

Equine masticatory organ

Part I

J. K. KURYSZKO, S. ŁYCZEWSKA-MAZURKIEWICZ

Department of Histology and Embryology,
Faculty of Veterinary Medicine, Agriculture University of Wrocław,
ul. Kozuchowska 5, 51-631 Wrocław

The masticatory organ is discussed in three parts. The first one is devoted to the macro- and microscopic structure of equine teeth, the second presents the structure of the parodontium formed by the cement, periodontium, periosteum and gingivae. The last part describes physiological relations between individual masticatory joints. The masticatory organ is a morphological-functional system associated with the digestive tract. It consists of the teeth, parodontium, the bones of the maxilla and the mandible, temporo-mandibular and alveodental joints, dento-dental junctions as well as the nervous and muscular complex.

Key words: equine dental tissues, enamel, molar teeth, collagen, bone mineral dentistry, cementum

1. Teeth

Teeth are basic structures of the masticatory organ and are the most resistant to wear structures of the organism. They are harder than bones, morphologically differentiated, and vary in shape, number and functional character, with their structure being closely associated with the kind of ingested food. Taking into account their function, structure and location, teeth are divided into incisors, canines, premolars and molars, which are located in two dental arches: maxillary (upper) and mandibular (lower) ones (figure 1). The macroscopic and microscopic structure of the dentition of herbivorous animals has been described here on the basis of equine molars.

All equine teeth belong to the class of long-crown (hypsodontic) teeth which are characterized by homogeneous structure throughout the whole length and constantly on-going growing process. Equine teeth are designated according to the following formulae:

Deciduous – (I3/3 C1/1 P3/3 M0) × 2, permanent – (I3/3 C1/1 P3/3 M3/3) × 2.

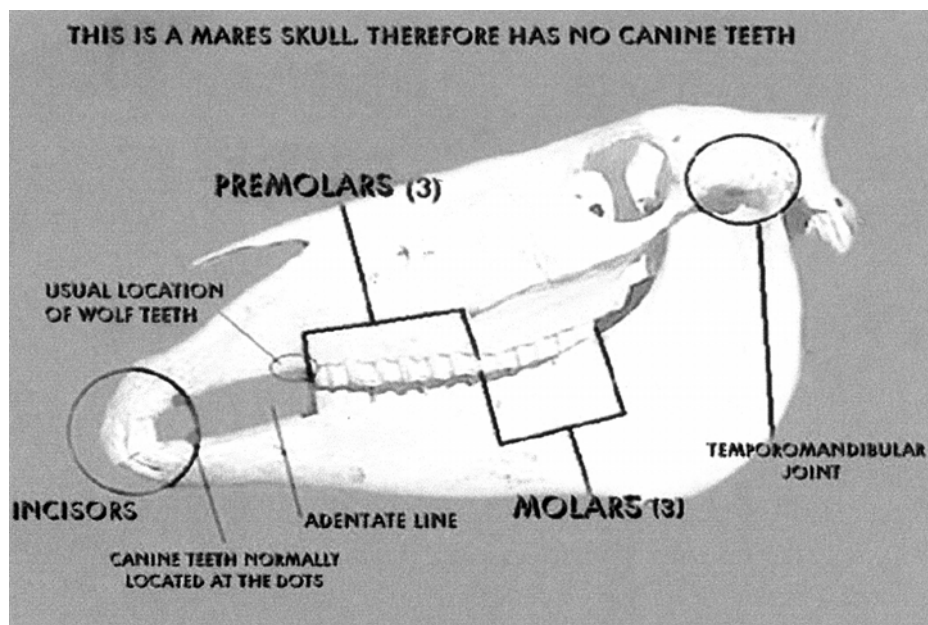


Fig. 1. Skull of a mare

Incisors (*dentes incisive*) are situated nasally. The horse has 6 incisors in each, the upper and the lower jaw. Incisors have a single root, are wedge-shaped with convex labial surface and concave lingual surface. The occlusal surface of permanent incisors, which have not been worn out yet, is equipped with dental depression (so-called register). It is filled with cement and is 7–10 mm deep. After the register has been worn out completely, a dark spot remains which is formed by reparation dentin filling the dental chamber. The shape of occlusal surface changes with age: young incisors are initially transversely oval, with time they become round, triangular, and finally, longitudinally oval. This is associated with protrusion of the teeth from the alveolar sockets accompanying attrition. The profile of incisors also changes with age, from regular arch to wedge-shaped. These changes are helpful in determining the age of the horse.

