G. A. Wilson.
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DENTAL AND ORAL HISTOLOGY

THE HISTOLOGY AND PATHO-HISTOLOGY

OF

THE TEETH AND ASSOCIATED PARTS

BY

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WITH FOUR HUNDRED AND NINETY THREE ILLUSTRATIONS IN THE TEXT, INCLUDING THREE HUNDRED ORIGINAL PHOTOMICROGRAPHS BY THE AUTHOR.

STUDENTS' EDITION.

Vol. I.—DENTAL HISTOLOGY AND EMBRYOLOGY.

(*To be read in conjunction with a study of Dental Anatomy.*)

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To

Sir James Crichton Browne, M.D., LL.D., F.R.S.

J. Howard Mummery, M.R.C.S., Eng., L.D.S., Eng.

and

Frederick J. Bennett, M.R.C.S., Eng., L.D.S., Eng.

as an

Expression

of Esteem and Sincere Regard

from

The Author

Uniform with this Volume.

By the same Author,

"Dental Microscopy," a Handbook of Practical Dental Histology.

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PREFACE

In presenting to the reader this humble effort to detail the essentials of his favourite study, the writer is fully sensible of the many shortcomings, textual as well as pictorial, which are necessarily attendant upon such an undertaking. It is extremely difficult to prevent subjective impressions and interpretations from obtruding themselves here and there, no matter how subsidiary to other weighty matters the author has endeavoured to make them. The personal equation is generally present and apparent in all work. The book represents an earnest struggle for an intimate knowledge of the truth, clear and unprejudiced. And if the expressions of personal opinions seem to be rendered too conspicuous they must be regarded on their individual merits, and tested and accepted or rejected, as the case may be. The astute reader must be the judge. The fallibility of him who now enters upon his task must not be forgotten, and where errors have been committed they must be condoned. But the honesty of the writer's purpose or of his convictions must never for one moment be impugned.

The establishment on a scientific and logical basis of the order, sequence, and internal composition of each chapter has been attempted. The manner of dealing with the variety of pathological facts and histological data in Chapters XIV., XV., and XVI. has been founded on two considerations. First, it has been deemed advisable to place on record an intelligent enunciation of what is implied by certain words.

Some writers, especially those of the Continent of Europe, are apt to confuse ideas, the result being a constant use of some terms found in ordinary dental nomenclature which possess a lack of uniformity of definition, &c. Second, this method of arrangement affords a convenient, and, therefore, suitable "setting" or background for the description of the histological characteristics of teeth and allied organs, which, after all, are intended to be the most distinguishing feature of the work.

An acquaintance on the part of the student with the simple elements of histology and pathology is pre-supposed. An extensive bibliographical mass, to which references are made throughout, has been consulted. In order not to burden the text with too great a number of the writings of many histologists, an attempt has been made to place their hypotheses on an eclectic basis, namely, those which in the eyes of the author are worthy, some of notice merely, others of serious consideration. Many fundamental propositions are not universally accepted, and some of these are here noted; so that the reader, interested in any special branch of Dental Histology or Patho-Histology, may receive hints and be guided and stimulated in taking up original research.

In this way, some prominence is accorded to the recent writings of Oscar Römer, who, with others, denies the existence *per se* of the sheaths of Neumann. On the other hand, the work of many is already sufficiently completed, and knowledge is, as far as can be ascertained, accurate enough. Thus, with no fear of being prolix, the researches of Aitchison Robertson on the growth of dentine may be cited extensively. But examples need not be multiplied.

The inclusion of Part III.—a preliminary histological examination of many of the commoner and some of the rarer morbid affections of the teeth, gums, and osseous framework of the mouth—affords the reader an opportunity of comparing the morphological differences between healthy and diseased conditions of the masticatory organs. This section of the book should, therefore, be read and studied in conjunction with Part I., and deductions drawn therefrom. The juxtaposition of the two should be of assistance to the thoughtful and enquiring student, and serve to extend and widen the area of his mental horizon.

The author desires to express his indebtedness to the published works of Mr. Charles Tomes, and to Drs. G. V. Black, Miller, Leon Williams, and Norman Broomell, for the use of some of the electrotypes which have accompanied their communications to *The Dental Cosmos*; and also for the same to the Council of the Odontological Society of Great Britain, and the Publishing Committee of the *Journal of the British Dental Association*. In addition, he is grateful for the loan of valuable material and sections to many personal friends at home and abroad. Finally, he wishes to thank Mr. Frank J. Butler, for his original water-colour drawings; and Mr. J. J. Ellison, of the Dental Manufacturing Company, for his unvarying courtesy and assistance in the production and publication of the book.

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CORRIGENDA

Page 16, line 12, *for* " hae " *read* " hake."
Page 93, line 1, *for* " coracoid " *read* " coronoid."
Page 97, under Fig. 77, *for* " inermous " *read* " abrachiate."
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Page 99, line 5, *for* " inermous " *read* " abrachiate."
Page 102, under Fig. 82, *for* " Inermous " *read* " abrachiate."
Page 154, line 17, *for* " Gowers " *read* " Gowers[2] " and footnote.
Page 227, last line, *for* " Fig. 212 " *read* " Fig. 211."
Page 228, last line, *for* " Chap. XXI." *read* " Chap. XXIII."
Page 360, under Fig. 284, *for* " Dentz," *read* " Dentz'."
Page 363, line 17, *for* " osteoblasts " *read* " osteoclasts."
Page 368, line 15, *for* " junction " *read* " function."
Page 471, line 9, *for* " thrown " *read* " thrown into."
Page 497, line 26, *for* " represent " *read* " represents."
Page 507, line 1, *for* " by " *read* " of the."
Page 509, line 20, *for* " was " *read* " were."
Page 509, line 31, *for* " Fig. 398 " *read* " Fig. 399."
Page 537, line 32, *for* " alveolar " *read* " cellular."
Page 551, line 24, *for* " vitiated " *read* " ciliated."
Page 554, line 1, *for* " comparably " *read* " comparable."
Page 605, line 1, *for* " forcing " *read* " forming."
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Part I

THE HISTOLOGY OF THE TEETH AND ASSOCIATED PARTS

CHAPTER I

PROLEGOMENA

To write a book is to build a house. When completed, the chapters are the rooms, adroitly planned and suitably furnished with pictures of interest. From the windows, the eye surveys many well-known fields and oft-trodden paths; but, beyond, it is unable to pierce the problem hills of uncertainty.

All literature relating to the theme of this thesis must, perforce, have its foundation stones laid on the classic work of Hunter, Kölliker, Owen, Tomes. It is impossible and unwise to ignore this work. In this manner the following pages are but comparable to a new wing of the house of Dental Anatomy, which these investigators have progressively and successfully raised; and if, from the windows, some instructive glimpses of the surrounding country can be obtained, and a few finger-posts pointing to the unknown, though by no means unknowable, be discovered by the eye—aided not by telescope, but by microscope,—then the writer will rest content.

That a treatise which deals chiefly with descriptions of the minute anatomy and pathology of the teeth and associated parts should be specially required may be questioned by some. Inasmuch, however, as these tissues, by reason of their unique constitution, differ most strikingly from other specialised organs, such as the eye, the nose, the larynx; inasmuch also, as general histological text-books treat somewhat sparingly, and sometimes incorrectly, of this subject, the production of these pages has seemed to the author perfectly justifiable, nay more, almost a necessity in these latter times "*Cui bono?*" was once a frequent question; but there can be only few (if any) who would to-day care to diminish rather than to increase the range of knowledge, and limit the speciality of Dental Surgery to mere mechanical manipulations.

Dr. Otto Walkhoff, Professor of Conservative Dentistry in the University of Munich, in an introduction to his "Normal Histology of the Human Teeth," 1901, declares:—

"The special study of the Histology of the Teeth is the binding link between practical dental surgery and general surgery. The branch of learning which deals with this subject is of great importance for the practical knowledge of the prospective dental surgeon. He learns not only the minute anatomy of the parts, but also the mutual relationships of those parts. Those dental surgeons who have had experience in making and examining sections of teeth are able to treat carious cavities with greater knowledge, and to appreciate and understanda ny complications that may arise, and therefore take more appropriate and more therapeutic measures than those unaccustomed to the science. With the fuller education of dental surgeons in this study, the production of false pathological and other statements will be relegated to the past. Thus one acquainted with the structure of the tissues could never claim to completely cleanse and solidly fill the root-canals of teeth. A due regard to the Histology of the tissues of the mouth (as well as its Bacteriology), and the most perfect execution of mechanical operations form the groundwork of the conservative dentistry of later years."

It must also be added, as has been expressed in another place, that the practice of microscopical work imparts to the student that delicacy of touch and nicety of adjustment of digital dexterity which is impossible of attainment by other means and methods.

This book, then, is published with the avowed purpose of drawing the attention of the reader to the essentials of a profoundly-fascinating branch of science; of indicating some difficult and apparently irreconcilable and irresolvable histological propositions; of attempting to elucidate, illuminate and complete other recondite and unfinished studies; and finally, of establishing upon a permanent and convincing basis many accepted postulates and uncontested facts.

Dental Histology, with its collaterals, is nearly, but not quite, an inductive science. Unfortunately, it is by no means an exact one, although, through the medium of new methods of research, there is no reason why, during the next half-century, it should not become so.

The science and art peculiar to it are ot paramount importance alike to student, pathologist and surgeon. In the interpretation of many ordinary and extraordinary phenomena connected with the genesis and evolution of the teeth ; in the solution ot certain obscure physiological and anatomical and pathological problems ; in the every-day diagnosis of oral and dental disease ; in short, in the undoubted assistance it can and does render to the earnest worker in the art of Dental Surgery, it may fairly be claimed for this subject that to-day it cannot be dismissed without recognition, or without the bestowal upon its varied aspects of such thoughts and labour and research as they deserve. In its scope and aims it is certainly ancillary to no other branch of learning.

On so slender a scaffolding it would seem somewhat difficult, it not well-nigh impossible, to build up such a large and diversified collection of valuable and interesting data ; nevertheless, a moment's reflection will soon assure the reader that this framework is extensive even in its limitations.

To attempt to recall and record the History of Dental Histology would form a congenial and satisfactory task. Mere mention of the names of those specially associated with it must, however, here suffice. As for the past, it is pleasant to an Englishman to dwell on the works of Thomas Huxley, Sir Richard Owen, Salter, Sir John Tomes, Storer Bennett ; while as tor the present, the bibliography of British dental science has been enriched by the writings of C. S. Tomes, who has patiently and laboriously investigated, among other subjects, the development of the teeth of fishes, reptiles, batrachians, and marsupial mammals; of Howard Mummery, to whom our knowledge of the development and growth of dentine is largely due ; of Milles and Underwood, in their researches on dental caries; of Leon Williams, the able and skilful exponent of the structure and pathology of human enamel; of Paul, who has successfully demonstrated the minute anatomy of Nasmyth's membrane; of J. G. Turner, who has identified himself with the etiology and pathology of dental cysts; and of Kenneth Goadby, the prolific contributor to current literature of a mass of information on dental and oral mycetology, &c. In America, the list of names must be headed by those of Andrews, Black, Norman Broomell, &c.; and on the Continent of Europe by those of Arkövy, von Ebner, Galippe, Grevers, Kölliker, Legros, Magitot, Miller, Retzius, Röse, Vignal, Walkhoff, Wedl, Weil, Zsigmondy, &c.

Rising out of a review of this subject come many thoughts, and chief among them are the remarkable scantiness of actual and reliable information concerning many things. Thus, with regard to the normal minute anatomy of the hard tissues, no answers have been returned to the questions, "How is enamel fixed so intimately to the periphery of the dentine?" "Whence comes its pigmentation?" "What is the manner of development of the branches of the dentinal tubes?" As to the pulp and alveolo-dental periosteum, some knowledge is available of the nerve endings in the first, while the histology of the latter still remains, as far as its nervous system is concerned, a *terra incognita*.

Turning to the realm of Pathology in general, and erosion of the teeth in particular, the causes of the occurrence of occlusion of the tubes requires further consideration, as do also the presence and sensitiveness or non-sensitiveness of the inter-globular spaces in hypoplasic teeth and ovarian cystic teeth, the changes in the dentinal tubes producing the "pipe-stem" appearance of caries, and their invisibility in senile affections. Tempting fields for research are all these and many others. The exigencies of this chapter disallow more than the brief consideration of one subject for discussion —viz., the pigmentation of enamel.

Thick sections of this tissue examined macroscopically before finally grinding, polishing and mounting always appear stained a more or less deep brown colour. This is different from and other than that of the brown striæ of Retzius. The thinnest sections ultimately reveal apparently but little, if any, pigmentation. Is this colouring, then, due to mere optical effects? In the opinion of the writer, No. Because, examples of the natural staining of epithelial tissues constantly occur—as in the case of the epidermis of the negro, where granules of melanin are found in the *rete Malpighii* of the epithelial layer of cells. Other analogies may be cited also—*e.g.*, the pigment corpuscles in the ramified nerve cells in the anterior cornua of the spinal cord of man, and the pigment bodies in the cortical substance of the hairs of man.

Again, the normal pigmentation of the enamel is a prominent feature of the teeth of many rodents. This also disappears on grinding very thin; and it is impossible to say whether it is resident in the enamel rods, or in the cementing substance, or in both. The tissue is unequally pigmented; if it was due to the chromatic aberrations of light it would most likely be uniform. Finally, in the case of pathological or congenital pigmentation of the cementum and dentine, the colour, though pronounced in thick sections or even before these have been made, has vanished when the thinnest are examined. The inference would be that this may also hold good with regard to enamel.

It would seem that the dental histologist of the future must more closely combine microscopical technics with a profounder knowledge of anatomy and physiology.

Of the utmost importance to such an one are three great principles,—the selection of material, the preparation of that material for experimental and histological research, and the correct interpretation of results.

First, the selection of material which is about to form the basis of investigation must not only be confined to perfectly fresh tissues, but as far as it is possible to determine to tissues absolutely unaffected by morbid conditions. This may be exemplified by the study, say, of the histogenesis of the teeth in normal well-developed embryos and fœtuses as compared with the different stages and rates of growth in rachitic individuals of a corresponding age. Contrasting the appearance of the two conditions may throw useful light on both; but conclusions drawn from examination of diseased tissues erroneously believed to be healthy, can only give rise to false deductions and misleading statements. Loose plans of procedure unfortunately militate strongly against that advancement of the science which is so earnestly desired.

Further, the preparation of the tissues is all important. The quotation of one single instance, in itself sufficiently striking, will be enough. The discovery of the real nature and characteristics of Nasmyth's membrane has followed the employment of proper methods of preparation.

Thirdly, tissues having been properly selected and prepared, suitably stained and carefully mounted—the risk of shrinkage or swelling having been reduced to a minimum—must be scrutinizingly examined and carefully and critically interpreted. It was undoubtedly the precipitation of amorphous silver chromate salts (as in Golgi's method of staining) or methylene-blue granules which lead Morgenstern and Römer to erroneously affirm the presence of non-medullated nerve fibres in the dentinal tubules and enamel. Check experiments must be conscientiously followed, and check stainings and methods of preparation adopted.

In conclusion, the original worker must be assisted in his accurate explanations of the meanings of the structures of cells and organs by keeping himself quite *en rapport* with the latest teachings of physiology and pathology. He will be most helped by devoting his attention to a preliminary thorough study of the knowledge we possess of the differentiated functions of cells; of the general principles that underlie and govern the physiological methods of tissue formation; of the metabolism of the cells forming the component parts of that tissue; and of the effects of pathological influences on the life-histories of the cells and other essential elements of the organs with which he has to deal.

CHAPTER II

NASMYTH'S MEMBRANE

MICROSCOPICAL ELEMENTS: (i) Cellular layer; (ii) Translucent pellicle

GENERAL CHARACTERISTICS

Definition.—A macroscopically-invisible cellulo-laminar film situated on the free surface of the adult enamel of man and certain animals.

Origin.—This tissue, which has recently been studied afresh microscopically, is now known to have its origin as an epiblastic formation of the epithelial cells of the enamel organ.

It is most probable that the cellular layer is derived from the external epithelium, and the pellicle or innermost layer from the spent cells of the internal epithelium, which have previously undergone a keratinous or somewhat analogous change.

With regard to its origin, R. R. Andrews ("The American Text-book of Operative Dentistry," p. 92, 1901), says that his investigations lead him to believe that the internal epithelium of the enamel-organ (ameloblasts) composes the cells in the membrane. These "having performed their function, have filled with calcoglobulin and have partially calcified, becoming somewhat like that tissue which we find on the borderland of calcification." That this is an entirely incorrect view is obvious when Paul's and the writer's sections are examined.

Distribution.—Situated externally on the cortical aspect of the unworn enamel of man, monkey and sheep, is found under suitable conditions Nasmyth's membrane. It is a thin continuous tissue spread flat over the enamel, dipping into the naturally-formed pits and fissures on the surface, and limited in extent by the cervical portion of the tooth, to the edges of which it is attached. *Synonym.*—The enamel cuticle. It has also been incorrectly termed "persistent dental capsule."

Bödecker[1] considers that it is in direct union with the outermost epithelial layer of the gum, being therefore the only layer which closes up the space between the neck of the tooth and the adjacent gum.

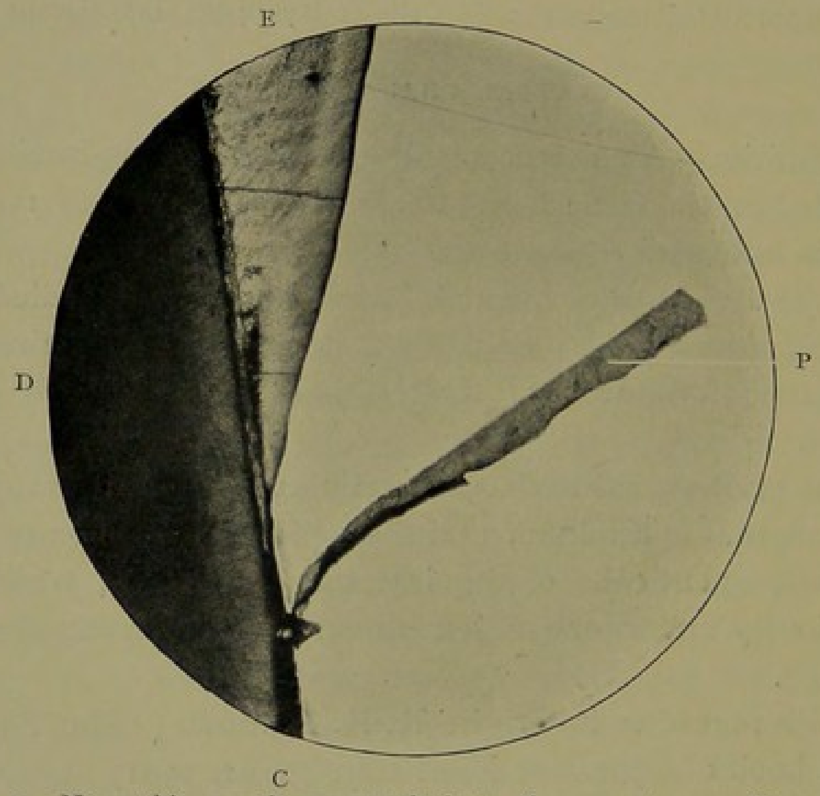

Fig. 1.—Nasmyth's membrane attached to the cementum. Prepared by decalcification of a ground section. Magnified 40 times. P. The membrane; E. Enamel; D. Dentine; C. Cementum.

In a well-developed adult premolar its measurements are 29 mm. in its widest part, 19 mm. in the narrowest, and 26 mm. round the cervical region of the tooth. All teeth possess the membrane in a more or less complete condition. Even senile teeth when treated with a decalcifying solution to remove the enamel have traces of it, but it is best observed in those teeth which, while still unerupted (premolars, for instance), have been removed for the treatment of irregularities, because

[1] "Anatomy and Pathology of the Teeth," p. 43, 1894.

in this case the cellular layer is undamaged, though it may be injured during the act of extraction. Portions of the cellular layer may remain attached to the inner aspect of the dental sac, which as a rule also comes away with the tooth. According to Kölliker it measures in thickness from 1μ to 2μ. This is probably erroneous, a measurement of 50μ being likely to be more accurate. Easily detached by the action of strong acids, it is only when Paul's method of preparing specimens is adopted that its real normal structure is ascertained.

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Nasmyth's membrane consists of two parts (i) an outer cellular portion, and (ii) an inner structureless translucent lamina or pellicle. These are both intimately adherent, not only to each other, but also to the free ends of the underlying enamel columns.

(i) *The Cells*

The cellular portion is interesting, inasmuch as its structure is made up of a layer or layers of large polygonal flattened epithelial cells, with pronounced nuclei. "The epithelial cells," writes Bödecker (*op. cit.* p. 92), "in transverse section, have the appearance of shallow spindles. Not infrequently there occurs also a stratified epithelium on the surface of the tooth. The enamel-fibres are in connection with these epithelial bodies which, if detached, show delicate offshoots adhering in regular intervals—the broken enamel fibres. Sometimes the surface of the enamel is coated by a thin uniform layer of protoplasm with regularly scattered nuclei. In such an instance single epithelia are not traceable, though scarcely any doubt can arise about the epithelial nature of this layer."

It is quite possible and most probable that the cells are more than one layer in depth. Preparations when correctly stained exhibit such a dense pattern of cells that this belief in the multiplicity of layers is probably well founded. It is doubtful, however, if more than three layers ever exist. The double or treble layers are not observed all over the surface of the pellicle, but only in those situa-

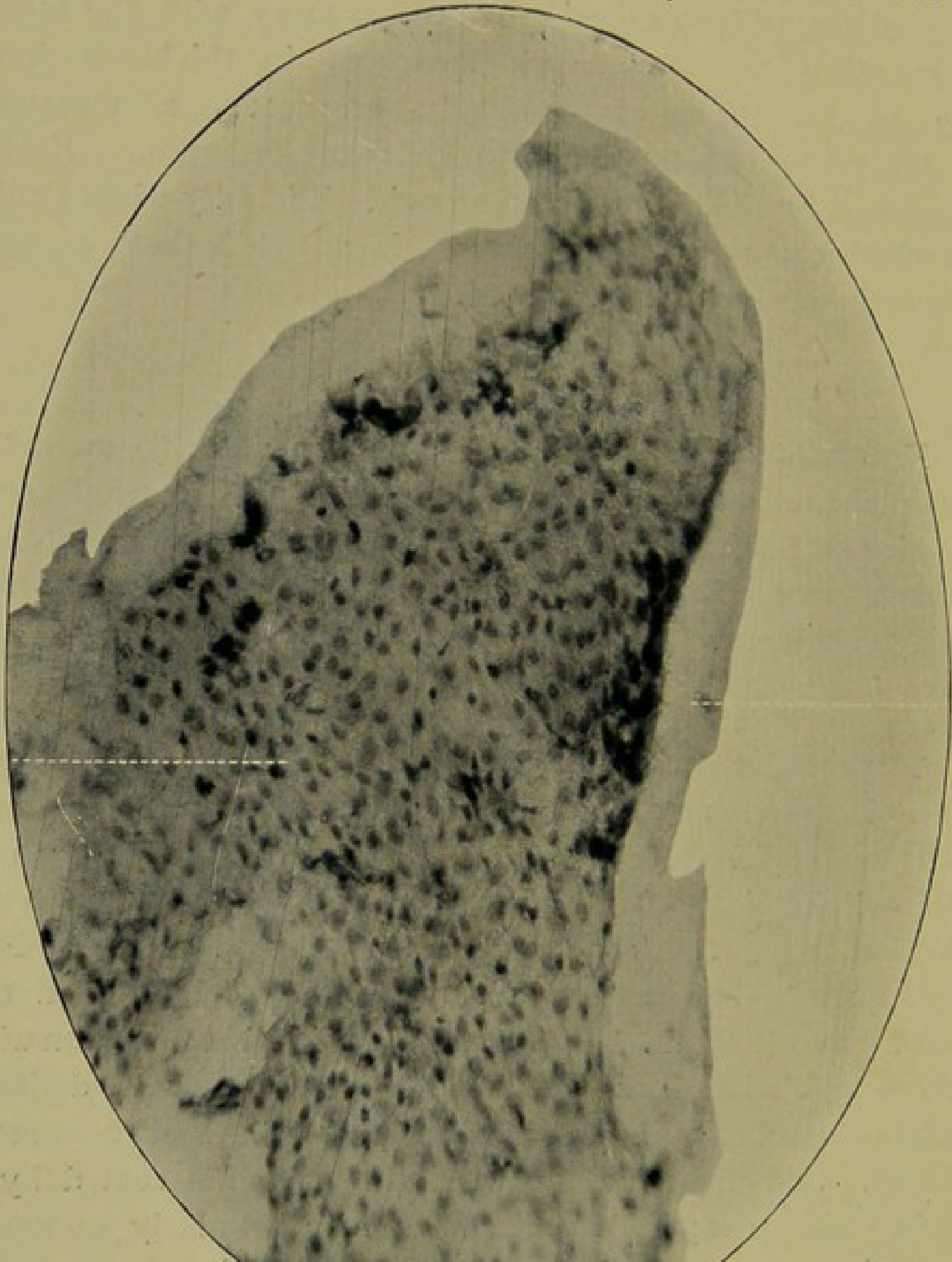


Fig. 2.—A piece of the thinnest portion of Nasmyth's membrane flattened out, and photographed from above. Its elastic nature made it impossible to critically focus it in all parts. Prepared by Paul's method. Magnified 200 times. C. Nuclei of the cells ; P. Translucent Pellicle.

tions where the membrane dips down deeply into the pits or crevices of the enamel ; and here too the pellicle itself is apparently thicker than elsewhere. The protoplasm of the cells is faintly granular. Under high powers, the spongioplasm and hyaloplasm may be clearly defined.[1]

Paul[2] attributes to the cells an average diameter of 12μ and a length of 25μ. Cells having "cogged" outlines—spiny-cells—are seen constantly (*Cf.* Fig. 160): and in places the polygonal cells are flattened, probably by mutual pressure, in one or more lateral directions, and may thus assume a cubical or even cylindrical shape. The nuclei are particularly large compared to the size of each cell, are ovoid in shape or nearly round in outline, and possess faint nucleoli. These are usually single, and often contain in their interiors, as well as near their exteriors, one or more vacuole-like, bright, shining globules.

(ii) *The Pellicle*

The inner or subepithelial layer is a delicate continuous membrane, apparently without histological structure of any kind. It is translucent, elastic and cornified, and resists the action of acids in a similar way to the sheaths of Neumann or the linings of Haversian canals. On its under surface, *i.e.*, the part nearest enamel, a reticulated pattern can be fairly easily demonstrated. This corresponds to and is probably produced by the free ends of the enamel prisms, which have left their hexagonal impressions on the membrane. It is to be noted that the hexagons of the pattern have sharp, clear margins made up of straight outlines, correspond in size to the diameter of the enamel prisms, and in no way approximate the size of the epithelial cells, being "at least ten times too large for the enamel prisms." (Paul.)

In sections of Nasmyth's membrane which have been obtained *in situ* it has been possible to find in the deep enamel-pits lacunæ similar to those of osseous tissue,

[1] The "spongioplasm," according to Schäfer, is a reticulum or network of protoplasm in the cell substance; and "hyaloplasm" is the name applied to the materia which occupies or fills its meshes.

