COMPONENTS AND PHYSIOLOGY OF PERIODONTAL STRUCTURES

COMPONENTES E FISIOLOGIA DAS ESTRUTURAS PERIODONTAIS

COMPONENTES Y FISIOLOGÍA DE LAS ESTRUCTURAS PERIODONTALES

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ABSTRACT

Introduction: The periodontium is a dynamic tissue complex, essential for the protection and support of dental elements, whose histophysiological understanding has significantly evolved with advances in mechanobiology.

Objective: The aim of this study was to conduct a narrative literature review on the anatomy and physiology of the periodontium, integrating classical concepts with recent scientific updates.

Materials and Methods: An electronic search was performed in the PubMed/MEDLINE database including publications from 2014 to February 22, 2026. A total of 67 articles were included, organized into four thematic axes: (1) periodontal ligament and mechanobiology; (2) junctional epithelium; (3) gingival crevicular fluid; and (4) alveolar bone remodeling. Additionally, classical textbooks of Periodontology and Oral Histology were consulted to support the anatomical and histological aspects of periodontal structures, serving as complementary theoretical support to recent scientific evidence.

Results: The studies showed that the interaction among cellular components, extracellular matrix, and vascular supply provides the periodontal complex with a high adaptive and reparative capacity. Thus, the functional balance between protective and attachment tissues proved to be essential for maintaining periodontal health stability.

Conclusion: The integration of classical literature and contemporary reviews allowed the development of an updated approach, grounded in established biological principles, which is essential for dental practice, enabling more accurate diagnoses and more predictable regenerative therapies.

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Keywords: Periodontium. Mechanobiology. Oral Histology. Periodontal Homeostasis. Tissue-microbiota Interaction.

RESUMO

Introdução: O periodonto é um complexo tecidual dinâmico, essencial para a proteção e sustentação dos elementos dentários, cuja compreensão histofisiológica evoluiu significativamente com os avanços da mecanobiologia.

Objetivo: O objetivo deste estudo foi realizar uma revisão narrativa da literatura sobre a anatomia e a fisiologia do periodonto, integrando conceitos clássicos às atualizações científicas recentes.

Materiais e Métodos: Foi realizada uma busca eletrônica na base de dados PubMed/MEDLINE com publicações de 2014 até 22 de fevereiro de 2026. Foram incluídos 67 artigos, em quatro eixos temáticos: (1) ligamento periodontal e mecanobiologia; (2) epitélio juncional; (3) fluido gengival crevicular; e (4) remodelação óssea alveolar. Adicionalmente, foram consultadas obras clássicas da Periodontia e Histologia Oral para fundamentação dos aspectos anatômicos e histológicos das estruturas periodontais, sendo utilizadas como suporte teórico complementar às evidências científicas recentes.

Resultados: Os estudos mostraram que a interação entre componentes celulares, matriz extracelular e suprimento vascular conferem ao complexo periodontal elevada capacidade adaptativa e reparadora. Assim, o equilíbrio funcional entre tecidos de proteção e de inserção mostrou-se essencial para a estabilidade da saúde periodontal.

Conclusão: A integração entre literatura clássica e revisões contemporâneas permitiu a construção de uma abordagem atualizada, ancorada em fundamentos biológicos estabelecidos, indispensável para a prática odontológica, para diagnósticos mais precisos e terapias regenerativas com maior previsibilidade de sucesso.

Palavras-chave: Periodonto. Mecanobiologia. Histologia Oral. Homeostase Periodontal. Interação Tecido-microbiota.

RESUMEN

Introducción: El periodonto es un complejo tisular dinámico, esencial para la protección y el soporte de los elementos dentarios, cuyo entendimiento histofisiológico ha evolucionado significativamente con los avances de la mecanobiología.

Objetivo: El objetivo de este estudio fue realizar una revisión narrativa de la literatura sobre la anatomía y fisiología del periodonto, integrando conceptos clásicos con actualizaciones científicas recientes.

Materiales y Métodos: Se realizó una búsqueda electrónica en la base de datos PubMed/MEDLINE con publicaciones desde 2014 hasta el 22 de febrero de 2026. Se incluyeron 67 artículos, organizados en cuatro ejes temáticos: (1) ligamento periodontal y mecanobiología; (2) epitelio de unión; (3) fluido crevicular gingival; y (4) remodelación ósea alveolar. Además, se consultaron obras clásicas de Periodoncia e Histología Oral para fundamentar los aspectos anatómicos e histológicos de las estructuras periodontales, utilizándose como soporte teórico complementario a la evidencia científica reciente.

Resultados: Los estudios demostraron que la interacción entre los componentes celulares, la matriz extracelular y el suministro vascular confiere al complejo periodontal una elevada

capacidad adaptativa y reparadora. Así, el equilibrio funcional entre los tejidos de protección y de inserción resultó ser esencial para la estabilidad de la salud periodontal.

Conclusión: La integración entre la literatura clásica y las revisiones contemporáneas permitió construir un enfoque actualizado, basado en fundamentos biológicos establecidos, indispensable para la práctica odontológica, favoreciendo diagnósticos más precisos y terapias regenerativas con mayor previsibilidad de éxito.

Palabras clave: Periodonto. Mecanobiología. Histología Oral. Homeostasis Periodontal. Interacción Tejido-microbiota.

1 INTRODUCTION

The periodontium corresponds to the set of structures that surround and support the tooth, constituting the insertion complex responsible for maintaining the functional integrity of the dental element. It is made up of hard and soft tissues organized in an integrated manner, whose main function is to provide mechanical support, absorb and properly distribute the forces generated during chewing (Newman *et al.,* 2020; Berglundh *et al*., 2024).

From a structural and functional perspective, the periodontal organ is a highly specialized and biologically integrated unit, composed of four interdependent components: (1) the gum, which covers and protects the underlying structures; (2) the periodontal ligament, a specialized connective tissue that connects the cementum to the alveolar bone, and acts as a cushioning system for occlusal loads; (3) cementum, avascular mineralized connective tissue that covers the root surface, and allows the insertion of periodontal fibers; and (4) the alveolar bone, responsible for inserting and supporting the tooth in the dental arch (Newman *et al.,* 2020; Berglundh *et al*., 2024)

The periodontal ligament plays a central role in this system, not only as a mechanical support element, but as a highly mechanosensitive tissue, capable of converting physical stimuli into cellular and molecular responses, which regulate bone remodeling and the maintenance of periodontal homeostasis through mechanotransduction and intracellular signaling mechanisms (Wen *et al.*, 2025).

Although there are numerous studies addressing isolated components of the periodontium, there is a relative scarcity of publications that integrate the classical anatomical and histological foundations with contemporary scientific evidence in a didactic way. In this context, this chapter aims to consolidate and update the knowledge about gingiva, periodontal ligament, cementum, and alveolar bone, presenting the periodontium as a dynamic functional unit.

2 METHODOLOGY

This chapter was prepared by a structured narrative review of the literature, associated with the consultation of consolidated classical works in the area of Periodontics and Oral Histology, used to support the anatomical and histological aspects of periodontal structures.

For scientific updating, an electronic search was performed in the PubMed/MEDLINE database until February 22, 2026, with delimitation of publications from 2014 and application of the "Review" and "Systematic Review" filters. The strategy was organized into four thematic axes: (1) periodontal ligament and mechanobiology; (2) junctional epithelium; (3) crevicular gingival fluid; and (4) alveolar bone remodeling.

