

STRUCTURE AND FUNCTIONS OF THE PERIODONTAL LIGAMENT

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Abstract. The periodontal ligament is a soft connective tissue between tooth and alveolar bone. In this article the structure and functions of the periodontal ligament are discussed. Similar to all the connective tissues, the main components of the periodontal ligament are collagen fibres. Other important parts are cells, blood and lymphatic vessels and extracellular fluid. The periodontal ligament has several important functions, the main of which is the damping of mastication forces. Besides, the periodontal ligament performs supporting, nutrition, sensor and barrier functions, takes part in all the tooth movements, in particular physiologic, orthodontic and eruptive ones. Furthermore the results of the microscopic and experimental investigations, which were carried out to study features of structure and biomechanical behaviour of the periodontal ligament are given.

Key words: periodontal ligament, function, structure, Sharpey's collagen fibres, extracellular fluid, microscopy, experiment

The periodontal ligament (PDL) is a soft connective tissue between the tooth and the alveolar bone. In humans, the width of the PDL varies between 0.1 mm and 0.4 mm and the alveolar socket has a form of an hourglass, narrowest in the region of approximately one third of the root length above the apex. The normal width of the PDL surrounding a lower tooth is less than one of the PDL surrounding its upper antagonist. Although the width of PDL averages 0.25 mm, this value may alter with age, tooth development and treatment, pathologic process. After loss of the antagonist the PDL width is halved. In addition the PDL width increases at a mature age [10].

Pathologic processes may also cause changing PDL width. If daily mechanical load is raised, then there take place PDL hypertrophy and alternations in alveolar bone; it may lead to expansion of the PDL space. If there is cement hypertrophy (hypercementosis), then PDL boundaries and dimensions may also change [10].

Similar to all the connective tissues, the main components of the periodontal ligament are collagen fibres [9]. Other important parts are cells, blood and lymphatic vessels and extracellular fluid.

The existence, anatomical form, structure and functions of the PDL as well as the other tissues and organs adapt to environmental changes in the process of the phylogenetic development of living organisms. Furthermore, these PDL characteristics change with age of living beings.

In this article the functions of the PDL are treated. It should be noted that many PDL functions are much like joint cartilage ones and that is the reason why the PDL is sometimes

called periosteum. The results of microscopic and experimental investigations are also given and discussed.

Functions of PDL

The PDL plays a broad spectrum of functions. A brief description of its principal functions is as follows [1, 6-12].

Supporting and restraining role

The three dimensional fibre structure of the PDL represents a stable supportive unit that attaches the tooth to the alveolar bone. Therefore it controls the reaction of the tooth on external forces like a shock absorber.

If the light forces (< 0.5 N) are acting on the tooth, they are softened by intravascular fluid that is pressed out of the vessels. In restraining moderate forces (0.5-1.5 N) the flow of extravascular tissue fluid into adjacent marrow spaces is added. Heavier forces (> 2 N) are absorbed through tension of fibre apparatus [1].

Through its function of restraining the tooth movement during masticatory process the PDL also limits the undesirable tooth movements. That way the oral tissues are protected from possible damage. Due to a high PDL compressibility the enamel is able to withstand masticatory forces up to 150 N [1].

Bone remodelling and conversion role

Different cells (osteoblasts, osteoclasts, cementoblasts), which are responsible for absorption and apposition of boundary bone and tooth, are embedded in the PDL tissue. By means of permanent differentiation process of the fibre apparatus (fibroblast cells), the tooth is able to adapt to different long-term load situations. The fibre architecture adjusts to the different load magnitudes and directions, choosing the optimised structure for different load situations [1, 9].

During orthodontic tooth movement, the PDL transforms the mechanical load into a signal for bone remodelling, initiating the long-term tooth movement.

Nutrition and sensor role

The blood vessels and nerves are embedded into the PDL. They provide the tooth and surrounding tissue with nutritive substances and transfer sensor information during mastication process.

Rich network of vessels is responsible for the trophic function of the PDL, i.e. nutrition of the PDL itself, tooth's cement and alveolar bone.

During mastication, a permanently changing blood flow occurs and repeated forces applied to a tooth alternately intensify and reduce blood flow. Therefore mechanical forces govern trophic processes in the PDL and surrounding tissues. This standpoint explains atrophic processes in the periodontinum after tooth loss [11].

Forces acting on a tooth during mastication are controlled by mechanoreceptors, i.e. terminal branches of the nerve endings embedded into the PDL. Due to existence of numerous nerve endings the sensor (reflexogenic) function of the PDL may be mentioned. Receptors send signals to masticatory muscles and that way the forces applied to a tooth are controlled [11].

