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Periodontal Ligament: As a Bite Force Distributor

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Abstract: ***Human masticatory system is special because of its framework stabilized the dental arches to withstand powerful occlusal force. Due to this system perfect correlation exists between occlusal force and tooth stability. Periodontium is one of the part of this masticatory system. Periodontium include gingiva, periodontal ligament (PDL), cementum and alveolar bone. Among this PDL plays an important role. Periodontal ligament is the connective tissue layer between the cementum and alveolar bone. Periodontal ligament is link between tooth and bone so it provides support, protection and sensory input for masticatory system. PDL contains cells, fibers and mechanoreceptor. With the help of mechanoreceptor PDL provide feedback mechanism against occlusal force. PDL has an ability to withstand considerable occlusal force and provide tooth stability through bone remodelling. This review focused on feedback mechanism of PDL against occusal force.***

Keyword: Periodontal ligament, Occlusal force, Mechanoreceptor, Signaling mechanism

1. Introduction

The human masticatory system is a classic example of a kinematically and mechanically indeterminate system. Chewing or Occlusion, it is phenomenon of collaboration of mandible and maxillary teeth, bones, and muscles. This process is called as mastication and the force acting during this process is known as masticatory force or biting force [1]. This force is formed by the dynamic action of the masticatory system during the physiological act of chewing. Bite force is divided in two main groups with physiological or pathological condition [2]Thus, Bite force is indicator of the functional state of the masticatory system.This bite force value depends on two factors: the force of the mastication muscles and reciprocal system which controls mastication forces via pressoreceptors of the periodontal ligaments. Normal value of the static bite force ranges from 100 to 1000 N, while dynamic or functional force ranges from 3.5 to 350 N. [3]. To reward such powerful forces nature formed system of the dental arches. Intact dental arch behaves as solid functional unit. While chewing, interaction of teeth and food combined with chewing force and structural resistance produce exclusive loading patterns in a skull based on chewing characteristics [4]. Morphological variation in masticatory structuresis evaluated by using concept of stress and strain. Stress is force per unit area; units are MPa (mega Pascal, equivalent to N/mm2). It is a quantitative measure of the intensity of internal forces. Strain is the measure of the local deformation material at some point, the insignificant changes in dimension of a loaded body, and is dimensionless. Stress and strain are vector quantities that measured magnitude and direction of force. [5]. Bone responds to stress and strain stimuli. In the masticatory apparatus, different masticatory behaviors cause different types and level of stress that affect the growth and development of bone [6]. Mechanical input affects bone morphology by stimulating or suppressing modeling and remodeling processes. Three principal factors that determine the optimal distribution of occlusal force on the dental arch is Proper occlusal contacts, solid proximal dental contacts and structure of the periodontal ligament [**7**]

1.1 Periodontal ligament

Periodontal ligament [PDL] is composed of soft complex vascular and highly cellular connective tissue that surrounds the tooth roots and connects to the inner wall of the alveolar bone [8]. Periodontal ligament also called as Periodontal membrane, Alveolo-dental ligament, Desmodont, Pericementum and Gomposis. PDL has hour glass appearance. Width of PDL is 0.15 to 0.35 with thinnest at the middle third of the root. PDL provide attachment of teeth to the bone. It offers support, protection and sensory response to the masticatory system. Under occlusal force, PDL allows the teeth to change position and maintains continuity between the alveolar bone and cementum. PDL also transmits blood vessels, supplies nourishment to the cementum. Remodeling of cells and fibers of the periodontal tissue takes place in the periodontal ligament. Absence of the PDL results in the loss of function of the teeth and resorption of the alveolar bone. During chewing, PDL transmit the occlusal force to the bone and also provide resistance to impact of occlusal forces.