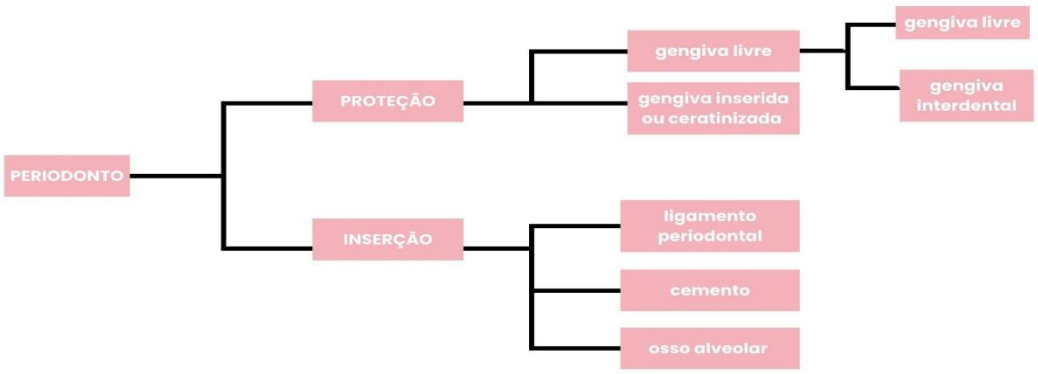
A total of 67 studies were identified, consolidated and screened by reading titles and abstracts. Reviews with a predominantly clinical-therapeutic focus, specific orthodontic applications, regenerative biomaterials, surgical techniques, adjuvant interventions, and exclusively methodological or systemic approaches with no direct relationship with periodontal physiology were excluded. Reviews that addressed structural, cellular, and molecular aspects related to the functional dynamics of the periodontal ligament, junctional epithelium, crevicular gingival fluid, and alveolar bone remained included.

The integration between classic literature and contemporary reviews allowed the construction of an updated approach, anchored in established biological foundations.

3 LITERATURE REVIEW

3.1 GENGIVA - MACROSCOPIC ASPECT

Figure 1



The gingiva constitutes the portion of the oral mucosa that covers the alveolar processes and surrounds the neck of the teeth, playing an essential role in protecting the underlying periodontal tissues against masticatory trauma and local irritants, such as bacterial biofilm (Newman *et al.*, 2020; Berglundh *et al.*, 2024). From a clinical point of view, gingival health is characterized by the absence of inflammatory signs, such as bleeding on probing, erythema, and edema, and can be present in both an intact and reduced periodontium, as long as tissue stability is maintained (Chapple *et al.,* 2018).

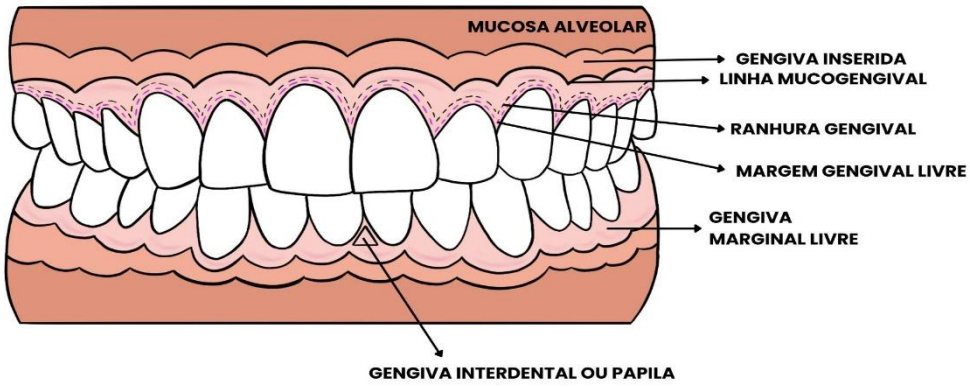
From an anatomical point of view, it is divided into **marginal (or free) gingiva and inserted gingiva (Figures 2, 3 and 4).** Although these regions present differences in thickness, degree of keratinization, and histological characteristics, they are all structurally

organized to act as an efficient barrier against mechanical aggression and the penetration of microorganisms into the deeper periodontal tissues (Newman *et al.*, 2020).

The **marginal gum**, also called free gum, corresponds to the coronary portion of the gum that surrounds the tooth in the form of a necklace. In approximately 50% of cases, the gingiva inserted can be delimited by a discrete linear depression called the free gingival groove. This gingival strip measures, on average, about 1 mm in width and constitutes the outer wall of the gingival sulcus. It can be removed from the tooth surface by carefully inserting a periodontal probe. The most apical point of the concave curvature of the marginal gingiva is called the gingival zenith, as described in the classic literature on Periodontics (Newman *et al.*, 2020).

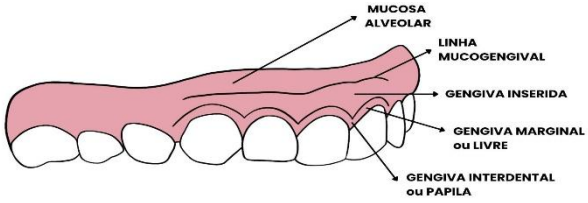
Figure 2

Illustration of the alveolar mucosa; inserted gingiva; mucogingival line; gingival groove; free gingival margin; free marginal gingiva; interdental gingiva or papilla



Source: Illustrated by the authors. Adapted from Lindhe's Treatise on Clinical Periodontics and Oral Implantology. 6. ed. 2018, page 35, figure 1.10.

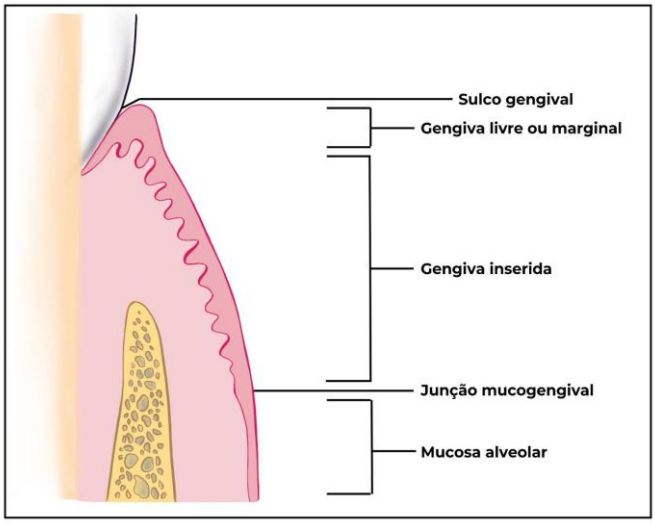
Figure 3
Anatomical components of the gum



Source: Illustrated by the authors. Adapted from Lindhe's Treatise on Clinical Periodontics and Oral Implantology. 7. ed. Rio de Janeiro: Guanabara Koogan, 2024, page 5, figure 1.5.

The **inserted gingiva** corresponds to the portion of the gingiva firmly adhered to the periosteum of the underlying alveolar bone, presenting a firm and resilient consistency. It extends from the marginal gingiva to the mucogingival junction, which is an important clinical reference. Unlike the alveolar mucosa, the inserted gingiva is keratinized and exerts a protective function against masticatory forces (Newman *et al.*, 2020; Nanci, 2019).

Figure 4
Anatomical components of the gum



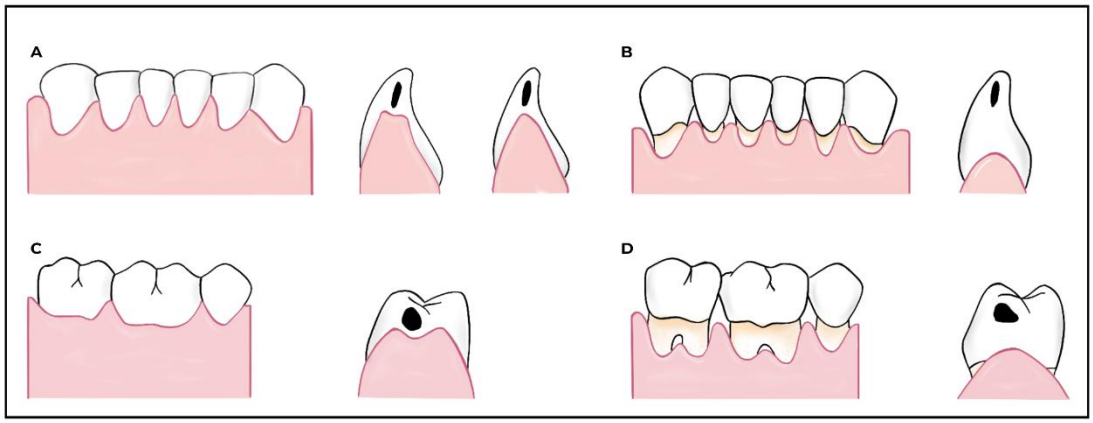
Source: Illustrated by the authors. Adapted from NEWMAN, Michel G. Newman and Carranza - Clinical Periodontics 13th ed. 2020, page 21, figure 3.2.

