Human & Veterinary Medicine
International Journal of the Bioflux Society

OPEN ACCESS
Review

Occlusal forces and their transmission to the periodontium

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Abstract. This article will clarify the function of the periodontal ligament, its anatomical structure and the way the occlusal forces are transmitted onto it. The periodontal ligament interconnects the teeth and alveolar bone functionally. The periodontal ligament provides support and protection, and it ensures the transmission of sensory impulses to the mastication system. It is the major absorption element of the occlusion forces in the jaws, and its biomechanical features influence the transmission of their effects onto the jaw bone. The pattern of load distribution in the periodontal ligament is influenced by the embedded of tooth, its position, the intensity and direction of the forces. Determining the direction of the forces transmitted in the periodontal ligament is a critical factor for a better understanding of the biological behavior of the supporting of the tooth in good functional condition or non-functional condition.

Key Words: eriodontal ligament, function, occlusal force, biomechanics

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Introduction

The periodontal ligament (PDL) is the only ligament in the body that connects two distinct hard tissues. It is a fibrous, complex, soft connective tissue that attaches the tooth root to the inner wall of the alveolar bone (Lin et al 2017; Lee et al 2015). Its width ranges from 0.15-0.38 mm, in human molars, with the thinnest part around the middle third of the root.

The periodontal ligament is the major absorption element of the occlusion forces in the jaws, and its biomechanical features influence the transmission of their effects onto the jaw bone. (Lin et al 2013)

The periodontal ligament interconnects the teeth and alveolar bone functionally. It provides support and protection, and it ensures the transmission of sensory impulses to the mastication system. (Newman et al 2014) The PDL allows the tooth to change its position under the load of the forces and it maintains continuity between the hard tissues of the periodontium, namely: the alveolar bone and the dental cement. The PDL is a unique tissue whose removal can cause the loss of the dental function and adjacent alveolar bone resorption. In the mastication process, the PDL provides sensory feedback during the mastication cycle and serves as a means of propagation of the forces between the teeth and the alveolar bone (Popa 2004; Ho et al 2013).

Occlusal forces transmission

The periodontal ligament acts as a shock absorber because it acts like a hydraulic system that serves to reduce the magnitude of the forces propagated to the surrounding alveolar bone (Matsuo & Takahashi 2002; Nobuto et al 2003).

Under the action of an occlusal force applied to the long axis of the tooth, the root performs an alveolar intrusion motion, and the oblique fibers elongate changing their folded, resting appearance. In this way, they take on most of the strain to resist the axial occlusal forces.

The action of horizontal forces which are perpendicular onto the long axis of the tooth causes the tooth to move in two phases. In the first phase the tooth moves under the restrictive action of the periodontal ligament, and in the second phase the tooth moves due to the deformation of the bone alveolar walls in the lingual and vestibular area.

Under the load of oblique or horizontal forces, the tooth tends to rotate around a horizontal axis, located slightly apically to the area of the junction between the root apical third and its middle third. This position of the root rotation axis changes with respect to the intensity of the force. The crown of the tooth moves in the opposite direction to the root apical third (Popa 2004).

The occlusal forces transmitted by the periodontal ligament to the inner layer of the alveolar wall are sustained by the spongy trabeculae which are supported by the vestibular and lingual compact tissue layer.

The spongy bone has a Young modulus between 272-489 MPa and a Poisson index of 0.31. The portion surrounding the spongy bone is called cortical bone and has a Young modulus of 13,800 N / mm and a Poisson index of 0.26 (Jones et al 2001; Martin 1998). The authors (McCulloch et al 2000; Martin 1998) found that the response of the cortical bone is related to the tension sensitivity rate. Asundi and Kishen (2000) compared the stress distribution onto the dental root and the support bone. They found stress being higher in the cervical region and lower in the apical one. The results suggest that the PDL and the adjacent