[2] "Nasmyth's Membrane.' *The Dental Record*, 1894.

surrounded by a capsule, and apparently associated very closely with the translucent layer of the membrane. Tomes[1] has repeatedly seen this condition. How these encapsuled cells get into the pits or fissures is not quite clear. There is an occasional appearance noticed in teased or spread-out

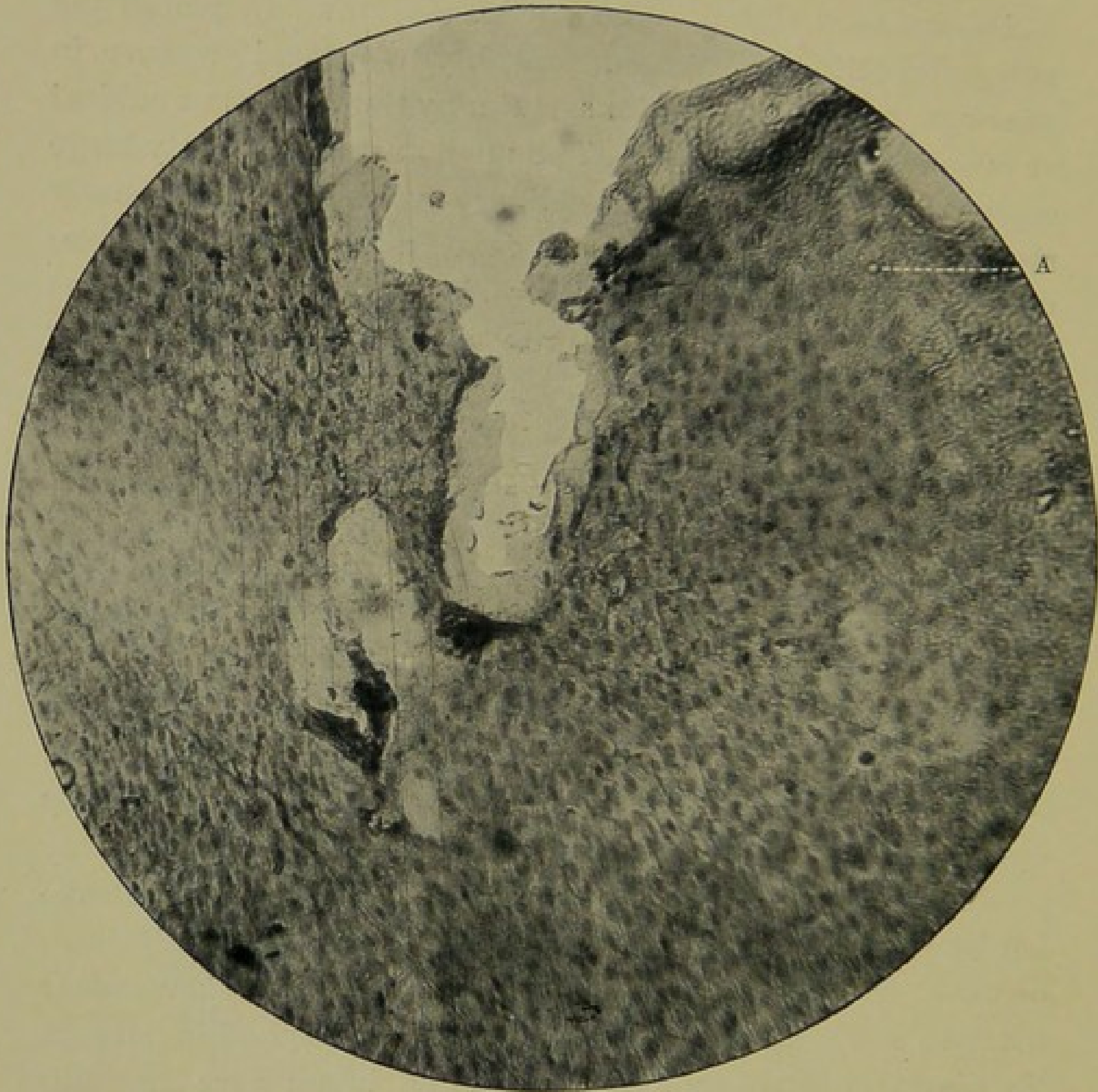


Fig. 3.—A thicker portion of Nasmyth's membrane than in Fig. 2. Magnified 200 times. A, Hexagonal impressions of the enamel rods.

pieces of the membrane of the cells being arranged concentrically round certain tiny spaces, and it may be that these represent in some way the spots where encapsuled lacunæ may be deposited. A lacuna may perhaps represent a persistent retained and imprisoned cell of the *stratum intermedium* of

[1] "A Manual of Dental Anatomy," p. 100, 1898.

the enamel organ where, owing to the formation of the cusps of the teeth, an involution of this layer of cells has taken place; or it may represent an aberrant osteoblast which has likewise remained unatrophied or unabsorbed.

Fresh research on this matter is needed before a dogmatic opinion can be expressed.

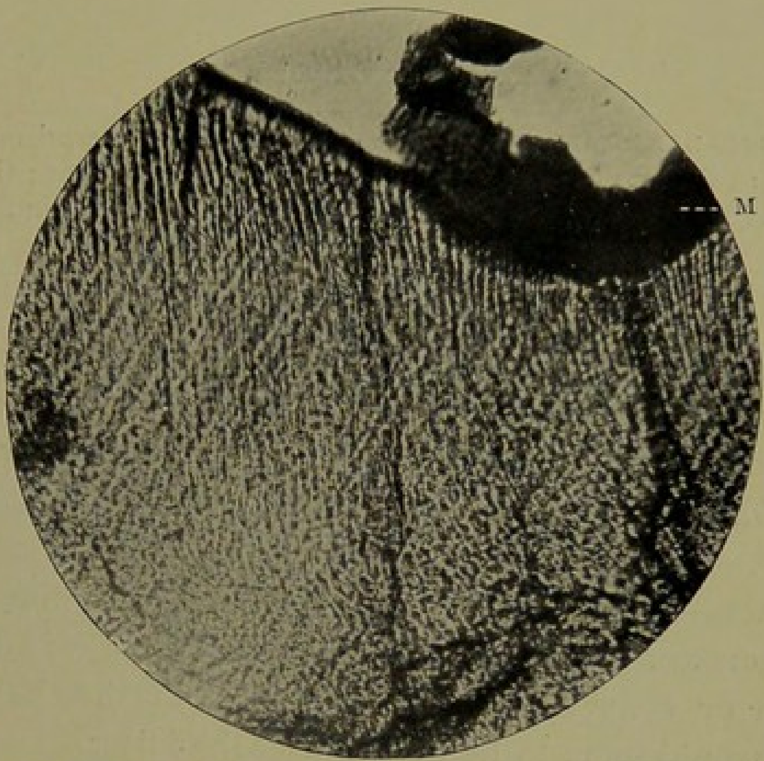


Fig. 4.—Enamel of a tooth, with Nasmyth's membrane on the free surface, removed from an oöphoronic dermoid cyst. Ground thin and then decalcified. Unstained. Magnified 250 times. M. Nasmyth's membrane.

From the enamel of recent teeth removed from ovarian dermoid cysts, the pellicle can be isolated by careful decalcification.

It is now perfectly established that Nasmyth's membrane can be regarded with certainty as an epithelial remnant of the enamel organ, and thus the theories of Waldeyer, Röse, and others are to be considered correct.

CHAPTER III

THE ENAMEL

MICROSCOPICAL ELEMENTS: (i) Enamel rods and interprismatic substance; (ii) Curvatures of rods; (iii) Supplemental columns; (iv) Brown Striæ of Retzius; (v) Lines of Schreger; (vi) Enamel "Spindles."

GENERAL CHARACTERISTICS

Definition.—The smooth, hard, glistening inorganic substance which partially or wholly envelopes the crowns or visible portions of the calcified teeth of the *Pisces*, *Reptilia*, and *Mammalia* classes of the vertebrata.

Origin.—It is the final product of the layer of cells—the ameloblasts—which constitute the internal epithelium of the enamel organ. It is yet undecided whether enamel is a secretion or conversion of these cells, but the balance of opinion would seem to be in favour of the latter.

Distribution.—Existing as (i) a tiny point or tip, as in the teeth of some members of the class *Pisces*, *e.g.*, the order *Anacanthini* — Merlucius vulgaris (the hae), the order *Physostomi*, family Murænidæ—Anguilla acutirostris (the eel); or (ii) a partial investment of the cutting edges of teeth, such as those of the incisors of *Rodentia*, the lower canines of some *Bunodonts*, &c.; or (iii) longitudinal bands, as in the upper canines (tusks) of the wild boar; or (iv) an entire cap of varying thickness, which covers over the normally-erupted parts of the teeth of mammalia generally,—except of the sub-order *Artiodactyla*, where a thick coating of cementum is developed in this situation,—enamel is the hardest tissue of the teeth or any of the organs of man and animals.[1]

[1] In the lower incisors of the *Chiromydæ* (e.g., the Aye Aye) enamel forms by far the greater portion of the teeth, exceeding in amount both dentine and cementum.

In man it intervenes between the translucent pellicle of Nasmyth's membrane, placed externally, and the periphery of the dentine which goes to make up the greatest part of the tooth substance internally. Nasmyth's membrane is invisible macroscopically; at least it is unrecognisable, and, therefore, as this film becomes abraded the enamel becomes the most external of the dental tissues.

In the *Artiodactyla* it occupies a position (Fig. 5) between the cementum and the dentine.

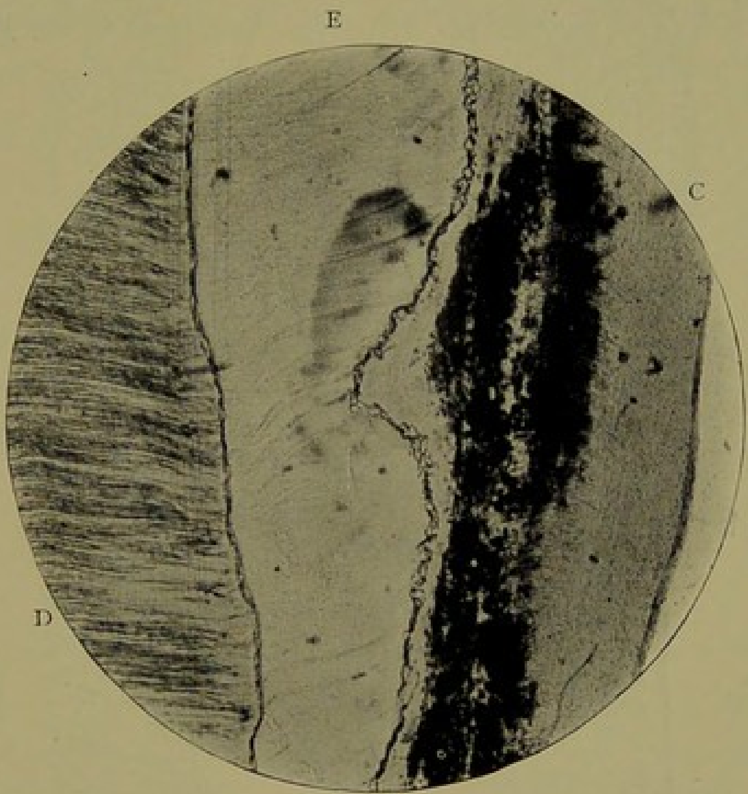


Fig. 5.—Vertical section of a molar of a young horse. Section ground thin. Unstained. Magnified 45 times. E. Enamel; D. Dentine; C. Cementum.

In sagittal (vertical labio-lingual) sections of the well-developed incisor teeth of man, unworn by attrition, it measures at the incisive edge about 2 mm. in depth; and then, as it gradually approaches the cervical margin, it becomes thinned down to zero. Over the cusps of premolars it is 2·3 mm., and over the cusps of molars it is 2·6 mm. in thickness.

The enamel of the deciduous teeth may be half the thickness of that of the permanent series.

At the gingival edge it may or may not slightly overlap the thin structureless border of cementum. Monsieur Jules Choquet, who investigated (1899) the question of the anatomical relationships of the two tissues, in an interesting *brochure*

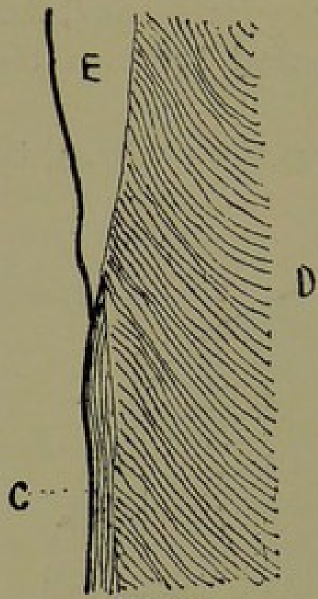


FIG. 6.

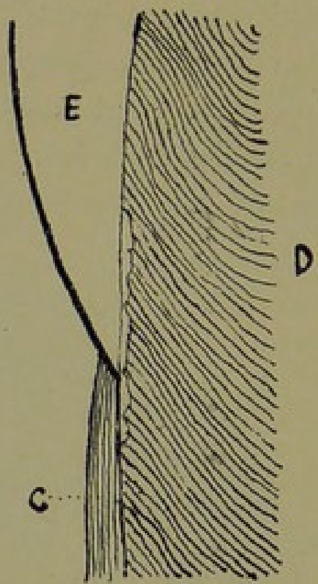


FIG. 7.

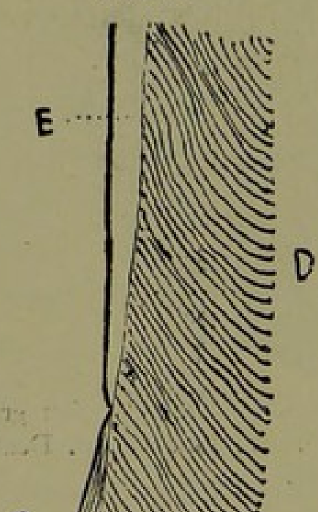


FIG. 8.

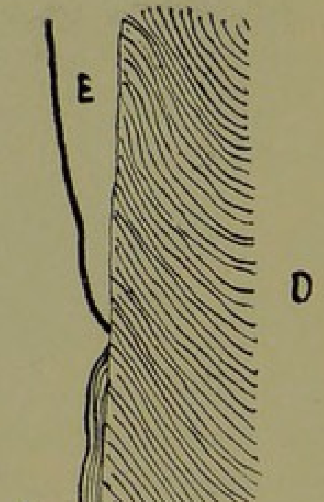


FIG. 9.

Figs. 6, 7, 8, and 9 adapted from photomicrographs by Jules Choquet, and published by *L'Odontologie*, 1899. Semi-diagrammatic. Human. E. Enamel; C. Cementum; D. Dentine.

entitled "Note sur les rapports anatomiques existant chez l'homme entre l'émail et le cément," has succeeded in throwing light on this subject. He examined and reported on twenty-nine human teeth; and found that the enamel covered the edge of cementum eight times (Fig. 6), while the cementum overlapped the enamel seven times (Fig. 7). This author also reports that, in the majority of cases, the enamel and cementum meet each other, and there is no overlapping (Fig. 8). Out of his twenty-nine sections this occurred nineteen times. Thus the rule would be that the two tissues are in absolute contact, and both lie in the same plane without any involution whatsoever. Choquet further found that in 27·5 per cent. of the cases he examined, there was a breach of continuity of these two structures, leaving a minute portion of the dentine fully exposed (Fig. 9). His sections were cut longitudinally,

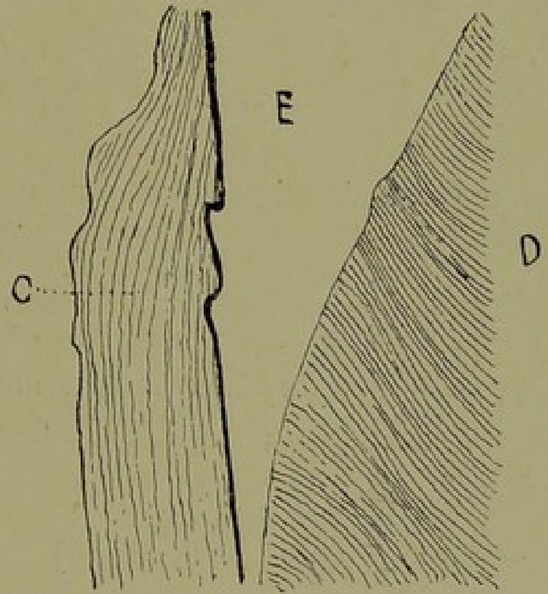


Fig. 10.—Vertical section of a Human tooth, from a photomicrograph. Semi-diagrammatic. E. Enamel; D. Dentine; C. Cementum.

and some were studied on both their aspects, whilst others only on one. "Cette différence tient à ce que dans certains cas il y avait eu fracture de l'émail d'un des bords pendant l'usure de la coupe." There was often a diversity of method of ending of the tissues: thus, one section would have on its labial aspect the enamel overlapping the cementum, and on its lingual surface, the former internal to the latter. The teeth were representative specimens from young, old, and gouty subjects.

On rare occasions, as in Fig. 10, from a section in the possession of Sydney Spokes, the margin of cementum may extend in a remarkable way, some considerable distance over the edge of enamel. From the structure of the tissue consisting as it did of matrix containing many large lacunæ and incremental lines, it is important to point out the fact that the cementum was in no sense normal. The tooth, a mandibular third molar, was slowly erupting in an irregular manner.

Macroscopical Appearances.—Surface smooth, shiny, sometimes traversed by tiny vertical or horizontal depressions, occasionally scrobiculated and normally deeply fissured in premolars and molars, and pure white in colour. When fractured, pure white, non-lustrous.

HISTOLOGY

On microscopical examination Human enamel reveals many interesting structures. These may be described in the order of their importance as: (i) The striated columns and calcified matrix; (ii) The curvatures or courses of the rods; (iii) "Supplemental" prisms; (iv) The brown striæ of Retzius; (v) The lines of Schreger; and, (vi) Certain spaces or "enamel spindles."

(i) *Enamel Rods* (Man)

Enamel is built up of minute solid prisms, or columns or rods, more or less hexagonal or pentagonal in shape, all united by a matrix or interprismatic cementing material of somewhat different refractive index. It is probable that the *real* shape of the columns is that of a solid cylinder. If an ameloblast could undergo complete segregation and continue its functional activity a rounded rod would, no doubt, result. The hexagons are most likely produced by the lateral pressure of lengths of contiguous rods, in much the same way as obtains in the six-sided cells of the bee's honey-comb. (See Fig. 14.) The matrix is not a connective tissue ground substance; but merely a more or less perfectly calcified cementing substance.

When isolated by means of the careful application of dilute acid solutions, the prisms have their cementing substance dissolved, and can then be examined critically (Fig. 14).

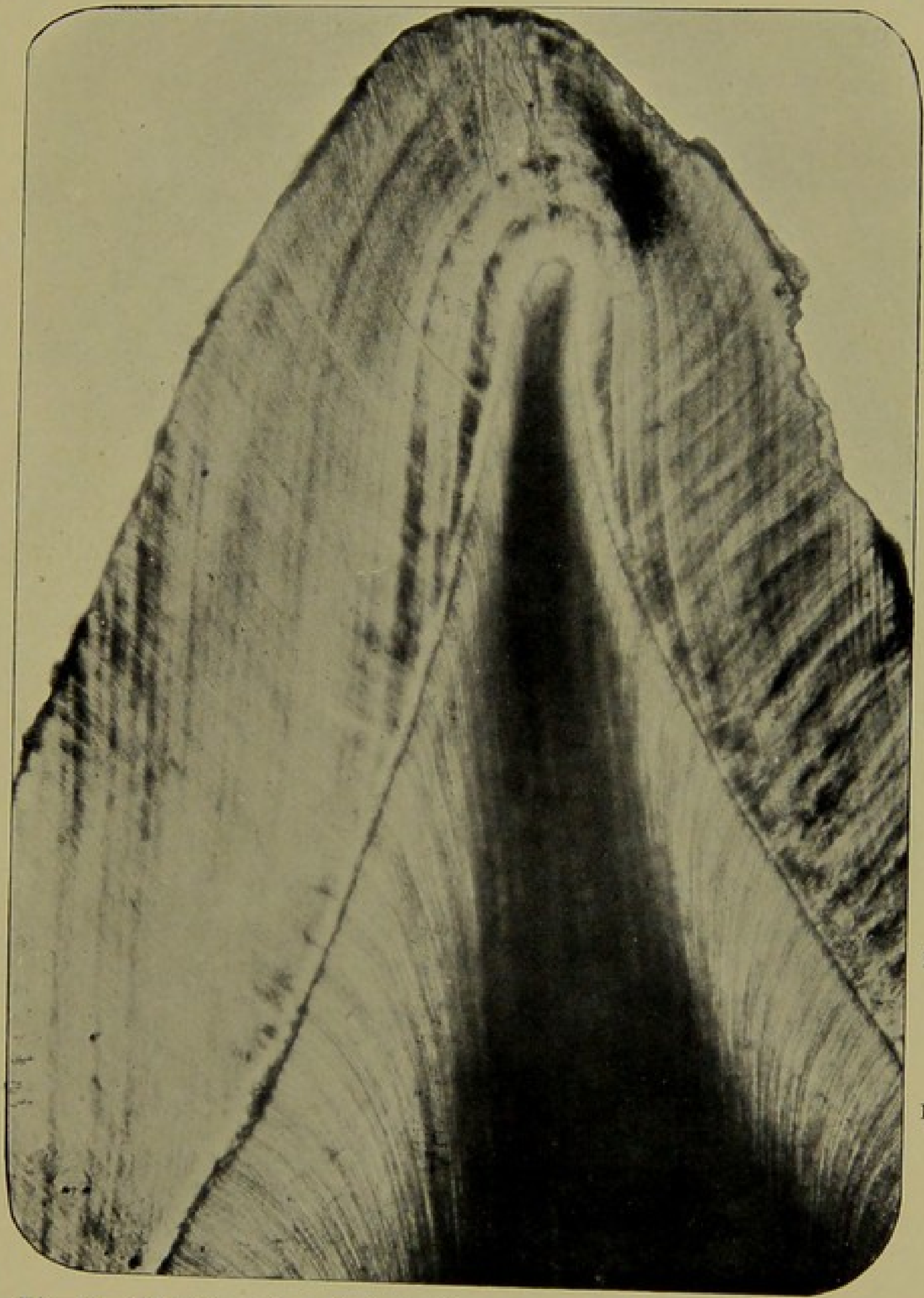


Fig. 11.—Sagittal section of the incisive edge of a Human incisor tooth. Ground thin. Unstained. Magnified 45 times. Shews the general pigmented appearance of the enamel. E. Enamel; D. Dentine.

They are absolutely solid in the adult or mature state, *i.e.*, when fully completed, rather flexuous or curved in contour, and measure ·005 mm. (5μ) in diameter. Kölliker in "A Manual of Human Microscopic Anatomy," 1860, gives their breadth as 6·4μ to 5·1μ. Their length may attain to 2 mm.

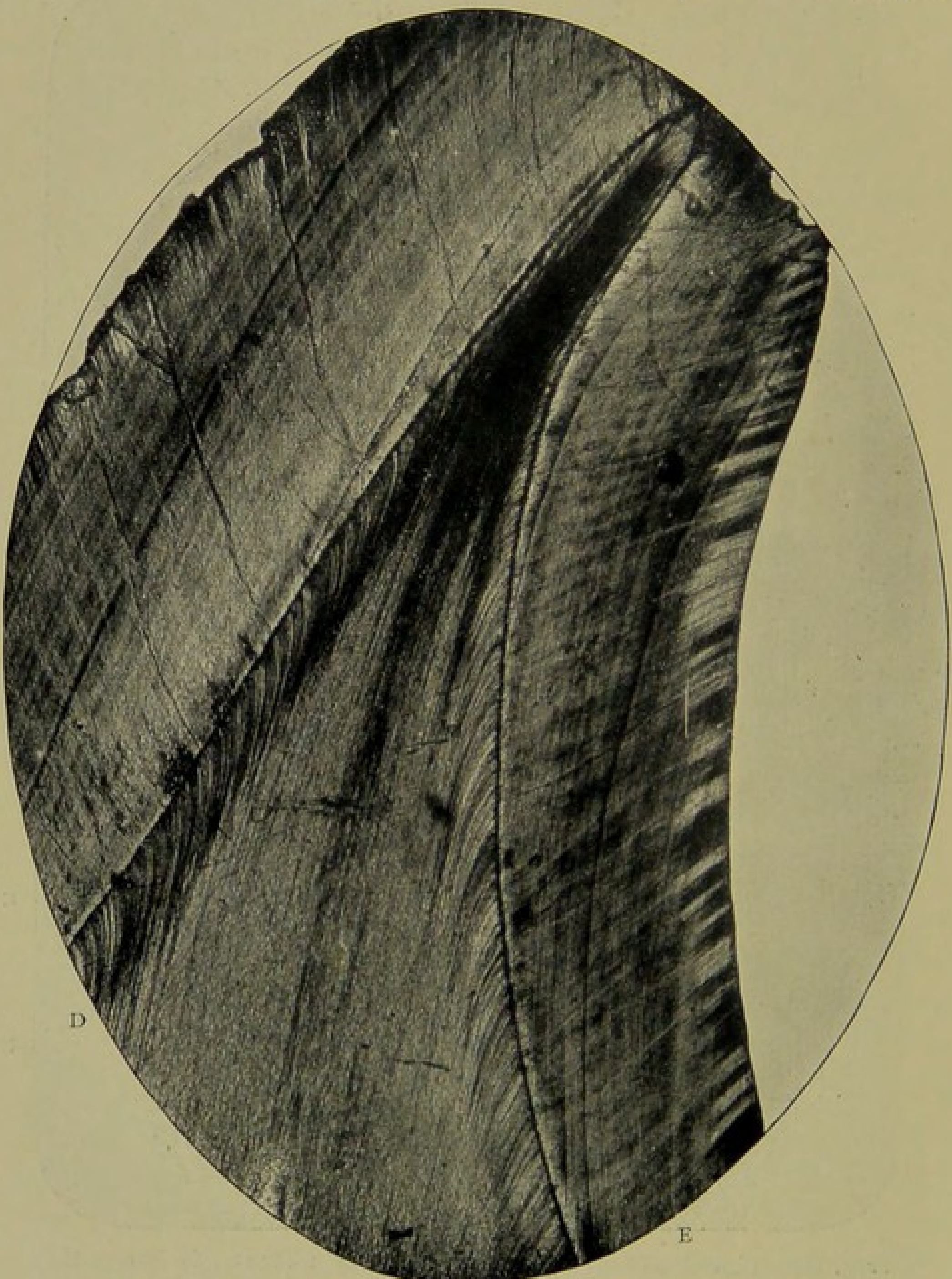


Fig. 12.—Sagittal section of the incisive edge of a Human canine tooth. Ground thin. Unstained. Magnified 45 times. E. Enamel; D. Dentine.

