results of recent studies have shown that older adults with more than 20 teeth have increased physical activity, skills, and quality of life. (Bermúdez Nur, 2016; Miyamoto et al., 2005, 2006; Tada et al., 2003; Trulsson, 2007).

Researchers simulated full dental arches and short dental arches using occlusal splints and measured brain activity during maximal voluntary clenching with near-infrared optical topography. OxyHb levels and blood volume were significantly lower in short arches than in full arches. A possible explanation may be the lower number of periodontal mechanoreceptors that produce fewer impulses, and therefore, result in less activation of the cerebral cortex. (Bermúdez Nur, 2016; Miyamoto et al., 2009; Ohkubo et al., 2013).

3.4. Temporomandibular disorders and brain activity

Patients with temporomandibular disorders (TMD) have abnormal cortical responses to tactile stimulation and decreased cognitive capacity and motor performance, demonstrating the correlation between the CNS and TMD. (He et al., 2014).

It has been observed that patients with TMD show increased anxiety traits, directly related to the functional activation of the anterior insula. Further, in these patients, the insula fulfills the role of monitoring and anticipating painful stimuli. (Dammann et al., 2020; Ocañez et al., 2010).

The limbic system is interconnected with the anterior insula, which connects somatosensory information with the internal emotional state (condition of fear or safety). When applying a neutral stimulus, the anterior insula processes aversive, anticipatory, and chronic pain associations. In contrast, the posterior insula processes multisensory body states as it is connected to the somatosensory cortex, thalamus, and superior temporal gyrus. (Dammann et al., 2020; Lickteig et al., 2013).

3.5. Effect of occlusal splints on brain activity

It has been shown that after splint therapy, movements during occlusion show altered brain control. The brain training induced by occlusal guards could be one of the main reasons for the observed effects. Oral tactile stimuli would likely change in the presence of an occlusal guard, which is a foreign object inside the mouth. (Lickteig et al., 2012).

Different occlusal functionality tasks cause differences in brain activation patterns. It has been suggested that occlusion with splints may reduce brain activation and relax muscle activation. Differences between the left and right hemispheres have been associated with masticatory laterality, and functionality during mastication has been related to the function of the sensorimotor cortex. (Kordass et al., 2007; Ohkubo et al., 2013).

Common brain activation regions, as well as exclusive activation zones, are associated with the use of guards. Splint use decreases motor activation and sensorimotor feedback, which could reduce the motor activity associated with mastication. (Lotze et al., 2012).

Other studies reported that, by increasing the vertical dimension through the use of a rigid splint, areas associated with reasoning, coordination of movements, and memory are activated, producing more generalized brain activity and a marked reduction in muscle activity during tightening. The use of a soft guard could affect afferent inputs in the same way as tightening without a splint. (Ariji et al., 2016; Narita et al., 2009).

Lickteig et al. (2013) found that wearing splints reduced the experience of pain and that this reduction was greater during mandibular movements than that during rest. Electromyographic activity during rest decreased with the use of a splint and increased during tightening with maximum intensity. The symmetry of mandibular movements improved due to lower activity of the left cerebellar hemisphere and right precentral gyrus. Pain was also reduced, which was associated with changes in blood oxygenation levels in the right anterior insula, left posterior insula, and right cerebellar hemisphere.

Occlusal splint therapy reduces mental exertion and anticipatory pain associated with anxiety by decreasing activation of the insula. The use of splints redistributes the distances between the condyle and the fossa of the temporomandibular joint and increases the symmetry of mandibular movements. The cerebellum is involved in motor function and is, therefore, activated during tightening; at the beginning of treatment, the right cerebellar hemisphere is activated, and once the mandibular movements become symmetrical, greater activation of the left cerebellar hemisphere is observed. (Dammann et al., 2020; Lickteig et al., 2013).

Intermittent occlusal splint use resulted in decreased brain activation during occlusion, with and without the splint. Greater activation was observed in the left superior parietal lobe owing to therapy adaptation. The activity of the insula also decreased, which is associated with a decrease in pain. (Lickteig et al., 2012).

4. Conclusion

This review examined the relationship between occlusion and brain functions. Changes in occlusion affect the sensorimotor cortex. Further investigations into the interactions between brain activity and chewing are needed to elucidate those parts of the brain that are affected when occlusion is disturbed and to determine whether brain function is altered. A limitation of this study was that only studies published in the English language and indexed in the selected databases were included, resulting in a relatively small number of reviewed articles. Furthermore, only positive results were obtained during the search; therefore, there may have been publication bias.

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CRediT authorship contribution statement

Sebastian Silva Ulloa: Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Ana Lucia Cordero Ordóñez:** Methodology, Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Vinicio Egidio Barzallo Sardi:** Conceptualization, Validation, Resources, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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