The **interdental papilla** occupies the interproximal space located below the area of contact between adjacent teeth, called the gingival niche. It can have a pyramidal or "col" shape, the latter characterized by a depression that connects the buccal and lingual papillae. Its morphology depends on the presence or absence of the contact point, the distance between the contact point and the alveolar bone crest, and the occurrence of gingival

recession. (Newman *et al.*, 2020; Berglundh *et al*., 2024). In the anterior region, the shape is pyramidal, in which the tip of the papilla is immediately below the point of contact. In the posterior region, the "col" shape is a valley-shaped depression that connects the lingual papilla with the buccal papilla and adapts to the shape of the interproximal contact of the posterior teeth (Figure 5).

Figure 5

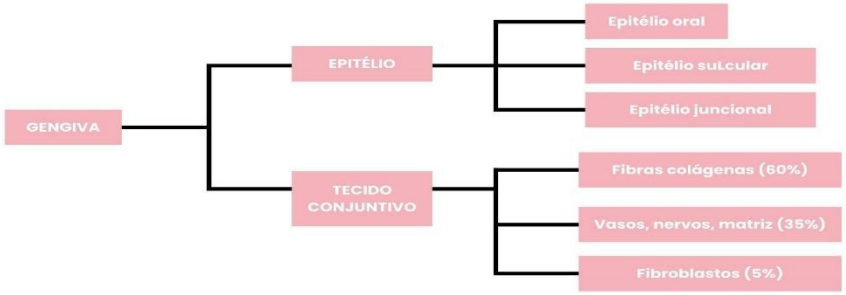
Diagram of comparisons of anatomical variations of interdental col in normal gingiva and gingival retraction



Source: Illustrated by the authors. Adapted from NEWMAN, Michael G. Newman and Carranza - Clinical Periodontics. 13th. ed. Rio de Janeiro: GEN Guanabara Koogan, 2020, page 22, figure 3.6.

3.2 GENGIVA - MICROSCOPIC APPEARANCE

Figure 6



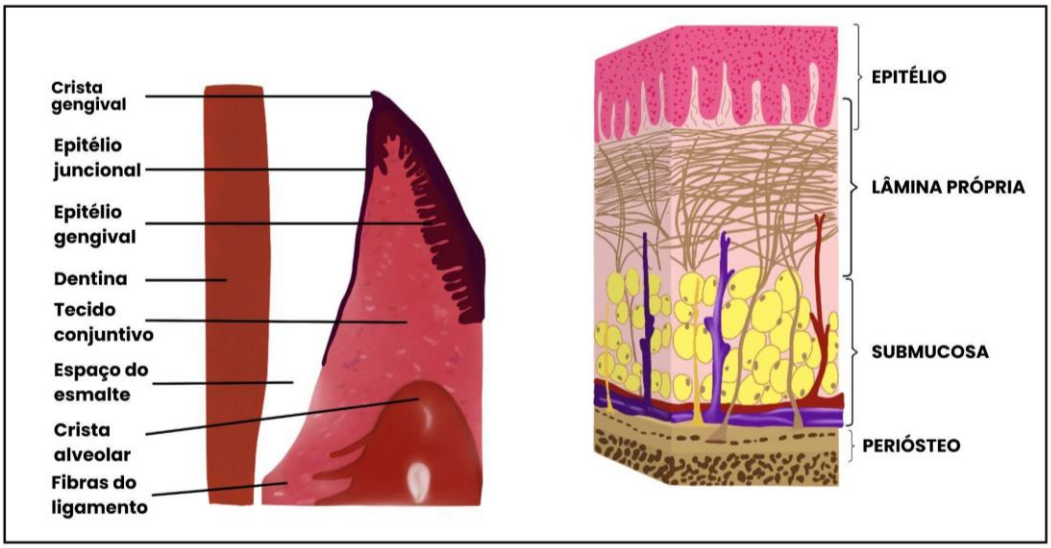
Microscopically, the gingiva is composed of stratified squamous epithelium that covers a core of underlying connective tissue. The epithelium is cellularly predominant, with little extracellular matrix and absence of blood vessels, while the connective tissue is vascularized,

consisting mainly of type 1 collagen fibers, produced by fibroblasts and immersed in an extracellular matrix. The interaction between these components ensures mechanical resistance and protection of periodontal tissues (Nanci, 2019).

The oral epithelium is a stratified squamous epithelium that lines the surface of the oral mucosa and constitutes the main protective barrier between the oral environment and the underlying connective tissues (Figure 5). Histologically, it is organized into well-defined cell layers, supported by intense intercellular cohesion by means of desmosomes and intermediate cytokeratin filaments. Its integrity is maintained by a continuous process of cell renewal, in which progenitor cells located in the basal layer — including stem cells and transient amplifying cells — undergo mitotic divisions and originate keratinocytes that migrate towards the surface, undergoing terminal differentiation and subsequent desquamation (Nanci, 2019).

Figure 7

Components of the oral epithelium.



Source: Illustrated by the authors. Adapted from Ten Cate - Oral Histology. 9. ed. 2019, page 283, figure 12-33.

Depending on the region of the oral cavity, this maturation process can follow two main patterns: keratinization, typical of the masticatory mucosa, and non-keratinization, characteristic of the lining mucosa. In the keratinized epithelium, the basal, spinous, granulosa and corneal layers are distinguished, with the formation of the cornified cell envelope rich in keratins and structural proteins, conferring greater mechanical resistance and impermeability. In the non-keratinized epithelium, the basal and spinous layers are followed by the intermediate and superficial layers, without evident formation of a granulosum

stratum or anucleated layer, maintaining nucleated superficial cells and greater tissue flexibility (Nanci, 2019).

In this anatomical niche is the crevicular gingival fluid (CGF), also called gingival crevicular fluid. In health conditions, it is described as a modified transudate derived from the vascular plexus of gingival connective tissue, which migrates into the gingival sulcus and participates in local homeostasis (Newman et al., 2020; Berglundh et al., 2024). It plays a relevant role in immune defense, including the physiological migration of neutrophils to the gingival cleft (Newman et al., 2020; Berglundh *et al.,* 2024).

From a functional point of view, FGC promotes mechanical sulcus cleaning, leukocyte transport, immunoglobulins (IgG, IgA), complement system components, and enzymes such as matrix metalloproteinases, reflecting both the immune response and tissue destructive activity. Thus, in addition to actively participating in local defense, the FGC stands out as a non-invasive diagnostic tool capable of identifying inflammatory biomarkers and bone resorption even before the evident clinical manifestation, reinforcing its relevance in contemporary periodontal practice (Barros *et al.*, 2016). Recent revisions reinforce the potential of FGC as a minimally invasive diagnostic tool for monitoring periodontal activity (Fatima *et al.,* 2021; Ghallab, 2018).

The **gingival sulcus** is defined as a shallow cleft around the tooth, bounded internally by the tooth surface and externally by the sulcular epithelium, which lines the inner surface of the free marginal gingiva. It has a "V" shape, allowing the insertion of the periodontal probe for diagnostic purposes (Newman *et al.,* 2020). The evaluation of the depth of the sulcus is a fundamental clinical parameter in periodontal analysis.

The clinical measurement of this depth is carried out by means of periodontal probing, a procedure in which the distance reached by the probe, when inserted inside the sulcus, is estimated, accounted for in millimeters, from the gingival margin, to the bottom of the gingival sulcus. However, the depth of probing can be influenced by factors such as the diameter of the instrument, the force applied, and the degree of tissue inflammation.