The outlines of the prisms, in addition to being curved, are beaded, or very slightly varicose. Their long axes are,

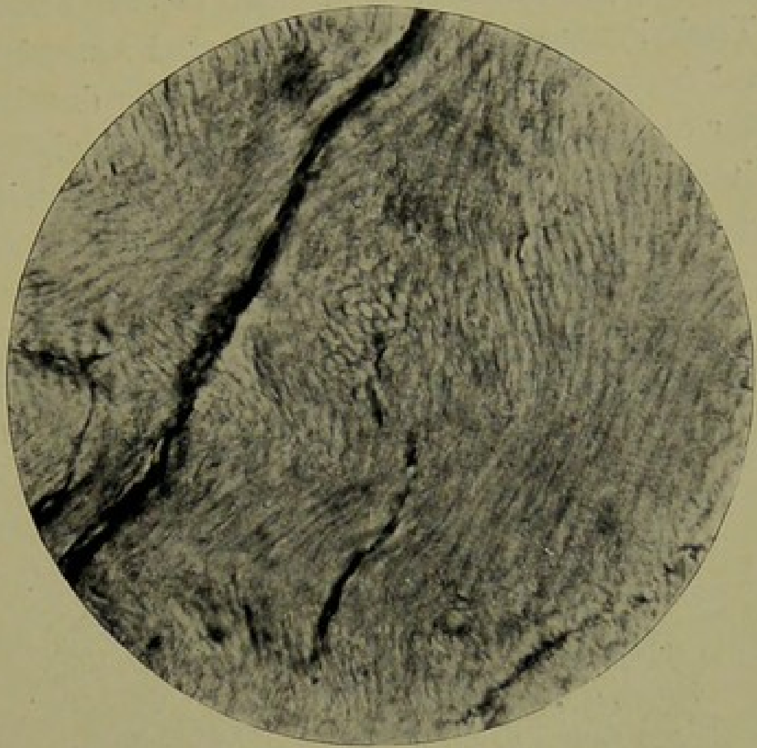


Fig. 13.—Human enamel. Prepared by grinding. Unstained. Magnified 250 times.

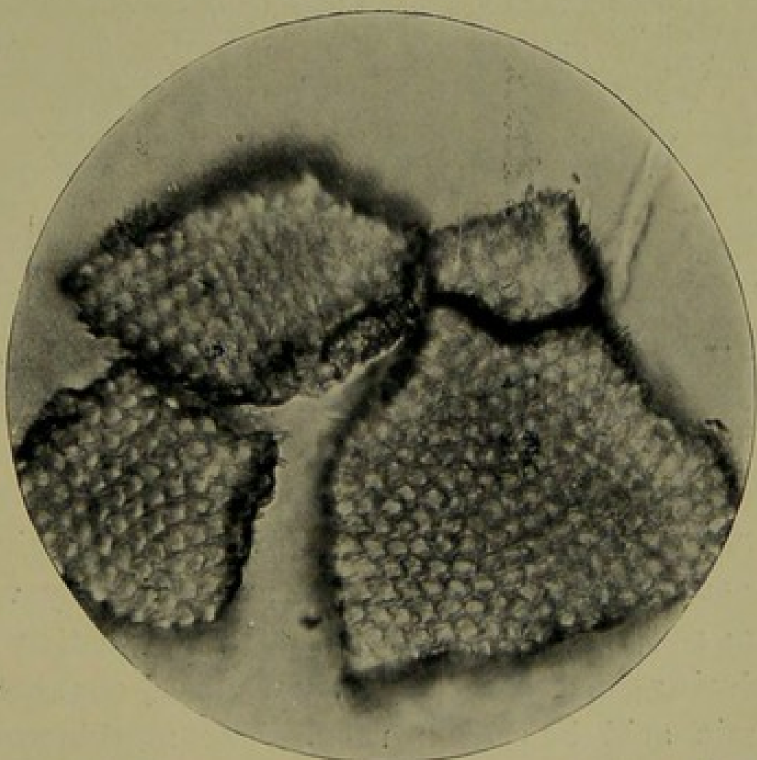


Fig. 14.—Enamel rods, as seen in transverse section. Decalcified and teased out. Magnified 500 times.

speaking broadly, placed at right angles to the surface of the tooth. Their inner extremities are inserted securely in tiny hexagonal depressions on the surface of the dentine: while their outer ends are free, and crop out of the periphery of the enamel itself, thus giving rise to faint markings on its cortical outer aspect, and probably affording close attachment to the pellicle of the enamel cuticle, to the hexagonal impressions of which they are ultimately and intimately fixed. (See Fig. 3).

At regular linear intervals, and at distances varying from 5μ to $3{\cdot}5\mu$, the enamel rods are crossed by distinct

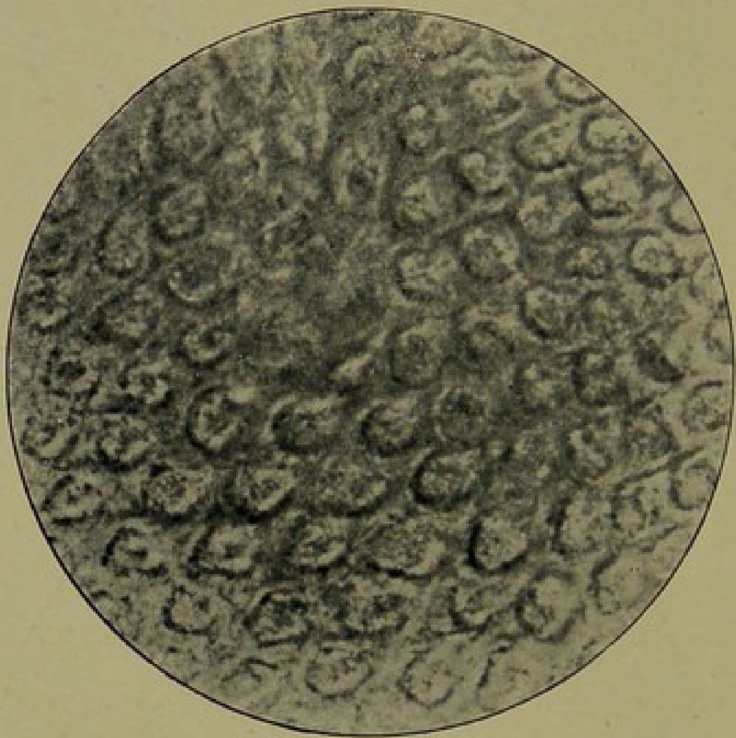


Fig. 15.—Transverse section of enamel rods, magnified 2,000 times. Photomicrograph by Leon Williams.

shadings called transverse striæ or varicosities, which closely resemble the stripes of striated voluntary muscle fibres (Figs. 17 and 23). These striæ are only seen in longitudinal or oblique sections of the prisms, and are ordinarily very faint. They are rendered more apparent by the action of dilute hydrochloric acid, and occasionally when a $\frac{1}{4}$ per cent. solution of chromic acid has been used. The markings are more clearly and easily seen in the outer portions of the enamel, and may be remarkably demonstrated in very pigmented or degenerated conditions of the hard tissues: they may be very indistinct, or even absent, in the region of the enamel near the dentine.

According to Bödecker the enamel is traversed by fibres of living matter located in the interstices between the enamel rods. The fibres are connected with one another by delicate fibrillæ, piercing the enamel rods in a vertical direction.

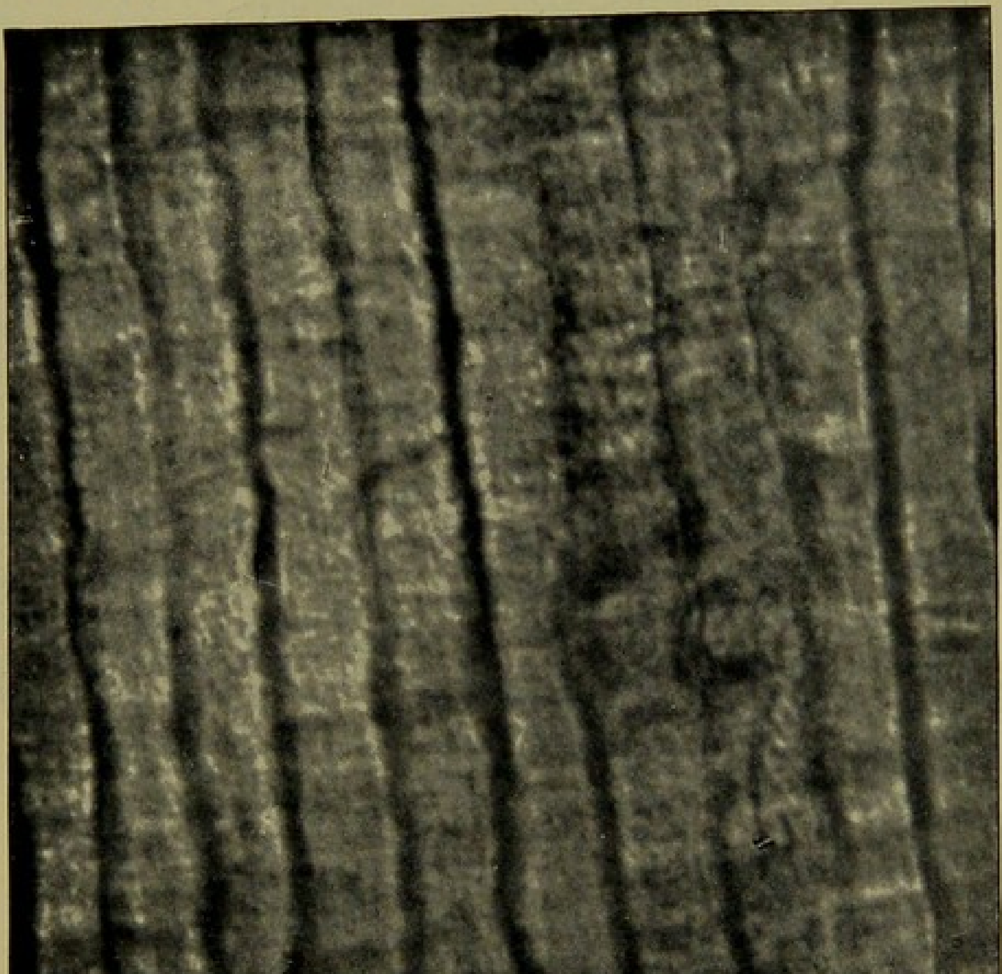


Fig. 16.—Section of enamel from Human tooth. Magnified 2,000 times. Dark ground illumination. Focussed in the middle of the section to show the granular calcified plasm-strings. The transparency of the cement-substance between the enamel rods is perfectly demonstrated in this illustration. Photomicrograph by Leon Williams.

Besides these rectangular unions, the basis-substance contains a minute network of living material which pervades it throughout its whole extent. The enamel fibres send conical thorns toward the enamel rods, and such thorns are visible in all interstices between the enamel rods.

The enamel fibres are continuous on the outer surface with the covering layer of flat epithelium, and on the inner surface with the dentinal fibres. The connection with the latter is either direct or indirect through a network of living matter, or through intervening protoplasmic bodies in the interzonal layer (Fig. 19).

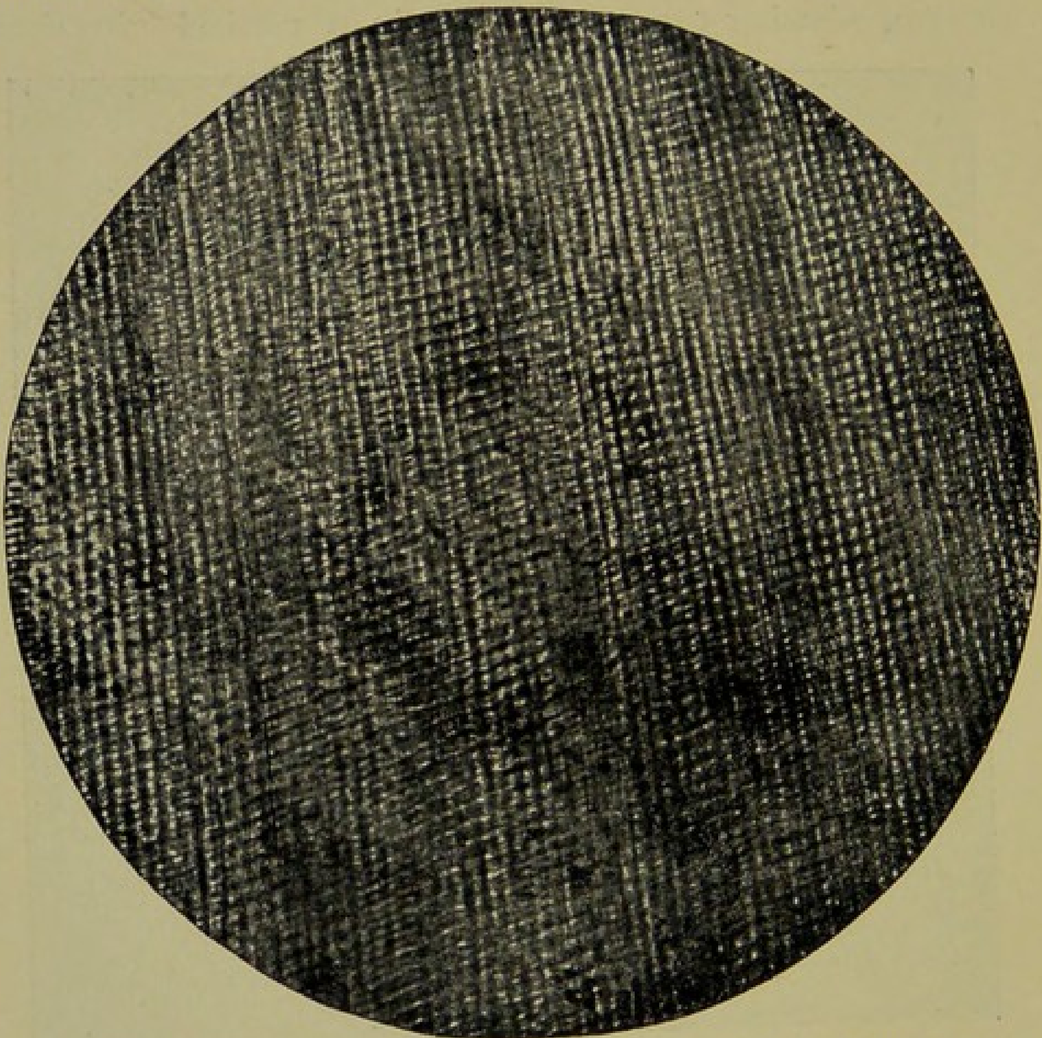
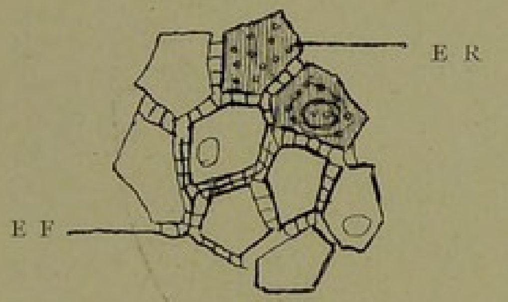


Fig. 17.—Section of enamel from Human tooth. Magnified 350 times. Section prepared by Howard Mummery. The transverse markings of the enamel-rods are very pronounced. The enamel-rods are everywhere seen to be united by projecting processes. Photomicrograph by Leon Williams.

And also Abbott (*op. cit.* p. 95) has further given a drawing showing the enamel-rods, the light reticulum within them, the intervening fibres, and the lateral off-shoots of the fibres.

The researches of Tomes, Leon Williams, and others, have, however, demonstrated the fallacy of such statements, and it must surely be an unpardonable hyperbole to affirm the existence of a chain of living material passing from the periphery of a tooth to its sentient pulp. The experiments of Tomes and Black have conclusively and for ever proved the inorganic nature of enamel.

Nearly every section of normal as well as pathological enamel, whether ground and mounted in balsam or glycerine, whether stained or unstained, whether decalcified slightly with weak acid, like one per cent. citric acid, or prepared under conditions resembling Nature as



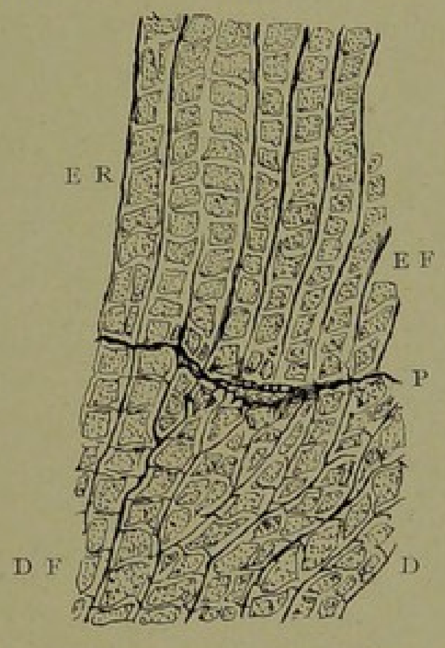


Fig. 18.—Transverse section of enamel, after Bödecker. Magnified 2,000 times. E.R. Rods of enamel, partly exhibiting formations like nuclei; the light interstices between the rods traversed by delicate beaded fibres E.F., or by vertical thorns.

Fig. 19.—Longitudinal section of enamel and dentine, after Bödecker. Magnified 1,200 times. E.R. Enamel rod; E.F. Enamel fibre; D. Dentine; D.F. Dentine fibres; P. Soft protoplasmic formations at the boundary between both tissues.

closely as possible, reveals a certain degree of pigmentation. If, however, treated with Golgi's rapid silver chromate method, this coloration in normal ground sections is intensified, as a reference to Figs. 20, 28 and 29 will shew.

The enamel of ovarian teeth, deciduous teeth, and nodules found on the necks or roots of teeth, exhibits also this pigmentation.

Of all investigators in the difficult subject of enamel histology, the name of Leon Williams will ever stand out preeminently. His magnificent work on the minute anatomy as well as the pathology of this tissue is well known, and he has contributed probably by far the greatest amount of knowledge on the matter.

According to this author[1] enamel rods are constructed by the successive deposition of certain "bodies" formed in the enamel cells, a deposition which goes on with the utmost order

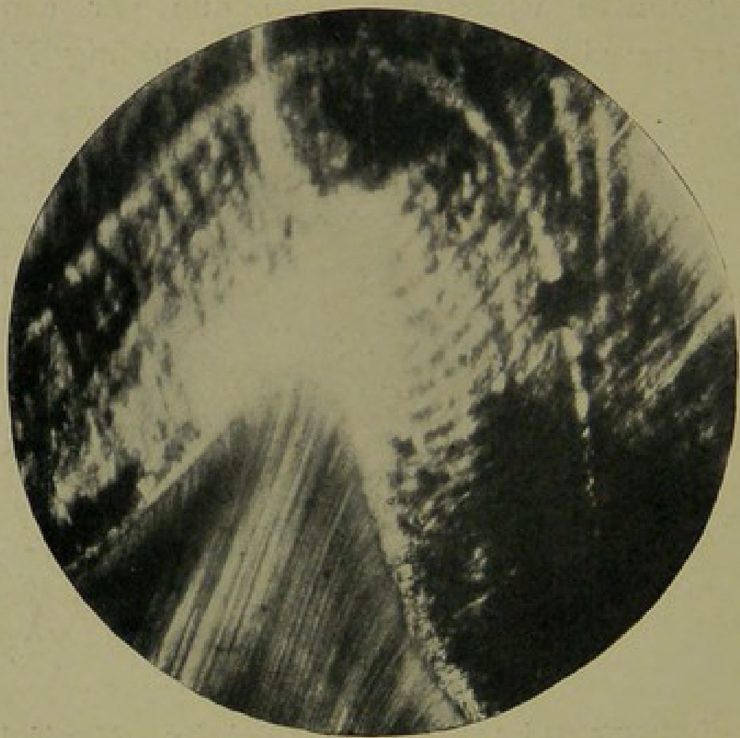


Fig. 20.—Vertical section of normal enamel treated by Golgi's rapid process. Magnified 45 times.

and regularity. The rods possess a more or less definite organisation. These "bodies" are beads of granular material, which, under high magnification, are joined together by calcified plasmic strings and processes. (Figs. 16 and 21). They lie exactly opposite each other, and the granular strings are larger and more clearly defined on the extreme margins of the enamel rods. Thus Leon Williams has demonstrated indubitably that the "bodies" are connected vertically

1 "On the Formation and Structure of Dental Enamel." *The Dental Cosmos*, 1896.

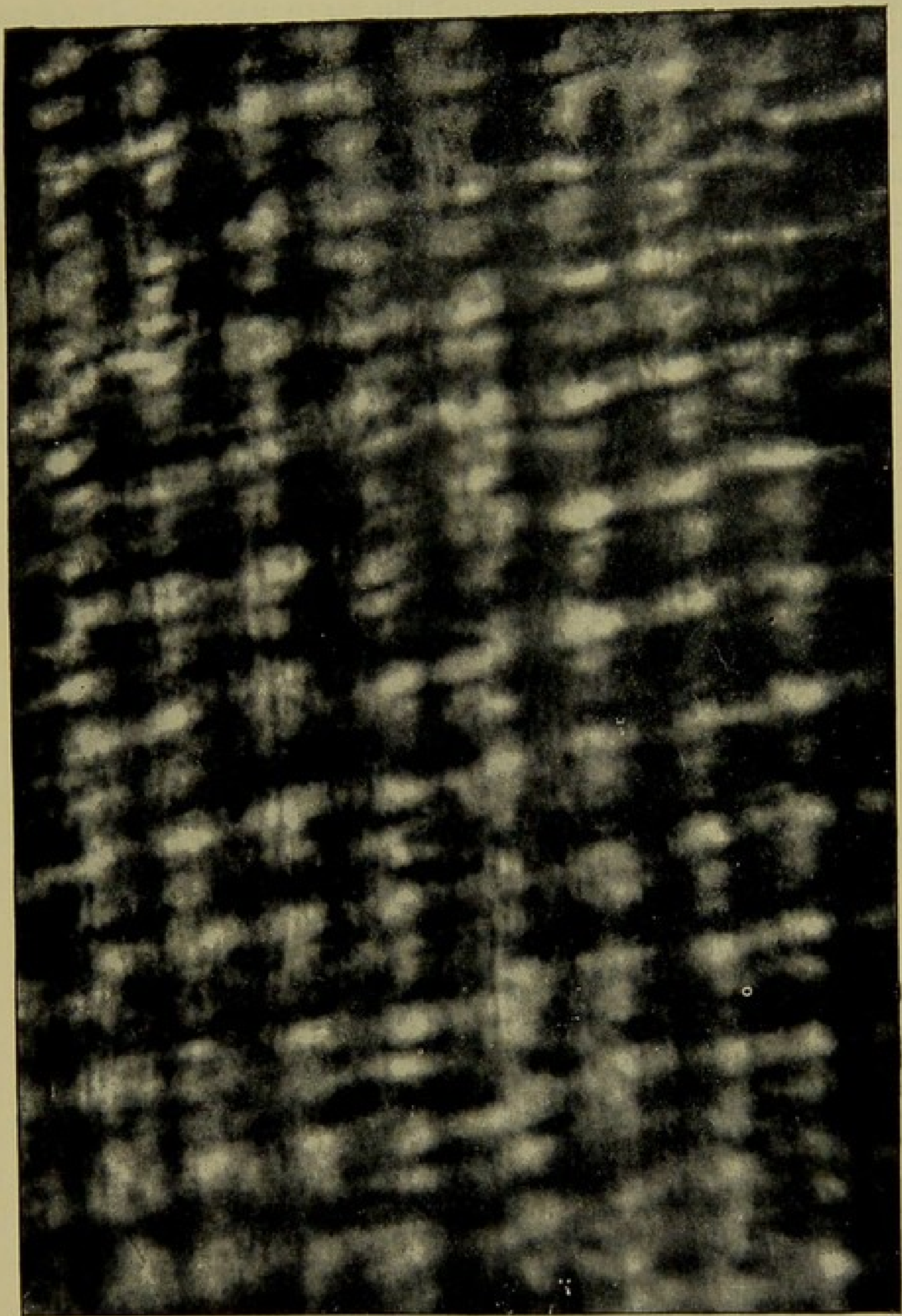


Fig. 21.—Longitudinal section of enamel from outer surface of Human incisor. Magnified 3,000 times. The structure of the calcified enamel-globules of which the rods are composed is very finely shewn in this illustration. This section represents normal human enamel of the finest type. Photomicrograph by Leon Williams.

by plasmic strings of granular origin which traverse the entire length of the rods; that they are also united to the bodies of contiguous rods by radiating processes, or even touch one another at the points of the greatest diameter of the rods; that there may be as many as fifteen or twenty calcified plasmic strings in each enamel prism; and that their ultimate structure is most suitably revealed by the action of

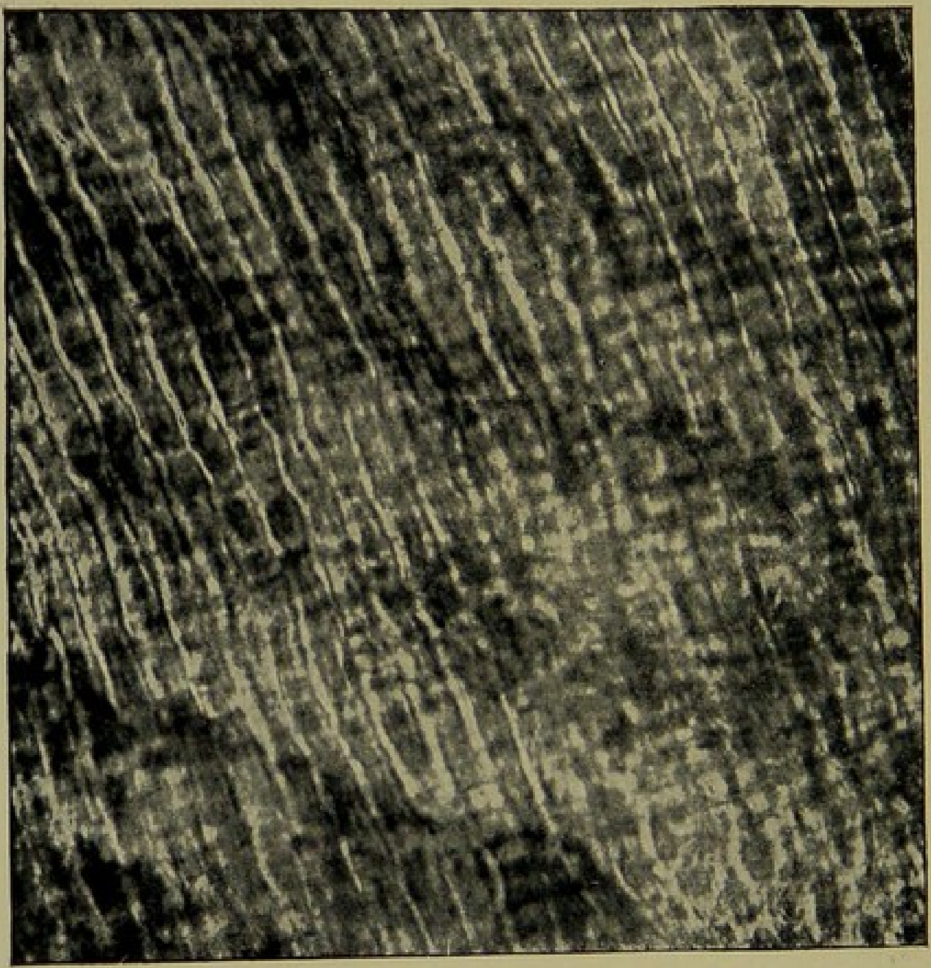


Fig. 22.—Longitudinal section of enamel from Human tooth. Magnified 1,000 times. Shows enamel-rods passing through Retzius bands without break of continuity. The rods are separated by rather more than the normal amount of cement-substance, and show imperfect formation in lower right-hand corner. Photomicrograph by Leon Williams.

weak acids, such as citric in lemon juice, which first removes the connecting threads.

