ISSN: 2581-5989
PubMed - National Library of Medicine - ID: 101738774

International Journal of Dental Science and Innovative Research (IJDSIR)
IJDSIR : Dental Publication Service
Available Online at:www.ijdsir.com
Volume – 7, Issue – 5, September – 2024, Page No. : 87 - 96

The Unsung Hero: Unraveling the Wonders of the Periodontal Ligament

[1]Dr Arjun Machingal Raveendran, Reader, Department of Periodontics, Mahe Institute of Dental Sciences and Hospital, Mahe, Puducherry, India

[2]Dr Marjana Shukoor, Post Graduate Resident, Department of Periodontics, Mahe Institute of Dental Sciences and Hospital, Mahe, Puducherry, India

[3]Rahfa Ismail, 4th Year Undergraduate, Department of Periodontics, Mahe Institute of Dental Sciences and Hospital, Mahe, Puducherry, India

[4]Prithima .R, 4th Year Undergraduate, Department of Periodontics, Mahe Institute of Dental Sciences and Hospital, Mahe, Puducherry , India

Corresponding Author: Dr Marjana Shukoor, Post Graduate Resident, Department of Periodontics, Mahe Institute of Dental Sciences and Hospital, Mahe, Puducherry, India

Citation of this Article: Dr Arjun Machingal Raveendran, Dr Marjana Shukoor, Rahfa Ismail, Prithima .R, “The Unsung Hero: Unraveling the Wonders of the Periodontal Ligament”, IJDSIR- September – 2024, Volume –7, Issue - 5, P. No. 87 – 96.

Type of Publication: Review Article

Conflicts of Interest: Nil

Abstract

The periodontal ligament (PDL) is a specialized connective tissue critical for the support, maintenance, and function of teeth. Situated between the cementum of the tooth root and the alveolar bone, the PDL plays a vital role in securing teeth within the jaw, absorbing occlusal forces, and facilitating the sensory feedback necessary for proper mastication. This dynamic tissue is composed of a complex matrix of collagen fibers, cells, and extracellular components that contribute to its unique biomechanical properties. Recent research has highlighted the PDL's regenerative capabilities and its potential role in periodontal therapy and dental regeneration. This review aims to elucidate the structural characteristics, biological functions, and clinical significance of the periodontal ligament, with a focus on its role in maintaining periodontal health and its implications for advanced periodontal treatments.

Keywords: Periodontal Ligament, Oral Cavity, Alveolar Bone, Collagen Fibers.

Introduction

The periodontal ligament (PDL) is an aligned fibrous network anchored firmly to the root cementum of the teeth on the one side and to the alveolar bone of the jaws on the other side. It provides mechanical stability and acts as a shock absorber to protect the tooth and alveolar bone from damage created by the high forces associated with mastication. In addition, together with the gingiva, the PDL forms a protective barrier against pathogens from the oral cavity [1]. Finally, the neural network in the PDL plays an important role in the sensory input of the mastication system [2]. These capacities deteriorate if the PDL is damaged by periodontitis, a commonly occurring and progressive disease that leads to loss of the PDL and the supporting alveolar bone. If left untreated, periodontitis eventually results in tooth loss [3]. Therapies for periodontitis exist, but primarily aim at controlling symptoms and stopping disease progression rather than at regeneration of lost tissues [4].

Definition

The periodontal ligament (desmodontium) is a fibrous joint (syndesmosis) that suspends the root of each tooth in its alveolar bone socket. The periodontal ligament fibres are anchored in the cement layer of the tooth and in the alveolar bone. The periodontal ligament holds the teeth in sprung suspension, with the result that each tooth is capable of small movements in its alveolar bone socket. Blood vessels and nerves are also found at the junction between the dental root and alveolar bone. The nerves there transmit proprioceptive information via the periodontal ligaments, enabling the teeth to use the periodontal ligaments to adapt to the prevailing forces and to reposition themselves to a limited extent [5].