The junctional epithelium (EJ) is described as a highly dynamic, non-keratinized epithelial barrier characterized by intense proliferative activity, functional permeability, and firm adhesion to the tooth surface. Their cells undergo continuous desquamation, contributing to the mechanical removal of microorganisms and to the control of bacterial invasion at the dentogingival interface (Nanci, 2019; Schroeder & Listgarten, 2003; Yuan *et al.,* 2021).

Structurally, the EJ is continuous with the adjacent keratinized oral epithelium (EO), and presents a specialized interface, composed of hemidesmosomes and a basal lamina, which ensure its attachment to the tooth. Underlying this interface is a zone of connective

tissue rich in collagen fibers, with organized marginal bone and a delicate vascular network, composing the periodontal support apparatus (Nanci, 2019; Schroeder & Listgarten, 2003). Morphologically, it is organized as an epithelial collar around the cervical portion of the tooth, delimiting the bottom of the gingival sulcus; it is thicker in the coronary region and progressively thins in an apical direction along the tooth surface. Its constant renewal results from the active proliferation of basal keratinocytes, which favors rapid repair and maintenance of the integrity of the tooth-gum interface.

From a structural point of view, EJ is distinguished by having intercellular junctions including desmosomes, adherent junctions and gap junctions, as well as wide intercellular spaces. This organization allows the controlled passage of gingival crevicular fluid and the migration of inflammatory cells towards the sulcus, composing a dynamic defense mechanism (Theodoro *et al.,* 2023). The integrity of these junctions depends on the organization of specific proteins, such as claudins and other adhesion proteins, which regulate epithelial permeability and contribute to the maintenance of biological sealing. At the same time, adhesion to the mineralized surface of the tooth is mediated by hemidesmosomes and an internal basal lamina, ensuring firm anchorage and effective biological sealing (Nanci, 2019; Schroeder & Listgarten, 2003; Theodoro *et al.,* 2023). This seal is not static, but results from a dynamic balance between cell adhesion, epithelial renewal, and local immune control (Nanci, 2019).

Functionally, EJ occupies a strategic position between hard tissue and soft tissue, acting as the first line of defense against bacterial invasion and contributing to periodontal homeostasis. the junctional epithelium should be understood as a dynamic, immunologically active structure that is essential for maintaining periodontal health (Newman *et al.,* 2020; Theodoro *et al.,* 2023). In addition to acting as a physical barrier, the junctional epithelium actively participates in the innate immune response, through the expression of inflammatory mediators and signaling molecules that modulate the recruitment of neutrophils to the gingival sulcus (Yuan *et al.,* 2021).

The underlying connective tissue, in turn, has its own characteristics, including the physiological presence of a discrete inflammatory infiltrate, in addition to abundant collagen fibers, fibroblasts, blood vessels, nerves, and extracellular matrix, composing the connective insertion that structurally supports the dentogingival complex. The fibers of the gingival connective tissue are fundamental components of the gums and play an essential role in its resistance, support, and functional adaptation. This tissue is rich in fibers produced mainly by fibroblasts, with collagen fibers being the most abundant and important. They are predominantly formed by type I collagen, with a lower amount of type III collagen, and provide

great tensile strength, allowing the gum to withstand the mechanical forces of chewing and remain firmly adhered to the dental and bone structures. In addition, these collagen fibers are organized into bundles that directly contribute to the stability of the gums around the teeth.

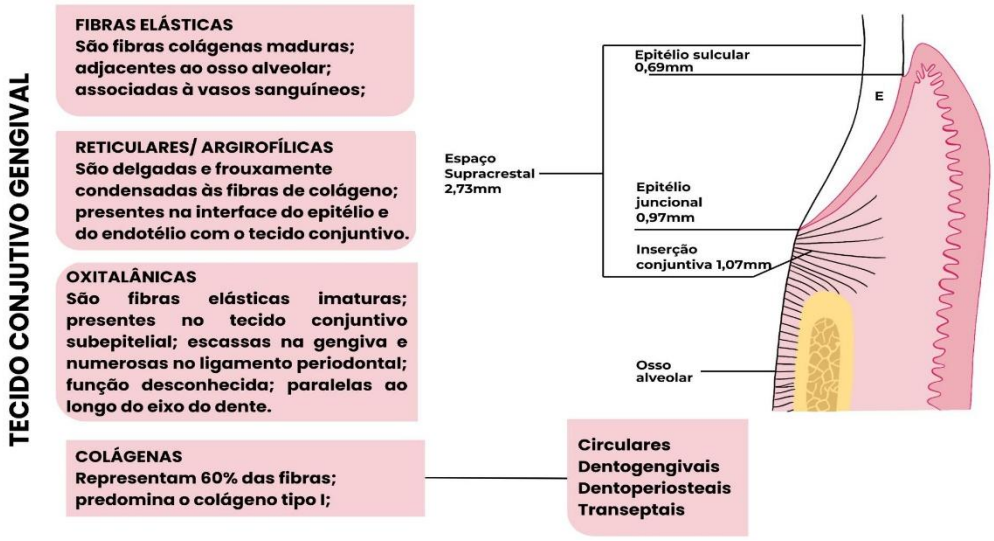
Although in smaller quantities, elastic fibers are also present, which include elastic fibers themselves, in addition to elauninic and oxythalanic fibers. These fibers are responsible for giving a certain elasticity to the gum tissue, allowing it to have a slight ability to adapt without losing its structural integrity. Even though they are discreet in the gums, they play an important complementary role.

Another type of fiber found is the reticular fibers, which are mainly made up of type III collagen. These fibers are thinner and form a delicate network that supports the cells and blood vessels present in the connective tissue. They contribute to the internal organization of the tissue, offering more subtle structural support compared to collagen fibers.

Thus, the gingival connective tissue has a predominance of collagen fibers, responsible for resistance and firmness, associated with elastic and reticular fibers that help with elasticity and internal support, ensuring the integrity and proper functioning of the gums.

Figure 8

Representation of elastic fibers; reticular fibers; oxytalany fibers; and collagen fibers - constitution of gingival connective tissue



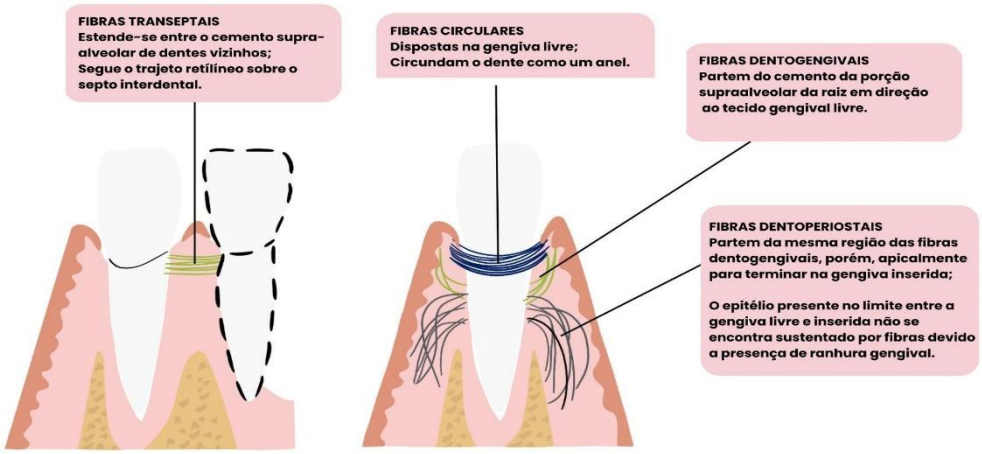
Source: Illustrated by the authors. Adapted from LINDHE *et al.* 2024, - Treaty on Clinical Periodontics and Oral Implantology - 7th ed. , page 7, figure 2.4.

The fibers present are mainly collagen fibers of the gingival connective tissue, organized in groups that help maintain the integrity and position of the gums around the teeth. The main types of fibers of the protective periodontium are: (1) Dentogengival fibers, which extend from the cementum of the tooth to the gums with the function of keeping the gums

adhered to the tooth; (2) Circular fibers surround the tooth like a "ring" with the function of keeping the gums firm around the tooth; (3) Dentoperiosteal fibers leave the cementum crossing the bone to the periosteum with the function of structural reinforcement of the gum; (4) Transeptal fibers extend from one tooth to the other (cementum to cementum) with the function of maintaining tooth alignment.