The Cementing substance or matrix varies considerably in amount. In the majority of cases, in the teeth of man, the prisms are more or less in actual contact throughout their entire course, being united by the varicosities or bodies: but in some sections they lie quite apart, separated sometimes by spaces which may equal one-fourth or one-fifth the diameter of a column (viz., 1μ.), (Fig. 15). This translucent, interprismatic, calcified substance has in it delicate connecting lateral processes and fine, tiny granules, and does not contain either the organic fibres, which Bödecker[1] and Abbott[2] affirm pass between the rods and give off "thorn-like" processes, or the channels which have been described by von Ebner[3]. (Fig. 18).

Otto Walkhoff,[4] *ex cathedrâ*, refuses to grant that this cement substance exists. He examined the enamel rods of certain *Primates*, *Carnivora* and *Ungulata*, in which the structural elements of the tissue are regular. He affirmed that vertical sections of enamel never give, for great distances, the contours of the rods in one plane, and that observations on such sections are untrustworthy. When magnified 3,500 times, a measurable, thick, doubly-coloured stripe was seen: viewed horizontally, the rods, at a magnification of 2,400, exhibited no cement substance. He wrote: "A series of photomicrographs with the apochromatic 3 mm. oil immersion, N.A. 1.40 objective, showed that enamel prisms consist of two parts optically distinctly divided from each other. The central part, or real body of the prism, is grainless, or, at the most, slightly spotted, but darker coloured than the peripheral layer, which appears whitish. A delicate, somewhat darker line forms the border between the two layers; the outer border lining the whole prism, which appears somewhat blacker, is sharply sectioned, even with high magnifications. Such pictures are produced only when focussing has been *most exact*, and where possible has been directed to the surface of the prism. In its surroundings there are immediately seen, if there is the slightest obliqueness in the section, diffraction seams, especially if

[1] "The Anatomy and Pathology of the Teeth," 1894.

[2] "Minute Anatomy of the Human Tooth" in *Trans. Dent. Soc., New York*, 1882.

[3] "Histologie der Zähne" in "Handbuch der Zahnheilkunde," 1891.

[4] "Contributions relating to the more minute structure of the Enamel, and to the Development of Dentine." *Deutsche Monatsschrift für Zahnheilkunde*, Jan., 1898.

oblique illumination has been used. With *inexact* focussing the picture totally changes. Between the prisms there is then shown a line which appears dark, which by increasing the inexactness grows in width. What previously was light now becomes dark, and such a picture gives only too well the delusion of cement substance between the enamel prisms."

A recurrence to the belief in the existence of an organic matrix in enamel has quite recently been furnished by the pages of the *Deutsche Monatsschrift für Zahnheilkunde*, August, 1902, by Viggo Andresen of Vejle, Denmark. His paper ("Beitrag zur Histologie des Schmelzes") is, however, inconclusive, and his illustrations unconvincing.

It is interesting to note the various opinions and theories in connection with the histology of enamel and its prisms. Thus:—

Abbott says that "normal enamel is non-striated."

Sudduth[1] denies that the rods have any internal structure.

von Ebner believes in the existence of the striæ but considers they are an artificial appearance, due to the action of acids.

The propositions advanced as to the origin of the shadings or transverse markings are:—

(i) An intermittent calcification of the prisms would produce the dark and light bands.—(Hertz.)

(ii) They are due to the existence of beads or varicosities in the rods.—(Kölliker, Waldeyer, Haycraft, Ewald, and Leon Williams.)

(iii) Or to inequalities on the surfaces of the rods.—(Sudduth and Febiger.)

(iv) The action of acids.—(von Ebner.)

(ii) *The Courses or Curvatures of the Prisms*

Individually each prism runs a more or less spiral course and often decussates with its neighbours, so that it is exceedingly difficult, if not impossible, to trace its entire course.

[1] "Dental Embryology and Histology" in "American System of Dentistry," 1887.

Collectively, the courses are neither perfectly straight nor perfectly parallel. At the cervical region they run horizontally outwards from the dentine; at the cutting edge or the

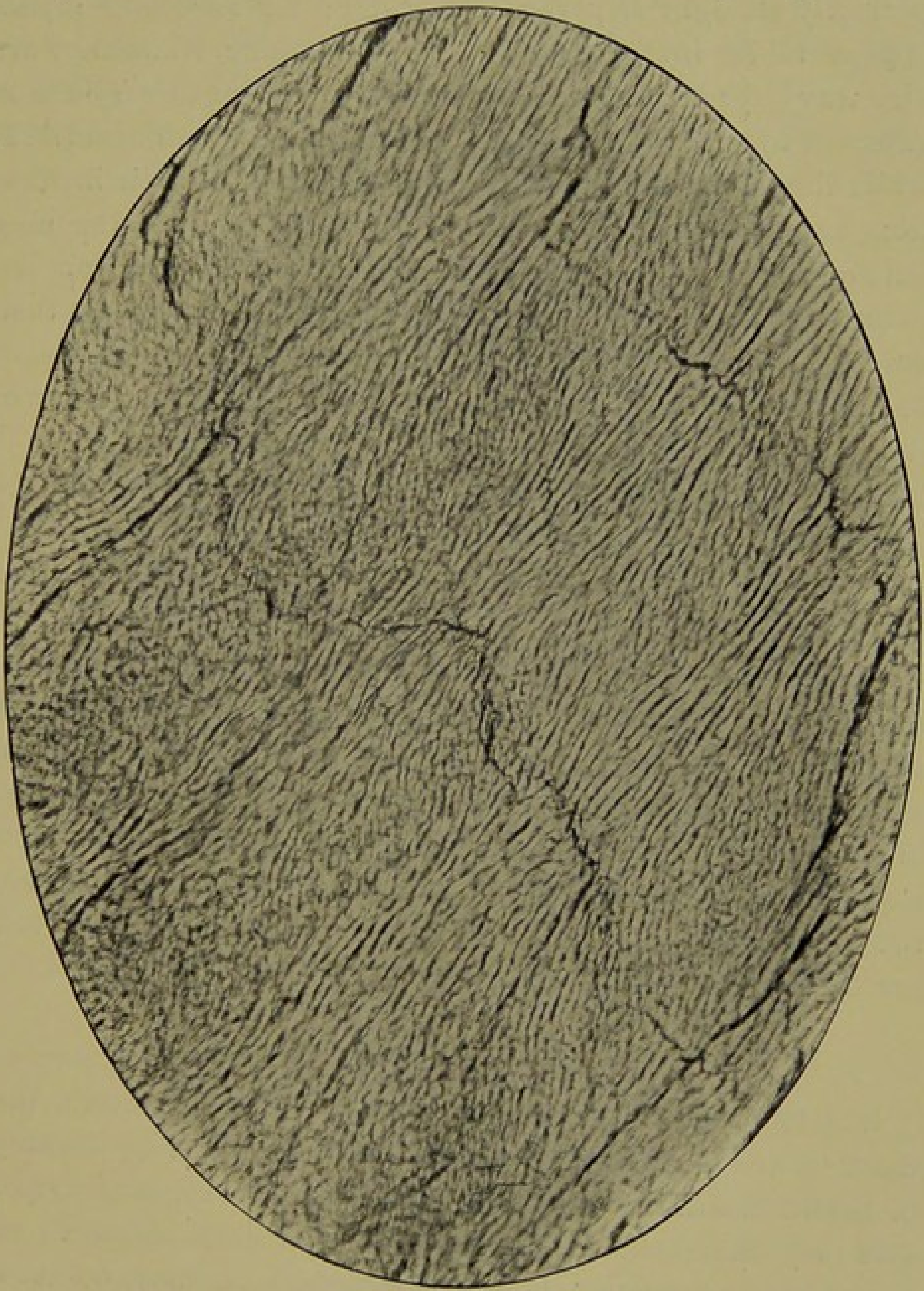


Fig. 23.—Vertical section of Human enamel. Unstained, and non-decalcified. Magnified 250 times. The lines which run across the rods are cracks in the tissue produced by grinding the section.

masticating surface they are chiefly set vertically with it. They thus radiate outwards all round. According to Tomes, "Dental Anatomy," 1898, "On the whole the prisms are parallel and run from the surface of the dentine continuously to that of the enamel. Their paths are not, however, either perfectly straight or perfectly parallel; for alternate layers appear to be inclined in opposite directions, while they are also wavy, forming several curves in their length. The curvature of the prisms is most marked on the masticating surface: while the layers, alternating in the direction of their inclination, as just described, are in places transverse to the long axis of the crown, and correspond to the fine striæ on the surface of the enamel, which appear to be caused by their outcrop. The curvatures take place in more than one plane; in other words, the course of the individual prism is more or less a spiral."

A general idea of the courses of the prisms may be obtained by macroscopic examination of a section.

(iii) "*Supplemental*" *Prisms*

As the rods run outwards, and approach the free surface, it is obvious that many narrow spaces must be left between them as they radiate centrifugally from the dentine, the total area of which is considerably smaller than that of the cortex of the enamel. These clefts are filled with numerous short supplemental prisms, which are histologically identical with the other columns, but are of varying length. These rods are best observed over the cusps of teeth.

(iv) *The Brown Striæ of Retzius*

Nearly every longitudinal section of enamel exhibits in a more or less degree these stripes. They appear as shadings or brown markings, arranged in the form of arcuate stripes; and they maintain a certain amount of parallelism to the boundary-line of enamel and dentine, which may be called the amelo-dentinal junction (Fig. 24). Crossing the prisms in various planes and in various directions, they are more pronounced on the cortical portions of the tissue, but extend right up to the junction. Between thirty-six and forty have been counted as crossing a segment of enamel, but the number varies very greatly. The bands are interrupted partially or completely. Sudduth calls them "the *broken* striæ," &c. Many are broad and many are narrow, the thickest and most marked of the former measuring sometimes, roughly, one-fifteenth part of the whole thickness of the enamel. These stratifications are only visible in vertical sections. Horizontally, the stripes are cut obliquely or transversely, and thus

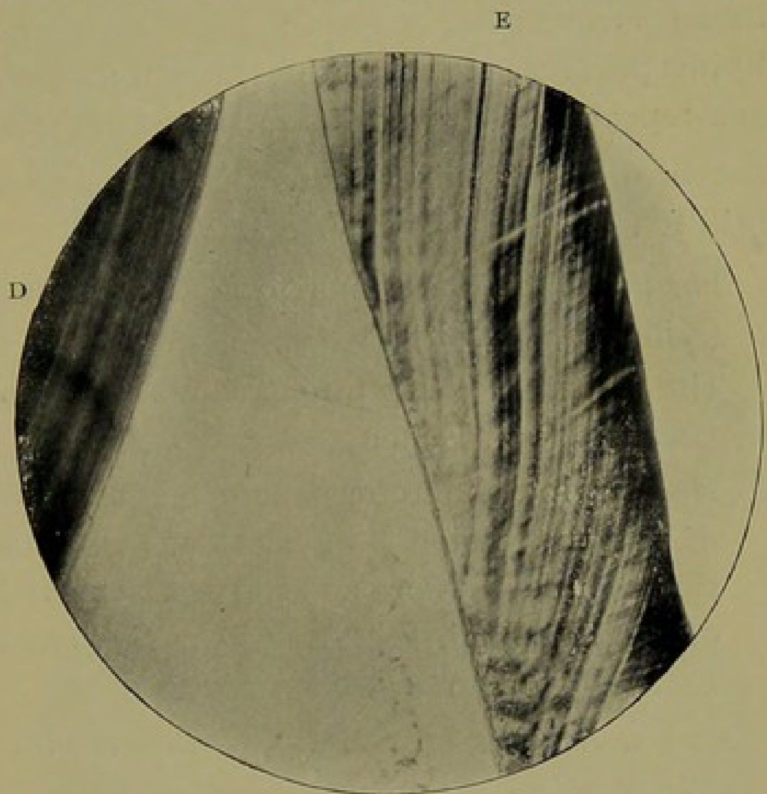


Fig. 24.—The Brown Striæ of Retzius in enamel. Prepared by grinding thin. Unstained. Magnified 40 times. E. Enamel; D. Dentine.

are seen as concentric bands, darker and more distinct at the edge than near the dentine; and therefore they give the enamel a more or less lamellated appearance.

The striæ of Retzius are due to pigmentary deposition in the prisms. The theories propounded by von Ebner and Kölliker have been dismissed by Leon Williams as incorrect. The former observer supposes that the bands are due to "imprisoned air or gas which has entered the ground-off ends of the rods through minute channels." And to this Leon Williams replies (*op. cit.* page 475) that the idea is a mistaken one, "first, because the supposed canals have no existence; secondly, because the ground-off ends of enamel prisms do not appear except when the section of enamel is ground at a certain angle."

According to Walkhoff (*loc. cit.*) the striæ of Retzius are nothing else than the ordinary transverse striping of the enamel rods on a large scale. He declares that both striæ are the expression of the deposition by the lime salts of the enamel-tissue strata-wise, a longer lasting interruption of the calcifying process producing the Retzian stripes, and one short, often-repeated, the transverse striæ of the prisms.

Thus the brown striæ of Retzius have been attributed in their origin to:—

(i) The lamellated mode of formation of the enamel. (Kölliker, Walkhoff).

(ii) The entrance of air into cavities between enamel prisms. (von Ebner).

(iii) The varying character of food taken by the mother during the period of gestation, some food being rich in lime salts of one kind and some rich in salts of another kind. ("American System of Dentistry," p. 656, 1887).

(iv) And finally, and correctly, pigmentation. (Leon Williams).

(v) *The Lines of Schreger*

By reflected light, as well as by transmitted light, it is often possible to distinguish in ground perpendicular sections of the teeth of man, entire band-shaped layers of prisms alternately decussating in such a manner as to produce lines. By the former, they appear white, by the latter black, as in the photomicrograph. These differ very markedly from the striæ of Retzius, inasmuch as they run transversely to them (Fig. 25) and are long, level, very broad bands, which bear some resemblance to flat clouds (Fig. 27) of the cumulo-stratus type. All sections by no means exhibit them;

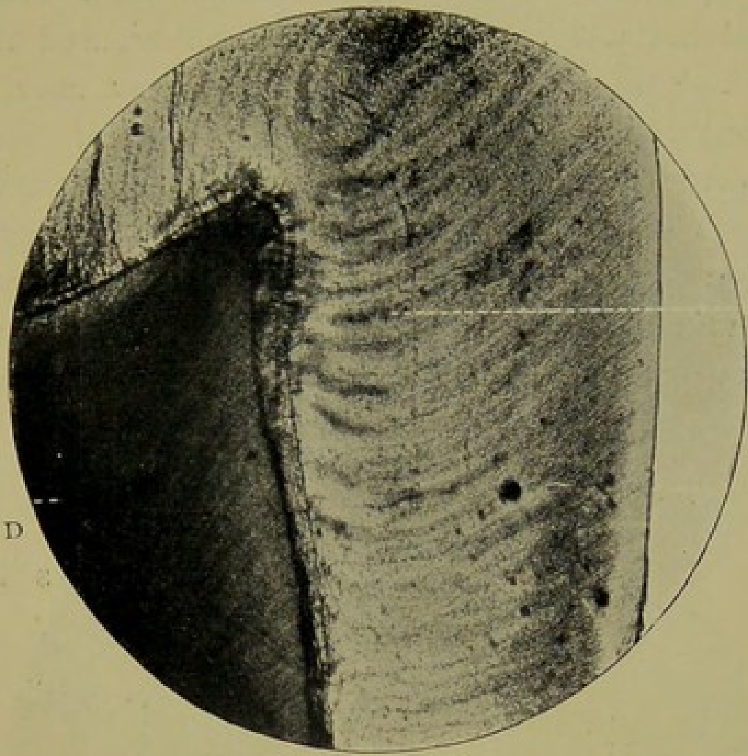


Fig. 25.—Vertical section of Human enamel shewing the lines of Schreger. Section ground thin. Unstained. Magnified 45 times. E. Free surface of the enamel; S. Schreger's lines; D. Dentine.

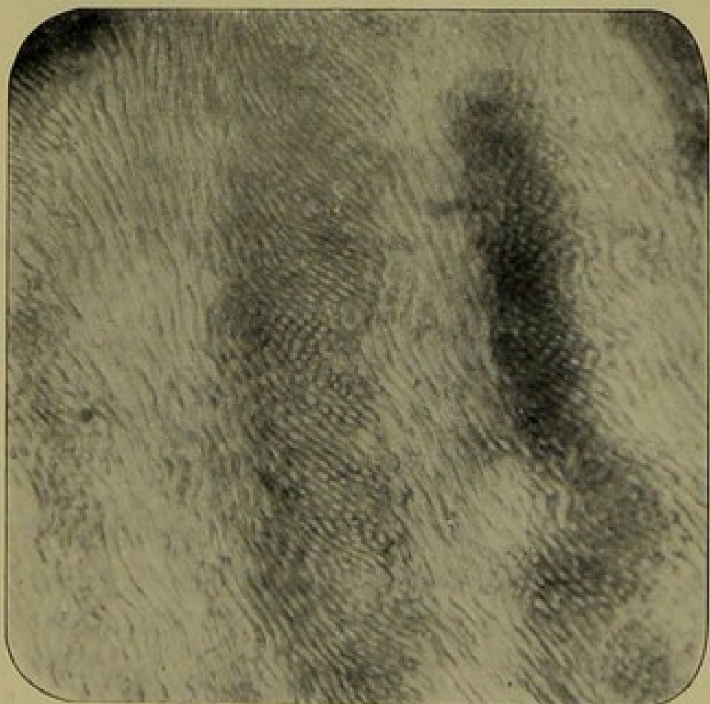


Fig. 26.—Same as preceding figure. Magnified 250 times.

but those specimens which do, commonly shew them most clearly and distinctly. They blend together, and therefore form blackish masses in the enamel. They may be distributed anywhere throughout the thickness of the tissue, but very often are confined to its inner aspect, particularly at the cusps of premolars and molars. High powers reveal the fact that the prisms are histologically normal, and it is only low magnifications which make apparent their occasional length-wise groupings.

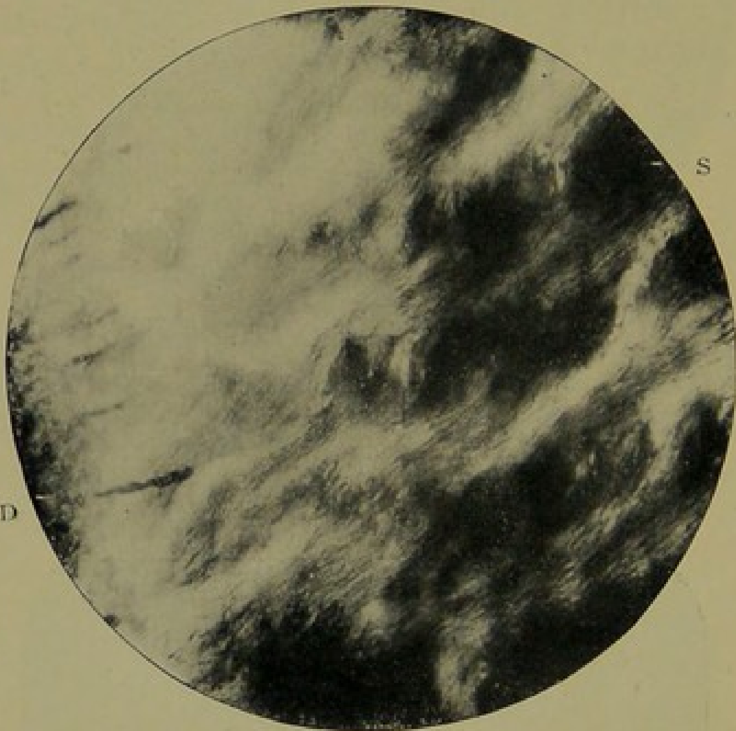


Fig. 27.—Schreger's lines in enamel, as cloud-like masses through dense pigmentation. Magnified 300 times. S. Schreger's lines; D. Dentine with enamel spindles.

(vi) *Certain Spaces or "Enamel Spindles"*

Independent of certain cavities or clefts on the free surface of enamel, which have no special structure, there can often be found in teeth free from any apparent structural defects, near the amelo-dentinal junction, irregularly-shaped chasms, which in ground sections are remarkably clear and brilliant. (See Fig. 30). They appear to be in direct continuity with those few dentinal tubes which manage to cross the boundary line of the two

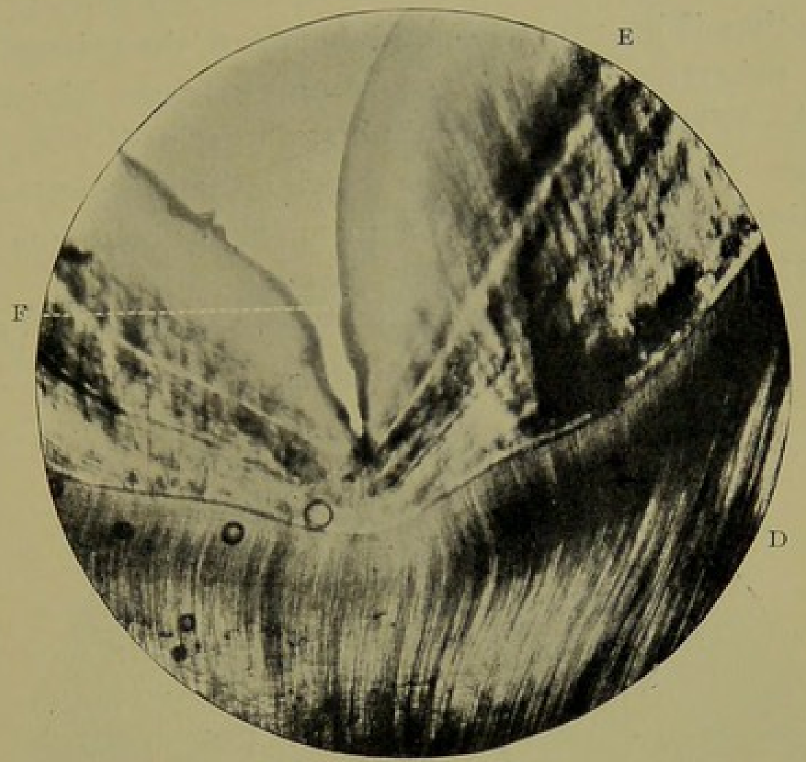


FIG. 28.

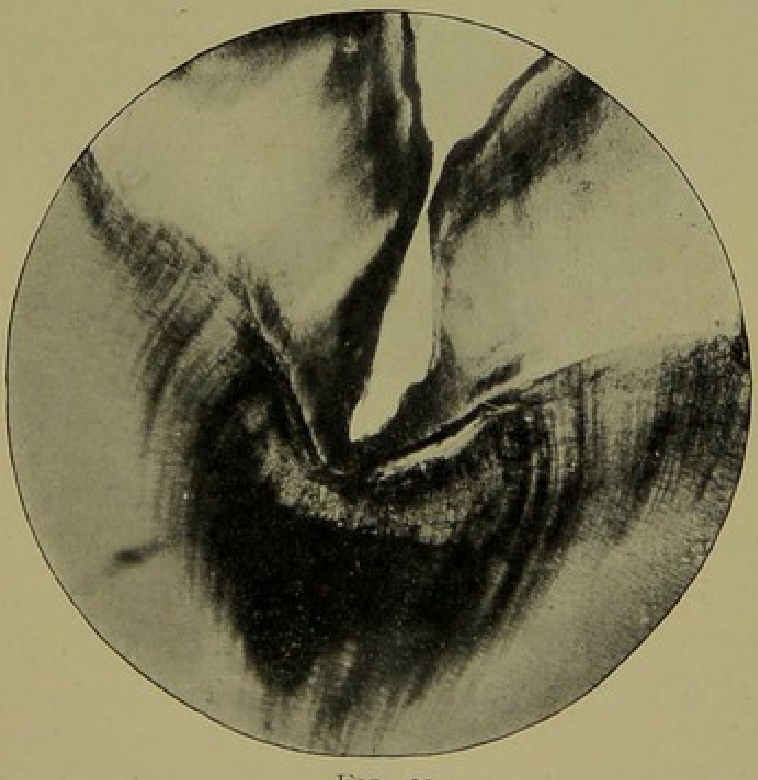


FIG. 29.

Figs. 28 and 29.—Vertical sections through cusps of Human molar. Stained with Golgi's rapid process. Magnified 45 times. E. Enamel; D. Dentine; F. Fissure with clear structureless margins.

hard tissues. In fact they resemble bulbous enlargements of the tubes (Fig. 31). Situated between the prisms, in the cement substance, which, according to von Ebner, and quoted by Römer in his "Zahnhistologische Studie," 1899, p. 39, is more abundant near the dentine than the cortex, they run vertically outwards, are narrow, and about 40μ long. They may be clubbed or spindle-shaped.

These spaces are not infrequently observed in vertical ground sections of molars or premolars.

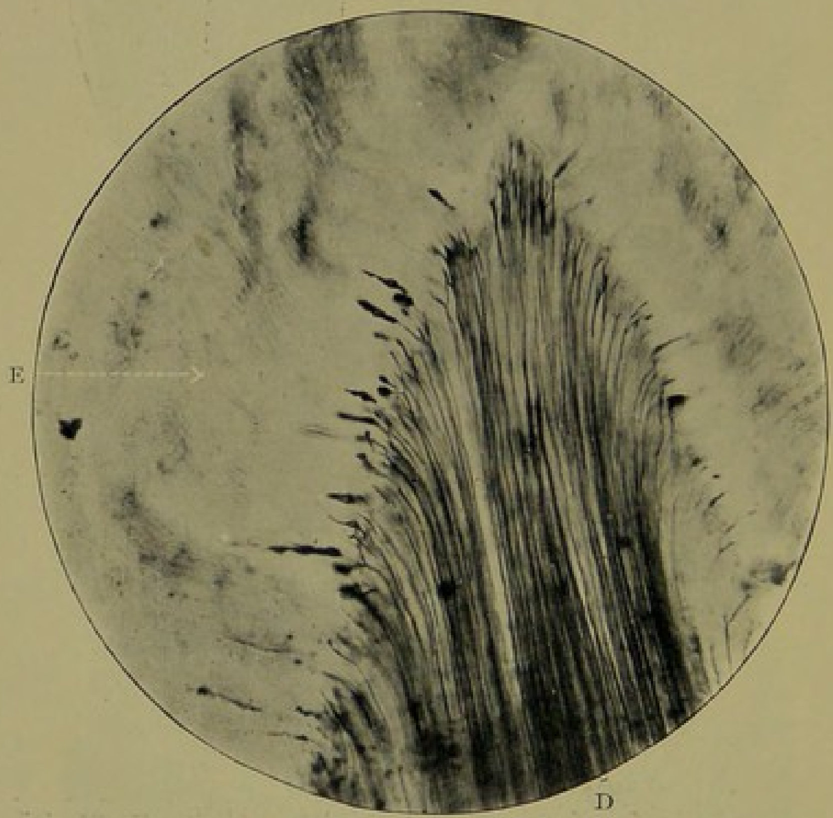


Fig. 30.—Vertical section through cusp of tooth. Magnified 50 times. E, Enamel; D, Dentine, many tubes of which end in the enamel spindles. Photomicrograph by Douglas Gabell.