Periodontal ligament composed of cellular element, periodontal fiber and ground substances. Cellular element consists of connective tissue cells including fibroblast, osteoblast, cementoblast, osteoclast, cementoclast, epithelial cell rest, immune system cells, and neurovascular cells. The most important elements of PDL are the principal Fibers. It is made up of collagen. Diameter of collagen fiber is 55 nm. Collagen fibers in PDL has high turn-over rate.Principal fibers of PDL areTrans septal fiber,Alveolar crest group fiber, Horizontal fiber, Oblique fiber,Apical fiber,Inter –radicular fiber. These PDL fibers are wavy in nature, extend from the cementum to bone and permit for tooth movement. [9]Sharpey'sfibres are terminal portion of principal fibresthat extend from cementum to bone. Once they embedded into the alveolar bone and cementum, thencalcification start and become associated with non-collagenous proteins.[8]Secondary fibers of PDL areoxytalan, elastin and eulanin. It also contains noncollgaenous protein like laminin, osteocalcin, osteopontin, osteonectin, fibronectin, tenascin. Ground substance fills the space between the fiber and cells. It consists of water [70%], glycosaminoglycans and glycoprotein.

1.2 Mechanical profile of PDL:

I] **Homeostasis:** The PDL is exposed to forces during mastication, speech and orthodontic tooth movement. PDL is squeezed in between two hard tissues that are tooth root and alveolar bone but still PDL has capacity to maintain its width throughout the life. It is because of PDL cells secrete the molecule that maintain and regulate the event of mineralization, e.g is bone sialoprotein, osteopontin, matrix Gla protein**.**This ability of PDL cells is a crucial factor of tissue remodeling and periodontal ligament homeostasis.[10]. Primary functions of the PDL are transmission of occlusal force to the alveolar bone and provide resistance to impact of occlusal force.

II] **Transmission of occlusal force to the alveolar bone:**The PDL is highly vascularized, a characteristic that traits to its viscoelastic behavior. Due to blood vessel, PDL behave like a 'shock absorber', , cushioning the alveolus from the occlusal load. [11]PDL as a shock absorber is explained by viscoelastic theory, tensional theory and thixotropic gel theory. Tensional theory suggests that when the force applied to the tooth, principal fibers change their orientation and became straight. These unfold fiber transmit the force to the bone causing elastic deformation of the alveolar bone. When alveolar bone reached to its limit, force transferred to the basal bone.

[12]. Viscoelastic theory suggests displacement of tooth to be primarily controlled by the fluid movements with fiber having secondary role. When forces are applied to the tooth, the extracellular fluid passes from the periodontal ligament into the marrow spaces of the bone through the foramina in the cortical layer. Holes in the lamina dura link the periodontal ligament with the cancellous portion of the alveolar bone.After exhaustionof the tissue fluids , the fiber bundles absorb and tighten, this leads to blood vessel stenosis , arterial back pressure and passage of blood ultra filtrates into the tissues there by replenishing the fluids and forces transferred to the bone. [13, 14].Thixotropic theory said thatPDL has behavior of thixotropic gel (property of becoming fluid when shaken or stirred and then becoming semisolid again). This property of PDL may be described by changes in the viscosity of the biologic system**.**[15]

There are various mechanical models which explain the relationship between occlusal force and viscoelastic property of PDL. These models suggested that as more amount of occlusal force is applied to the tooth then force-displacement curve became non-linear. The initial resistance is low but as the force is increased the resistance increases until at its high limit. Beyond that limit additional displacement is very small [16]. Ralph in 1982 [17] did a study and suggested that the close interaction between PDL fibers and capillaries may produce a closed fluid system which would permit for distribution of occlusal force to the alveolar bone. Pini et al in 2004 [18] found that the maximum tangent modulus, strength, strain and strain are increased with depth of tooth root (except for the apical region of molars). This feature associated with the width of the PDL is different along the length of the tooth root. So, result of various study suggest that the PDL is biphasic material, similar to articular cartilage but Martin et al. 1998 [19] established that the cartilage and tendons are inflexible at higher amount of force, indicating that PDL is not biphasic material under normal physiologic occlusal force.

