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#### EXPLANATION OF PLATES

##### Plate 1

Photomicrographs of the human tooth germ.

- a. At the cap stage of development. The black punctate material is glycogen.
  - b. At the bell stage of development.
  - c. Undecalcified section illustrating the marked Schiff positivity of the odontoblast cytoplasm during dentinogenesis.
  - d. Undecalcified section illustrating the distribution of alkaline phosphatase. Note the intense enzyme activity in the stratum intermedium and the subodontoblastic layer. The black precipitate in the dentine and enamel is caused by the presence of calcium salts and should be ignored.
  - e. Montage photomicrograph of a tooth germ illustrating the disappearance of glycogen from the ameloblasts with the onset of amelogenesis.
- a., ameloblasts; d., dentine; d.p., dental papilla; e., enamel; e.o., enamel organ; o., odontoblasts; p.d., pre-dentine; s., subodontoblastic layer; s.i., stratum intermedium; t., Tomes process.

##### Plate 2

Amelogenesis. Diagram based on results of investigation by electron microscopy of enamel-matrix formation in rodents (after Fearnhead, 1958).

O.E.E., external enamel epithelium; B.V., blood vessel; S.I., stratum intermedium; R.N.A., ribonucleic acid.

### The structure of the human tooth

By A. I. DARLING, *University of Bristol Dental School*

The human tooth consists largely of dentine. In the centre of the dentine is a cavity which contains the soft tissue of the dental pulp. The dentine is covered on the outer surface of the root by a thin layer of cementum and the dentine of the crown is covered by a layer of enamel. The tooth is slung in its socket by the fibres of the periodontal membrane which stretch from the bone of the alveolus to the cementum.

At the neck of the tooth there is a form of attachment between the oral mucosa and the enamel which is itself of ectodermal origin.

### *Dentine*

Dentine gives the tooth its elasticity. Chemically, it consists after drying at 100° of about 75% of inorganic constituents, approximately 20% of organic material and about 5% of water (Stack, 1951). The 20% of organic material consists of 18% collagen and 1% citric acid with small amounts of insoluble protein, mucopolysaccharides and fat. The inorganic constituent appears to be chiefly hydroxyapatite.

There are two main structural components of dentine. These are the matrix which when calcified forms the bulk of the dentine and the dentinal tubules which run through the dentine from the pulp to the amelodentinal junction carrying the processes of the odontoblasts.

The matrix is collagenous in nature, the fibres being arranged, at least to some extent, parallel to the dentine surface, but in the dentine next to the amelodentinal junction they tend to lie at right angles to this plane (Kramer, 1951).

In development the dentine is built up in increments by the pulpal cells and these increments are recognizable in the mature dentine. The matrix of the dentine is calcified throughout except at its junction with the pulp where a zone of uncalcified dentine can be seen during development and often in later stages also.

The crystallites of the dentine appear to be arranged in modified globules with the crystallites radiating from the centre of each globule. In the root there is a zone of small interglobular spaces which is a normal feature of all human teeth. This zone is known as the granular layer of Tomes and lies just inside the junction between dentine and cementum, being separated from it by a narrow zone of clear dentine.

Through the matrix run the dentinal tubules carrying the processes of the odontoblasts from the pulp to the amelodentinal junction or the granular layer of Tomes. These tubules follow a curving course branching profusely in a lateral direction and dividing and arborizing in their terminal portions beneath the amelodentinal junction. It is by no means certain whether the lateral branches carry branches of the odontoblastic processes. For many years it has been argued that there is a space surrounding the odontoblastic process within the tubule, but recent work by Bradford (1955) seems to deny it and show it to be an artifact.

With ageing of the tooth, the tubule gradually closes down, the process of the odontoblast seems to withdraw and the tubule is eventually obliterated. This change seems to be achieved by calcification within the tubule. A similar process seems to occur more rapidly as the result of attrition or some other mild chronic irritation of the dentine.

If subjected to a more acute irritation the processes may degenerate and the pulpal end of the tubules may be closed off by a layer of hyaline dentine. Further protection may then be provided by the deposition of secondary dentine which may again be tubular, though the tubules are unlikely to be as regular as those in the primary dentine. Throughout life there is a slow physiological production of dentine which gradually narrows down the pulp chamber and pulp canals.

The degree of calcification of the dentine is highest at the amelodentinal junction and, whatever developmental faults may occur, this zone of so-called mantle dentine is usually well formed. A few tubules send processes across the amelodentinal junction to end in the enamel as enamel spindles, but the degree of penetration is very slight.