Figure 9

Representation of transeptal fibers; circular fibers; dentogengival fibers; and dentoperiostal fibers

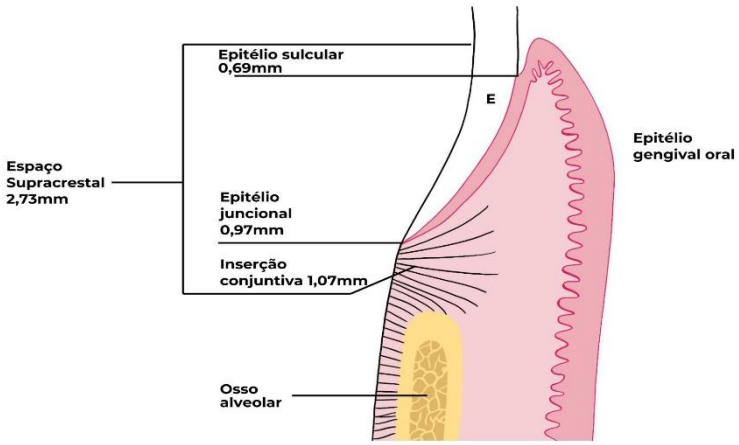


Source: Illustrated by the authors. Adapted from LINDHE *et al.* 2024, - Treaty on Clinical Periodontics and Oral Implantology - 7th ed. , page 16, figure 1.6.

The supracrestal insertion space - formerly called biological space - corresponds to the dimension composed of the junctional epithelium and the supracretal conjunctive insertion, totaling approximately 2 mm, as described in classical histometric studies (Gargiulo *et al.,* 1961) and conceptually redefined in the 2018 World Workshop (Caton *et al.*, 2018). Its integrity is essential for all gingival tissues to remain attached to the tooth, preventing periodontal changes, so it acts as a defense area of the body and must be respected in dental rehabilitation procedures (Caton *et al.*, 2018; Lyra *et al.,* 2022; Bertolini *et al.,* 2024).

Figure 10

Dentogingival unit



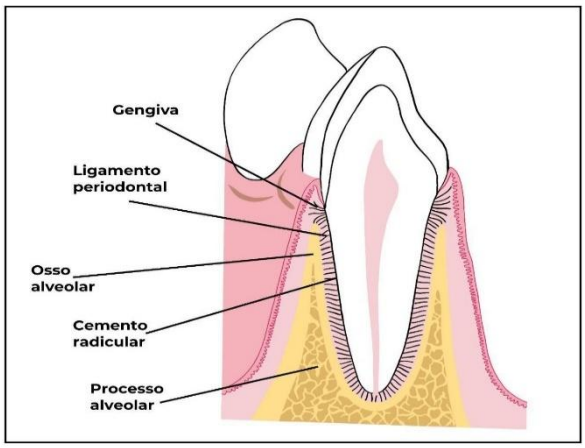
Source: Illustrated by the authors. Adapted from LINDHE *et al.* 2024, - Treaty on Clinical Periodontics and Oral Implantology - 7th ed. , page 9, figure 1.15.

3.3 PERIODONTAL LIGAMENT

The periodontal ligament is a loose, highly vascularized connective tissue with a large number of cells, which surrounds the tooth roots and promotes the union between the root cementum and the lamina dura, that is, the alveolar bone itself. In addition to its structural function, the periodontal ligament is considered a biologically active tissue, capable of responding adaptively to mechanical and inflammatory stimuli (Berglundh *et al.,* 2024; Zhao *et al.,* 2025). Towards the coronal portion, it maintains continuity with the lamina propria of the gingiva, being delimited by bundles of collagen fibers that extend from the crest of the alveolar bone to the root of the tooth, known as alveolar crest fibers (Berglundh *et al*., 2024).

Figure 11

Anatomy of the components of the periodontium



Source: Illustrated by the authors. Adapted from LINDHE *et al.* 2024, - Treaty on Clinical Periodontics and Oral Implantology - 7th ed., chapter 3, page 2, figure 1.1.

The periodontal ligament is assigned several functions, which can be grouped into four main categories:

1. It performs the physical function by anchoring the tooth, promoting a firm union between the cementum and the alveolar bone;
2. Ensures mechanical stability and acts as a shock absorber capable of protecting both the tooth and the alveolar bone against the impacts of intense forces generated during chewing;
3. It also performs a formative and modeling function, functioning as an essential cellular reservoir for the maintenance of tissue homeostasis, as well as for the repair and regeneration of cellular components and collagen fibers;
4. It has a nutritional function, as it ensures the blood and nutrient supply to cementum, alveolar bone and the periodontal ligament itself, while contributing to the removal of metabolites;
5. It has a sensory function, since its rich innervation allows, through specific receptors, the perception of forces of different intensities applied to the teeth (Newman *et al.,* 2020; Berglundh *et al*., 2024; Nanci, 2019).

Thus, the periodontal ligament should be understood as a dynamic tissue, which integrates mechanical, biological, and sensory functions in a coordinated manner (Newman *et al.,* 2020).

Its average thickness is about 0.2 mm, and may vary according to the species, the age of the individual, the distance from the JCE and the functional demands. The existence of the periodontal ligament allows the forces generated during mastication and other occlusal contacts to be distributed and absorbed by the alveolar process, through the alveolar bone itself. In addition, it plays a fundamental role in tooth mobility, which largely depends on the width and height of this ligament (Berglundh *et al*., 2024).

The periodontal ligament is made up of several cell types and a specialized extracellular matrix. Among the cells present, fibroblasts stand out, which are the most numerous and are arranged parallel to the main collagen fibers, being responsible for both the synthesis and degradation of collagen, which ensures constant tissue renewal. Also present are cementoblasts, located on the surface of the root cementum adjacent to the periodontal ligament space, where they act in the formation of cementum, and osteoblasts, located on the surface of the alveolar bone facing the periodontal space, playing a fundamental role in bone formation. In addition, there are osteoclasts, responsible for bone resorption, and odontoclasts, related to the resorption of dental tissues (Berglundh *et al*., 2024).

The periodontal ligament also contains histiocytes and different defense cells, such as neutrophils, macrophages, eosinophils, and mast cells, which participate in inflammatory and immune responses. Cells associated with neurovascular elements are also present, as well as nerve fibers and blood vessels, which contribute to the sensory and nutritional functions of the tissue (Newman *et al.,* 2020).

This tissue is in a permanent process of renewal, in which aged cells and fibers are continuously degraded and replaced by new structures. Mitotic activity is often observed, especially in fibroblasts and endothelial cells. Fibroblasts are responsible for the production of collagen fibers, while remaining mesenchymal cells can differentiate into osteoblasts and cementoblasts. The speed at which the formation and differentiation of osteoblasts, cementoblasts, and fibroblasts occurs directly influences collagen production, as well as cementum and bone formation (Newman *et al.,* 2020). Recent studies demonstrate that this continuous renewal process involves regulated mechanisms of cell proliferation and programmed cell death, essential for the maintenance of periodontal tissue homeostasis (He *et al.,* 2023).

In addition to the cellular elements, the periodontal ligament has an extracellular matrix that fills the spaces between fibers and cells. It is presumed to consist largely of solvation water and the rest corresponds to the fundamental components (fibronectin, proteoglycans, structural glycoproteins, electrolytes, hormones, laminin and mineral salts). Its function would be mainly nutritious. This tissue also has a neural network and an extensive blood supply (de Jong *et al.*, 2017; Newman *et al*., 2020). The organized arrangement of these groups of fibers allows the periodontal ligament to distribute occlusal forces efficiently to the alveolar bone (Nanci, 2019).

In the periodontal ligament, the predominant types of collagen are types I, III, and XII. Most collagen fibrils are organized into well-defined bundles, which resemble braided cords. Although the individual fibrils undergo constant remodeling, the bundle as a whole maintains its structure and function, which allows the ligament to continuously adapt to the forces and mechanical stresses to which it is subjected (Nanci, 2019).