Canines (*dentes canini*) are situated between incisors and premolars within the edentulous edge, dividing it into a shorter anterior part and a longer posterior one. They have single root and are cone shaped, and in older horses they undergo attrition. They are missing or occur extremely rarely in mares – dental dimorphism associated with different number of teeth in females (36 permanent, 24 deciduous teeth) and males (40–42 permanent, 24–28 deciduous teeth).

Premolars (*dentes premolares*) and **molars** (*dentes molares*) are called cheek teeth. The horse has 12 cheek teeth in each of the dental arches. Molar teeth (figure 2) provide extremely thorough breakdown of hard, solid food. Premolars are

diphodont except for P1 (lupine or residual tooth), which may erupt only in the upper dental arch.

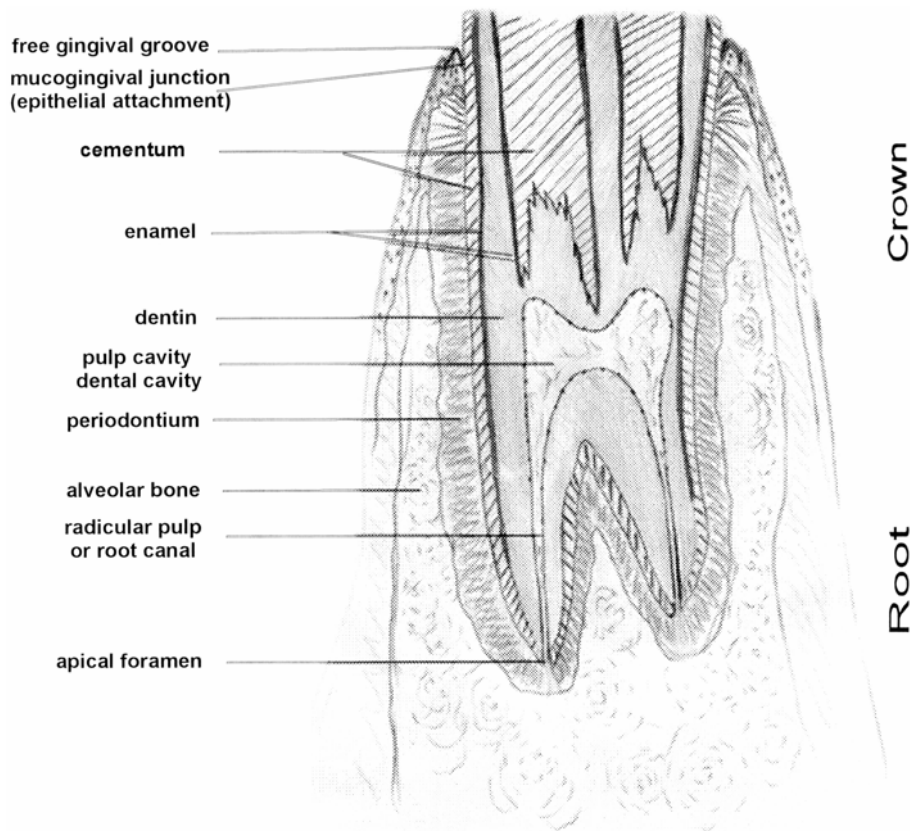


Fig. 2. Schematic drawing of a section through a molar tooth

Molar teeth are non-replaceable and appear in permanent dentition: M1 erupts in 9–14 months of life, M2 at the age of 2–2.5 years, and M3 at the age of 3–4 years. Five dental surfaces are distinguished: occlusal-grinding, buccal, labial, adjacent proximal and adjacent distal. Border teeth P2 and M3 have three walls. The occlusal surface of young teeth is equipped with 2 or 4 cusps which are paired buccal-lingual. Between the cusps there is a pit or infundibulum (in the case of 2 cusps there is 1 pit, in the case of 4 cusps there are 2 pits). After attrition