Shape

The periodontal ligament (PDL) is a soft connective tissue that surrounds the root of a tooth and connects it to the bone. The space of the PDL is shaped like an hourglass and is narrowest at the mid-root level. The PDL is made up of collagen bands, mostly type I collagen that connect the cementum of teeth to the gingivae and alveolar bone. The morphology of the PDL varies in terms of tooth anatomy and even tooth surface. For example, it is thinner in the middle of the root and slightly wider near the root apex and alveolar crest, suggesting that the fulcrum of tooth physiologic movement is located in the thinnest area of the PDL. Radiographically, the PDL is seen as a radiolucent space between the lamina dura and the tooth root. The normal width of the PDL ranges from 0.15 mm to 0.21 mm, which may decrease with age. Widening of the PDL is one of the most important changes in the circumvented structures and may be related to different abnormalities.5 It is important to detect whether the widening is regular or irregular in shape and if the lamina dura is still present[6].

Width

The periodontal ligament was simulated as 0.15 mm and 0.24 mm. These widths of the PDL were taken as the average width of the PDL is 0.2 mm and the width ranges from 0.15 to 0.38 mm with the thinnest portion around the middle third of the root. Since there is a variation in the PDL widths with regards to the age of the patient, we decided to assess the stress with 2 different PDL width [7].

Synonyms

- Desmodont
- Gomphosis (fibrous joint)
- Pericementum
- Dental periosteum
- Alveolar ligament
- Periodontal membrane

Development of Periodontal Ligament:

The pdl is produced mainly from fibroblast before teeth eruption, which originates in the dental follicle and starts to differentiate during root development. The dental follicle is a condensation of the ectomesenchymal tissue – its cells differentiate into cementoblasts during their apical development and form the cementum lining the surface of the root (8)

- shortly after the beginning of root formation and the formation of the outer dentinal layer of root, the pdl is formed.
- The cervical loop of dental organ proliferates and extends to form Hertwig's epithelial root sheath. This sheath is double layered. The root sheath is stretched with root formation and then it fragments to form the discrete clusters of the 'epithelial cells called as epithelial cell rests of Malassez.
- The enamel organ is surrounded by a dental sac formed by condensed cells. A thin layer of these cells lied adjacent to the dental (enamel) organ. This is known as dental follicle.
- The cells of the dental follicle divide and differentiate into the cementoblasts, fibroblasts, and osteoblasts.
- The fibroblasts synthesize the fibres and ground substance of the pdl. these fibres of pdl then get embedded at one end into the newly formed cementum laid by cementocytes and at the other end into the bone laid by osteoblasts.
- When tooth erupts in oral cavity, the fibres get oriented in a characteristic manner. The fibre bundles of the pdl gradually thicken.
- The damaged periodontal fibres are replaced and remodelled by newly formed fibres [9].

Periodontal Fibres

The fibres of the periodontal ligament are made up of collagen and oxytalan.

Principal fibres are divided into

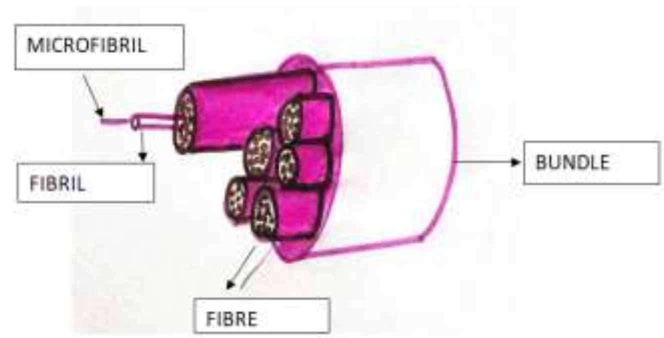
1. Principal fibres
2. The accessory fibres
3. The oxytalan (elastic) fibres.

Fibers: The predominant collagens of the periodontal ligament are type I, III, and XII, with individual fibrils having a relatively smaller average diameter than tendon collagen fibrils, a difference believed to reflect the relatively short half-life of ligament collagen, and hence less time for fibrillar assembly. The vast majority of collagen fibrils in the periodontal ligament are arranged in definite and distinct fibre bundles, and these are termed principal fibres. Each bundle resembles a spliced rope; individual strands can be continually remodelled while the overall fibre maintains its architecture and function. In this way the fibre bundles are able to adapt to the continual stresses placed on them. The extremities of collagen fibre bundles are embedded in cementum or bone. The embedded portion is referred to as Sharpey's fibres. Sharpey's fibres in primary acellular cementum are fully mineralized; those in cellular cementum and bone are generally only partially mineralized at their periphery. Other fibre bundles (gingival ligament fibres) are found extending from the cervical region of a tooth to that of the adjacent tooth (transseptal ligament fibres), and in the lamina propria of the gingiva. These, together with the main alveolo-dental ligament fibres, constitute the periodontal ligament-fibre system. Elastic fibres: There are three types of elastic fibres: elastin, oxytalan, and elaunin. Only oxytalan fibres are present within the periodontal ligament; however, elaunin fibres may also be found in association with fibre bundles in the gingival ligament. Oxytalan fibres are bundles of microfibrils that run more or less vertically from the cementum surface, forming a three-dimensional branching meshwork that surrounds the root and terminates in the apical complex of arteries, veins, and lymphatics. They are also associated with neural elements. Although their function has not been fully determined, they are thought to regulate vascular flow in relation to tooth function.