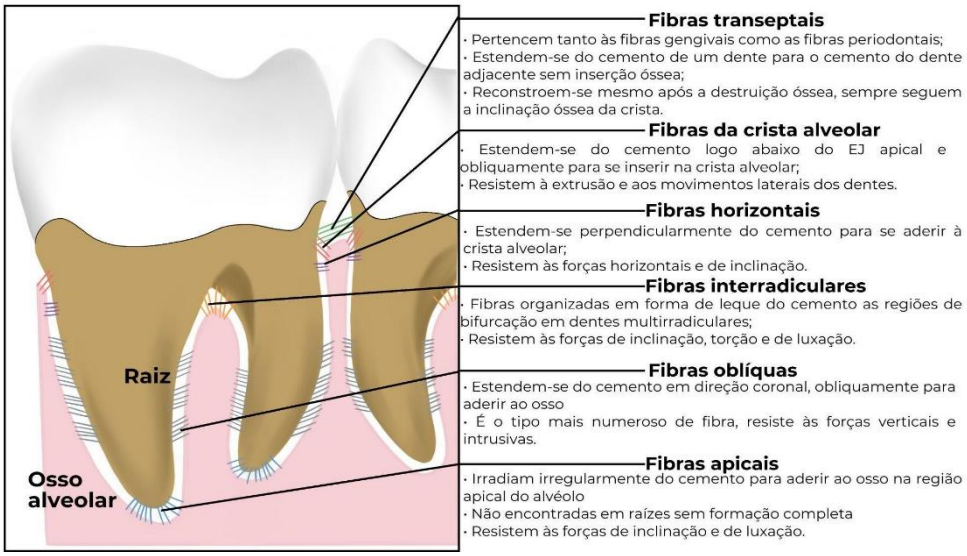
The bundles that extend between the root cementum and the alveolar bone constitute the main groups of fibers of the periodontal ligament. Among them, the alveolar crest group stands out, which attaches to the cementum just below the cementocementary junction and runs in an inferior and lateral direction to insert itself into the crest of the alveolar bone. Just below this group is the horizontal group, whose fibers are arranged perpendicular to the long axis of the tooth, extending from the cementum to the alveolar bone (Nanci, 2019).

The oblique group is the most abundant of the periodontal ligament and has fibers that start from the cementum in an oblique direction, inserting into the alveolar bone in a more coronary position. The apical group, on the other hand, is distributed around the root apex, radiating from the cementum to the alveolar bone and attaching to the base of the alveolus. Finally, the interradicular group is present only in teeth with multiple roots, extending from the cementum to the alveolar bone in the region of the crest of the interradicular septum (Nanci, 2019).

Elastic fibers such as oxythalanes are present in the periodontal ligament, while elaunin fibers, also elastic, can be found in the gingival ligament (Nanci, 2019). Oxithalanic fibers are made up of bundles of microfibrils widely distributed in the periodontal ligament. They have a predominantly vertical orientation, extending from the surface of the cementum in the apical direction and forming a three-dimensional branched network that surrounds the tooth root and ends in the region of the apical complex, where arteries, veins and lymphatic vessels are located. In addition, these fibers maintain association with nerve bundles and small blood vessels. In the cervical region of the periodontal ligament, oxythalanic fibers are particularly numerous and dense, and are arranged parallel to the group of gingival collagen fibers (Nanci, 2019). Although their function is not yet fully understood, they are thought to play a role in regulating blood flow in response to masticatory function. Because they are part of the elastic system, they have the ability to stretch in the face of tension changes, allowing these variations to be transmitted and perceived by the walls of vascular structures. These characteristics reinforce the role of the periodontal ligament as a tissue capable of continuously adapting to the functional variations of mastication (Nanci, 2019).

Figure 12

Schematic representation of the main groups of periodontal ligament fibers - transeptal fibers, alveolar crest fibers, horizontal fibers, interradicular fibers, oblique fibers, and apical fibers



Source: Illustrated by the authors. Adapted from NEWMAN, Michael G.; ELANGOVAN, Satheesh; Irina F. Dragan; et al. Newman and Carranza - Essential Clinical Periodontics. Rio de Janeiro: GEN Guanabara Koogan, 2022, page 16, figure 2.3.

At the molecular and cellular levels, the loads on the periodontal ligament trigger mechanobiological events in the alveolar bone, which leads to bone remodeling, since the stretching of the periodontal ligament fibers causes increased blood flow, cell division, and fiber production, especially in orthodontic movements (Dutra *et al.,* 2016; Zhao *et al.,* 2025). This ability to adapt to forces is essential to allow controlled tooth movement and the maintenance of alveolar bone integrity (Dutra *et al.,* 2016).

Periodontal tissues derive from the neural crest, and it is precisely from remnants of these cells that CTLPs (Periodontal Ligament Stem Cells) with regenerative potential arise. In the microenvironment of the oral cavity, these cells are subjected to continuous and dynamic exposure to two predominant stimuli: mechanical forces and inflammatory signals (Nanci, 2019; Zhao *et al.,* 2025). In a physiological context, CTLPs respond to cyclic loads arising from normal chewing, while in orthodontic treatments, controlled forces are applied to stimulate these cells and promote programmed tooth movement.

However, in pathological scenarios, excessive mechanical stress—from occlusal trauma or inadequate orthodontic forces—can cause severe ligament damage, resulting in adverse outcomes such as root resorption or alveolar bone loss. In addition, the presence of inflammation of bacterial origin can trigger destructive processes in DPL, culminating in the degradation of soft tissues and adjacent bone structures (Zhao *et al.,* 2025). In this scenario, CTLPs emerge as central regulators, playing a decisive role both in the progression of

periodontal pathogenesis and in mediating therapeutic resolution and tissue remodeling. The characterization of these cells is based on specific criteria of multipotentiality and cellular markers defined in the specialized literature (Bartold; Gronthos, 2017). In addition, cell populations associated with blood vessels, such as pericytes, may also contribute to the regenerative potential of the periodontal ligament (Komaki, 2019). It is also observed that aging can reduce the proliferative and regenerative capacity of these cells, influencing tissue response throughout life (Tang & Yang, 2024).

Gingival innervation occurs through terminal branches of periodontal ligament fibers, in addition to contributions from the infraorbital, palatine or lingual, mentoni, and buccal nerves. In the inserted gingiva, most of the nerve endings are located in the lamina propria, and its presence among the epithelial cells is less frequent. There are specialized endings, such as nociceptors and mechanoreceptors, that allow the perception of pain, pressure, and touch. The presence of receptors in the periodontal ligament makes it possible to identify small forces applied to the teeth, which, in association with the proprioceptors of muscles and tendons, is essential for controlling movements and intensity of forces during chewing. In the mandible, the teeth and their periodontal ligaments are innervated by the inferior alveolar nerve, while in the maxilla, this innervation is performed by the superior alveolar plexus (Berglundh *et al.*, 2024).

3.4 ROOT HARVESTING

Cementum is characterized as an avascular mineralized connective tissue that plays the fundamental role of covering the root surfaces of dental elements. According to the precepts of Nanci (2019), the classification of this tissue is primarily based on two pillars: the presence or absence of cellular components embedded in its matrix and the nature of the origin of the collagen fibers that constitute it. The process of cementum formation, or cementogenesis, is structured in two distinct biological moments: the pre-functional stage, which covers the entire period of root development, and the functional stage, which is established when the tooth reaches the plane of occlusion, remaining active throughout the individual's life.

This temporal and structural differentiation results in types of cement with specific properties. The acellular cementum, formed early, plays the predominant role in the firm fixation of the tooth to the alveolus. On the other hand, cellular cementum has a markedly adaptive character, being deposited in response to physiological demands such as occlusal wear and tooth movement, in addition to having a direct and essential participation in the repair processes of periodontal tissues (Nanci, 2019).