### *Cementum*

This tissue is very like bone in almost every respect except that it covers the root of the tooth. It is responsible for embedding the fibres of the periodontal membrane which form a sling between the bone and the cementum and attach the tooth to the socket. As with bone, it consists of a matrix of collagen in which calcium salts are deposited. Histologically it shows laminations which reflect its mode of development but, as distinct from bone, it shows little evidence of resorption except in pathological conditions.

Two types of cementum are distinguished histologically. These are primary and secondary cementum. Primary cementum is found all over the root of the unerupted and recently erupted tooth, next to the dentine. It is almost completely acellular. The collagen fibres of the matrix appear to run around the root or along the length of the root in alternate layers, whereas the periodontal fibres pass inwards from the surface at an angle, towards the apex.

Secondary cementum is usually found around the apex of the erupted tooth and usually increases slightly in amount with age. It also is laminated but the layers are irregular and usually thicker than in primary cementum. The fibres of the matrix run in bundles in an irregular manner through the tissue but are occasionally seen in a system very similar to the Haversian systems in bone. The cells are usually arranged parallel to the laminae and are seen as lacunae or spaces in the ground section. From them numerous small canaliculi radiate into the surrounding tissue where some appear to communicate with similar processes from neighbouring spaces.

### *Enamel*

Mature dental enamel in man is the hardest tissue in the body. It consists of about 0.5% by weight of organic material and 99.5% of inorganic salts and water (Stack, 1954). The organic matrix is laid down before calcification begins and the actual amount of organic content appears to vary during development. In mature enamel, the main component is probably a keratin, but Stack (1954) has also described the presence of a soluble organic fraction which is principally protein in nature. There is probably a third fraction consisting of carbohydrate which is also soluble.

The inorganic part is almost certainly a hydroxyapatite with, in addition, some carbonate and trace elements such as fluorine, copper and iron. The carbonate is probably adsorbed on to the surface of the hydroxyapatite lattice; the trace elements may be actually within or adsorbed on to the surface of the lattice and occur almost exclusively in the surface enamel.

The enamel matrix is laid down in increments whose surfaces lie at an angle to the enamel surface. The pauses between increments are at times seen as striae of

Retzius or incremental lines. Calcification begins soon after the deposition of the matrix and is probably not completed till shortly before eruption.

The classical unit of enamel structure is the prism which appears to be produced by a single ameloblast. Each prism is approximately 6–8  $\mu$  in diameter and is separated from its neighbour by interprismatic substance. In decalcified sections the outer margin of the prisms shows a layer of organic material known as the prism sheath. With the aid of electron microscopy it has also been possible to demonstrate a fine organic matrix in the centre of the prism and the interprismatic substance. Recent work suggests that the prism sheaths are keratinous and insoluble but the matrix of the interprismatic substance and the prism core probably consists of Stack's (1954) soluble organic material.

The classical concept of the prism as hexagonal in shape, with a complete sheath surrounding it, is rarely seen. More frequently the prisms show a scallop form in cross section and in electron microscopy the prism sheaths are often seen to be incomplete. It seems probable that the prism sheaths in the outermost enamel are more complete than in the inner enamel. In unabraded enamel the prism sheaths are continuous with a fine organic surface layer which is the enamel cuticle. It is lost with attrition or abrasion of the enamel surface, but some workers believe it may be reformed.

Each prism appears to begin at the amelodentinal junction from which groups of prisms run in a tortuous path until they reach the middle third of the enamel where they begin to straighten out, being almost completely straight in the outer third. In certain media, cross-striations can be seen in the prism. They are placed at intervals of approximately 4  $\mu$  and probably indicate some segmentation of the prism. The striae of Retzius appear to consist of well-marked cross-striations associated with enhanced segments of interprismatic substance giving a staircase appearance. Sognnaes (1949) has said that the prism sheaths are thickened at the striae of Retzius. This thickening together with a thinning of the interprismatic substance probably occurs just beneath the striae.

The amelodentinal junction is scalloped in form, with the concavities facing outwards. From the points between the concavities tufts of prisms pass outwards in a spiral form and the enamel is often hypocalcified in these areas. A few dentinal tubules also seem to cross the junction, ending in small spindle-shaped spaces in the enamel which are also hypocalcified.

The enamel surface shows ridges known as perikymata corresponding to the developmental increments. In section the outer 20–30  $\mu$  of enamel shows little structure. It is also harder and more radio-opaque than the inner enamel. From the surface there is a falling off in radio-opacity towards the amelodentinal junction, but at the junction with the dentine it rises again.