III] Bone- remodeling: Teeth are continuous in contact. When the occlusal force is applied, tooth rotate along the axis of rotation of root and force is transfer from tooth to alveolar bone via PDL. So, PDL plays a crucial role in bone remodeling. Various hypotheses have been suggested to understand the interaction between tooth movement and bone remodeling. One of the eldest hypotheses is known as the "pressure-tension hypothesis". This suggests that tooth movement occur in the direction of applied force. In the direction of force compression of PDL occurs and opposite side PDL is stretches. Compression leads to pressure area and stretches leads to tension area. (Fig. 1, fig 2a). In the pressure area bone resorption and in tension area bone formation takes place. This continuous bone remodeling resist tooth displacement and bear the occlusal force. [20]

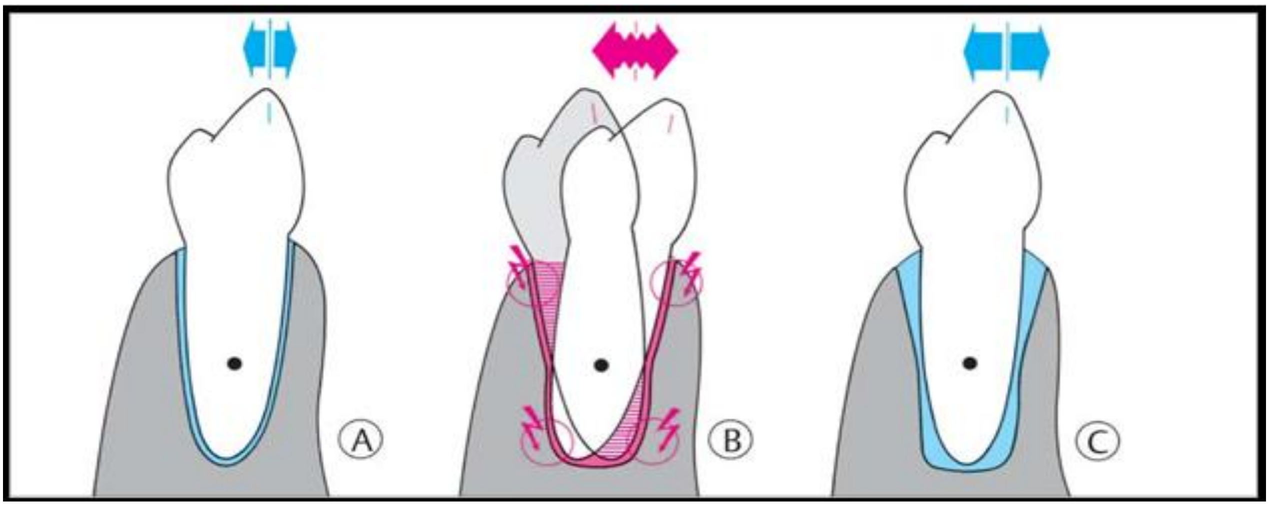


Figure 1: When the force is applied ,tooth movement occurs and that produced the area of tension and pressure in PDL

Second hypothesis is “alveolar bending hypothesis” reported by Baumrind. This suggests that tooth movement cause PDL and alveolar bone deformation. In this hypothesis (Fig. 2b), the walls of the tooth socket perform like cantilever beams, that is, they are essentially fixed at one end (towards the apex) and free at the other (towards the tooth crown). When an excessive force is applied, free end may displace but the other end is fixed. So, a minor bending of the tooth socket walls occurs.The side to which the tooth is pushed, bone bent away from the tooth and on the opposite side bone pulled towards the tooth.[21]According to Currey, strain gradients are responsible for defining the nature of bone adaptation, under the application of a load. Bone depth from surface is increase then strain in the bone become more tensile. If strains become less tensile with depth then bone is removed from that place.[22] Applying this idea to the alveolar bending hypothesis (Fig. 2b), bone formation takes places at compressive surfaces of the alveolar bone and resorption take placeat tensile surfaces. Thus, tooth move in the direction of the applied load are resist the excessive occlusal force.

Third hypothesis suggested by Melsen is the “stretched fiber hypothesis”. However, Melsen suggested that PDL fibres will be compressed on the side to which the tooth is pushed, and stretched on the opposite side (Fig. 2c). Thus the PDL fibres will only exert force on the surrounding bone where they are in tension, not where they are in compression. Therefore, the PDL will provide little resistance to tooth movement in the direction of the applied force and so will transfer negligible load to the alveolar bone on that side. Conversely, the fibres will be stretched on the opposite side and thus the applied load will be essentially transferred there. [23]