In the margins of the apices of the dentine cusps (Fig. 32) they are more numerous than in the saddle-shaped depressions between them, in which situation they are only to be met with singly or in sparse numbers. The knobs sit on the dentinal tubules exactly like ears on the stems of the straw of corn bound up into sheaves. Those found in the highest parts of the cusps appear to stand upright; while on the contrary those at the slopes incline more or less to the horizontal

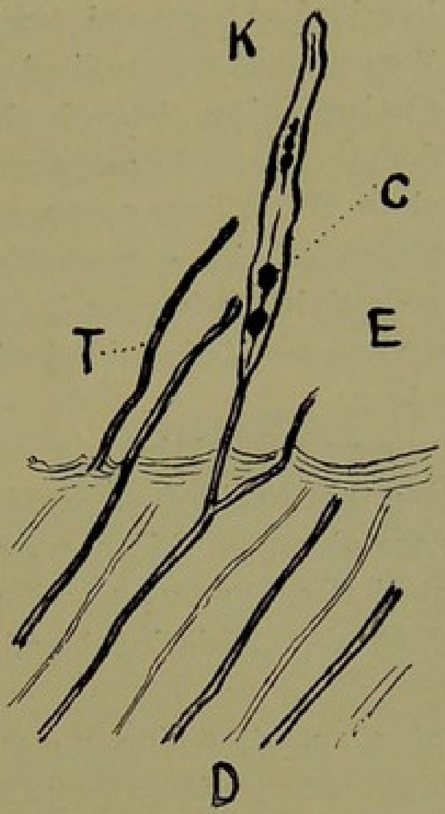


FIG 31

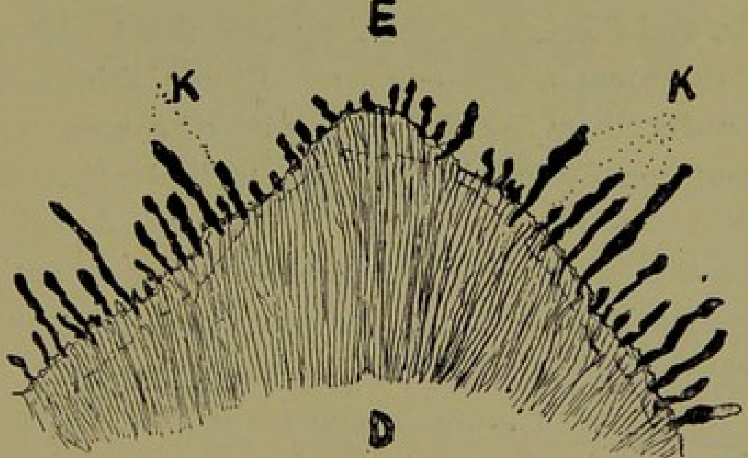


FIG. 32.

Figs. 31 and 32.—Adapted from two drawings by Kretz, in Römer's "Zahnhistologische Studie," 1899. Fig. 31.—Vertical section through amelo-dentinal junction in molar of a child, stained with gold chloride, and potassium iodide. Magnified 1,500 times. D. Dentine; E. Enamel; T. Dentinal tube; K. Enamel spindle; C. Dark red corpuscle in the interior of the enamel spindle. Fig. 32.—Vertical section through the amelo-dentinal junction of a cusp of a left maxillary first molar of a boy, aged 13 years. Stained as in last Figure. Magnified 250 times. E. Enamel; D. Dentine; K. Enamel spindles.

plane. Thus, in a longitudinal ground section through the middle of the cusp they are cut perpendicularly, whereas in a tangential ground section going through the lower portion they are found for the most part cut transversely.

In sections ground in the ordinary way, and subsequently treated in the usual manner, these enamel-knobs stand out black or dark grey on a light background. There is no internal structure visible, the space being filled with detritus, &c., from the act of grinding.

Whether protoplasm ever filled them is a difficult matter to decide. It is probable that in the fresh condition it did.

Various accounts are given by different authors as to their histological characteristics, amongst whom Tomes, von Ebner,[1] Höllander,[2] Wedl,[3] Bödecker,[4] and Oscar Römer[5] may be cited.

Charles Tomes (*op. cit.* p. 27) makes no mention of their contents, and concludes that "perhaps they are to be regarded as pathological."

That hollow spaces constitute these enamel-spindles von Ebner and Wedl are agreed : but the former holds that they contain air, and the latter that they are filled with amorphous dark calcareous masses. von Ebner thinks they are actually produced by the shrivelling up of cement substance, which is more easily possible at the amelo-dentinal line than at the free surface of the tissue. Höllander describes their presence in the juxta-dentinal zone of enamel, but regards them as non-pathological. Bödecker says "They invariably contain protoplasmic bodies of distinctly reticular structure and sometimes one or more compact clusters, which may be spoken of as nuclei. The spindle-shaped corpuscles stand at their central terminations in direct connection with the ends of the dentinal *fibres*, as these originated from repeated branchings. At many places, especially those corresponding to the crown apices, the spindle-shaped enlargements of the

[1] Scheff's "Handbuch der Zahnheilkunde," Vienna, 1891.
[2] "Die Anatomie der Zähne des Menschen und der Wirbelthiere," Berlin, 1877.
[3] "Pathologie der Zähne," Leipzig, 1870.
[4] Heitzmann's "Mikroscopische Morphologie," Vienna, 1883.
[5] *Nerven in Zahnbein*, "Zahnhistologische Studie," Freiburg, 1899.

dentinal fibres are very numerous and nearly regular in size and direction. . . . . In the teeth of younger persons the spindle-shaped swellings are relatively larger and more regular than in those of older people." This is called the "Bio-plasson theory."

Römer coincides on the whole with Bödecker's view, with the reservation that he would apply the term "dentinal tubules," instead of "dentinal fibres," to those formations

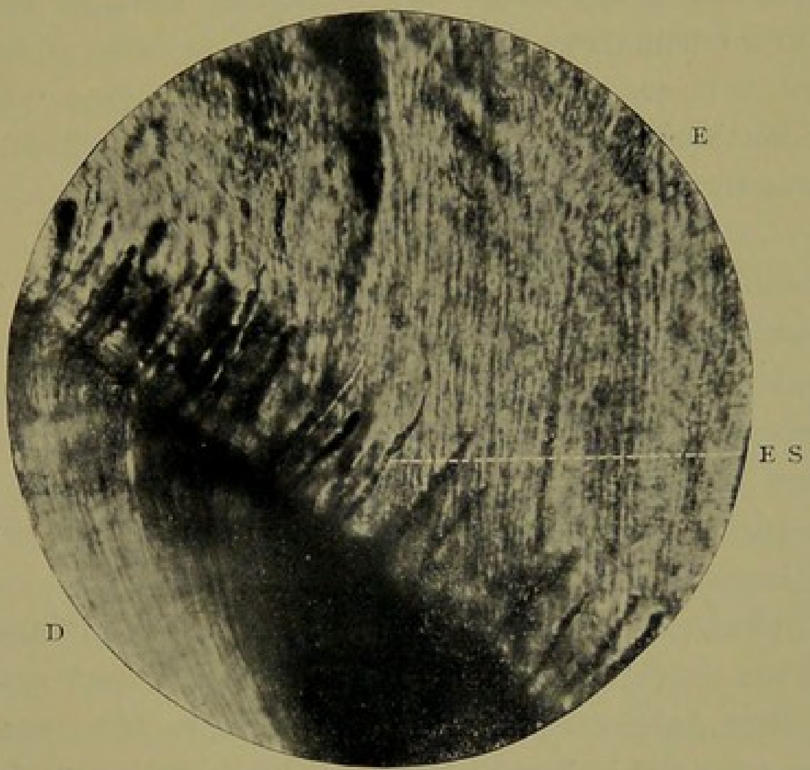


Fig. 33.—Vertical section through the coronal part of a tooth. Prepared by Weil's process. Magnified 250 times. E. Enamel; D. Dentine; E.S. Enamel spindle critically focussed to shew Römer's corpuscles.

which widen out into clubs or spindles in the enamel. He declares that the spaces contain an organic matter capable of becoming stained with chloride of gold, and appear of a reddish tint, varying from a rose-colour to a dark-red hue (marked C in Fig. 31). He admits that in most cases they are merely filled with air, through the shrinking of some of the organic material; but affirms that when teeth are treated by the Koch-Weil method there is no shrinkage, and that a non-reticulated organic substance is really present inside the knob. He describes and figures (Fig. xxxiii., Tafel vii.) in one space "several spherical corpuscles hanging together by a fine, scarcely measurable fibre, also stained dark-red and running out into a fine point." (See Fig. 31, also Fig. 33). In conclusion, he writes :—"I should not, however, call these round or oval corpuscles cell-nuclei, as Bödecker does; especially I cannot, like him, in defending his 'Bio-plasson' theory, testify to a connection between these knobs and 'the living enamel material'; but I think we should much rather venture to see in these fine corpuscles, so often arranged in rosary-like order, *sensitive nerve-end apparatus* of the nerve filaments which run in the dentinal tubules." For the arguments which Römer advances in favour of this extraordinary hypothesis, see his paper.

The tubes of the dentine themselves often traverse the boundary line and penetrate the enamel sometimes to a depth of 30μ. They run in the cement substance, not in the interior of the prisms.

Before altogether dismissing these theories, one or two more instances may be given of other opinions on this most interesting subject.

F. T. Paul (*The Dental Record*, p. 495, 1896) explains their occurrence in this manner:—"In early mammalian tooth-germs, the ameloblasts and odontoblasts are seen to be separated by a thin band of transparent dentine matrix, due to certain changes in the surface of the pulp. This band has two sets of processes of formed matrix. One, as Howard Mummery first showed, passes between the odontoblasts to communicate with the connective tissue matrix of the pulp, and the other extends outwards between the ameloblasts, which, in some instances, are therefore kept apart, and thus form elongated spaces filled with the imperfectly calcified matrix of dentine. 'That processes of dentine matrix thrust up between the enamel prisms should never calcify, is certainly nothing surprising when one remembers that the first layer of dentine usually only calcifies imperfectly, being characteristically the site of the interglobular spaces of Tomes.'"

Waldeyer (in Stricker's "Handbuch der Lehre von den Geweben," Leipzig, 1871) denies that the spindle-shaped spaces in enamel exist at all, as structural elements, either as developmental errors or pathological lesions. He bases his view on the assumption that the least defect in the parallelism of the sections would be likely to lead to incorrect appearances. Cracks or fissures in the enamel, produced by manipulative interference, would also yield deceptive results. Hertz, too, another of the earlier investigators, interpreted the meaning of these spaces in a similar way.

But Walkhoff[1] has often seen them.

One of the most difficult problems in the whole of dental histology is that connected with the relationship of enamel and dentine; for not only is it hard to conceive how enamel, an epiblastic substance, should be so securely fixed on the surface of a mesoblastic substance, and by what means they are thus bound together; but the transpiercing of the amelo-dentinal boundary by the dentinal tubes is infinitely still more perplexing. Walkhoff has published (*op. cit.*) an ingenious hypothesis in attempting to explain this phenomenon. In common with Wedl (*op. cit.*) and von Ebner, he assumes that at this border-line there must have been an absorption (or, more correctly translated, resorption) of the first deposited dentine. His arguments in favour of this are founded on the facts that under the enamel, Tomes' granular layer is never seen, because, though once existing, it has in the process of time become absorbed: that the dentinal canals run up to the edge without much narrowing of their diameters, thus apparently proving that they have been diminished in *length*: and, finally, that here, too, there are practically no branchings, these having disappeared in consequence of the resorptive process.

Granting that the interpretations of these phenomena are correct, he proceeds to explain that, owing to an especial vitality on the part of certain individual tubes, they are

[1] *Deutsche Monatsschrift für Zahnheilkunde*, January, 1898; also "Die Normale Histologie Menschlicher Zahne," Leipzig, 1901.

enabled to completely resist the absorption of the defectively-built dentine which is going on all round, remain *in situ*, and, therefore, have the appearance of actually projecting beyond the amelo-dentinal junction. Walkhoff adds that the canals appear as if sharply cut off, a proof that their terminations are absorbed. The direction of their courses is not always parallel with the enamel columns, because they frequently break through the prisms transversely. There occur forma-

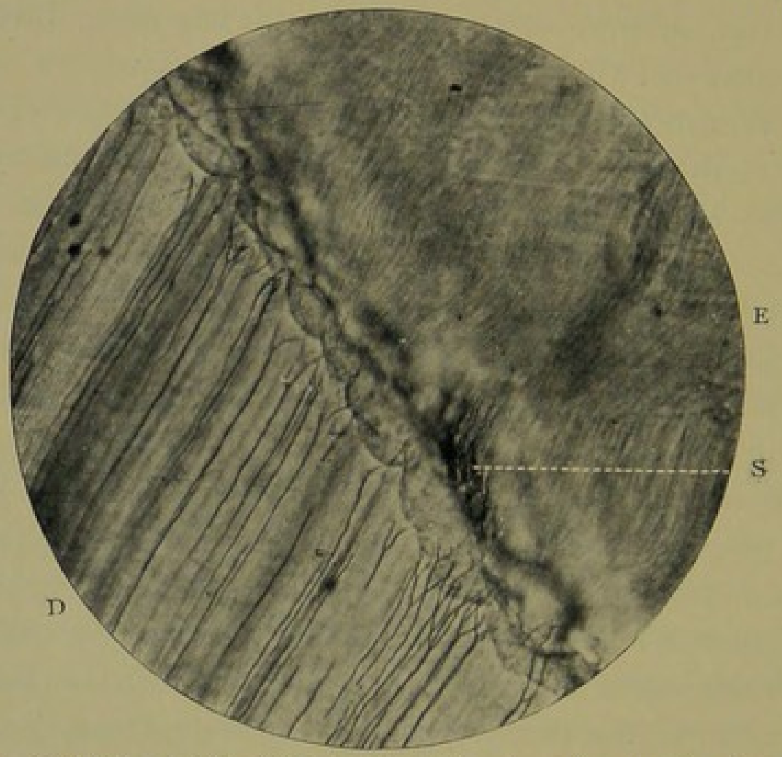


Fig. 34.—Vertical section through coronal region of a tooth, shewing the amelo-dentinal junction. Prepared by grinding. Unstained. Magnified 250 times. E. Enamel; D. Dentine; S. Stained enamel-rods of irregular formation.

tions (the enamel-knobs) at the apices of the dentine cusps in the teeth of *primates* and *carnivora*, which may reach far into the enamel, and do not consist of simple dentine tubes, but may have round them a large amount of uncalcified basal substance or matrix.

Walkhoff summarises his investigations by asserting that the club-like processes represent simple dentinal tubes, which, through unusual vitality, have opposed sufficient resistance to the absorption of the dentine, which takes place during the formation of the enamel; and that there were certain masses of basal substance already formed round each tube which the resorption was unable to destroy.

The amelo-dentinal line, junction, or boundary, is made up of a fairly straight or slightly undulating line with pale homogeneous tissue on either side. The tubules do not end on the line, but near it, while the enamel prisms themselves are structureless or faintly granular. This condition obtains in horizontal sections of premolar and molar teeth taken at the cervical margin, and at the narrow part of that margin. In its broadest part the boundary is represented by a linear series of tiny enamel convexities looking towards the dentine. Here the tubules are strong and thick and come quite up to the edge of the convexities, and the structure of the enamel convex surface is pale, bright, and glistening when viewed by transmitted light (Fig. 34). The enamel in the immediate neighbourhood is translucent and structureless.[1]

The same thing is found in vertical sections, but the enamel crescents are more constant. They closely resemble that edge of the layer of formed but uncalcified dentine—the dentogenetic zone—in developing teeth which is in juxta-position to the calcified dentine.

As has been already stated, tubules from the dentine with or without their bulbous enlargements occasionally cross this border.

The only elements of histological interest in the fissures on the periphery of enamel are the so-called encapsuled lacunæ, described by Tomes (*op. cit.* p. 100). They are fairly common in occurrence, and, as a rule, a group of twelve or more are seen occupying and filling a deep pit. They are brownish in colour, and "are to be regarded as individual osteoblasts, or nests of osteoblasts, which have to some extent preserved their individuality during calcification."

[1] It is of great interest to note that when sections of sound teeth have been subjected to impregnation with coloured collodion, as first advocated by Charters White, isolated patches of the enamel of this region may become stained. (See Fig. 34.) This often occurs, and may show that the chemical properties of the enamel is different here. The fact may probably throw some light as to the actual method of production of secondary enamel decay.

CHAPTER IV

THE DENTINE

MICROSCOPICAL ELEMENTS.—(i) Matrix; (ii) Tubes; (iii) Sheaths of Neumann; (iv) Interglobular spaces; (v) Granular layer; (vi) Schreger's Lines; (vii) Contour lines of Owen; (viii) Laminæ. Secondary dentine.

GENERAL CHARACTERISTICS

Definition.—That hard tissue of the tooth, which, while comprising its greatest bulk, forms the natural boundary of its pulp.

Varieties.—There are four varieties:—Hard or unvascular dentine, plici-dentine, vaso-dentine, and osteo-dentine. This is Tomes' classification. Dr. Med. C. Röse,[1] of Leipzig, basing his opinion on the definition of dentine as "a hard tissue with a smooth surface, which is developed under an epithelial sheath (enamel organ), and grows on one side only," groups the different kinds under the headings of (i) "Normal tubular dentine," (ii) "Vitro-dentine" which contains *no* protoplasmic processes, (iii) "the vaso-dentine of Tomes," and (iv) "trabecular dentine." The latter—a new term—is defined as "a hard tissue, rich in short dentinal canals, and capable of increase in all directions; but not growing immediately beneath, and in dependence upon an epithelial sheath." Here will be considered the first-named variety, viz., hard dentine, or, more scientifically, ortho-dentine.

[1] "On the various alterations of the Hard Tissues in the lower vertebrate animals." From the *Anatomischer Anzieger*, 1898. (Bd. xiv., Nos. 1, 2, and 3.)

Origin.—The matrix or intertubular cement substance is formed by calcification proceeding from certain cells of the pulp; the walls and contents of the tubules are manufactured probably by the columnar cells on the surface of the pulp, these as well as the other cells being derived from the stomodæal mesoblast.[1]

Distribution.—Hard unvascular dentine is found in the teeth of man, and most mammals; also in some reptiles and fishes. In the adult human dentition it measures about 2 mm. in the radicular regions, and 4 mm. in the normal, over the cornua of the pulp.

Macroscopical appearances.—Yellowish-white in colour, dull, and slightly lustrous on cleavage.

HISTOLOGY

In considering the minute anatomy of dentine, it will be convenient to describe its (i) Matrix, (ii) tubes, (iii) sheaths of Neumann, (iv) interglobular spaces, (v) granular layer, (vi) lines of Schreger, (vii) contour lines of Owen, and (viii) lamellæ or laminæ.

(i) *The Matrix*

The matrix, or inter-tubular substance, called also the basis-substance by some authors, appears to be perfectly homogeneous, translucent and hyaline. The researches of von Ebner[2] (who first successfully demonstrated the existence of a connective tissue stroma in bone) and Howard Mummery (*Philosoph. Trans. Roy. Soc., 1892*), have, however, proved that a delicate network of fine connective tissue fibres pervades it. The latter says (p. 537) "We can no longer look upon the

[1] Throughout these pages the conventional use of the word "odontoblast" (meaning each of the large columnar cells on the surface of the pulp) will be retained. The author's view as to the term being a misnomer when applied to these cells is well-known; the reader is, however, referred to a Note in the Appendix for the arguments. It may be possible, a few years hence, to properly attach the name to the other round central pulp cells, and not to the constituents of the *membrana eboris*, which may be designated "pulp corpuscles."

[2] "Histologie der Zähne mit Einschluss der Histogenese," in Scheff's "Handbuch der Zahnheilkunde," Vienna, 1891.

matrix of dentine as being a homogeneous substance, but must regard it as composed of a reticulum of fine fibres of connective tissue, modified by calcification, and when that process is complete, entirely hidden by the densely-deposited lime salts."

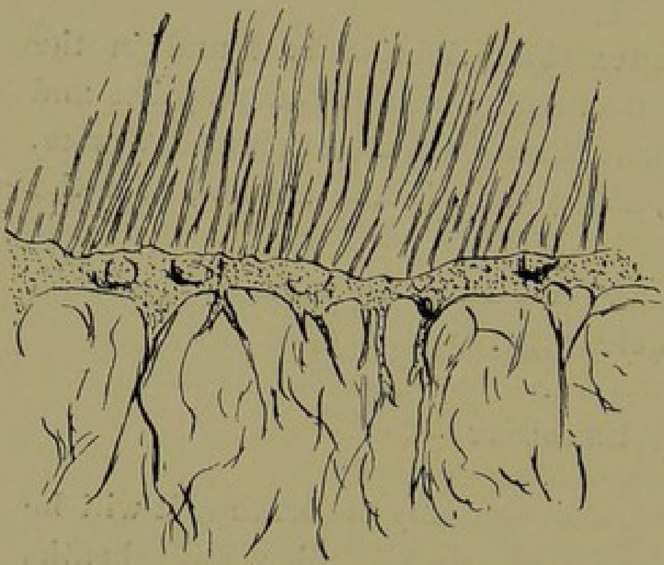


FIG. 35.

FIG. 36.

Fig. 35.—Longitudinal section at apex of radicular portion of pulp in Human premolar, shewing odontogenic fibres in continuity with the dentogenetic zone. Magnified 350 times. After a drawing by Howard Mummery in the *Philosoph. Trans. Royal Society.*

Fig. 36.—Transverse section of pulp of crown of a Human premolar, shewing fine fibres in connection with the dentine on one side, and the pulp on the other, crowded with cell nuclei. Magnified 230 times. After a drawing by Howard Mummery from the same source.

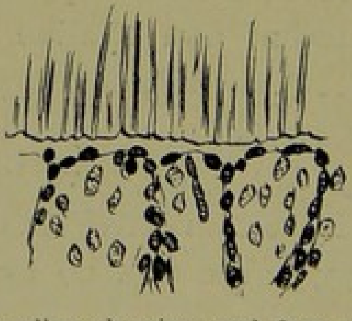


Fig. 37.—Same as preceding drawing, and from the same source. The larger nuclei belong apparently to odontoblasts. Magnified 230 times.

"These fibres decussate freely with one another, and I believe them to be analogous to the decussating fibres of bone. They are rendered visible, in some instances, by the slow decalcifying action of caries, as they appear to resist the action of acids more than do the lime salts." He suggests for these the term "odontogenic fibres." They are, therefore,

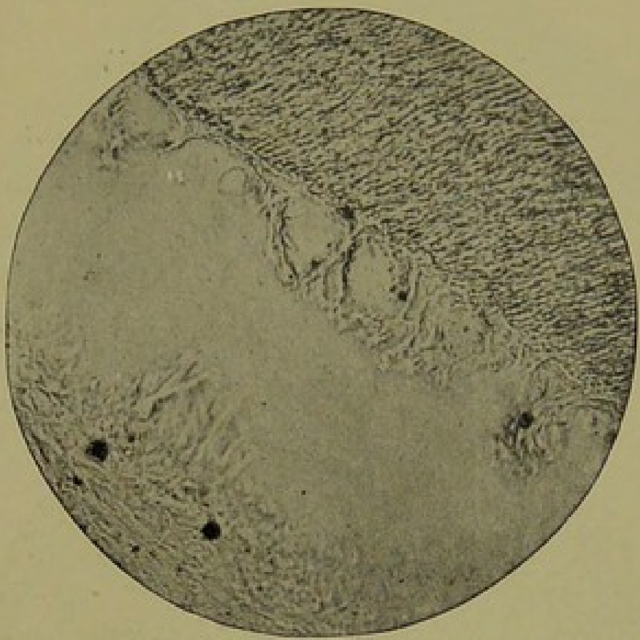


Fig. 38.—Odontogenic fibres. Photomicrograph by Howard Mummery.

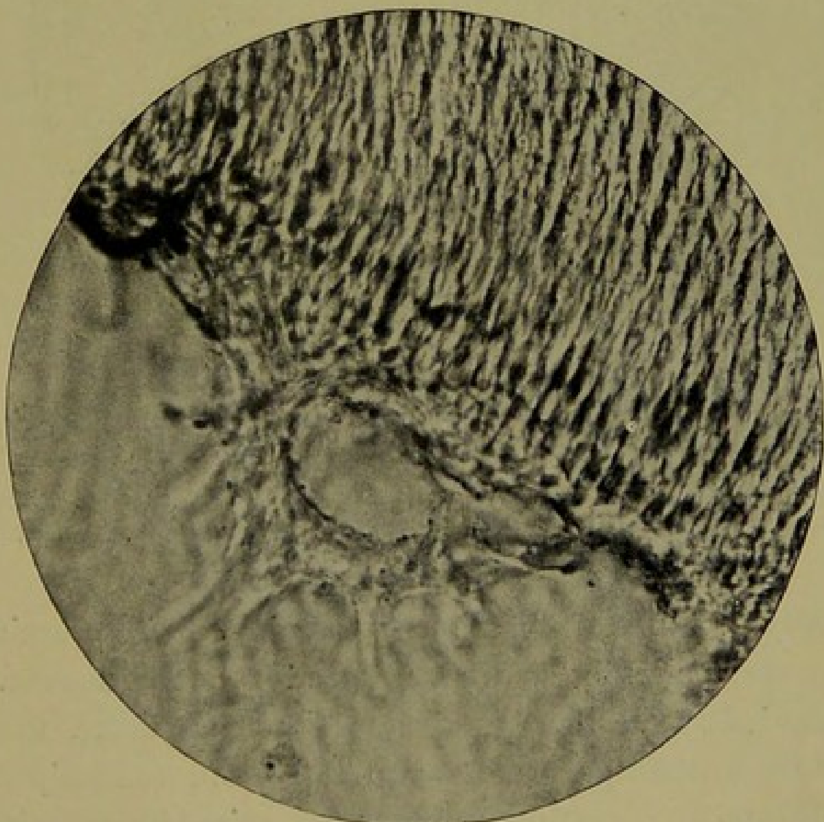


Fig. 39.—Same as preceding figure. Photomicrograph by Howard Mummery.

most likely, morphologically and chemically, identical with those found in the matrix of bone, and have their origin in connection with or are closely attached to certain connective tissue fibres of the pulp. They are uncalcified.

(ii) *The Tubes or Tubules*

The microscopical examination of a section of dentine, whether lengthwise, crosswise, or oblique, whether decalcified or not, discloses the fact that, interpenetrating it everywhere, are very numerous, fine, ramulous, fibril-transmitting channels. Ground sections exhibit the tubes better than those

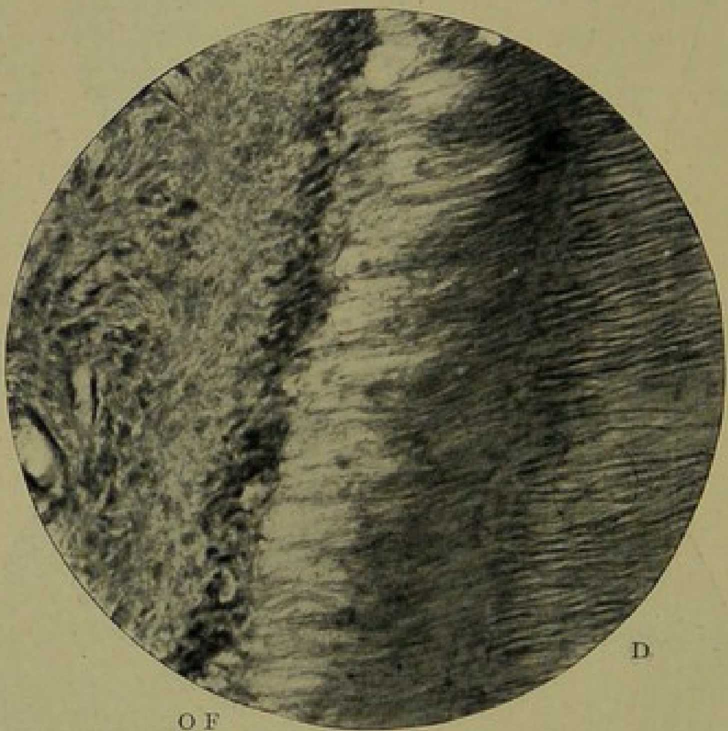


Fig. 40.—Odontogenic fibres in a vertical section of carious dentine, the decalcification of which has rendered them very apparent. The crown of a molar tooth of man. Decalcified by the author's process. Stained with Ehrlich's acid hæmatoxylene. Magnified 420 times. D. Dentine; P. Pulp; O.F. Odontogenic fibres.

chemically softened, because they retain *débris* and air, and are thus more strikingly differentiated from the matrix.