According to the specialized literature (Nanci, 2019), the biochemical composition of cementum has a remarkable similarity with that of bone tissue, consisting of an inorganic phase of approximately 45% to 50% hydroxyapatite, while the remaining volume is filled with collagen and non-collagen proteins from the matrix. Type I collagen is established as the predominant organic component, representing 90% of the matrix in the cellular cementum of intrinsic fibers and playing a crucial role in structuring mineral deposition, in a manner equivalent to what occurs in osteogenesis. This protein is also essential in the periodontal ligament, where it organizes the bundles of fibers responsible for tooth anchorage and the dissipation of masticatory loads. In addition to type I collagen, the presence of type III collagen, associated with tissue development and repair processes, although its concentration declines with tissue maturation, and type XII collagen, which interacts with fibrils and non-collagen proteins to help maintain the functional integrity of the periodontal ligament in the face of occlusal forces. As Nanci (2019) points out, other variants, such as type V, VI, and XIV collagens, are detected in vestigial proportions in the mature cementum, possibly as byproducts of fibroblast activity from the adjacent periodontal ligament.

As for the non-collagen content, cementum shares with bone a number of signaling and structural molecules, including alkaline phosphatase, bone sialoprotein, osteocalcin, osteopontin, and several growth factors, as well as proteoglycans and proteolipids. However, research cited by Nanci (2019) suggests the existence of molecules potentially exclusive to this tissue, such as a specific adhesion protein and an insulin-analogous growth factor, whose full functional characterization still depends on complementary investigations. The biological similarity between cementoblasts and osteoblasts is further reinforced by the expression of the Bril protein, a membrane component characteristic of these cell lines, consolidating the ontogenetic and functional proximity between these two mineralized tissues.

With these constant depositions throughout life, different types of cementum are formed, which are classified according to Schroeder & Page (1990) as follows:

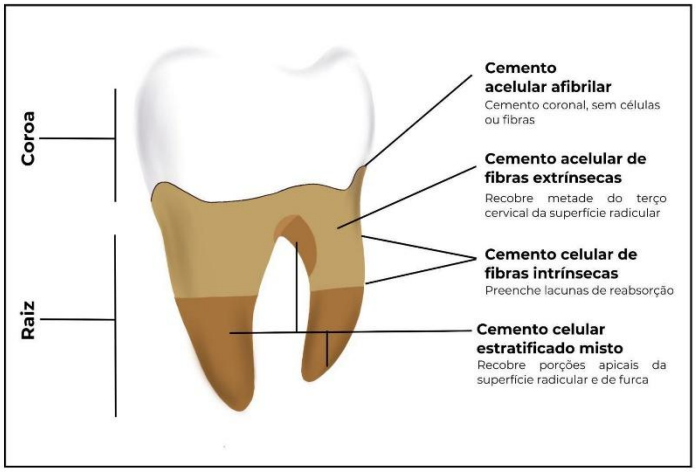
1) **Afibrillary acellular cementum** - is found in enamel, particularly along the cementary junction.
2) **Fibrillary acellular cementum** - it is composed almost entirely of bundles of Sharpey fibers (Sharpey's fibers). They are arranged perpendicular to the root surface, are thick and dispersed). It is often found at the cervical and middle root level. It is involved in the insertion of the tooth into the adjacent bone and has a potential for adaptation to functions such as mesial displacement and occlusal wear.
3) **Intrinsic fiber cellular cementum** - is initially deposited on the root surface in places where there is no acellular cementum of extrinsic fibers. It can be found in the apical

and furcation regions, and has no immediate function in the fixation of the teeth. (Intrinsic are produced by the oriented cementoblasts parallel to the long root axis, are delicate and clustered).

4) **Mixed fiber cellular cementum** - is made up of both extrinsic and intrinsic fibers within a calcified matrix that contains cementocytes.

Figure 13

Types of cement with specific properties



Source: Illustrated by the authors. Adapted from NEWMAN, Michael G.; ELANGOVAN, Satheesh; Irina F. Dragan; et al. Newman and Carranza - Essential Clinical Periodontics. Rio de Janeiro: GEN Guanabara Koogan, 2022, page 18, figure 2.4.

The biological functions of cementum are fundamental for maintaining the integrity and position of the dental element in the arch, being categorized primarily as anchoring, adaptation and repair. Anchorage is made possible mainly by the acellular cementum of extrinsic fibers, with complementary participation of the mixed stratified cellular cementum; in both varieties, the insertion of Sharpey fibers is the mechanism that ensures effective attachment of the tooth to the socket (Newman *et al*., 2022).

Regarding the adaptive function, it is mostly performed by the cellular cementum through a continuous deposition, especially in the apex and furcation regions, which allows to compensate for occlusal wear and maintain contact with the antagonist teeth. In addition, this deposition occurs more markedly on the distal surfaces to counteract the mesial physiological displacement of the teeth throughout life (Newman *et al*., 2022).

In addition, the repair capacity of the periodontium is an attribute of the cellular cementum of intrinsic fibers, which is manifested in areas of root resorption or fracture lines. This repair process occurs in an accelerated manner and, because it usually lacks extrinsic

fibers in its initial phase, it focuses primarily on restoring tissue integrity and filling the defect, rather than acting directly on the immediate mechanical anchorage of the tooth (Newman *et al.*, 2020).

Cementum deposition occurs continuously throughout life, with variations in the rate of formation according to age and functional requirements, being more intense in the apical region, where it compensates for tooth eruption resulting from occlusal wear (Newman *et al.,* 2020). In the coronary half of the root, its thickness varies between 16 and 60 µm, while in the apical third and in the bifurcation areas it can reach 150 to 200 µm. The distal surfaces tend to be thicker than the mesial, possibly due to the physiological mesialization of the teeth. With aging, the average thickness of cementum can triple between 11 and 70 years, from about 95 µm at 20 years to approximately 215 µm at 60 years (Newman *et al.,* 2020).

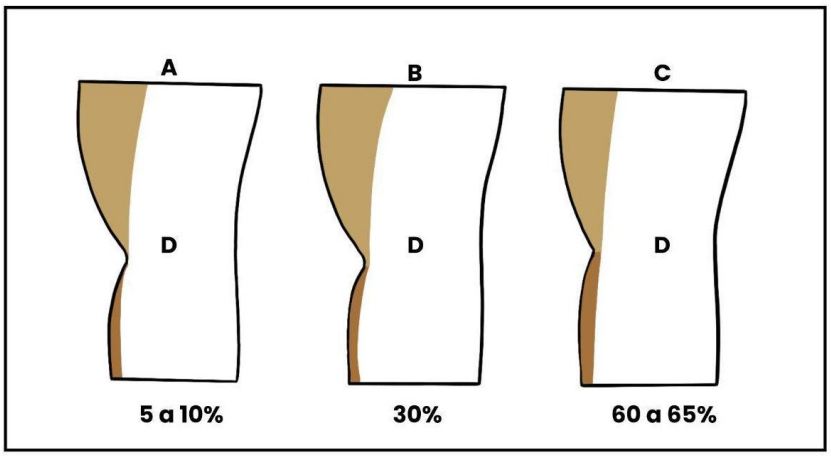
Alterations in this process can generate hypercementosis, an exaggerated thickening that, although often physiological, can hinder extraction procedures or be associated with fibro-osseous pathologies.

The cementum of erupted teeth is subject to resorption, which may occur due to systemic and local causes such as occlusion trauma, orthodontic movement, pressure from erupting malpositioned teeth, reimplanted teeth, periapical and periodontal disease, vitamin D and A deficiency, calcium deficiency, hypothyroidism, Paget's disease, or may occur without apparent etiology (Newman *et al.,* 2020). Cementum is more resistant to resorption than alveolar bone. Due to their continuous growth, resorptions can be repaired if the intensity of the pressure is reduced and if the surrounding connective tissue remains intact.

There can be three different types of situations involving the relationship between cementum and enamel: a) in about 60 to 65% of cases, cementum overlaps enamel; b) in approximately 30% the union is top to top and; c) in 5 to 10% there is no union between cementum and enamel (Newman *et al.,* 2020).