of the cusps on the occlusal surface, the enamel laminae become apparent and they are located peripherally and centrally on the surface. Characteristic enamel infundibula are filled with cement, which undergoes attrition most rapidly. These hollows are surrounded externally by dentin which is visible on the occlusal surface and fills the area between external enamel surrounding the body of the tooth and the enamel covering the surface of the infundibulum. Thus the surface of a tooth is composed of the dentin, the enamel and

the cement. Due to this structure of the occlusal surface in the horse, the teeth are called lamina-type (lophodontic), while the ruminants have half-moon type of teeth (selenodontic), since the cusps and pits are half-moon shaped.

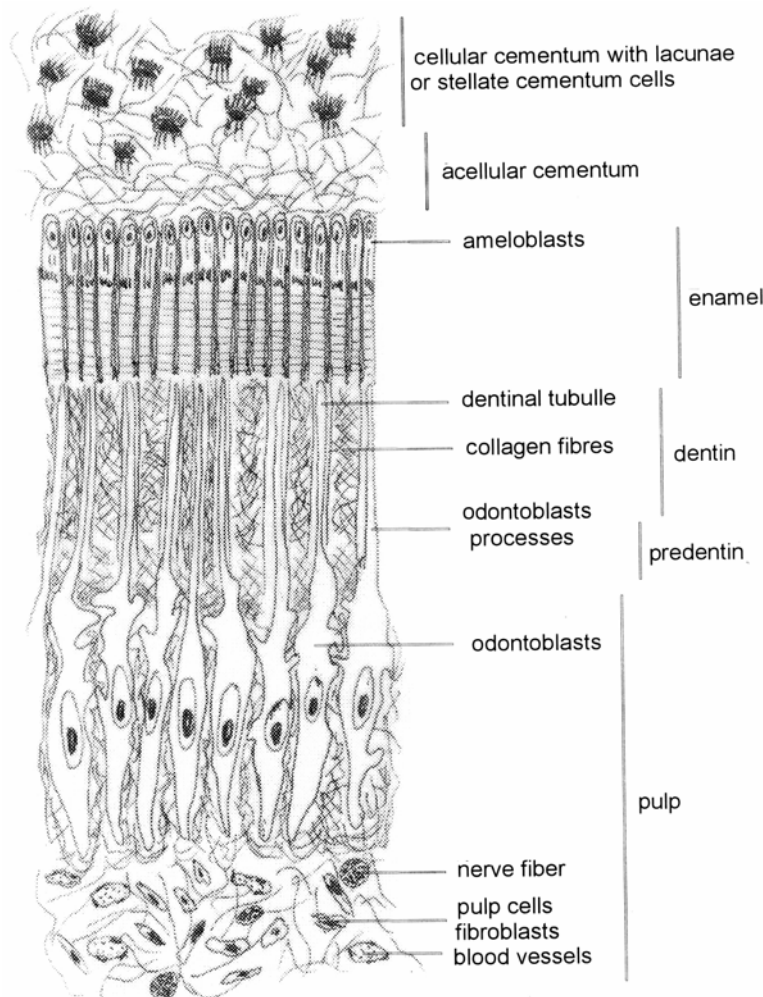


Fig. 3. Schematic drawing of substances which make tooth

In the horse, the maxillary molars are more massive, wider and shorter than their mandibular counterparts. They are distributed more widely in relation to each other, thus making extraction easier. In transverse section they appear square and have three radical branches. Occlusal surfaces of both upper and lower molars are smooth, cream-yellow or cream-brown. On the buccal surface of the upper molars there are three longitudinal folds of enamel separated by two distinct grooves. Anterior and medial laminae are well developed, while the posterior one is poorly marked. On the lingual surface there are one