When viewed vertically, it is at once apparent that the tubes run centrifugally and radially from the pulp-cavity. They maintain a certain amount of coincidence with the direction of the peripheral cells of the pulp (the so-called odontoblasts)—that is, they leave the soft tissue in lines nearly always continuous with the long axes of the odonto-

Fig. 41.—Vertical section of dentine, coronal portion, shewing the arrangement of the primary curvatures of the tubules. Unstained. Magnified 40 times. E. Enamel; D. Dentine; F. Interglobular spaces.

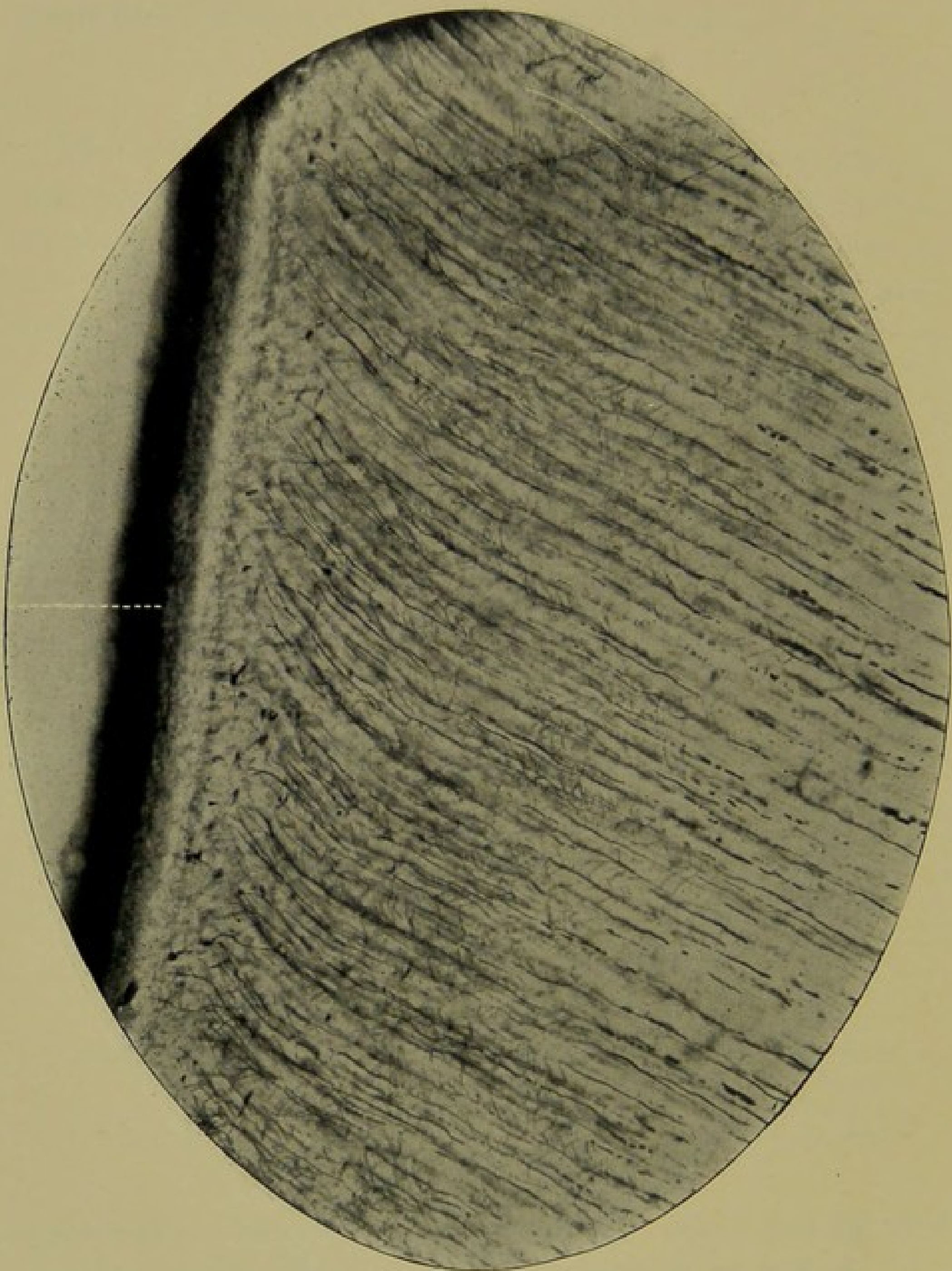


Fig. 42.—Vertical section of dentine, radicular portion, shewing the branching and terminations of the tubules. Prepared by grinding, after staining by impregnation with coloured collodion. Magnified 240 times. D. Dentine; C. Cementum.

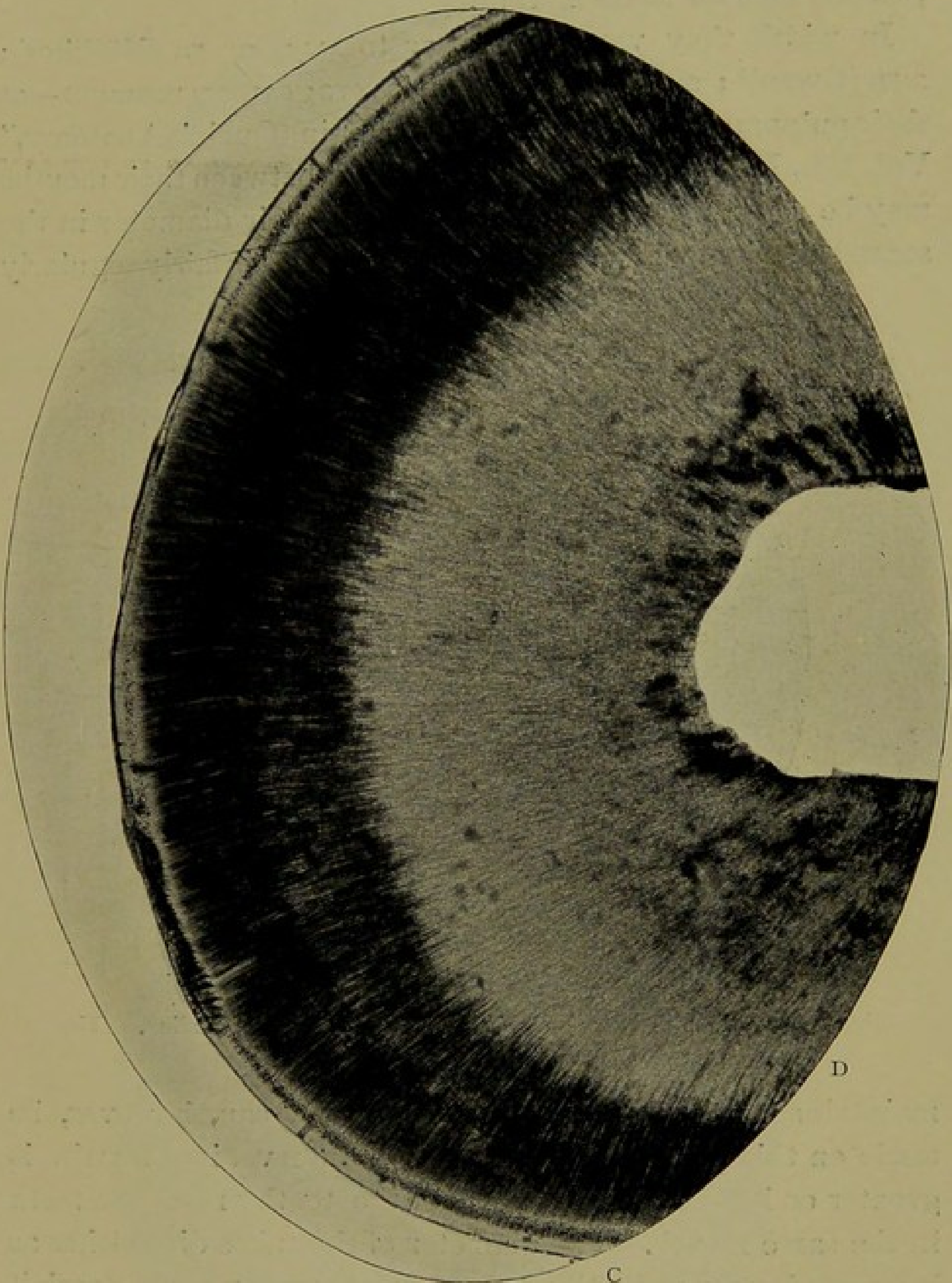


Fig. 43.—Transverse section of dentine, radicular portion, shewing the radiation of the tubes from the pulp cavity. Prepared by grinding. Unstained. Magnified 40 times. D. Dentine, C. Cementum.

blasts. They are arranged side by side in an approximately parallel manner to each other.

In width they vary from 1·7μ to 2·2μ, or 5μ (Kölliker); 2·5μ (Owen)[1]; or 0·0055 mm.—an average measurement—at their pulpar or larger extremity (Schäfer in "Quain's Anatomy," Vol. III., Part IV., 1896). The distance between their mouths may be considered to be twice or thrice their diameter in the same situation, where, too, it—the distance—is fairly regularly

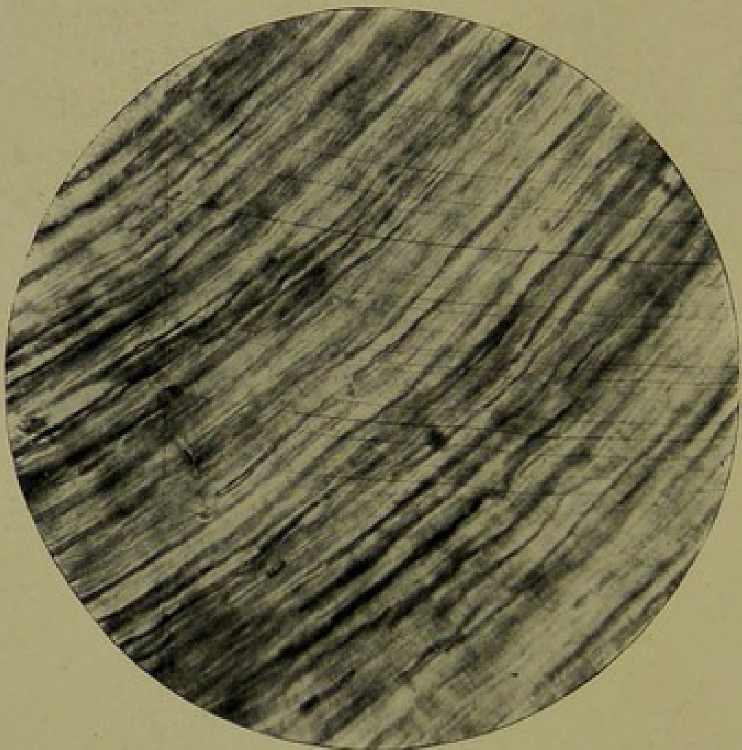


Fig. 44.—Longitudinal section of dentine. Prepared by grinding. Unstained. Magnified 420 times.

maintained. No hard-and-fast statement can, however, be made on this point, as the amount of intervening matrix is greater or less in different parts of the tooth and of the teeth in the same mouth. The diameter of the tubes diminishes as it proceeds outwards, till at the cervical region of the tooth it becomes immeasurable. Their greatest lengths may equal from 5 mm. to 6 mm.

The inner extremity of a canal is a wide open orifice looking on to the surface of the pulp; the other near the enamel

[1] "Odontography," p. 459, 1845.

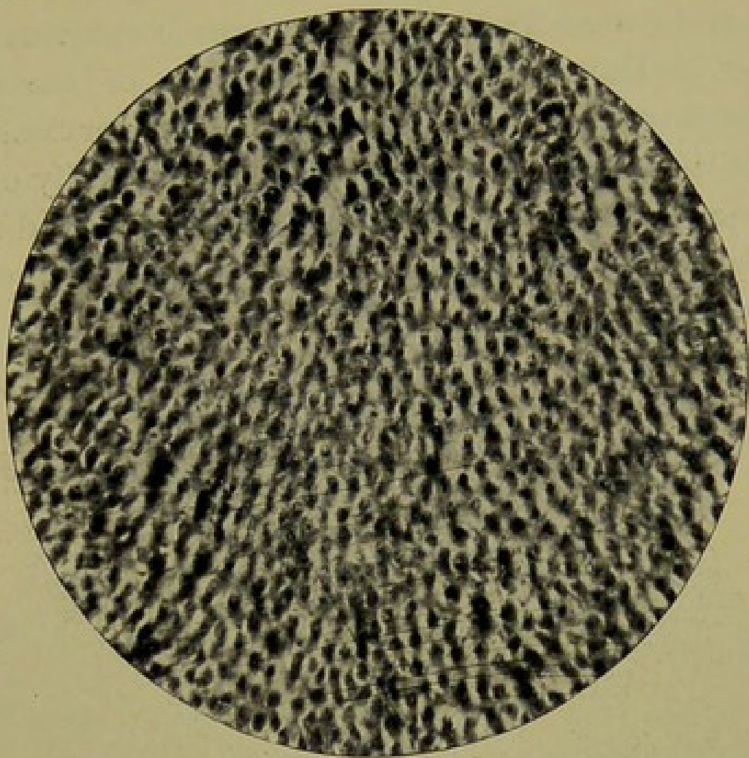


Fig. 45.—Dentine. Nearly transverse section. Prepared by grinding. Stained by Weil's process. Magnified 160 times.

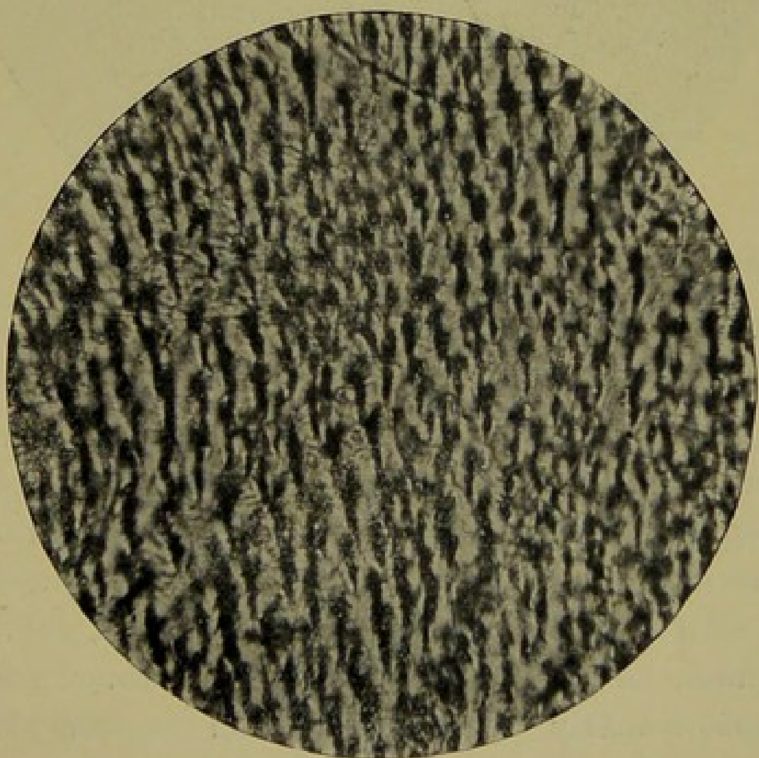


Fig. 46.—Dentine. Oblique section, shewing the branches of the tubes. Prepared as in last figure. Magnified 420 times.

or cementum is a cul-de-sac of large dimensions in the former locality, and generally one or more minute spherical knobs in the latter. Those in the coronal part of the tooth run vertically from the pulp cavity, at the cervical margin obliquely, and in the radicular region horizontally or with an inclination towards the apex. This difference in direction is gradually brought about, and varies considerably in different specimens. (Fig. 41).

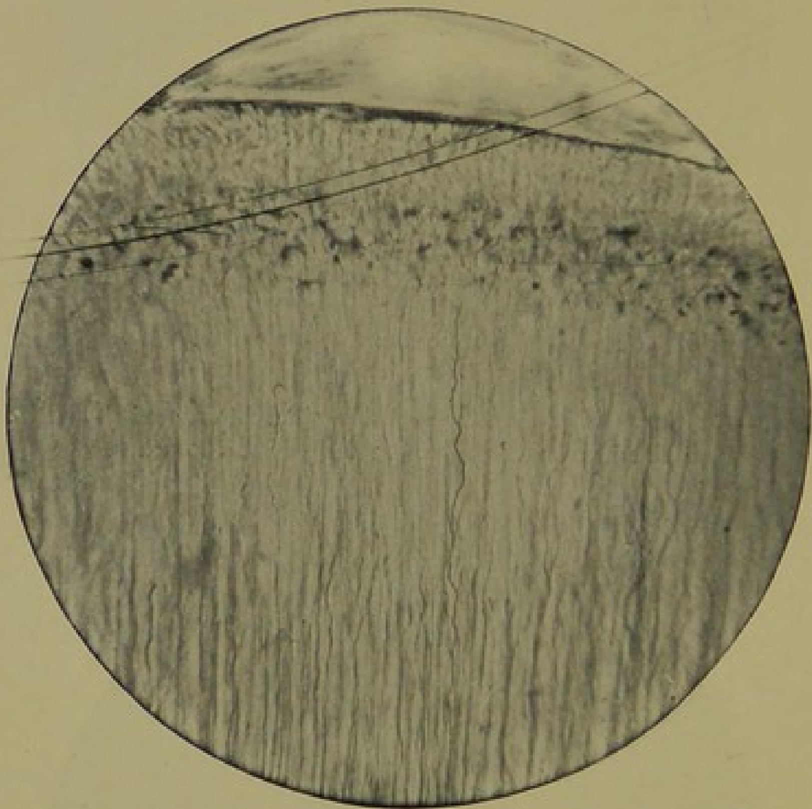


Fig. 47.—Dentine, radicular portion, shewing secondary curvatures of the tubes. Magnified 160 times. Photomicrograph by Douglas Gabell.

Each tube describes in its somewhat divergent course certain curves or flexures. These are called the "primary" and "secondary" curvatures of the dentinal tubules. The former are more marked in the crown than the root, the latter the root than the crown ; the former are large, gentle undulations, the latter small spiral twists ; the former are on the same plane or nearly so, the latter not on the same plane ; the former two or three in number, the latter very numerous, as many as two hundred in a line—$\frac{1}{12}$ of an inch—according to

Retzius. Welcker has likened a tubule to "the thread of a corkscrew stretched so that the turns are drawn far apart," its breadth thereby being proportionately diminished. In thick longitudinal and transverse sections of the dentine of the root this corkscrew-like appearance is easily noted. (Fig. 47).

The tubules of dentine in deciduous teeth are sometimes constricted at short intervals, and thus present a moniliform appearance.

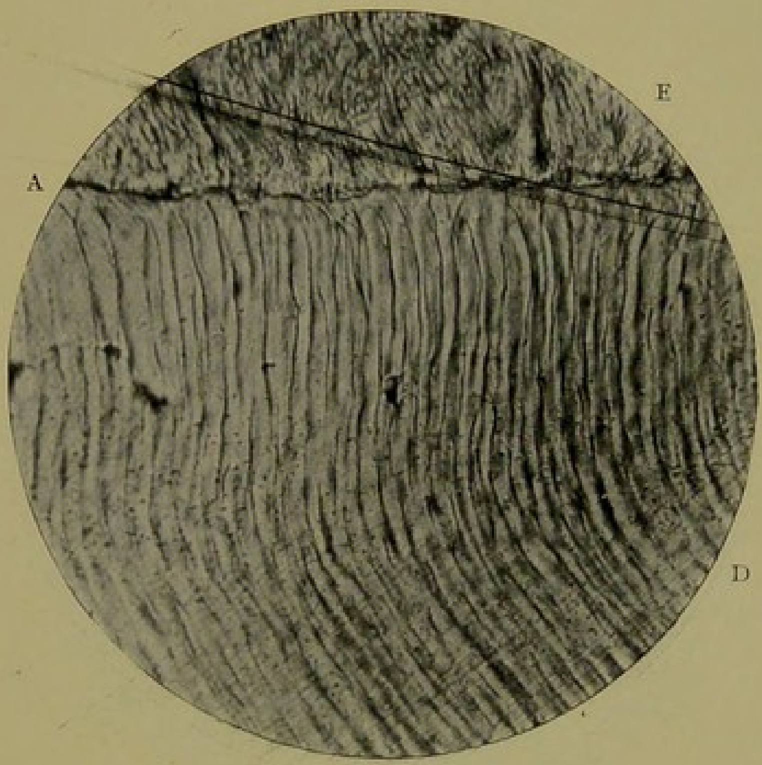


Fig. 48.—Dentine. Coronal portion, shewing tubes and spherical dilatations of the terminations of the branches. Prepared by grinding. Unstained. Magnified 160 times. D. Dentine; E. Enamel; A. Amelo-dentinal junction.

Branches.—As they proceed outwards, the tubes give off exceedingly fine subsidiary tubes. These are branches which somewhat simulate those on a twig of a tree. They come off alternately and laterally from the stem or main trunk sometimes at right, sometimes at acute angles to it; they are particularly abundant in the dentine of the roots, less frequent in or almost absent from that of the crowns, where they are only found as the tube approaches its free termination. These channels may end, either in the form of branches or not, (i) in tiny spherical culs-de-sac near the margin of the enamel; (ii) by anastomoses with their neighbours—"the terminal loops" of Kölliker; (iii) in the inter-globular spaces; (iv) in the granular layer of Tomes; (v) in the cementum; (vi) in the enamel-spindles beyond the amelo-dentinal junction or as straight cæcal terminations in the interprismatic cement substance. In the crown they often divide dichotomously (*i.e.*, by pairs). These divisions, most commonly ob-

Fig. 49.—Terminations of the dentinal tubes in the spaces of the granular layer of Tomes. Prepared by grinding. Unstained. Magnified 420 times.

served near the pulp cavity, are frequently bifurcations which Kölliker has described as being "repeated two to five times or more, so that at length four, eight, sixteen or more canals may arise from a single one." He also mentions certain "ramifications" which would seem to him to be the sub-divisions of the main tubes. He says (*op. cit.* p. 291) "the canals, now narrower after their division, run close together and nearly parallel towards the surface of the dentine; and except in the fang, just begin to send out ramifications in the outer half or outer third of their course.

These ramifications appear in the fangs chiefly as fine branches issuing from the main tubes, but in the crown bifurcated terminations of them. In the latter case they are for the most part few in number: it is otherwise in the fang, where the branches, being generally close to each other, and passing off from the canals at right or acute angles, give them sometimes the appearance of a feather, sometimes of a brush, the latter especially when the branches are large and ramify still more."

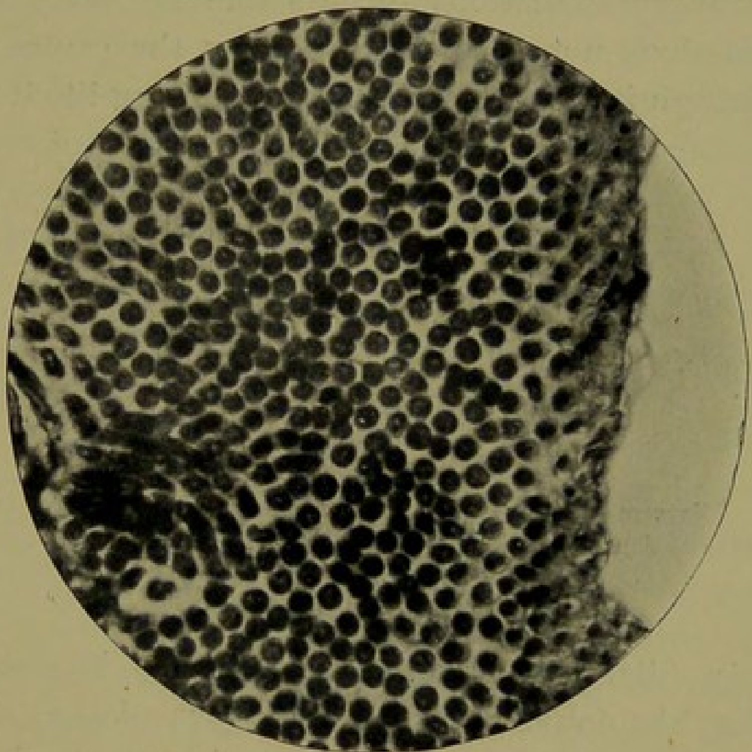


Fig. 50.—Dentinal tubes in transverse section. Prepared by Weil' process. Magnified 800 times.

The off-shoots, like the main tubes, taper towards their terminations.

Transverse sections of dentine, in which the tubes are cut across, show abundant rounded piercings of the matrix, each having a slightly modified boundary or wall. The boundary is represented by a yellowish ring—black or grey if stained by Golgi's rapid process—which, when unstained, is often quite unrecognisable; but nevertheless exists as one of the sheaths of Neumann. The walls are very minute, and, in thickness less than the diameter of the aperture of the tubule.

Kölliker gives a description of and pictures (*op. cit.* p. 291), a transverse section through the dentine of the roots of teeth in which the tubes are intimately connected by extremely numerous anastomoses. Probably it was taken close to the pulp surface, as there are no indications in the drawing of any spherical or other termination of the branches.

The channel, in the fresh state, contains the dentinal fibril which in transverse sections appears like a delicate roundish dot.[1] This does not necessarily occupy the centre of the canal, although it is most probable that during life it fills, or

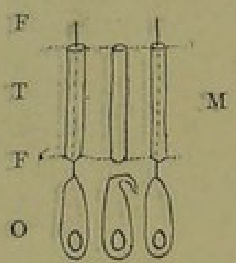


Fig. 51.

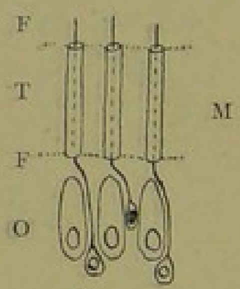


Fig. 52.

Fig. 51.—Diagram shewing Tomes' conception of relations of (O) odontoblasts; (F) dentinal fibril; (T) dentinal tube, with its sheath; and (M) matrix.

Fig. 52.—Klein's conception of the same.

very nearly fills, its entire length. It is impossible to prepare, for histological purposes, sections of the hard and soft tissues of teeth in combination, without altering their normal characteristics. Hence it seems reasonable to believe that not only does the protoplasmic filament traverse the tube from pulp to extremity, but that also it rarely, if ever, completely occludes it.