There are several types of nerves in the PDL, as a result of which it can perceive a number of irritations. The PDL is one of the most tactile organs of the human organism. The PDL nerves as discussed before control masticatory reflex. Besides taction, the PDL can perceive painful and thermal stimulations, and feel pressure.

Moreover the PDL takes part in dental growth and eruption. What is more, due to originality of anatomical structure the PDL performs the barrier function, in particular tolerance to unfavourable environmental factors (excessive mechanical loads, bacterial factor and so on).

Because of many different functions, the structure of PDL is highly complicated. In this study experimental observations of PDL in animals have been performed with the goal of more closely investigation of the PDL structure. The results of these experiments are given below. These findings may help in turn to better appreciate the mechanisms of performing functions by the PDL. In particular they give us better insight into the mechanism and the nature of the providing mechanical load amortisation by the PDL.

Microscopic investigation of the PDL structure*

Understanding the structure of the PDL tissue is very important for comprehension of the tooth behaviour under mechanical load in orthodontic movement and masticatory process. In this article the PDL architecture was studied by means of two microscopic techniques: light microscopy and scanning electron microscopy.

For both techniques the specimens were taken from mandibular segments of young and adult pigs. First the front segment of the mandibular bone containing four front teeth was separated from the rest of the bone. Afterwards, transversal sections (see Fig. 1) of approximately 1 mm thickness were made with a low-speed circular saw.



Fig. 1. Cross-section of a tooth in the mandibular bone.

^{*} This part of work was carried out at University Clinic of Ulm, Department of Orthodontics.



Fig. 2. The PDL tissue surrounded by the bone (left) and tooth (right).



Fig. 3. The Sharpey's fibres entering the bone tissue (at the top).

Preparation for light microscopy

The specimens for the light microscopy have to be cut out of the transversal sections in slices of a few micrometer thickness. Before cutting process the tissue has to be fixed and decalcified, otherwise the desolvation process could change the tissue structure and the hard substances (lime) could damage the microtome knife [2]. The specimens were fixed with formaline and decalcified afterwards. For details of the preparation procedure refer to [2, 8]. After the cutting the specimens were coloured in order to make different parts of the structure visible under the microscope. The substances for colouring of the tissue were Haematoxylin-Eosin [2], which turns the collagen fibres red and cell cores blue and Azan [2], which colours the fibres blue.

Preparation for scanning electron microscopy

The preparation of the tissue for electron microscopy differs from the preparation in the light microscopy. Complete specimens (Fig. 1), containing the bone, tooth and PDL tissue were put in a phosphate buffer solution with the enzyme *alpha amylase* and incubated at 37° C for one day [3]. *Alpha amylase* initiates the digestion of the ground substance, which is holding the fibrils together in fibre bundles. As a result of the enzyme application fibre bundles unfold into single fibrils. After such preparation all specimens were fixed in formaline and dried to the «critical-point» [4]. Finally, a thin layer of gold-palladium-alloy was evaporated over the specimen, for the reason of better emissivity of the secondary electrons and prevention of the electrical charging of the sample.

Figures of PDL tissue

The architecture of the PDL structure can be recognised well under the light microscope. In Fig. 2 fibres between the tooth and the bone are surrounded with cells and empty spaces, where extracellular fluid is stored. On the tooth- and the alveolar bone-surfaces the bundles of the Sharpey's fibres attach the PDL tissue to the bone and tooth (Fig. 3), allowing stabile connection between hard and soft tissues.

Figure 4 shows the three-dimensional structure of the fibre bundles. It is not possible to follow one fibre along its way from the tooth to bone. Single fibre bundles are branching out in parts containing several fibrils, which join with fibres of other branches. In this way a complicated three-dimensional network is created, which allows good support of the tooth in the alveolar socket. Between the bundles there are cells, vessels and empty spaces filled with extracellular fluid.

When the PDL is treated with enzyme called *alpha amylase*, the bundles unfold and the single fibres can be seen. In Fig. 5 the single collagen fibres of the PDL surface are shown. The specimen corresponds to the one shown in Fig. 1. The direction of fibres corresponds with the direction of a cut.

Single fibres are wavy (Fig. 6) when unstrained. If an external load is applied on the tooth the fibre bundles unfold in regions of the tension until the complete stretch is reached, whereas in region of compression the fibres fold together. If the tensional force is constantly increased, failure will occur (Fig. 7) and bundles will break gradually in steps.

Experimental investigation of the PDL fluid role in mechanical load amortisation*

In this part of the article the experimental investigation is described [5] in which the proposal was tested that a part of fluid constituent of the PDL might be free under the certain conditions and this fluid might move within the PDL under pressure gradient between the

^{*} This part of work was carried out at Perm State Technical University.