Because they are elastic, they can expand in response to tensional variations, with such variations then registered on the walls of the vascular structure [10].

Collagen

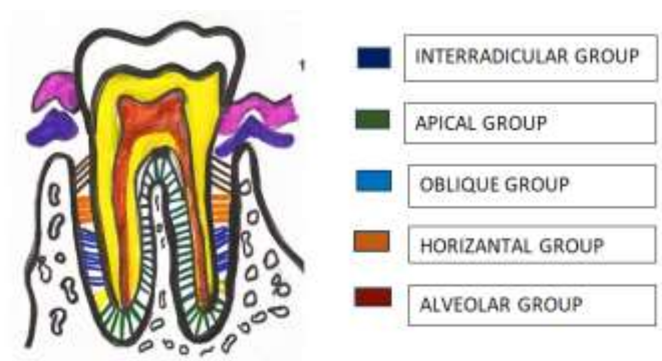
- A genetically distinct family of structural macromolecules of the extracellular matrix that contains one or more domains assembled in a triple helix. These proteins form a wide variety of structures.
- Collagen fibers are the principal fibers of the pdl and basically made up of type I and type III collagen.
- Collagen is high molecular weight protein
- Sugars and glycoproteins are attached to collagen.
- There are approximately 19 types of collagens
- Each collagen is produced by a different gene.
- Collagen macro molecules are rod-like and are arranged in the form of fibrils. The fibrils show an ordered periodic banding pattern. These fibrils are of very small diameter so these cannot be seen by a light microscope.
- Fibrils are packed side by side to form bundles or fibres. These fibres are the smallest order of collagen that can be seen by light microscope. The collagen fibres show deep green color by Masson's trichrome stain.
- Many collagen fibres are arranged in larger bundles and are termed principal fibres.
- The half-life of collagen fibres is between 3 to 23 days.
- Vitamin C helps in the formation and repair of collagen.
- Collagen are divided roughly into three groups based on their abilities to form fibrils [9].



Figuure1: Collagen

Principle Fibres

Most of the PDL composition comes from principal fibres, which are oriented bundles of collagen fibres. They are placed at inclinations that are important to their functions. The principal fibres have two groups, which are named according to their location with respect to the teeth. They are the gingival fibre and dentoalveolar fibre groups. Each individual collagen fibre is roughly 55 nm in diameter, which is small in comparison with 100-250 nm in length soft collagen fibre in tendons. This difference could suggest the short half-life of PDL



Collagen, resulting in less time to assemble fibrils. The larger the diameter, the more it is

Figure 2: Principal Fibres of PDL

Certified as an older fibre, and the smaller diameter are liable to be due to high rate of collagen turnover. PDL fibres are usually wavy in nature, enroute from the cementum and bone to permit for tooth movement. The ligament collagen bundle fibre composition is primarily interstitial collagen I and III, which then arrange as banded fibrils. Collagen V is also involved with these fibrils and is located in the interstitial spaces between the bundles or within the centre of the fibrils. Other minor collagens involved in the fibrous meshwork of the PDL are collagens IV, V, VI and XII, which are important to maintain the normal architectural structure of the PDL and in the regeneration of ligament function during remodelling from tooth movement [8].

Sharpey's Fibres

Sharpey's fibres are extension of the principal fibres of the ligament into the tooth cementum and bone. Once they insert themselves into the alveolus wall or the cementum, they calcify and become associated with non-collagenous proteins in cementum and bone [11]. The fibres are commonly longer on the appositional side of the ligament, which is where tension is formed. This may show interstitial fibre growth where the bundles are integrated into the surrounding bone. Also, Sharpey's fibres are coupled with high levels of osteopontin and bone sialoprotein. This could give useful physical properties to the hard and soft tissue interface. When bone remodelling occurs in the alveolar bone, this serves the fibres as the old bone is replaced by new bone. Therefore, the link between Sharpey's fibres and non-collagenous proteins would permit constant embedding pf periodontal ligament into the alveolar wall [11].