longitudinal enamel lamina and two grooves situated laterally, the posterior one being broader, the anterior one – narrower. Lower cheek teeth are on transverse section quadrangular, flattened laterally and have two roots which are formed only during growth. They are longer than upper molars and closely fitting one another. Since the peripheral enamel is deeply infolded, the enamel infundibula are not distinguished on the occlusal surface. Long crowns are embedded deeply in the alveolar sockets and function as roots. In the initial stage of their growth these teeth are deprived of roots, which appear with age as the teeth wear down and protrude from the sockets. The process of growing lasts until 7 years of age, and the maximum length of the teeth is up to 8–10 cm. When the horse is 8 years old, the process of shortening of the cheek teeth begins. As the occlusal surface undergoes attrition and the body becomes shortened, the tooth moves upward from the socket in order to replace the loss. Also the epithelial attachment of the gingiva becomes displaced and this process may lead to atrophy of the alveolar sockets and lowering of the gingivae. Long-crown teeth move outwards from the sockets as they wear until they are lost. This process is called “passive eruption” of the teeth [3], [4], [11], [12], [16]. The maxillary as well as mandibular molars are covered with enamel on their whole length and surrounded externally by cement, which covers the whole enamel, gets on the surface of the crown and fills dental infundibula. Since the division into crown and neck is not clear, it is assumed that a tooth consists of the body (the part visible above the edge of the gingiva) and the root (the part in the socket). The body of the tooth contains a wide hollow – dental chamber, which becomes narrower passing down and becoming the root canal. The dental chamber and root canal are filled with dental pulp. At the end of the root canal there is the periapical foramen. The substances forming the tooth differ as to the degree of mineralisation, origin and location. They are divided into soft and hard dental tissues. The soft tissues are pulp and periodontium. The hard tissues are dentin, enamel and cement (figure 3).

A) Dental pulp (*pulpa dentis*). Dental pulp fills the pulp chamber (coronal pulp) and root canal (radical pulp) and communicates with the periodontium through the apical foramen. Its role is to form new layers of dentin, provide normal metabolism, nourish the dentin which is devoid of vessels, reception of stimuli acting on the dentin, protection against harmful factors by means of odontoblasts and immunological cells.

Mature pulp resembles mature gelatinous connective tissue in which there are fibroblasts, stellate cells of fibroblastic and fibrocytic character; collagen fibres are arranged randomly and with aging they form bundles. Three layers are distinguished:

- a) layer of odontoblasts,
- b) acellular layer,
- c) cellular layer, i.e., dental pulp proper.

The acellular layer contains very small amounts of fibroblasts which may transform into odontoblasts. Collagen fibres in these two layers do not form bundles, instead they form a network entangling odontoblasts. The dental pulp proper contains a large amount of fibroblasts and fibrocytes. With aging, the radical pulp contains more collagen fibres arranged in bundles and less cells and capillaries.

Thick reticular fibres arranged spirally between odontoblasts and predentine appear in the peripheral portion of the pulp. On the surface of the pulp on the border with the dentin the odontoblasts are arranged in series creating a dentinogenic layer – they are cylindrical within the body of the tooth and cubical or flat within the root [3], [10], [15], [18].

There are two classes of odontoblasts:

resting odontoblasts (cubic) in which the nucleus occupies the majority of the cytoplasm poor in cell's organelles,

active odontoblasts (elongated) possess a well formed Golgi apparatus, mitochondria, granular endoplasmatic reticulum, which is associated with the production of dentin (is a proof of active participation in mineralisation process and protein synthesis); they take part in production of procollagen.

Between odontoblasts there are intracellular spaces rich in precollagen and nervous fibres. Short odontoblastic processes run towards the pulp, while their long processes penetrate into the dentin. Odontoblasts also have lateral processes by means of which they communicate with each other.

B) Dentin (*dentinum s. substantia eburnea*) covers the outer surface of the pulp and is joined to the layer of odontoblasts. It is formed by dentinal tubules (in the lumen of which are long odontoblastic processes) running radially towards the surface of the pulp. Dentinal tubules (figure 4) in the vicinity of the pulp are about 4 μm in diameter, while nearby the surface of the enamel they are much finer and less abundant. Various species differ in the degree of penetration of odontoblastic processes into the lumen of dentinal tubules.