Figure 14

The tooth support structures



Source: Illustrated by the authors. Adapted from NEWMAN, Michael G.; ELANGOVAN, Satheesh; Irina F. Dragan; et al. Newman and Carranza - Essential Clinical Periodontics. Rio de Janeiro: GEN Guanabara Koogan, 2022, page 37, figure 2.14.

3.5 ALVEOLAR BONE

Together with LP and root cementum, the alveolar bone constitutes the supporting periodontium, whose main function is to distribute and absorb the stresses generated by mastication and other dental contacts (Berglundh *et al*., 2024). The alveolar process consists of the maxilla and mandible bones that house the dental alveoli in their structure. The maintenance of the alveolar process depends on the presence of teeth and the stimulation they cause in the bone walls through collagen fibers of the periodontal ligament (Berglundh *et al*., 2024).

The alveolar process is formed by different structural components that, although they can be described separately from an anatomical point of view, act in an integrated manner in the support of the teeth. Externally, it has a layer of cortical bone composed of Haversian bone and compact bone lamellae, providing strength and protection to the structure. Internally, the alveolar wall is made up of a thin layer of compact bone called the alveolar bone itself, which radiographically corresponds to the lamina dura. Histologically, this region has multiple perforations, characterizing the cribriform lamina, through which neurovascular bundles pass that connect the periodontal ligament to the central portion of the alveolar bone, represented by the cancellous bone. Between the two layers of compact bone are the spongy bone trabeculae, responsible for providing structural support to the alveolar process, and the interdental septum is formed by cancellous bone delimited by a layer of compact bone, supporting the adjacent teeth. In addition to these structures directly related to the teeth, the

maxillary include the basal bone, which is located more apically and is not directly related to the dental elements (Newman *et al.*, 2020).

The bone and wall of the sockets need to adapt to the forces of tension and deformation, as the teeth are constantly in motion. The plasticity of the hard lamina is reflected in the various morphologies (rigid, adhesive, woody, and continuous) of Sharpey fiber attachment (Nanci, 2019).

Osteoblasts are responsible for the formation of alveolar bone. During the mineralization process, some cells are incorporated and are called osteocytes. It is currently recognized that osteocytes act as mechanical sensors and regulators of bone remodeling, influencing the activity of osteoblasts and osteoclasts (Huang et al., 2023). Osteoclasts play an essential complementary role in the remodeling of alveolar bone, promoting controlled resorption and allowing continuous renewal of bone tissue (Omi & Mishina, 2022).

According to the functional demand of the alveolar process, osteoblasts and osteoclasts perform bone matrix deposition and remodeling of the newly formed tissue. Thus, there is a balance between bone formation and resorption, but this can be altered by local and systemic factors. In inflammatory conditions, this balance can be disrupted by immune mediators that stimulate osteoclastic activity, a phenomenon described in the field of osteoimmunology (Tompkins, 2016). In areas where collagen fibers are under constant tension, bone matrix deposition occurs, and in areas under pressure, reabsorption occurs, which is believed to be caused by decreased vascularization and the number of cells at the site. Thus, it is suggested that the size and orientation of the bone trabeculae are related to the intensity of the stimulus to which they are exposed (Newman *et al.*, 2020).

3.6 PERIODONTAL PHYSIOLOGY

The blood supply to the periodontium derives primarily from the superior and inferior alveolar arteries, which emit the intraseptal artery before penetrating the alveolus. The terminal branches of the bone, known as perforating branches, penetrate the alveolar bone itself through the canals at all levels of the alveolus (Nanci, 2019; Berglundh *et al.*, 2024). In the space of the periodontal ligament, they anastomose with the blood vessels originating from the apical portion of the periodontal ligament and with the other terminal branches of the intraseptal artery. Before penetrating the root canal, the dental artery supplies branches that supply the apical portion of the periodontal ligament (Berglundh *et al.*, 2024).

The gingiva receives its blood supply primarily through the supraperiostal blood vessels, which are terminal branches of the sublingual, chin, buccal, facial, greater palatine, infraorbital, and posterior superior dental arteries. In the periodontal ligament, the blood

vessels are organized in a polyhedral-shaped network that surrounds the entire tooth root. The free gingiva, on the other hand, receives blood supply from three main sources: supraperiostealal vessels, vessels originating from the periodontal ligament itself, and vessels originating from the alveolar bone (Berglundh *et al*., 2024).

The periodontal ligament has a rich sensory innervation, and is largely supplied by nerve fibers capable of conducting tactile, pressure, and pain stimuli through the trigeminal nerve pathways. The nerve bundles reach the ligament from the periapical region and also through channels present in the alveolar bone, following the path of the blood vessels. Inside the ligament, these bundles are subdivided into myelinated fibers that, as they approach their endings, lose the myelin sheath and differentiate into four main types of nerve endings. Among them are the free endings, with an arboriform aspect, mainly responsible for the perception of pain; the Ruffini-type mechanoreceptors, located predominantly in the apical region; Meissner's spiral corpuscles, also mechanoreceptors, most often found in the middle third of the root; and the fusiform endings sensitive to pressure and vibration, surrounded by a fibrous capsule and located mainly in the region of the root apex. Thus, the regulation of masticatory movements and forces is due to the association of the proprioceptors of the muscles and tendons with the receptors of the periodontal ligament (Newman *et al.*, 2020; Berglundh *et al*., 2024).

The ability to adapt quickly to functional changes while keeping its thickness relatively constant is a notable feature. This capacity is essential for the maintenance of tissue homeostasis, reflecting the performance of biological mechanisms responsible for regulating the metabolism and spatial organization of the cells involved in the formation of bone, cementum, and periodontal fibers. In addition, the cells of the periodontal ligament have a high capacity to produce and release several regulatory molecules, which plays an essential role in tissue remodeling processes and in maintaining the functional balance of the periodontal ligament (Newman *et al*., 2020).

In general, the teeth and periodontal elements of the maxilla are innervated by the superior alveolar plexus. The maxillary gingiva is also innervated by the ramifications of the infraorbital nerves (buccal gingiva of the incisors, canines, and premolars), greater palatine (palatal gingiva of the molars and premolars), and nasopalatine nerves (palatal gingiva of the incisors and canines region) (Berglundh *et al*., 2024). In the periodontium, small-caliber nerves largely follow the same path as blood vessels. In the gums, they travel through the most superficial connective tissue towards the periosteum and, along this path, emit several branches destined for the oral gingival epithelium, continuing to the region of the free gum.

The innervation of the periodontal ligament occurs both through the apical route, through branches of the dental nerve, and laterally, through the perforations in the wall of the alveolus, known as Volkmann's canals. Inside the ligament, these nerve fibers are grouped into larger bundles, which follow parallel to the longitudinal axis of the tooth. From these ascending bundles, small branches depart that supply specific areas of periodontal tissue (Berglundh *et al*., 2024).

According to Berglundh et al. (2024), in the periodontium, lymphatic drainage is directed to the lymph nodes of the head and neck. In general, most of the teeth and their adjacent periodontal tissues drain into the submandibular lymph nodes. The gums of the mandibular incisor region drain primarily to the submental lymph nodes, while the palatal gingiva of the maxilla is directed to the deep cervical lymph nodes. The third molars, on the other hand, drain into the juguodigastric lymph nodes.

4 CONCLUSION

In short, the periodontium is configured as a dynamic biological unit, where tissue morphology is intrinsically linked to sensory and immunological functions. The current literature consolidates that the periodontium is not only a passive support, but a highly responsive system, because while the gingiva and the junctional epithelium guarantee the biological seal and the defense against pathogens, the periodontal ligament (DPL) acts as the main mechanobiological sensor of the complex.

The homeostasis of alveolar bone and root cementum is dictated by the ability of LPD to convert mechanical stimuli into biochemical signals, allowing continuous adaptation to masticatory and orthodontic loads. Therefore, the success of clinical interventions and regenerative therapies depends on the preservation of this functional integrity. Ultimately, detailed knowledge of periodontal physiology is the pillar that underpins safe and effective clinical decisions, allowing the dentist to act in harmony with the patient's biology to ensure biomechanical stability and long-term periodontal health.

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