Cellular Elements

A healthy, functioning periodontal ligament consists of numerous cell types, which involve fibroblasts, cementoblasts, progenitor cells, bone- associated cells, epithelial cell rests of Malassez and connective tissue cells [1]. They all act together to sense applied physical forces and respond to them by maintaining PDL width and preserving cell viability [11]

Fibroblast

Fibroblasts are the main component cell type in the PDL. In rodents, they make up 35 % of the volume space of the ligament, approximately 20 % in sheep and 25-30 % in humans. The fibroblasts are interconnected by gap junctions and adherence-type junctions [12]. Fibroblasts are responsible for forming and remodelling the PDL fibres. They break down collagen in a controlled manner, intercellularly through phagocytosis. Fibroblasts migrate in thee PDL of continuously erupting teeth, during wound healing and in teeth with restricted eruption during usual function. They also have many cytoplasmic microfilament systems, which are indispensable to be able to contract and move. [13]

Epithelial Cell Rests of Malassez:

These cells originate from Hertwig's epithelial root sheath and occur in close proximity to the cementum as clusters or strands. The fact that the epithelial cells are in connective tissue is a unique characteristic [14]. They are connected by desmosomes and a basal lamina surrounds them. With age, they tend to decrease along every part of the root, in humans and other mammals. They may maintain normal PDL width and do not prevent ankyloses and root resorption. [15]

Osteoblast and Osteoclast

Osteoblast are bone-forming cells located along the alveolar bone surface, which differentiate locally from mesenchymal cells when needed. They are only prominent when there is active bone formation. Bone is constantly being turned over. Therefore, the osteoblast will form new bone in that area of alveolar bone being remodelled. [16]

Osteoclasts originate from monocytes within the blood vascular system and are found in areas where bone and cementum are being reabsorbed. They are actively involves in the resorption process in instances of tooth movement and periodontal disease. When they resorb bone, the surface of the alveolar bone has lacunae, resorption concavities, in which the osteoclasts lie in to form as multi-nucleated cells. (17)

Cementoblast and Cementum:

Cementum is a mineralized tissue that lines the tooth root surface. It is required to form functional PDL attachment during attachment. It is also thought to have vital function in the reparative process during tissue regeneration after disease (18). They take part in the development of cellular cementum, which is found in the apical two-third of the root. They are also able to separate from the cementum surface and contribute to early PDL fibroblasts [19]. Cementum is resorbe, for example due to changes in tooth movement or occlusion, which results in the activity of new cementoblasts in the repair of resorbed cementum or root dentin. [20]]

It has an important responsibility in permanent teeth being resorbed pathologically. They are created under pathological conditions and cause permanent tooth roots externally resorb due to stress, re- implanted teeth or induced by proliferation of tumorous lesions. [21]

Defence Cells

Macrophages are derived from blood monocytes and make up approximately 4 % of the PDL population. They phagocytose particulate matter and invading organisms and synthesise a range of molecule with important functions, such as interferon, prostaglandins and factors that enhance the growth of fibroblast and endothelial cells. Mast cells are often associated with blood vessels and have numerous functions, for instance they produce histamine, heparin and factors associated with anaphylaxis. Eosinophils are only occasionally seen in the normal ligaments. They are capable of phagocytosis and possess granules that consist of one or more crystalloid structures. (8)

Progenitor Cells

Progenitor cells are undifferentiated mesenchymal cells, which can potentially produce cementum or ligament-like tissue regeneration in vivo. Human ligament from the root surface contains these stem cells, which can be transplanted and increased in vitro, as potential therapeutic approach to recreate tissues devastated by periodontal disease. Periodontal disease is common and has a major effect on worldwide public health. The ability of PDL tissue to regenerate periodontal tissues. [8]. khoshhal et al. Found that mesenchymal stem cells of the periodontal ligament can be successfully isolated from primary teeth. [22]