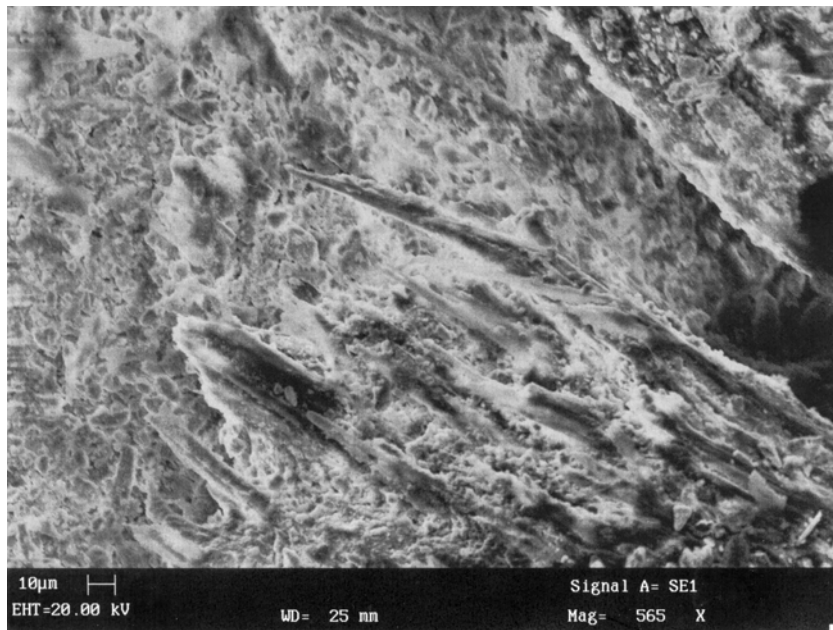


Fig. 4. Dentinal tubules – the occlusal surface (cross-section) SEM, $\times 565$

In ovine teeth, the odontoblastic processes are present throughout the whole length of the tubules. In the cat, the processes are limited only to 1/3 of the internal dentin, while in bovine teeth there are no processes at all.

In the equine molar teeth, odontoblastic processes extend from the pulp to the dentino-enamel junction, moreover the tubular lumen may contain more than one odontoblastic process [4], [5], [7]. In incisors, odontoblastic processes are limited to the most circumpulpal part of the dentinal tubules of incisors in both old as well as young horses.

Apart from odontoblasts, the tubular lumen may contain two different types of structures:

- **Process-like structures**, which are called laminae limitans. They extend from predentin–dentin junction to dentino-enamel junction. Laminae limitans have been described as homogeneous, organic structures forming the deepest layer of poorly mineralized peritubular dentin. Lamina limitans is usually adjacent to the internal wall of the peritubular dentin slowly passing into the tubular lumen. In equine teeth, the uncovered dentin is exposed on the masticatory surface. Odontoblastic processes are present in external dentin, in which the dentinal tubules are subject to attrition, which is a typical process in equine teeth (they are relatively resistant to wear).

In herbivorous animals, this surface is composed mostly of dentin which is five times softer than enamel.

- **Collagen fibres** are most abundant in the circumpulpal portion of the tubules. Collagen is the main component of tubular structure and is present in more than 60% of human dental tubules. It is neither age nor functions of the teeth that determine the presence of intratubular collagen. Intratubular collagen is more prominent in the circumpulpal dentin. The mechanism of intratubular collagen fibres production by odontoblasts consisting in the change of orientation from intratubular collagen surrounding tubules to intratubular fibres, is still unknown. Moreover, the relations between non-collagenous circumtubular dentin and intratubular collagen fibres still remain unknown.

Dentinal tubules are surrounded by a network of collagen fibres produced from collagen types II and IV, which run perpendicularly to the long axis of the tubules. The main bulk of the dentin contained between the tubules consists of collagen fibres and matrix composed of glycosamineglycans and proteoglycans. Crystals of hydroxyapatite, fluoroapatite, magnesium, calcium and sodium carbonate are found around the fibres forming dentinal tubules running in various directions and forming a network as well as within intranodular parts of the collagen fibres and in collagen fibres themselves.