It is evident that the contents of the tubules are protoplasmic processes or fibrils which emanate from the odontoblasts of the pulp. They represent their distal or dentinal

[1] Bödecker, "Dentin, Cement und Schmelz," in Heitzmann's "Mikroscopische Morphologie," Vienna, 1883, describes the fibrils as angular, not round—under enormous magnifications. He thinks they give off tiny off-shoots which run into the matrix of the dentine through the sheaths of Neumann. The action of reagents used for fixing and hardening the fibrils *in situ* possibly produced this effect of angularity.

processes. E. Klein, "Atlas of Histology," 1880, p. 185, considers that the odontoblasts do not furnish the dentinal fibrils. He says: "I cannot find convincing evidence of the odontoblasts doing more than producing the dentine matrix. The dentinal fibres appear to me to be derived solely from the deeper layer of cells which are wedged in between the former." The fibrils themselves are soft structureless threads, devoid of a covering of any kind, and continuous through all the length of the tubule and its branches. They are bathed during life with a serous exudation from the surface of the pulp. This exercises, no doubt, a trophic influence upon them, and prevents injury, which might occur if they were brought into immediate contact with the lining membrane of the tubule.

All authors are not agreed on this elementary question of their contents. Magitot ("Traitè de Carie Dentaire," 1878), says that "during life the dentinal canaliculi contain a colourless transparent fluid;" and Morgenstern ("Ueber die Innervation des Zahnbeins" in "Archiv. für Anatomie und Physiologie," 1896), declares he has seen many *nerve filaments* in the tubes. "It is the dentinal canaliculi," he writes, "which for the most part contain the larger nerve filaments." His arguments are weak and valueless, depending as they do on the results obtained from the vagaries of so uncertain and unreliable a method of staining as that of Golgi, when applied to sections of dentine.

The matrix and tubes of dentine show marked translucency in places, especially the roots, in senile and functionless teeth. (See Chap. XVI).

(iii) *The Sheaths of Neumann*

After careful decalcification there remains a soft, mucoid, felt-like mass, the organic part of dentine—the walls of the tubes. Highly elastic and slightly cohesive to the intermediate matrix, when thus isolated the sheaths look like long yellow-elastic connective tissue-fibres: but they are, of course, quite hollow. They possess no histological significance. They were first accurately and most fully described by Neumann in 1863[1]. He demonstrated that all soft tissues of the tooth having first been removed, subsequent maceration in boiling acids, of various strengths for varying periods of time, led to dissolution of the whole of the inorganic elements, and left behind a tube-like formation, which was characterised by and distinguished from the dentine matrix by the peculiar property of resisting the action of chemical substances, and by great elasticity, and slight cohesion with

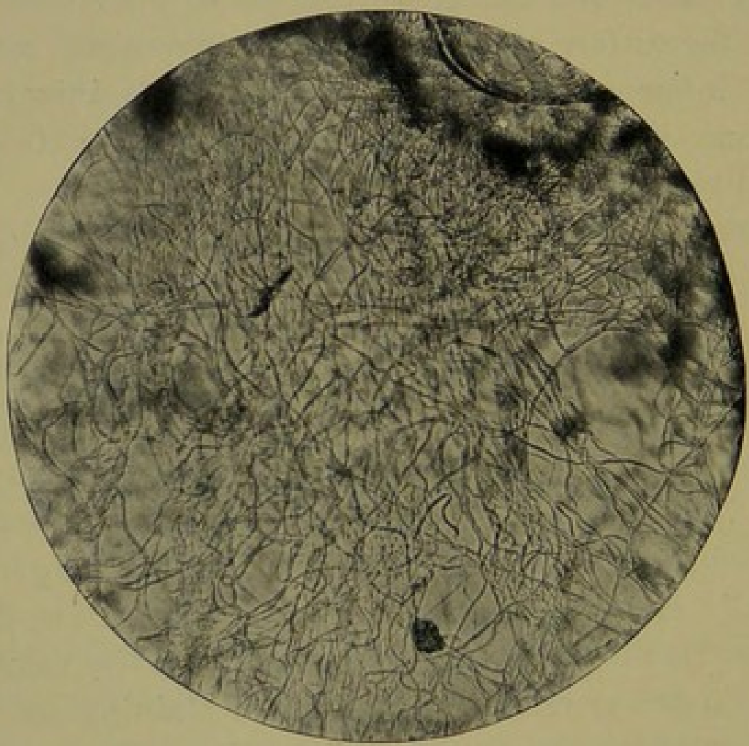


Fig. 53.—The sheaths of Neumann. Prepared by decalcification, and teasing out. Stained with borax-carmine. Magnified 240 times.

the inter-tubular material. Some attention has lately been again given to the question of the existence or non-existence of these sheaths; and interest revived in what seems a simple, but is, in reality, a complex study. Optical effects are so easily produced when examining dentine: its collagenous substance is so hard: its association with the soft protoplasmic easily-destructible soft tissues so direct and

[1] "Ein Beitrag zur Kenntniss des Normalen Zahnbein-und Knochen-gewebes." Leipzig.

complete, that it can be no small matter for wonder that investigators still hold opposite opinions which give rise to considerable confusion.

Neumann affirmed that the tubules possess proper walls. He called them "Dental Sheaths" ("Zahnschieden") and he added that: "In the dental tubes are contained fibrous non-calcified processes of the peripheral pulp-cells ("Tooth-fibres.") In this way was corroborated the original statement of John Tomes in 1856, in his classical contribution to the *Philosophical Transactions of the Royal Society*, entitled "On the presence of fibrils of soft-tissue in the dentinal tubes."

Kölliker, who actually first discovered them by acid maceration, points out that the apparent walls of the tubes in transverse sections are not the *real* walls, but a certain length of the canals themselves, which appear as dark rings. If, however, an edge, very narrow in width, and yellowish in colour, is seen, this he regards as the *true* wall ("Mikroscopische Anatomie," Leipzig, 1854).

Oscar Römer denies *in toto* the existence of these sheaths of Neumann. In his monograph already quoted, Part I. is devoted entirely to the consideration of their presence or non-presence in dentine. According to his measurements, they are 1μ to 2μ in width at their broadest part. He contends that the *contents* correspond to the *walls* of the tubes; in other words, "that the odontoblast *processes* (or dentinal fibrils), really correspond to Kölliker's dentinal *tubules*," and continue as, and do not enter into Neumann's sheaths. He sums up his arguments with the following assertions:—

(*a*) The fibrils described and depicted by Tomes in 1856 are no new formations, but completely identical with the dentinal fibrils described by Kölliker in 1834, while Tomes' membrane of the fibrils corresponds to the wall of the tubules, and to Neumann's sheath; and the contents of the fibrils, described by Tomes as semi-fluid, correspond to the contents of the tubules described as fluid by other writers.

(*b*) The dentinal tubes assumed by Tomes do not correspond to the dentinal tubules of Kölliker, but are artificially-produced, wall-less, tube-shaped hollow spaces produced in the matrix of dentine by decalcification and dissolution, spaces from which Kölliker's tubules and Tomes' tubes can be easily isolated.

(*c*) The odontoblast processes, designated "Tooth-fibres" or "Tomes's fibres," are not the contents of Kölliker's dentinal tubules, but represent both *the sheath* of Neumann and *the contents* together. Therefore, the conception of "Tooth fibres" or "Tomes's fibres," as the contents of Kölliker's

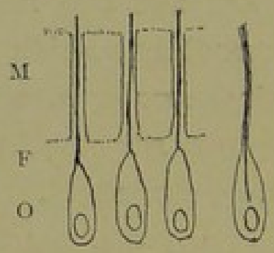


Fig. 54.—Diagram shewing Römer's conception of relations of (O) odontoblasts; (F) dentinal fibril; and (M) matrix.

tubules, must be dropped, and we must content ourselves for the present with the original assumption, that the contents of the dentinal tubules are a fluid or semi-fluid material, or one that has not yet been adequately investigated.

And he concludes :—"According to my observations, there do not exist in the dentinal substance any tubules other than those of Kölliker. The dentinal tubes of Tomes are only tube-shaped holes produced in the dentinal substance by maceration; one cannot perceive, even under the strongest magnifying power, and even in stained section-preparations of *normal non-carious* dentine—whether in transverse, longitudinal, or diagonal section—any intervening space whatever, between odontoblast process (or the dentinal tubule) and the matrix of the dentine."

The various contradictory theories concerning the existence and non-existence, the walling, and the contents of the dentinal tubules may be briefly mentioned as follow :—

(i) Their absence is affirmed by Magitot (1880.)

(ii) Their presence in mature dentine is denied by Xavier Sudduth (1887), who ("American System of Dentistry," p. 594), says: "The salts of calcium are deposited around the fibrils of the odontoblasts, and in a certain sense, dentinal tubuli may be said to exist at that time. We may say that this tissue is an aggregation of tubes containing fibrils, but in the process of aggregation they lose their identity as such, becoming cemented together into a solid tissue." And further, "The fact that dentine is not capable of being broken up into tubes is, in my mind, conclusive evidence against the theory of the existence of a *dentinal sheath per se* as the wall of a dentinal tube."

(iii) There are two kinds of tubules in dentine, one containing the processes of the odontoblasts, the other, finer, to receive *nerve fibres*. An unproved postulate of Franz Boll, 1868, "Untersuchungen über die Zahnpulpa" in "Archiv. für Mikroskopische Anatomie." Bd. iv.

(iv) The processes of the odontoblasts (dentinal fibrils) are Kölliker's dentinal tubes. Lent, 1885, "Ueber die Enturcklung des Zahnbeins und des Schmelzes," "*Zeitschr. für wissensch. Zoologie,*" Leipzig.

(v) The sheaths of Neumann are dependent on calcified dentine substance, because they are invisible (absent) in the dento-genetic zone. Erwin Höhl, 1896, "Beitrag zur Histologie der Pulpa und des Dentins" in "Archiv. für Anatomie."

(vi) The membrane of the processes of the odontoblasts form the sheaths which run in wall-less tubes. The sheaths *in situ* are wider than those artificially isolated by acids. Römer, 1899, *op. cit.*

(vii) Their existence as separate structures is doubted by Underwood, "Aids to Dental Anatomy and Physiology," 1902.

(viii) The tubules have definite walls (sheaths), and contain Tomes' dentinal fibrils,—processes from certain cells of the pulp. Tomes *op. cit.* 1898; as well as many other authors.

(iv) *The Interglobular Spaces of Czermak*

At varying distances below the amelo-dentinal junction are found in apparently sound as well as in imperfectly developed dentine numerous globular markings arranged in linear series, and running transversely to the dentinal tubes. Defective dentine exhibits them remarkably well. They were first described by J. Czermak in 1850, and designated by him the "interglobular spaces." "Beitrag zur Mikro-Anatomie der Menschlicher Zähne."

As Tomes has pointed out, they are due to an arrested development of the tissue during certain early stages of its growth, when, for some cause or other, the calco-globular masses have not fused, or have only partially melted together. The functions of the lime-bearing cells of the pulp have become temporarily modified, and instead of the dentinal basis-substance being deposited in proper amount and regularity—making a homogeneous whole—the calco-globular masses have remained unchanged or slightly changed, and the matrix has flowed around, and become, in time, fully calcified.

Seen under advantageous circumstances, *e.g.*, in sections which have been carefully ground thin, and stained by Golgi's silver chromate method, or impregnated with coloured collodion, the spaces vary greatly in shape and size. Their scalloped edges are made up of the rounded or oval margins of spheres of calco-globulin mutually pressed together. If these bodies retain their rotundity, the spaces have here three, four, five, or more concavities forming their outline, the semi-lunes being often dissimilar in size and shape; there, they have a lobulated appearance; while elsewhere, by the process of union of two or three spaces, they become elongated and irregular. In diameter they vary from $2{\cdot}5\mu$ to $4{\cdot}2\mu$, or less.

As to their contents they are generally believed to hold in their interiors, in the fresh state, soft protoplasm which fills them entirely. Dentinal tubules often traverse them.

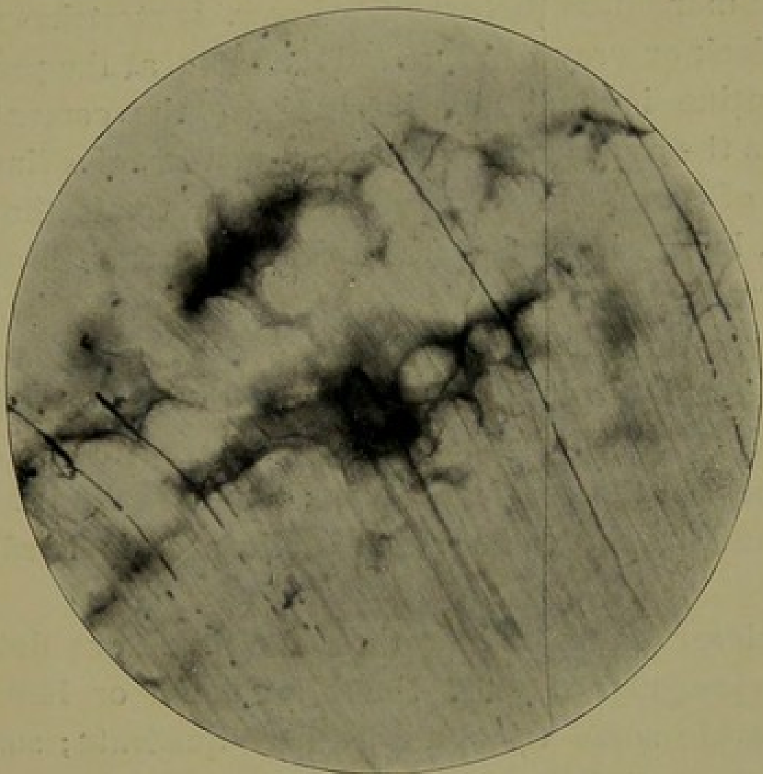


Fig. 55.—Interglobular spaces crossed by dentinal tubes. Prepared by Weil's process. Magnified 240 times.

Tomes has proved this by noting in fragments of carious dentine, that the tubules which cross, not only contain micro-organisms, but have themselves become occasionally enlarged. The protoplasm, under favourable conditions, undergoes calcification, and the dentine is said to be areolated.[1]

Dentinal tubules may terminate in the inter-globular spaces.

[1] These areolations of dentine are most likely perfectly analogous with those irregularly-shaped layers made up of solid rounded calcified bodies seen occasionally near the surface of the shafts of long bones, lying in their osseous laminæ. They differ, however, in the fact that, whereas the former betray certain developmental defects, the latter mark various sites of absorption and re-deposition of bone.

In dried sections, they contain air, a fact which is easily demonstrated by soaking thin slices of dentine in coloured collodion, which runs into and fills every part. They are therefore in dried specimens veritably "spaces."

(v) *The Granular Layer of Tomes*

In the radicular portions of teeth, and beginning at the cervical margin, is the granular layer. It stretches as a fairly thick black or grey band, round the roots, at the periphery of the dentine immediately internal to the cementum. It presents the appearance, under low powers, of a line of black grains of sand. Near the neck of the tooth the layer is narrow, but as it reaches the apical foramen, it broadens out considerably, and soon is more pronounced. This is not, however, constant. The writer possesses a section in which the rows of interglobular spaces and the granular layer are coalescent at a spot immediately subjacent to the ending of the enamel at the cervical region; and here the latter is very broad and marked. In some sections it is hardly at all visible.

On closer examination, these multitudinous dots assume various irregular shapes. Some are more or less circular, others oval; some triangular, others quadrate; some claviform, others stellate; a granule—in a word—represents a compromise between an inter-globular space and a lacuna in pathological cementum.

Many instances are noted where the terminations of the dentinal tubules end in these tiny spaces; and when canaliculi seem to lead from them, they can be traced to one of the endings of a tubule.

Approaching the apex of the root, the spaces increase greatly in numbers, and are much larger and more irregular. Occasionally, a large spindle-shaped lacuna may be found. The layer is situated in a matrix of dentine which is distinctly granular; though the term "granular layer" refers obviously to the spaces.

Their contents, according to Bödecker, are soft protoplasm which is in connection with the contents of the tubules on one side, and the canaliculi of the cemental lacunæ (when they exist) on the other. It would seem, however, that it is by no means easy to prove this assertion. The granular layer is stained with the utmost difficulty by the action of carmine or any of the other basic, acid, or aniline dyes. It is more likely to be beyond the pale of nutrition.

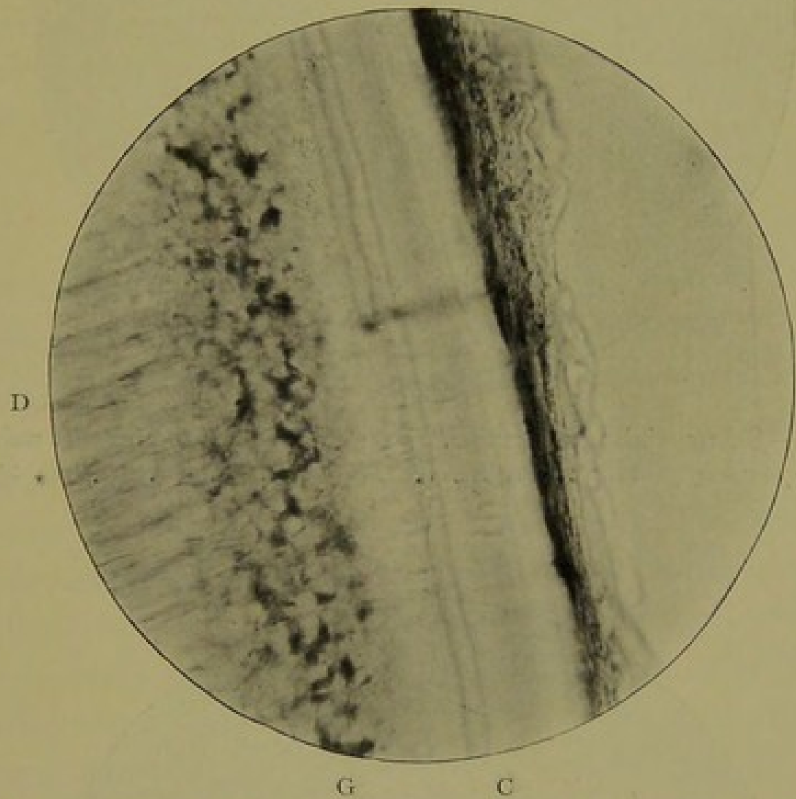


Fig. 56.—The granular layer of Tomes. Prepared by grinding and staining with coloured collodion. Magnified 240 times. D. Dentine; C. Cementum; G. Granular layer.

Bounding the granular layer externally is a very narrow strip of homogeneous dentine: then comes a dark line—it is nothing more than that—which forms the point of demarcation between dentine and cementum. The homogeneous zone and this line are devoid of any structure whatever.

(vi) *Schreger's Lines*

These, sometimes seen in horizontal sections of dentine must not be confounded with Schreger's lines in enamel.

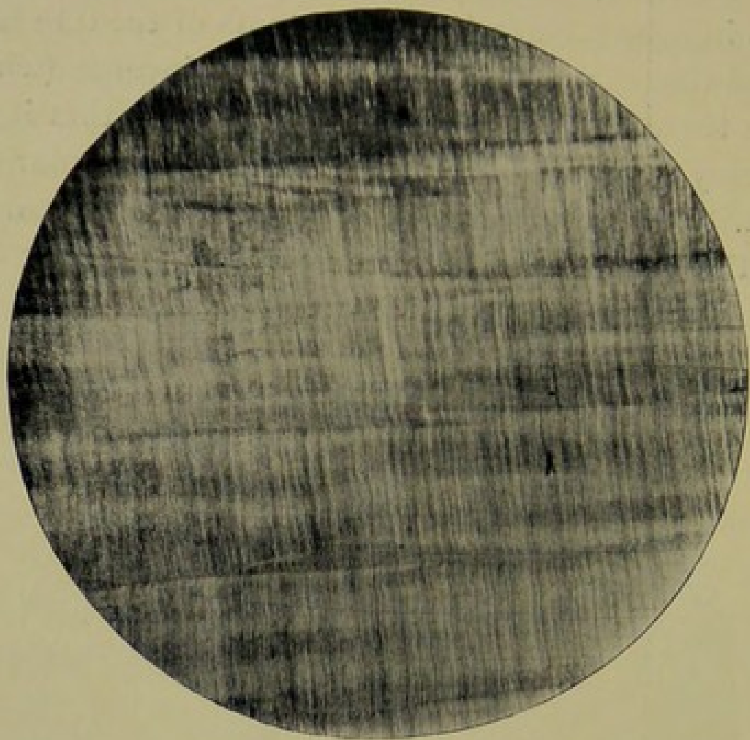


Fig. 57.—Schreger's lines in dentine. From the ivory of the tusk of a walrus. Prepared by grinding. Unstained. Magnified 45 times. *Cf.* Fig. 25.

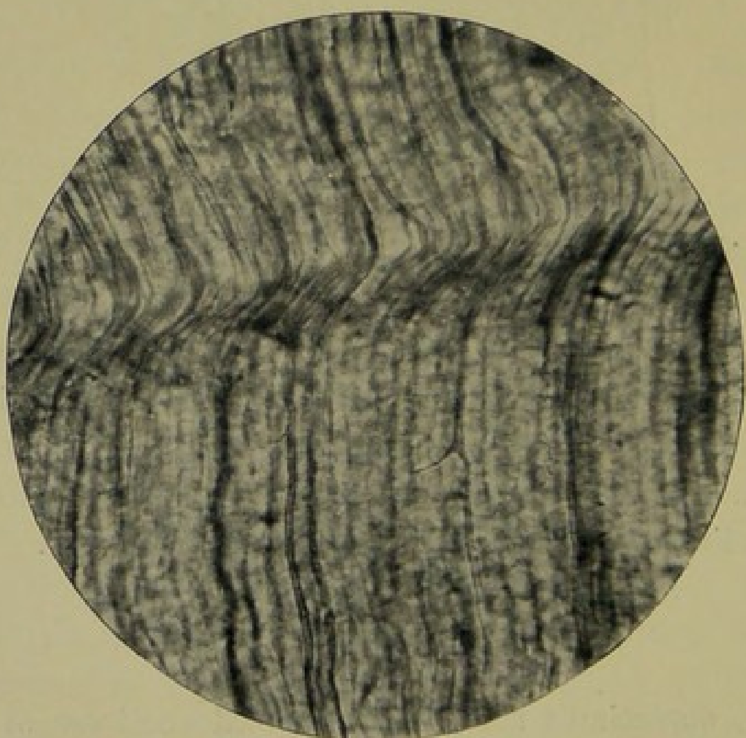


Fig. 58.—Same as the preceding. Magnified 420 times. *Cf.* Fig. 26.

Many of the dentinal tubes as they course outwards form the artificial appearance of bands, through the primary curvatures passing in the same direction. Thus, Schreger's lines are merely markings which, running parallel to the external edge of dentine, are produced by the coincidence of the primary curvatures of the tubules. (See Fig. 58).

They are well—perhaps best—exhibited in sections of the ivory of the tusk of walrus, where they appear to be due to sudden short bends or twists of the primary curvatures, occurring at identical places in their lengths. The effect under low powers is a much striated character of the tissue.

(vii) *The contour lines of Owen*[1]

comprise (i) Schreger's lines in dentine, and also (ii) rows of so-called "dentinal cells." Under low powers these rows resemble lines, particularly in human molars and in the teeth of *Cetacea*, and it is to them that he refers when he describes them as "contour lines." On page 460, he says, "Both the primary and secondary curves of adjacent tubes are parallel; and occasionally the tubes make a short bend along a line parallel with the outer contour of the crown, giving rise to the appearance which may be called "contour lines," the parallelism of the entire tubes being affected only by the amount of divergence in radiating from the pulp cavity." Again (p. 464), "These lines are not equally conspicuous in every tooth; I have usually found them most so in the molars of the human subject, where without being regularly equidistant, they have presented intervals of about one hundredth of an inch, commencing at thrice that distance from the periphery of the dentine."

With regard to the last-named histological formation, *i.e.*, the "dentinal cells," Owen remarks, "In many teeth, moreover, and especially in the tusks of the elephant, the secondary branches of the dentinal tubes dilate into inter-tubular cells along lines, which in like manner are parallel

[1] Owen: "Odontography."

to the coronal contour of the tooth; hence another cause of the appearance of concentric lamellæ, and of the actual decomposition of such teeth into super-imposed lamelliform cones." These dentinal or "calcigerous cells," as this distinguished author also designates them, form many layers having a certain amount of parallelism with the contour of the pulp

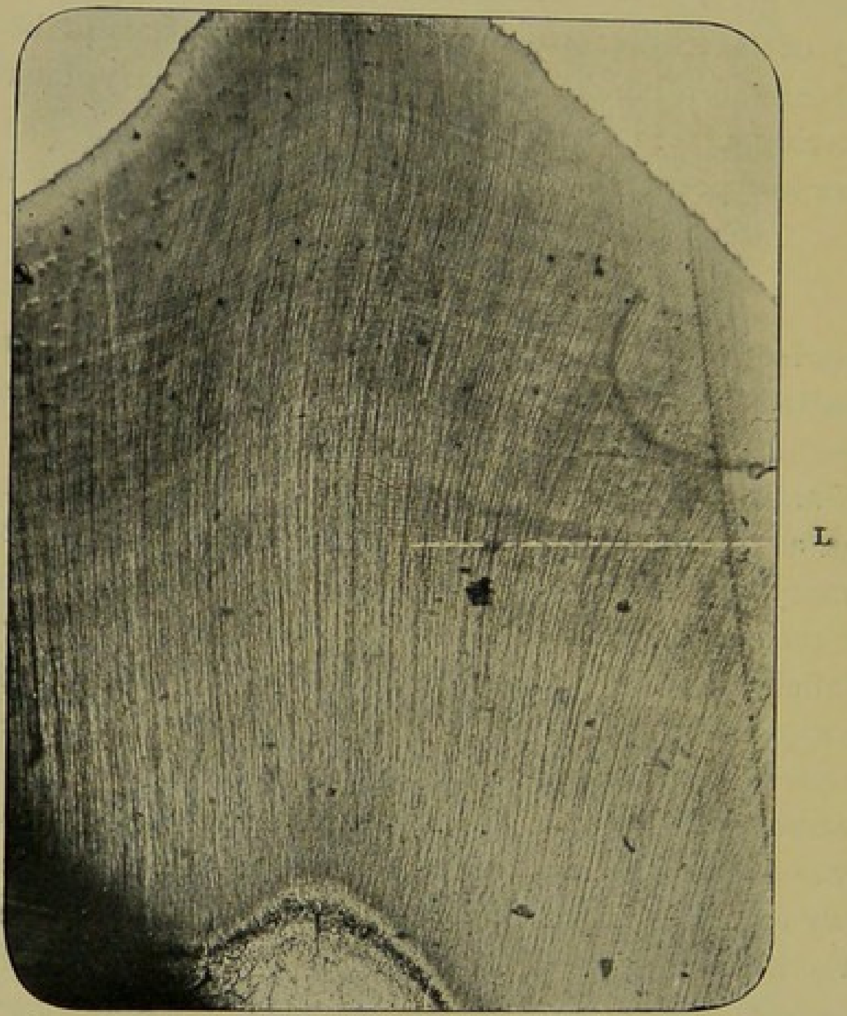


Fig. 59.—Contour lines of Owen in dentine. Vertical section of Human molar. Decalcified. Stained with Ehrlich's acid hæmatoxylene. Magnified 40 times. L. Owen's lines, running in a transverse direction.

cavity. He described them first in a Report to the British Association in 1838 (vol. vii., p. 144). They are not animal cells in the modern acceptance of the term, but in the interspaces of the tubes they include a "tubular structure." "The intertubular space is not cellular, but clear and structureless." To-day, histologists would prefer to think of them as representing merely the calcified outlines of what might have been interglobular spaces. Owen's contour lines were seen by Salter,[1] who, however, prefers to call them "incremental lines," as indicating more accurately the manner in which the tooth substance is built up.