Ground Substances

All components of the PDL ground substance may be secreted by fibroblasts. Its composition varies according to the developmental state of the tissue and location [8]. The ligament is predominantly tissue rich in ground substances, even though it appears to be rich in collagen. The ground substances have similarity to most other connective tissues. It consists mainly of non-collagenous extracellular matrix proteins; alkaline phosphatase, hyaluronate glycosaminoglycan. Glycosaminoglycans exist as anionic polysaccharides, which form proteoglycans when covalently attached to a protein core. proteoglycans are able to interact with fibrillar components, for example collagen, which shows that they may retain the organisation of connective tissue. Fibronectin and tenascin are important identified glycoproteins. Fibronectin is uniformly disturbed throughout the ligament is erupting and erupted teeth, whereas tenascin is not normally localised but is concentrated adjacent to the alveolar bone and cementum. The ligament ground substance is approximately 70% water and has significant ability of the tooth to withstand stress loads. When injury and inflammation arise, the tissue fluids within the ground substances matrix increase. [8]

Function:

Eruptive

Ligament fibroblast play a key role in tooth eruption. It has been suggested that they actively move during tooth eruption, to pull the tooth out of its socket simultaneously. The changes in shape and the way that PDL fibroblasts are oriented are stimulated by a shift from unimpeded eruption [23]. The importance of the eruptive function can be emphasised by pathologies of the PDL. Traumatic injuries to the teeth, most commonly by subluxation, also result in local injury or a defective PDL, followed by ossification during the healing process, which may lead to ankyloses. [24]

Homeostasis

Homeostasis between ligament fibroblasts and bone cells that line the inferior of the alveolus is one way that the periodontal width is maintained. Therefore, as PDL cells can inhibit osteogenesis, they can prevent ankylosis. However, ankylosis may result if this homeostasis is interfered with. [25].The width of healthy PDL varies from 0.15 – 0.38 nm and shows a progressive decrease in thickness with age. Inflammation can be associated with widening the ligament width by disturbing its homeostasis, for example in periodontitis (8). Mesenchymal stem cells derived from an inflamed ligament have markedly dysfunctional immunomodulatory properties, which may contribute to an imbalanced immune response, acceleration osteoclastogenesis and inflammatory alveolar bone loss in periodontitis [26].

Sensory

Mechanoreceptors exist within the ligament, which respond to force application. Periodontal mechanoreception is very sensitive and important in reflex mechanism. It is also been suggested that the periodontal sensory that the periodontal sensory innervation may interact with immunocompetent cells to assist their migration to inflamed areas of the ligament, for example to take part in the remodelling process during orthodontic tooth movement (27).

The PDL functions to provide unconscious sensory feedback during mastication. Humans can detect small particles between the occlusal surfaces of the teeth. Teeth can also be very good at judging material proprioceptive sensors in the ligaments give sensory information as to how fast and hard to bite. (8)

Bone remodelling:

All structures of the periodontium, including the principal fibres, are constantly undergoing remodelling. When bone remodelling occurs in the alveolar bone, this severs the fibres as the old bone is replaced by new bone. The osteoblasts maintain the bone of the socket by producing new bone physiological tooth movement, occlusal forces, repair of injuries and regeneration following periodontal therapy. Pressure stimulates bone resorption, whereas tension on the ligament fibres tends to stimulate bone and cementum formation [8]. Severe pressure products rapid bone resorption. It may also result in resorption of the more resistant cementum and destroy areas of the ligament. [28]

Nutrition:

The nutritive function is served by the presence of blood vessels in the ligament. They provide nutrition to the cells of periodontium through the blood vessels of the principal fibre groups, because they contain various anabolites and other substances, which are required by the ligament cells. Compression of the blood vessels, due to heavy forces applied on the tooth, leads to cell necrosis. Blood vessel also remove catabolites. The PDL protects the blood vessels and nerves from injury by mechanical forces. It also attaches the tooth to the bone in the socket, and the absorption of occlusal forces protects the vessels, nerves and bone from injury. [29]

Tooth support mechanism

A primary role of the ligament is to act as a medium of force transfer during mastication. [30] The ligament may contribute to 'shock absorber' behaviour of the PDL, to cushion the alveolus from occlusal load. The ligament exhibits viscoelastic behaviour, where the fluid component of this tissue modifies the action of the fibres in withstanding transmitted loads. As increasing levels of force are applied to the tooth, the initial resistance is low. The resistance increases until at high levels of force, the additional displacement is very small. [8]