### *The pulp*

This tissue occupies a central cavity in the tooth and communicates, through the small apical foramen, with the periodontal membrane. It is the remnant of the dentine-forming organ and consists mainly of connective-tissue cells, with a layer

of specialized cells, the odontoblasts, next to the dentine. The odontoblasts lie at the inner end of the dentinal tubules and each sends a process out along a tubule. The pulp receives its nervous and vascular supply through the apical foramen.

Nerves reach the pulp in considerable numbers and break up into small branches beneath the odontoblastic layer. From this point it is quite clear that nerve fibrils pass into the uncalcified layer of pre-dentine. Beyond this point they are extremely difficult to demonstrate, but the recent work of Cocker & Hatton (1955) and others leaves little doubt that they continue much further into the dentine. It seems most unlikely that any nerves reach the enamel.

The vascular and lymphatic supply of the pulp is quite rich and is closely related to the supply to the periodontal membrane. It has been suggested that a lymphatic circulation exists through the communicating dentinal tubules, but recent work on the tubules and their contents (Bradford, 1955) makes it less probable.

#### *Permeability*

Much work has been done on the passage of a variety of materials into the dental tissues (Atkinson, 1947, 1948, 1949; Bélanger, 1953; Wainwright, 1950, 1953; Wainwright & Belgorod, 1955; Wassermann, 1941). These materials include dyes, tracer elements, and other substances, sometimes by a simple process of diffusion, sometimes by osmosis, and at other times by cataphoresis. Experiments have been carried out both in vivo and in vitro. It is very difficult to interpret the results, but it appears that there are pathways from the pulp through the dentine and cementum to the periodontal membrane, and from the pulp through the dentine and enamel to the oral surface and vice versa. There is little doubt that the permeability of the dentine and cementum is very much greater than that of enamel. It has been suggested that the permeability of enamel decreases with age but the process is not very clear. It has also been shown that sugars can assist the passage of other materials through the enamel (Berggren & Hedström, 1951). The real problem which has not yet been settled is how far these pathways are used in life for purposes of exchange. So far as we can tell at present the exchange in dentine is probably much less than that in bone and the exchange in enamel is so small as to be almost infinitesimal by comparison. When enamel is impermeable it seems that the barrier is probably at the enamel surface.

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### Food and the periodontal diseases

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The periodontal diseases, as the name is intended to imply, are a group of diseases which affect the tissues around the teeth, the gingiva or gum, the alveolar bone, the fibrous joint or periodontal membrane, and the cementum. It is important to note that this is a motley collection of tissues, one epidermal, the gingiva, and three mesodermal, two of which, the alveolar bone and the cementum, are calcified. It is only to be expected, therefore, that the effect of particular dietary deficiencies is confused and the subject of controversy.

If we look more closely at the fibrous joint between the tooth and the bone, we find that it is similar to other fibrous joints in the body. On the one side is the alveolar bone which is very cancellous, therefore very labile, and presumably easily affected by changes in the metabolism of the individual, and also by changes in the stresses applied to the tooth. From it, collagenous fibres run to the cementum, which invests the tooth and, as the name implies, cements the fibres to the tooth and is a very stable tissue which once formed is unlikely to be affected by the general bodily metabolism. This joint, however, differs from other fibrous joints in that, to all intents and purposes, the fibrous connective tissue of the periodontal membrane is exposed to the mouth, the ingress of bacteria and food debris being prevented by the physical adaptation of a cuff of epithelium around the neck of the tooth. If this cuff loses its tonicity for any reason, then invasion of the underlying tissues can occur.

Although the loss of teeth is not a lethal disease, yet it presents a serious public health problem. If people have no teeth, they cannot masticate properly and their diet becomes restricted: they must therefore be provided with some at a cost to the country of millions of pounds a year. Unfortunately even this expenditure restores the masticatory efficiency at best to only about half of that of the natural dentition. Unfortunately, the denture wearers are in charge of the selection and preparation of food for the younger generation and their own inclination is to provide food that requires no chewing, which, as we shall see later, predisposes the rising generation to poorly developed periodontal tissues.

Of the two dental-disease groups, dental caries and periodontal diseases, by far the greater number of teeth are lost as a result of the latter. The profession knows all too little about these diseases, so that what I have to say will be to a great extent theory rather than fact, and it will be important to distinguish the one from the other.

Periodontal disease, like most other diseases to which man is prone, can be looked upon as the result of a battle between the forces of destruction on one side and the resistance of the individual on the other. In more particular terms, between the forces