There are several types of dentin:

- **Type I: predentin** is present on the border of the dentin and pulp as a narrow layer of poorly mineralized dentin, weakly staining in decalcified preparations. Its lack points to damage of the odontoblasts resulting for instance from dental caries or iatrogenic factors. Production of predentin is inhibited when the occlusal surface has

been reached (termination of “eruption” process) and the apical foramen has finally formed in the root.

- **Type II: primary dentin** is produced by odontoblasts at the start of the process of attrition of the masticatory surface and the action of occlusal forces.

- **Type III: secondary dentin** appears when factors damaging odontoblastic processes come to force. It performs protective function and does not replenish tissue loss.

Secondary dentin appears in two sub-types:

- a) regular dentin – straight dentinal tubules, occurs on physiological attrition of the masticatory surface,

- b) irregular dentin – dentinal tubules are curved, wider layer of predentin (occurring from the side of the pulp).

- **Type IV: reparation dentin** is a kind of secondary dentin, but unlike secondary dentin, it builds up lost issue; it is characterized by lack of tubules and the odontoblasts are embedded in the matrix. Reparation dentin can be subdivided into:

- structural, revealing irregularities in shape and pattern of dentin-forming cells,
- structureless, which does not have any cells and tubules.

Both types of reparation dentin occur on the surface of exposed pulp and are produced by newly formed odontoblasts similar in structure and function to osteoblasts.

All kinds of dentin may be found next to each other, i.e., peritubular (lining tubules, highly mineralized) and intratubular. Dentin forms the bulk of the tooth and gives it its shape. Due to its chemical composition (10% water, 20% organic substances, 70% inorganic substances) and morphological structure, dentin shows a certain degree of resilience, which causes that the enamel covering it externally does not chip off [2]–[4], [14], [15], [18].

C) Enamel (*enamelum*) is the hardest of tooth building tissues of ectodermal origin (figure 3).

In the process of development, it is formed from epithelial cells (ameloblasts). It is built of enamel prisms and interprismatic substance. Enamel prisms are parallel and perpendicular to the dental surface. They are longer than enamel thickness since they run from the amelodentinal line towards free space obliquely and spirally (which increases the enamel endurance).

The enamel surface is covered by a thin, delicate membrane called dental cuticle, which is the final product of ameloblasts and serves as a mechanical barrier protecting the teeth against micro-organisms; it is resistant to acids and alkali. It covers the surface of unworn, freshly erupted tooth. It undergoes attrition quite rapidly and it consists of two layers: internal, structureless and external, epithelial ones. Chemically, enamel consists of 96–97% of inorganic substances. They are mainly calcium phosphates in the form of dihydroxyapatites. Organic substances are glycosaminoglycans, phosphoproteins and glycoproteins. Studies carried out by KILIC et al. [6], [8], [9] revealed that the occlusal surface may take various forms: alongside

polished areas, there are local fractures, wedge-shaped pits, striations and depressions. The thickness of equine enamel varies, being the thickest in areas where folds are parallel to the long axis of the maxilla and the mandible. The thickness of enamel does not change in the longitudinal axis of the tooth (in transverse plane). Peripheral enamel is more deeply involved in lower cheek teeth than in the upper ones, which results in the absence of infundibulum in the lower cheek teeth (bulb-like indentation which, like enamel notch, is partially filled with cement).

Ultrastructural examinations carried out by KILIC et al. [6], [8], [9] have revealed three types of enamel. The division has been made based on the morphology of enamel prisms as well as the amount of interprismatic enamel.

- **Type I enamel** covers alternating rows of oval prisms and thick interprismatic enamel plates. This type is adjacent to amelodentinal junction.

- **Type II enamel** consists of circular, round or “horseshoe” shaped prisms with little or no interprismatic enamel and is located at the amelocemental junction.

- **Type III enamel** is composed of rounded prisms surrounded by large amounts of interprismatic enamel. However, it is not always present in a thin layer at the amelodentinal and amelocemental junctions.