Evidence from connective tissue elsewhere in the body, particularly from tendons, suggests that the ligament collagen crimps play a role in the preliminary stages of masticatory loading, which permits some movement prior to the tissue experiencing tension. Experiments involving relatively long-term changes in the mechanical demands placed on the PDL, for example pinning a tooth to completely prevent tooth movements, produced no major changes in the structure of the periodontal ligament. They also provide evidence that the ligament is not affected by the mechanical demands placed upon it, compared to tissues elsewhere in the body. [31]

Conclusion

There is abundant research on the areas associated with the development, structure and function of the PDL. Further experimental evidence relating to ligament stem cells should be gathered because of the vast potential they have to offer as stem cell-based therapies in various aspects of dental and medical care [8].

References

1. Beertsen W, McCulloch CA, Sodek J. The periodontal ligament: a unique, multifunctional connective tissue. Periodontol 2000. 1997 Feb;13:20-40. doi: 10.1111/j.1600-0757.1997. tb 00094.x. PMID: 9567922.
2. Trulsson M. Sensory-motor function of human periodontal mechanoreceptors. J Oral Rehabil. 2006 Apr;33(4):262-73. doi: 10.1111/j.1365-2842.2006. 01629.x. PMID: 16629881.
3. Page RC, Kornman KS. The pathogenesis of human periodontitis: an introduction. Periodontol 2000. 1997 Jun;14:9-11. doi: 10.1111/j.1600-0757.1997. tb00189.x. PMID: 9567963.
4. de Jong T, Bakker AD, Everts V, Smit TH. The intricate anatomy of the periodontal ligament and its development: Lessons for periodontal regeneration. J Periodontal Res. 2017 Dec;52(6):965-974. doi: 10.1111/jre.12477. Epub 2017 Jun 21. PMID: 28635007.
5. Cranial osteopathy (second edition) – chapter: the orofacial structures, pterygopalatine ganglion and pharynx.
6. Review of common conditions associated with PDL widening.
7. Determination of stress distribution on PDL and alveolar bone by various tooth movement.
8. The periodontal ligament: development, anatomy and function – Rabia Dean.
9. Essentials of periodontics & oral implantology. – Dr. Syed Wali Peeran &Dr. Karthikeyan Ramalingam
10. Giannopoulou C, Cimasoni G. Functional characteristics of gingival and periodontal ligament fibroblasts. J Dent Res. 1996 Mar;75(3):895-902. doi: 10.1177/00220345960750030601. PMID: 8675800.