Hysteresis: Hysteresis is the gap in the reaction of a material to the application/removal of a force. Itis a main characteristic of viscoelastic materials. It measures the ability of a material to storeand disperse energy. Pini et al. 2004 suggested that under physiologic compression PDL exhibits high levels of hysteresis. Hysteresis resulting from tension is due to the uncoiling and abrasion between principal fibers. [18]

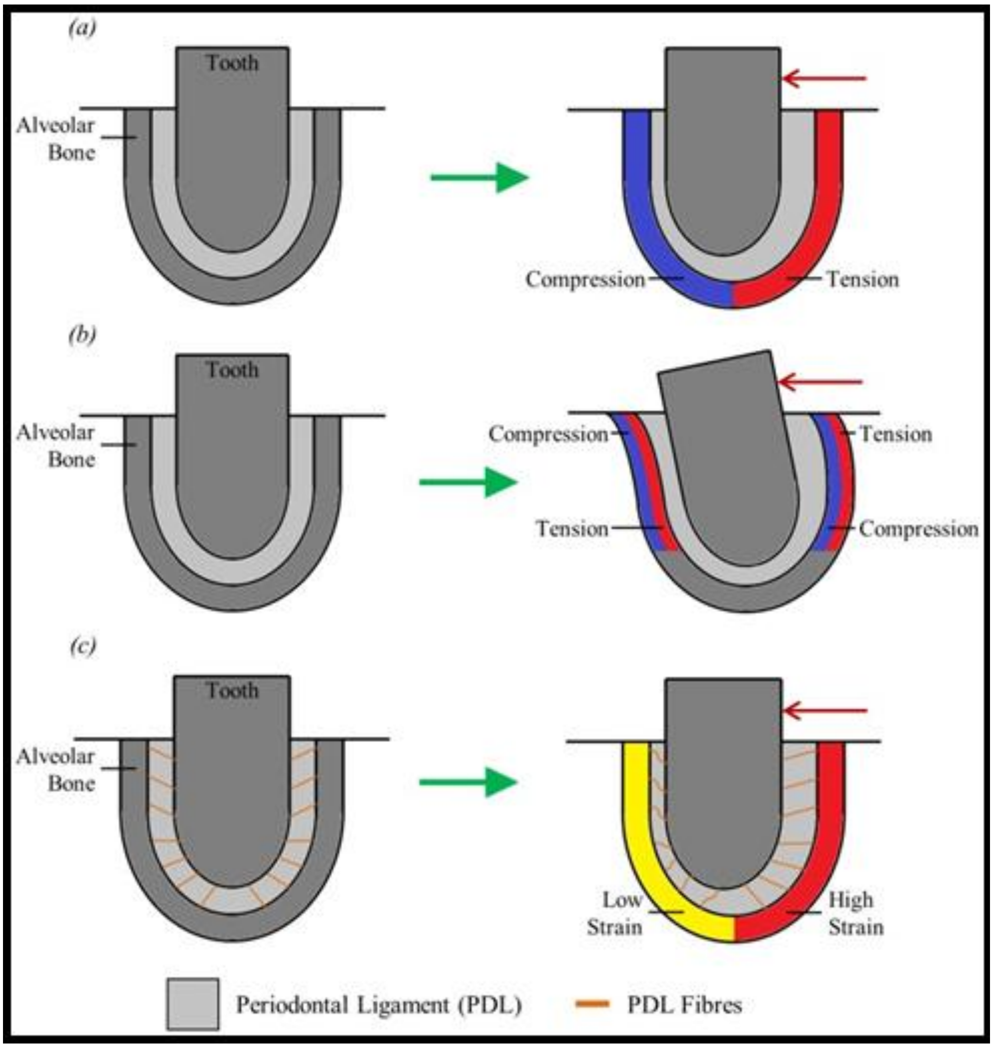


Figure 2: Tooth-PDL-bone complex demonstrating three hypotheses for strain-based bone remodeling during applied force.(a) “pressure-tension hypothesis” showing tooth displacement leading to compression and tension in the surrounding bone; (b) “alveolar bending hypothesis” showing tooth movement causing bending of the alveolar bone; (c) “stretched fiber hypothesis” showing stretching and compression of PDL fibres leading to low and high strain areas in the surrounding bone. The red arrows indicate the direction of the applied force.[24]

IV] Mechanoreceptor:

One of the main functions of the PDL is to provide sensory feedback during chewing. PDL contained pressure, touch and pain receptors. PDL also contain propriocepters giving information about tooth movement and position. Mechanoreceptors present in the ligament, which respond to force application. Humans are capable of identifying the presence of very small particles between the teeth. If any inert particles detect in chewing then tooth movement is arrested reflexively and altered into on opening movement. Thus receptor in PDL together with proprioceptor in muscles and tendons plays an important part in regulation of chewing movement and chewing forces. So, these PDL proprioceptive sensors provide sensory information about how fast and how hard to bite.[25] Mechanoreceptor activated by the tooth movement as little as 1-3 microns. Lund and Lamarre in 1973 [26] anesthetized patient's teeth and found a 40% reduction in applied bite force. This result indicates that PDL proprioceptors play an important part in the control of bite force. Proprioceptors are also present in edentulous patient but patient with teeth have more interocclusal forces and can easily differentiate between fine particles between occlusal surfaces of teeth. [25] The PDL is abundantly supplied with sensory nerve fiber. Nerve bundles pass in to the PDL from periapical area and through channels from the alveolar bone follow the course of the blood vessels. They are divided into single myelinated fibers which ultimately lose their myelin sheath and end in one of these types of neural termination.**1-Free endings**have a tree like configuration which include nociceptors (pain receptors),that carry pain sensation through a small diameter nerve fibers. **2-Ruffini like** mechanoreceptor are flatted, elongated capsule containing a few nerve fibers, they respond typically to heavy continuous touch or pressure and located primarily in apical area. **3. Tactile (meissners) corpuscles** also mechanoreceptors are tall, ovoid shaped consist of 2 or 3 nerve fibers and are phasic receptors for light touch, texture and low frequency vibration. Mainly found in the mid root area. **4. Spindle like endings** surrounded by fibrous capsule and rarely found at apex of root.[27] Periodontal mechanoreceptor population can be divided into two groups, rapidly adapting and slowly adapting.**Rapidly adapting receptors** are loosely attached to the surrounding tissue and slippage occurs during sustained displacement of the tissue. When initial contact with food or opposing teeth occurs they produce signals. **Slowly adapting receptors** are those which are more firmly attached to the surrounding tissue. They are useful for selective tooth stimulation, direction of the stimulus, intensity and change of pressure applied to the tooth.[28]

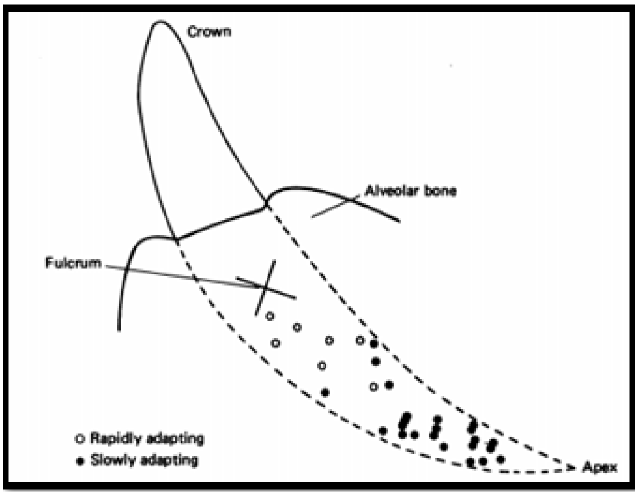


Figure 3: Demonstrating the distribution of the thirty periodontal mechanoreceptors located in this side of the periodontal ligament. [28]