Intersected prisms occur in the thickest, peripheral enamel in the upper cheek teeth, but the prisms present in incisors' enamel reveal the same pattern of arrangement, which makes them extremely resistant and resilient to cracking. Enamel prisms are cylindrical on transverse section (SEM examination). Mature enamel does not contain cellular elements, thus it cannot be restored [7]–[9], [1].

Over the whole area of long-crown tooth enamel is covered externally by cement.

D) Cement (*cementum*) is the substance which is one the borderline between soft and hard tooth substances. Morphologically, two types of cement can be distinguished; acellular and cellular (figure 3). Acellular cement is found in the layer starting from amelocemental junction. The layer becomes thicker the closer it gets to the apex. Cellular cement is found on the surface of the acellular cement. Its layer becomes thicker as it approaches the apex. Cellular cement contains cementocytes. These cells are equipped with numerous, long, radially extending processes which communicate with neighbouring cells. Processes of cells situated marginally are directed towards the dental periosteum, from which they derive nutrients. The processes transport nutrients further down. In physiological conditions, cement does not undergo resorption, with aging of some segments the cementoblasts produce new layers and supplement the loss of cement resulting from resorption. Constant accumulation of cement overlying in the region of apical foramen of the root causes its obliteration and eliminates the effect of pathogenic factors originating from the root canal. These factors play a significant role in the etiopathogenesis of periapical tissues disease – pathological processes occurring in these parts of cement, periodontium, alveolar bone and gingivae which surround the root apex. Thus the thickness increases with age, but this does not result in better maintenance of

the tooth in the socket. Cement is fused with periodontium, the fibres of which attach only to the newly produced layers of cement [9], [18], [1], [2].

E) Periodontium is formed by plexiform connective tissue (figure 5). This type of tissue is built of cells and intercellular substance. The cells of periodontium are fibroblasts, osteoblasts, osteocytes (responsible for physiological reconstruction of the alveolar bone consisting in constant resorption of old and buildup of new bone), cementoblasts (occurring on the surface of the cement between penetrating periodontal fibres). Periodontal intercellular substance consists mainly of collagen fibres and small amount of elastic fibres responsible for securing the tooth in the socket and shock absorption of masticatory forces created on chewing. Periodontal collagen fibres are made of type I collagen and form intertwining bundles. They run in waves from cement to the alveolar bone, which enables them to elongate and shorten. Fibres extending from the alveolar bone join with those running from the cement and in the mid-thickness of periodontium they form so-called intermediary plexus. It enables lateral movements of a tooth under the effect of forces of mastication.



Fig. 5. Photo-micrograph of equine molar, $\times 40$

Within the apical foramen periodontium joints with the pulp and forms ligamentous apparatus, which consists of:

- alveolar-dental ligament,
- circular ligament,
- interdental ligaments.

Alveolar-dental ligament consists of four groups of bundles differing in their course and attachment site: process crest ligament situated uppermost, horizontal bundle, diagonal bundle, vertical bundle securing the tooth in the socket. This differentiated arrangement pattern counteracts forces of mastication acting from various directions.

Periodontium has a rich nerves supply with numerous sensory nerves endings. Sensory, pain and touch receptors which are distributed alongside cement and alveolar

wall by trigeminal nerve control involuntarily the process of chewing – every pressure exerted on the tooth is transmitted by periodontium to the sensory nerve endings which determine direction, degree and intensity of the pressure. On biting and chewing of hard food particles, irritated sensory endings regulate the chewing muscles tone decreasing their activity – in this way periodontium protects the tooth against excessive overload and prevents its forcing into the socket [1], [3], [18].

Due to its differentiated structure, periodontium performs a number of functions:

it maintains teeth in the sockets and provides their physiological stability,

it resorbs and produces alveolar bone,

it produces radical cement,

it performs protective and reparative functions,

it nourishes cement,

it receives stimuli acting on the tooth.

Periodontium is a soft tissue which connects and stabilizes a tooth in the alveolar socket. It provides physiological stability to the tooth. It surrounds the tooth externally and – together with cement, periosteum and gingival – creates parodontium.

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