11. McCulloch CA, Lekic P, McKee MD. Role of physical forces in regulating the form and function of the periodontal ligament. Periodontol 2000. 2000 Oct;24:56-72. doi: 10.1034/j.1600-0757. 2000. 2240104.x. PMID: 11276873.
12. Beertsen W, Everts V. Junctions between fibroblasts in mouse periodontal ligament. J Periodontal Res. 1980 Nov;15(6):655-68. doi: 10.1111/j.1600-0765.1980.tb00326.x. PMID: 6461749.
13. Bellows CG, Melcher AH, Aubin JE. Contraction and organization of collagen gels by cells cultured from periodontal ligament, gingiva and bone suggest functional differences between cell types. J Cell Sci. 1981 Aug;50:299-314. doi: 10.1242/jcs.50.1.299. PMID: 6798046
14. . Rincon JC, Xiao Y, Young WG, Bartold PM. Production of osteopontin by cultured porcine epithelial cell rests of Malassez. J Periodontal Res. 2005 Oct;40(5):417-26. doi: 10.1111/j.1600-0765.2005.00823.x. PMID: 16105095.
15. SIMPSON HE. THE DEGENERATION OF THE RESTS OF MALASSEZ WITH AGE AS OBSERVED BY THE APOXESTIC TECHNIQUE. J Periodontol (1930). 1965 Jul-Aug;36:288-91. doi: 10.1902/jop.1965.36.4.288. PMID: 14326694.
16. Caetano-Lopes J, Canhão H, Fonseca JE. Osteoblasts and bone formation. Acta Reumatol Port. 2007 Apr-Jun;32(2):103-10. PMID: 17572649.
17. Wiebe SH, Hafezi M, Sandhu HS, Sims SM, Dixon SJ. Osteoclast activation in inflammatory periodontal diseases. Oral Dis. 1996 Jun;2(2):167-80. doi: 10.1111/j.1601-0825.1996.tb00218.x. PMID: 8957930.
18. D'Errico JA, Ouyang H, Berry JE, MacNeil RL, Strayhorn C, Imperiale MJ, Harris NL, Goldberg H, Somerman MJ. Immortalized cementoblasts and periodontal ligament cells in culture. Bone. 1999 Jul;25(1):39-47. doi: 10.1016/s8756-3282(99) 00096 -4. PMID: 10423020.
19. Cho MI, Garant PR. Radioautographic study of [3H]mannose utilization during cementoblast differentiation, formation of acellular cementum, and development of periodontal ligament principal fibers. Anat Rec. 1989 Feb;223(2):209-22. doi: 10.1002/ar.1092230214. PMID: 2712347.
20. Bosshardt DD, Schroeder HE. Initial formation of cellular intrinsic fiber cementum in developing human teeth. A light- and electron-microscopic study. Cell Tissue Res. 1992 Feb;267(2):321-35. doi: 10.1007/BF00302971. PMID: 1600564..
21. Wise GE, King GJ. Mechanisms of tooth eruption and orthodontic tooth movement. J Dent Res. 2008 May;87(5):414-34. doi: 10.1177/ 154405910808700509. PMID: 18434571; PMCID: PMC2387248.
22. Khoshhal M, Amiri I, Gholami L. Comparison of in vitro properties of periodontal ligament stem cells derived from permanent and deciduous teeth. J Dent Res Dent Clin Dent Prospects. 2017 Summer;11(3):140-148. doi: 10.15171/ joddd. 2017.026. Epub 2017 Sep 20. PMID: 29184628; PMCID: PMC5666212.
23. Weinreb M, Gal D, Weinreb MM, Pitaru S. Changes in the shape and orientation of periodontal ligament fibroblasts in the continuously erupting rat incisor following removal of the occlusal load. J Dent Res. 1997 Oct;76(10):1660-6. doi: 10.1177/ 00220345970760100701. PMID: 9326898.
24. Hellsing E, Alatli-Kut I, Hammarström L. Experimentally induced dentoalveolar ankylosis in rats. Int Endod J. 1993 Mar;26(2):93-8. doi:

10.1111/j.1365-2591.1993.tb00549.x. PMID: 8330940.

25. Wesselink PR, Beertsen W. Ankylosis of the mouse molar after systemic administration of 1-hydroxyethylidene-1,1-bisphosphonate (HEBP). J Clin Periodontol. 1994 Aug;21(7):465-71. doi: 10.1111/j.1600-051x.1994.tb00409.x. PMID: 7929858.
26. Auluck A. Widening of periodontal ligament space and mandibular resorption in patients with systemic sclerosis. Dentomaxillofac Radiol. 2007 Oct;36(7):441-2. doi: 10.1259/dmfr/82985174. PMID: 17881608.
27. Vandevska-Radunovic V, Kvinnsland S, Jonsson R. Delayed recruitment of immunocompetent cells in denervated rat periodontal ligament following experimental tooth movement. J Dent Res. 1999 Jun;78(6):1214-20. doi: 10.1177/ 00220345990780060401. PMID: 10371244.
28. Cho MI, Garant PR. Development and general structure of the periodontium. Periodontol 2000. 2000 Oct;24:9-27. doi: 10.1034/j.1600-0757.2000.2240102.x. PMID: 11276876.
29. Wills DJ, Picton DC, Davies WI. The intrusion of the tooth for different loading rates. J Biomech. 1978;11(10-12):429-34. doi: 10.1016/0021-9290(78) 90054-4. PMID: 103879.
30. Matsuo M, Takahashi K. Scanning electron microscopic observationof microvasculature in periodontium. Microsc Res Tech. 2002 Jan 1;56(1):3-14. doi: 10.1002/jemt.10008. PMID: 11810702.
31. Pilloni A, Annibali S, Dominici F, Di Paolo C, Papa M, Cassini MA, Polimeni A. Evaluation of the efficacy of an hyaluronic acid-based biogel on periodontal clinical parameters. A randomized-controlled clinical pilot study. Ann Stomatol (Roma). 2011 Mar;2(3-4):3-9. Epub 2012 Jan 27. PMID: 22545183; PMCID: PMC3314319.