alveolar sheath are closely correlated in the distribution of the mastication forces.
For good functionality, it is necessary to keep the relationship between the alveolar bone and occlusal forces in a steady state. The alveolar bone reaction takes place depending on the direction, intensity and duration of the forces. Under this action, the tooth root creates tension and compression zones onto the alveolar walls, through the periodontal ligament. The vestibular and lingual walls of the alveolus get elastically deformed in the direction of the occlusal forces resultant. The occlusal forces can shape the alveolar bone by resorption and bone apposition, altering the height, number and thickness of the trabeculae (Lindhe & Thorkild 2008).
Thus, traumatic occlusal forces are considered as one of the local factors that accelerate bone resorption (Zhu 2004). The PDL tolerates varied directions of occlusal forces. The vertical forces resulting from teeth contacts are well tolerated by the periodontal ligament. They completely turn the compressive dental forces into traction forces, the tooth being suspended in the alveolus by the PDL that acts as a hammock (de Jong et al 2017). In the case of horizontal forces things happen differently. These forces generate pathological bone reactions by proprioceptive impulses, modifying the neuromuscular activity.
The PDL is subjected to the forces generated by the phonetic process, mastication, or teeth movements for orthodontic purposes (Dutra & Nanda & Yadav 2016; Lin et al 2014; Naveh et al 2012). In the tooth alveolus, because the stress transmitted through interdental contact during mastication is not purely axial, the PDL is subjected to both compression and traction forces (Pini 2002). In the traction area, the periodontal fibers change their folded shape, allowing settling and distending. In the compression zone, the fibers get folded. In addition, as the tooth gets moved, deformation of the alveolar bone occurs in the direction of the root displacement. If the periodontal ligament affects the response of the alveolar bone to the action of the occlusal forces and if the value of the occlusal forces exceeds the periodontal ligament resistance capacity, it gets destroyed. The effects of this process lead to the appearance of occlusal trauma. Moreovere, in case of absence, or decrease in the teeth load caused by occlusal forces, the periodontal ligament undergoes a process of inactivity that manifests by thinning, disorientation, reduction of the number and density of the fibers. The decrease in the functional value of the periodontal ligament and alveolar bone alters the balance between the action of the occlusal forces and the reaction of the tooth support ligament.
The healthy and functional periodontal ligament comprises several types of cell. Naturally, PDL is composed of fribroblasts (the most numerous), endothelial cells, systemic sensory cells, bone-associated cells, and cementoblasts (Jiang et al 2016). These cells act under the impact of occlusive forces and respond by maintaining and preserving the viability of PDL cells (McCulloch et al 2000).
The ectomesenchymal cranial neural crest cells constitute the basis from which the periodontal ligament fibroblasts originate. The latter present a high turnover rate of collagen, occurring by simultaneous synthesis and degradation of collagen fibrils (Conti 1991). A low level of periodontal ligament stem cells is contained in the periodontal ligament. These stem cells also originate from the ectomesenchymal cranial neural crest cells and possess the capacity to differentiate into periodontal ligament fibroblasts, cementoblasts and osteoblasts (Nishide 1997; Carter & Beaupre 2001; Hu 1994).
The PDL sensory mechanisms and receptors are not fully elucidated. The PDL cells respond directly by means of a mechanism triggered by the action of biomechanical forces, and the activation of mechanical-sensory signals. These systems include the activation of ion channels for adenylate cyclase and changes in the cytoskeletal organization. Immediate responses to mechanical forces induce the production of intracellular messengers. High concentrations of inositol phosphate and calcium variations were observed in response to substrate tension (Jones et al 2001). Furthermore, the PDL fibroblasts and osteoblasts also have receptor and effector mechanisms capable of perceiving the forces and responding to them by remodeling. For example, intermittent pressure applied to PDL cells enhances bone resorption (Beertsen et al 2000).
Although the receptor and cell mechanisms responsible for the PDL behavior are unclear, the PDL is known to be essential for quick bone remodeling under the action of biomechanical forces, which act on the teeth (Saito et al 1991).
A key function of the PDL within the mastication cycle is to provide sensory feedback during cycles. In the PDL there are proprioceptors and tactile receptors that have the ability to detect and identify the quality and location of the forces acting on the teeth.
Although there is high concentration of sensory fibers in the oral cavity, the PDL plays a special role by initiating the engrams in the transmission of the subconscious feedback within the mastication system. Lund and Lamarre performed anesthesia on several teeth and observed a 40% reduction in the mastication force, thus demonstrating that PDL proprioceptors play an important role in controlling mastication forces (Dean 2017).
Some researchers have shown that patients with severe periodontal disease presented a high detection threshold of the vibration transmitted through the teeth due to the inflammation of the periodontal ligament. Edentulous subjects also possess some proprioceptive abilities, while those who are not edentulous have an increased ability to produce much stronger interocclusal forces, making it possible to distinguish fine particles with high accuracy (Giovani et al 2016).
Mülhemann observed that the PDL blood vessels contributed to “shock absorption” through the viscoelastic behavior of the PDL, in which the fluid components of the tissue modified the action of the fibers in order to functionally take over the transmission of forces (Popa 2004).
Other authors (Komatsu & Chiba 1993) examined the biomechanical responses of the PDL in mice by applying different forces onto the incisors and molars. Mechanical strength and fiber density were higher in the case of molars, suggesting their different arrangement in the two groups of teeth. Both ligaments showed mechanical differences depending on the action speed of the forces. The results suggested reducing stress load which acted at a lower speed using viscoelastic materials to measure energy absorption and its storage.
Mechanical compression-traction tests on bovine PDL suggest that the PDL response to physiological compression reflects high hysteresis levels. Hysteresis due to tension is produced by the depolymerization of the collagen fibers and is caused by

the friction between the main fibers. The density of the fibers was accounted for the level of vascularization. Moreover, the intensity of the vascularization may affect the action potential of reduced forces (0.5 - 3.5 N) in vitro (Wills et al 1976; Jones et al 2001; Panagiotopoulou et al 2011).
Significant progress has been made with regard to understanding forces transfer and sensory feedback. However, many aspects remain unclear. What is obvious, though, is the fact that PDL is an important part of the mastication system and its structure and function cannot be neglected.

Conclusions

The study of PDL can provide us with a multitude of information, ranging from bone metabolism up to the biomechanics and physiology of mastication. The PDL is a vital component of the mastication system within the dental-alveolar complex and the physiological and biomechanical data, correlated with it, are essential for a clear understanding of the mastication system as a whole.

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Citation	Ispas A, Craciun A, Kui A, Lascu L, Constantiniuc M. Occlusal forces and their transmission to the periodontium. HVM Bioflux 2019;11(1):18-21.
Editor	Antonia Macarie
Received	22 December 2018
Accepted	20 January 2019
Published Online	20 January 2019
Funding	None reported
Conflicts/ Competing Interests	None reported