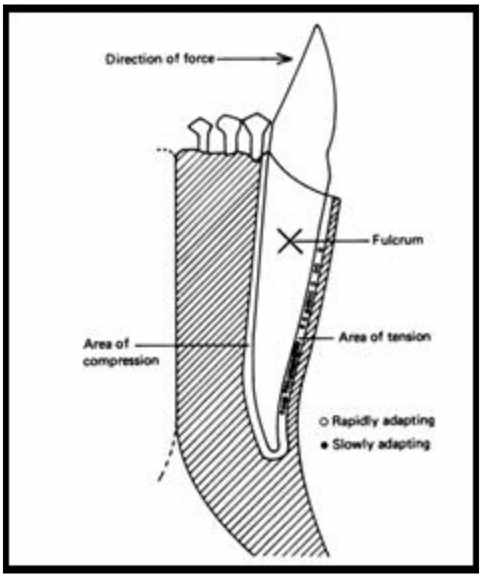
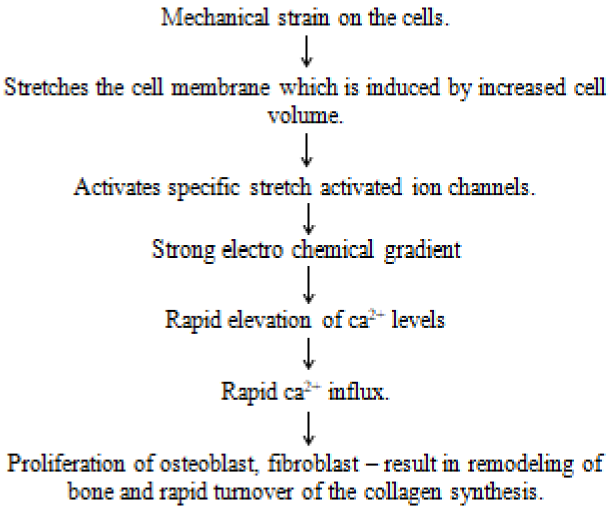


Figure 4: Shows the direction of force needed to be applied to the tooth in order to stimulate maximally the thirty located periodontal mechanoreceptors. All thirty receptors responded to tension and not compression of that part of the ligament in which they lay. [28]

V] Mechanoprotection:

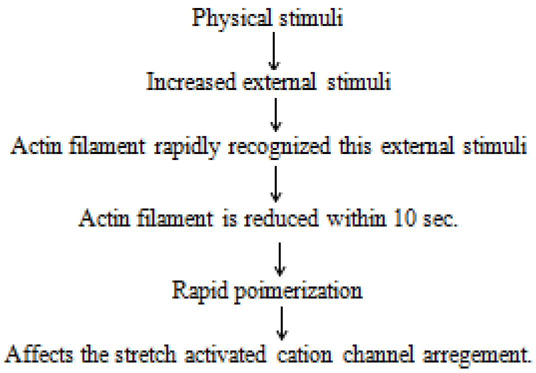
PDL cells respond directly to mechanical forces by activation of mechanosensory signaling systems. These signaling systems include adenylate cyclase and stretch-activated ion channels and by alterations in cytoskeletal organization. Because of this alternation production of intracellular second messengers such as intracellular calcium ion concentration ([$Ca2^+$]$_i$),inositol phosphate (IP3) takes place. Intracellular calcium ions are seen in periodontal cells responding to substrate tension (6), and increased IP3 has been observed after physical stretching of osteoblasts. When the force is applied on teeth, change in arachidonic acid metabolites takes places. In vitrostudy shows that elevated level of prostaglandin and interleukin 1 inresponse to cyclic tension force. [29,30]. So, intermittent pressure application to PDL cells increases bone resorption due to increased level of prostaglandin and interleukin 1. Thus, these data suggest that applied force to PDL may lead to alveolar bone remodeling by direct or indirect mechanism.

Signaling mechanism: [31, 32]



It is proposed that the stretch activated ion channels are

regulated by microfilament actin filament.



All these data indicate a dynamic and reciprocal relationship between cation channel, cytoskeleton structure and stromal cells that is osteoblast and fibroblast. Thus PDL is an absolute requirement for fast remodeling of alveolar bone when physical forces are applied to teeth.

2. Conclusion

The periodontal ligament functions as a shock absorber, helping to distribute and dissipate the occlusal forces across the teeth and supporting structures. Understanding the role of the periodontal ligament as a bite force distributor is crucial in the diagnosis, treatment planning, and management of various dental conditions, including occlusal disorders, malocclusions, and dental prosthetics. Its unique properties contribute to effective chewing function and overall oral health. By considering the biomechanics of the periodontal ligament, dental professionals can develop appropriate treatment approaches that optimize occlusal stability, function, and overall oral health.Further research in this area can deepen our understanding of the intricate biomechanics of the periodontal ligament and its clinical implications.

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