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Fig. 4. Fibre bundles.

fibre bundles and the walls of vessels. The specimens were taken from maxillary segments of guinea pigs. Each animal was anaesthetised and sacrificed. Then the mandible was extracted and the face skin, muscles and other soft tissues were dissected from the mandible.

The special device was developed for the conducted experiment. It was composed of syringe needle, tube, tee, manometer and appliance guaranteeing uniform supply of coloured fluid (dye) to a needle (PSMA rationalization proposal, №2190).

As a dye, the 1% solution of cyanolum (blue colour) was used for it fulfilled the necessary experiment requirements. The dye was dissolved in the isotonic solution (0.9% solution of NaCl in water). Moreover, due to its small sizes (less than 1 nm) the dye might move together with the solvent (the PDL fluid) within the porous medium of the PDL.

The dye solution was injected under given pressure into the certain zone of the PDL through the circular ligament of the incisor. As a result the non-uniform distribution of the PDL fluid pressure occurred and the PDL fluid might move under pressure gradient within the PDL. It resulted in turning of the PDL and the tooth's root on the opposite side from the injection zone to a blue colour within 1-2 sec after injection.



Fig. 5. Fibres treated with alpha amylase (no fibre bundles visible).



Fig. 6. Single fibers in unstrained state.



Fig. 7. Fibre bundles at failure.

This result supports to the view that the PDL fluid moves within the PDL under pressure gradient. Notice that the dye solution may move only together with a free fluid. Hence it follows that a part of fluid constituent of the PDL must be free under the certain conditions.

So the PDL fluid may move within the PDL. Under mechanical load the directions of PDL fluid movement may be as follows: from an area of compression to an area of tension, towards the gingival sulcus, and/or into the alveolar marrow spaces.

Therefore one can make conclusion that the PDL fluid takes part in load amortisation as well as the fibre bundles.

In addition, the permeability coefficient of the periodontal ligament involved in the Darcy's law equation was estimated. It turns out to be in the order of 10^{-8} m²/(Pa·sec).

Conclusions

In this article the structure and functions of the PDL were described. Moreover some microscopic and experimental results obtained by the authors were also presented.

Microscopic observation of alveolar complex provided useful information on the structure and the main characteristics of the PDL. Collagen fibres, cells and extracellular fluid were observed in the light microscope, together with the Sharpey's fibres, which attach the PDL tissue to the bone and the tooth. By means of scanning electron microscopy figures of the PDL and single fibres inside of the tissue were made. Unfolding of the fibre bundles was initiated by means of *alpha amylase*. That way the single collagen fibres on the surface of the specimen were observed, together with the unstrained fibres and fibre bundles in tension.

Furthermore it was experimentally shown that PDL structure provided the fluid to move within it from heightened pressure regions to lessened pressure ones. Therefore under certain conditions a part of PDL fluid may be free. The experiment enabled to estimate the permeability coefficient of the PDL. It proved to be in the order of 10^{-8} m²/(Pa·sec).

It should be emphasised that the fact on possibility of PDL fluid movement within the PDL could shed light upon process of load amortisation by the PDL. Relying on the experiment one can conclude that amortisation is provided by not only the PDL collagen fibres but also significantly the PDL fluid.

It may be thought that at the moment of mechanical load application there occurs elastic deformation of the PDL collagen fibres, blood and lymphatic vessels. Further within the period of 10–20 seconds the PDL fluid redistributes within the PDL, thereafter the tooth occupies new equilibrium position. If load is removed, then the tooth gradually returns to its original equilibrium position.

It is important to keep in mind that if mechanical load acts during rather extended period (hours or even months), then there occur irreversible remodelling processes in the PDL, alveolar bone, tooth. It is the basis for the orthodontic treatment.

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СТРУКТУРА И ФУНКЦИИ ПЕРИОДОНТА

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Периодонт представляет собой соединительную ткань, расположенную в пространстве между компактной пластинкой альвеолярной кости и цементом корня зуба. В статье обсуждаются структура и функции периодонта. Как и у всех соединительных тканей, одними из основных компонентов периодонта являются коллагеновые волокна. Кроме того, в периодонте имеются клетки, кровеносные и лимфатические сосуды, тканевая жидкость. Одной из главных среди множества функций периодонта является амортизация механический нагрузок, действующих на зуб. Кроме того, эта ткань выполняет поддерживающую, трофическую, сенсорную, барьерную функции, принимает участие при всех видах перемещений зубов, в

частности, физиологическом и ортодонтическом. Также в статье приводятся результаты собственных микроскопических и экспериментальных исследований структуры и свойств периодонта. Библ. 12.

Ключевые слова: периодонт, функция, структура, коллагеновые волокна, тканевая жидкость, микроскопия, эксперимент

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