(viii) *Lamellæ or Laminæ*

Occasionally, though seldom, vertical sections of roots or human molars, when ground, reveal very clearly certain markings in the periphery of the dentine. Ranged at right angles to the tubules, and running concentrically with the pulp chamber, these short straight stripes are very numerous in some sections, sharply defined and bright when unstained, of variable length, and cross the tubes near their extremities. They are non-pathological in origin, and are not artificially made by the action of reagents. Most probably they represent marks of stratification during the development of the tissue.

A second class of laminæ is often seen in the matrix of mature dentine when decalcified in hydrochloric acid, and stained with hæmatoxylene. Vertical-transverse (labio-lingual) sections of molars, show over the cornua of the pulp, regularly-arranged faint shadings, separated by brighter less-coloured lines; and in the cervical and radicular regions, rounded dots (which are probably the same as Owen's dentinal cells[2]) of darker colour near the pulp, and near the cementum long looped lines running in the direction of the tubes. These long lines or laminæ are joined at their distal ends by delicate arcuate markings, the concavities of which always look towards the pulp.

Thus, lamellæ in dentine include two groups: the former, short, tube-like, straight; the latter, long wavy bands and spherical shadows, and lines joined by an arch.

These laminæ are not due to staining, nor are they optical

[1] "Dental Pathology and Surgery," page 10, 1874.

[2] Owen's "Odontography." Pl. xcv. fig. 2, also cxiii., fig. 2, and cxix., fig. 1.

illusions. The first group obtains in natural conditions; while the others are evidently rendered more apparent by decalcification, and more striking by staining. They both certainly indicate the manner in which calcific deposition has taken place.

F. J. Bennett,[1] in a paper on "Certain points connected with the Structure of Dentine;" has described laminæ in dentine which has been acted upon, for some length of time, by glycerine. In certain longitudinal sections the dentine bordering the margin of the pulp cavity "presented a ringed appearance, and was slightly laminated." This was due to "the dentinal tubes, in this situation, having lost their surrounding intertubular tissue, which left them clearly defined; but this removal of the matrix had not completely freed them. Their course appeared to be interrupted, at regular intervals, by layers of membrane having a general direction parallel to the surface of the pulp. The layers of membrane (laminæ) bore a general resemblance to that seen in interglobular dentine; in this case, however, circular apertures and not solid globules occupied the surface of the membrane. Oval spaces were also found between the layers of membrane." Bennett put forward the following hypotheses, as being the explanation of such phenomena :—

(a) The laminæ might represent a part of the matrix of dentine, which, possessing a greater power of resisting the solvent action of glycerine than the rest, represents a new transitional stage or phase in its calcification; or

(b) Unequal expansion or contraction of certain parts of the matrix, producing separation of the layers; or

(c) Evidences of cell structure in the matrix.

SECONDARY DENTINE

Secondary dentine is a physiological product. In the strictest sense of the term, it should be used to designate *every* form of new tissue deposited in the substance or on

[1] *Trans. Odonto. Soc. of Gt. Britain, Vol. xxi., p. 6, 1889.*

the surface of the pulp, which occurs after full development of that organ and of the dentine. It has been hitherto used, however, for describing both physiological and pathological conditions. Salter's[1] patient and remarkable investigations in that particular portion of dental pathology which deals with degenerative changes in the dental pulp, led him to classify all forms of dentinal deposition as secondary dentine, and in a sense this was perfectly correct. But the term seems to require a more definite meaning; for he describes under this one heading three kinds:—"Dentine of repair," "dentine excrescence," and "osteo-dentine" or "intrinsic calcification."

It would be more scientific in modern days, since so many varieties of pathological dentine have become known, to restrict the expression entirely to physiologically-constructed dentine found, *e.g.* (i) in the incisive margins of the persistently growing teeth of *Rodentia*, etc., in Man (ii) in the accompaniments of old age, or (iii) the deposits sometimes found in long-retained deciduous teeth. Senile teeth constantly possess a complete mass of secondary dentine occluding the pulp cavity, the occurrence of this having been brought about in a physiological manner. As a non-pathological result of an active state of the pulp, secondary dentine may lastly be associated with (iv) attrition, abrasion or fracture of the teeth, when not complicated by caries of enamel or dentine.

[1] "Dental Pathology and Surgery," chaps. xi. and xii., 1874.

CHAPTER V.

THE CEMENTUM

MICROSCOPICAL ELEMENTS: (i) Matrix; (ii) Incremental lines; (iii Perforating fibres.

GENERAL CHARACTERISTICS

Definition.—The thin hard substance situated immediately external to the dentine of the roots of teeth of Man and many animals.

Origin.—It is a product of the osteoblasts of the periodontal (alveolo-dental) membrane, *i.e.*, the thin inner layer of the dental follicle.

Distribution.—In the great class *Mammalia* cementum or *crusta petrosa*—a former appellation—forms the cortex of the radicular dentine: but also in the ox, horse, elephant, capybara, and other animals, it not only unites the roots of teeth, but before attrition has taken place, exists as the coronal integument.

In Man, it normally measures, in width, from 175μ to 250μ.

It is rarely found in the teeth of *Pisces* and *Reptilia*; and is absent from the roots of anchylosed teeth generally. Ovarian teeth also do not possess it.

Macroscopical appearances.—Whitish-yellow in colour, smooth, dull, line of junction with enamel pronounced and darker than rest of cementum.

HISTOLOGY

The structures calling for special microscopical attention in this the least important of all the hard dental tissues of man, are, (i) Matrix, or basis-substance; (ii) Incremental lines; and (iii) Perforating canals and fibres.

(i) *The Matrix*

The matrix or basis-substance makes up the greater part of the tissue. It extends as a narrow non-vascular lamina round the roots of teeth external to the granular layer of dentine,

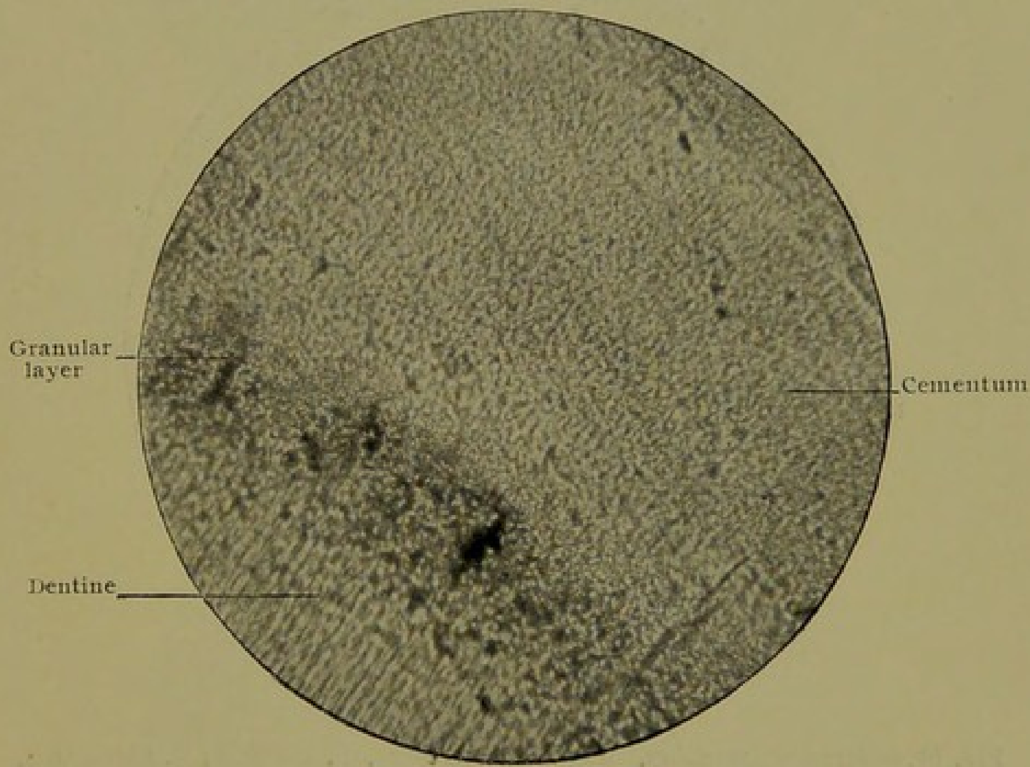


Fig. 60.—Granular appearance of cemental matrix. Magnified 1,000 times. Photomicrograph by Norman Broomell.

beginning at the cervical region and covering over the apices of the roots, though like the dentine it is discontinuous at the apical foramina. Its relationship to enamel has already been alluded to; its relationship to dentine is such as to make it difficult, if not at times impossible, to determine where the one begins and the other ends. Often no sharp line of demarcation—as in the case of enamel and dentine—exists.

The general appearance of this tissue varies very much—thus it may be hyaline, finely granular, or even made up of bodies of an amorphous type.

It is capable at times of being stained, especially at its outermost part. Normal cemental matrix in young and old subjects is therefore nearly structureless. Roots of simple teeth unaffected by morbid processes show this thin layer, which maintains the same degree of thinness throughout its whole extent. In the case of bi-rooted premolars or in molars, however, there is a tendency for it to become slightly thicker on

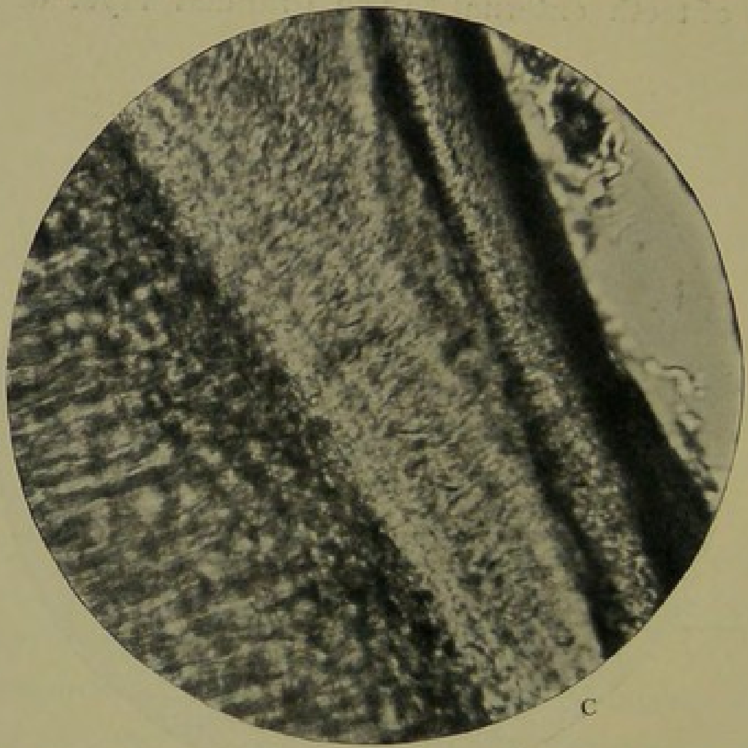


Fig. 61.—Same as preceding. Magnified 420 times. D. Dentine ; C. Cementum.

their alveolar or inner aspects. In old age it is somewhat thicker. (See Chapter XVI)

But in every section of structureless cementum, faint shadings of a slightly different refractive index to other parts of the tissue can, on careful examination, be clearly differentiated. Normally they are but feebly revealed. These shadings are arranged in two ways: The more pronounced run parallel to the periphery, and without doubt represent immature incremental lines: the others, which are very numerous, cross

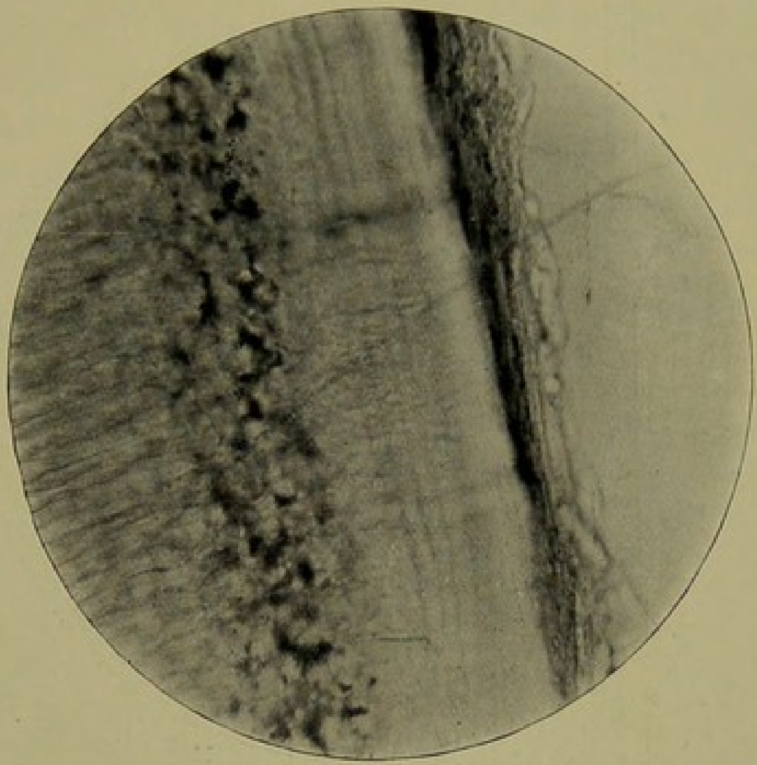


Fig. 62.—Incremental lines. Prepared by grinding. Unstained. Magnified 400 times.

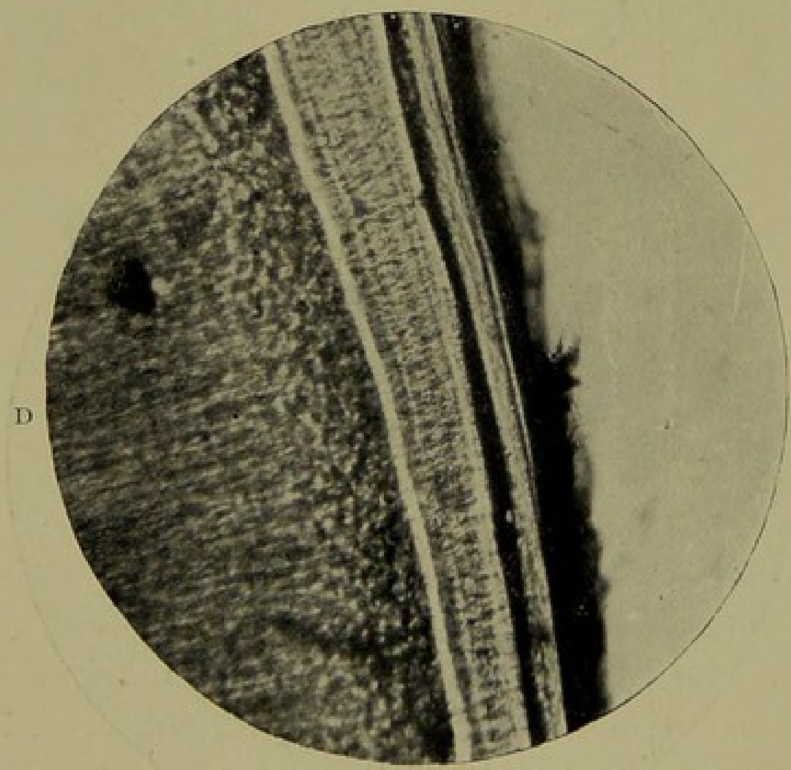


Fig. 63.—Perforating canals and fibres in cementum. Prepared by grinding. Stained with chloride of gold. Magnified 40 times. C. Cementum; H. The homogeneous layer; D. Dentine.

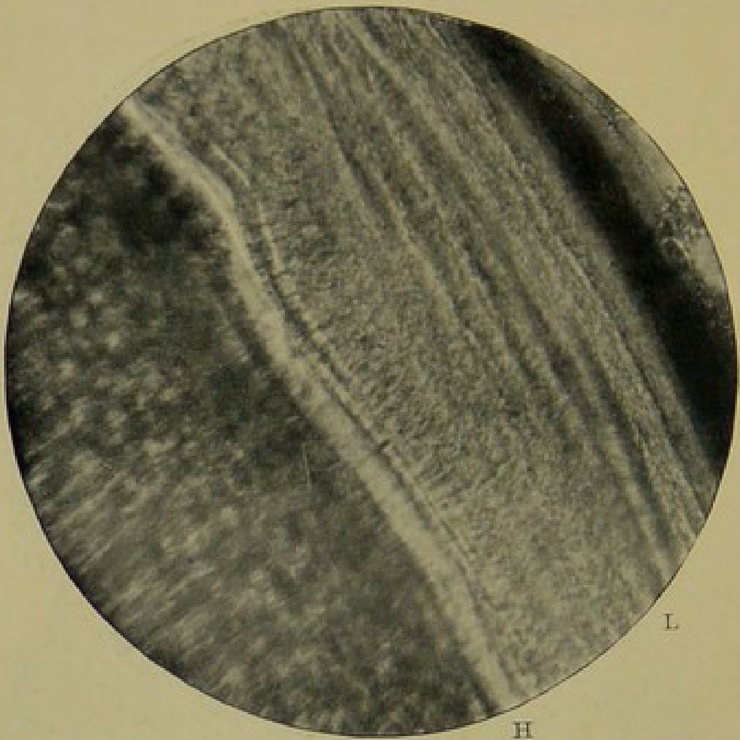


Fig. 64.—Cementum. Prepared as in last figure. Incremental lines and homogeneous layer well defined. Magnified 400 times. L. Incremental lines ; H. Homogeneous layer.

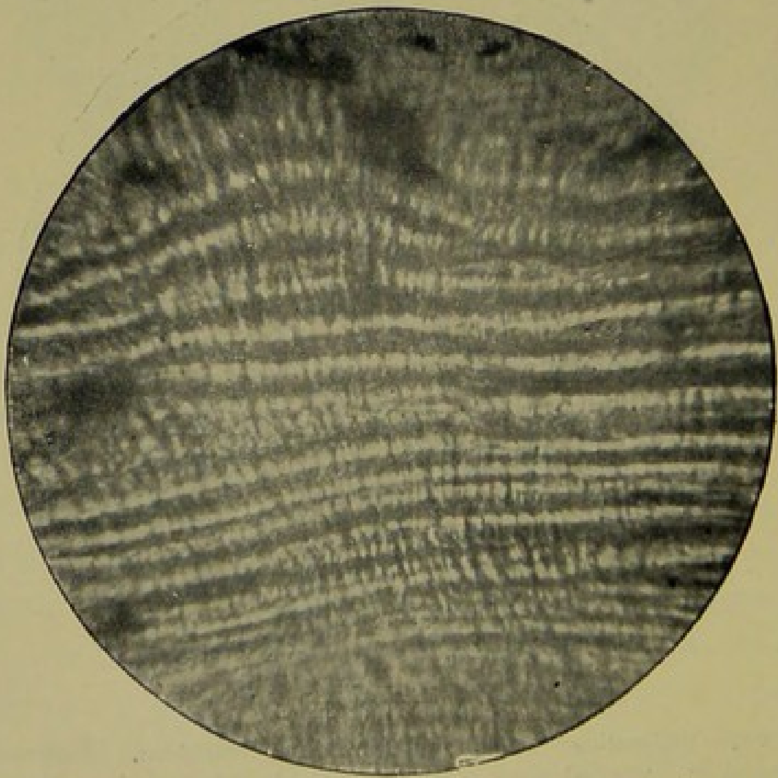


Fig. 65.—Longitudinal lamellæ of cementum, shewing numerous varicosities. Magnified 1,000 times. Photomicrograph by Norman Broomell.

the first-named at right angles. Both classes can be observed in vertical as well as horizontal preparations. (Fig. 64).

In thus describing the minute organisation of this tissue, the writer would like to emphasize the fact, that in his opinion, formed as the result of the examination of many sections, the cementum of the teeth of man is usually free from lacunæ and canaliculi, being nothing more nor less than a dense, solid, nearly homogeneous band of calcified basis-substance, ex-

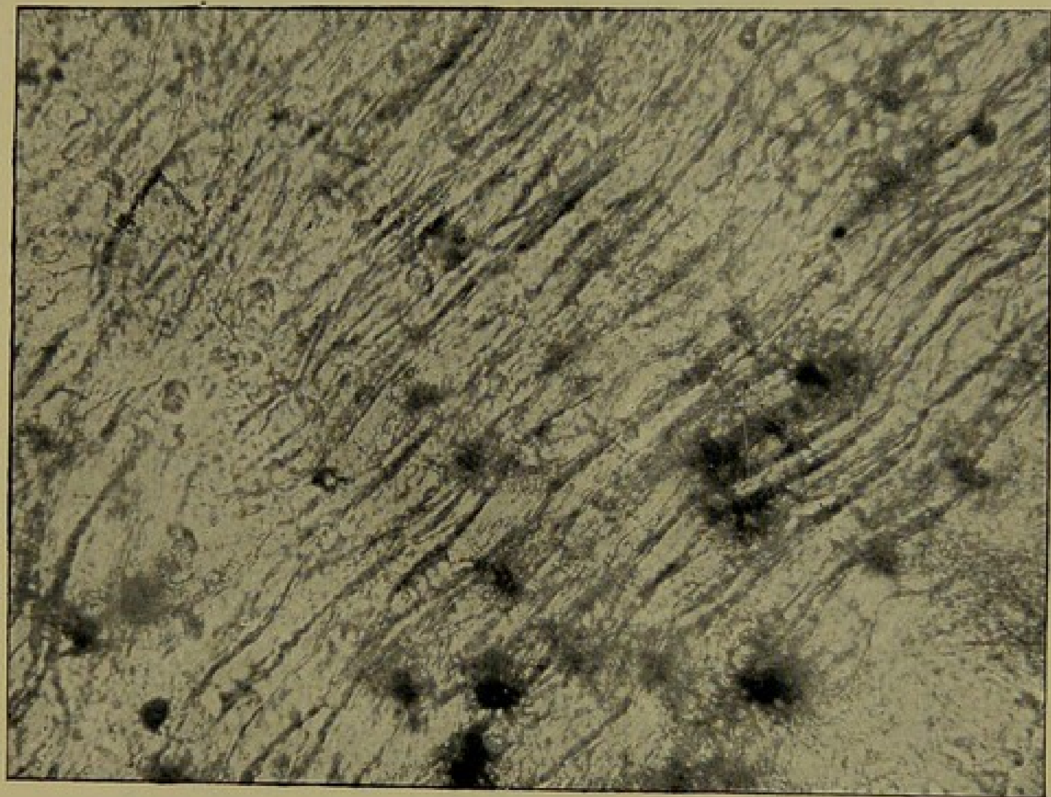


Fig. 66.—Striated cementum from radicular region of tooth, near apex, to shew the complex character of the thicker tissue, viz. :—"The longitudinal striæ, transverse fibres, cement-corpuscles and zones of apparently unbroken granular matrix." Magnified 100 times. Photomicrograph by Norman Broomell.

tending round the roots. The teeth of monkeys and sheep (root portions) have been inspected microscopically; and here, as in man, it exists as a thin strip almost devoid of histological elements, such as those characteristic of bone. In the opossum and certain other marsupials, however, a thick layer of cementum is found sufficiently often to be practically a characteristic of this class. The reader is referred to page 121 in this connection. This lack of lacunæ in normal cementum has also been observed by Otto Walkhoff (*op. cit.* pp. 142, 143) and figured by him in Plates v. and ix.: both statement and photographs having been brought to the notice of the writer since the preceding lines were penned.

But one of the after-effects of a morbid change or a series of morbid changes in the alveolo-dental periosteum—however

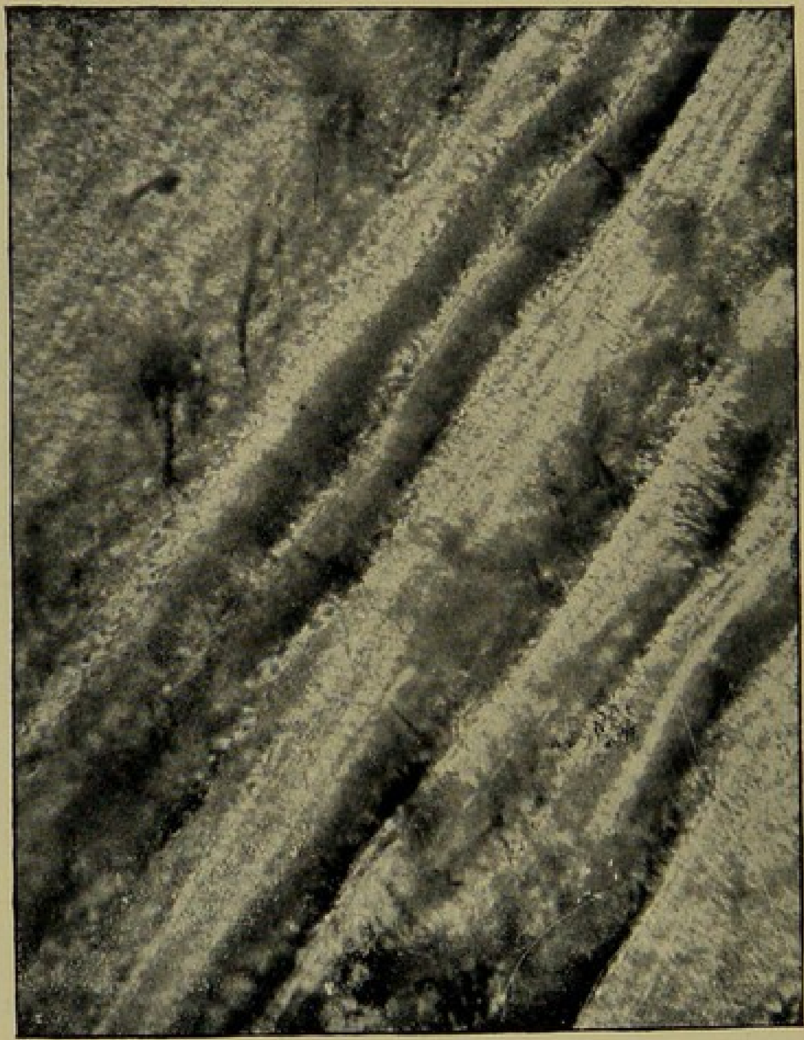


Fig. 67.—To shew partial calcification of the incremental lines. Magnified 1,000 times. Photomicrograph by Norman Broomell.

slight, is the stimulation of the otherwise quiescent osteoblasts, to deposit osseous material on the periphery of the tissue: and lacunæ are then formed, imprisoning the osteogenetic cells. A single lacuna may not infrequently be observed situated near the granular layer of Tomes; and this would indicate abnormal processes going on about the time the earliest deposited cementum is completed. There is, therefore, under healthy conditions, no chain of living matter joining the pulp to the periodontal membrane.

(ii) *Incremental Lines*

represent the marks of stratification during development. They look like sinuous unbroken lines placed in a fairly regular and uniform manner one over the other. Sharply

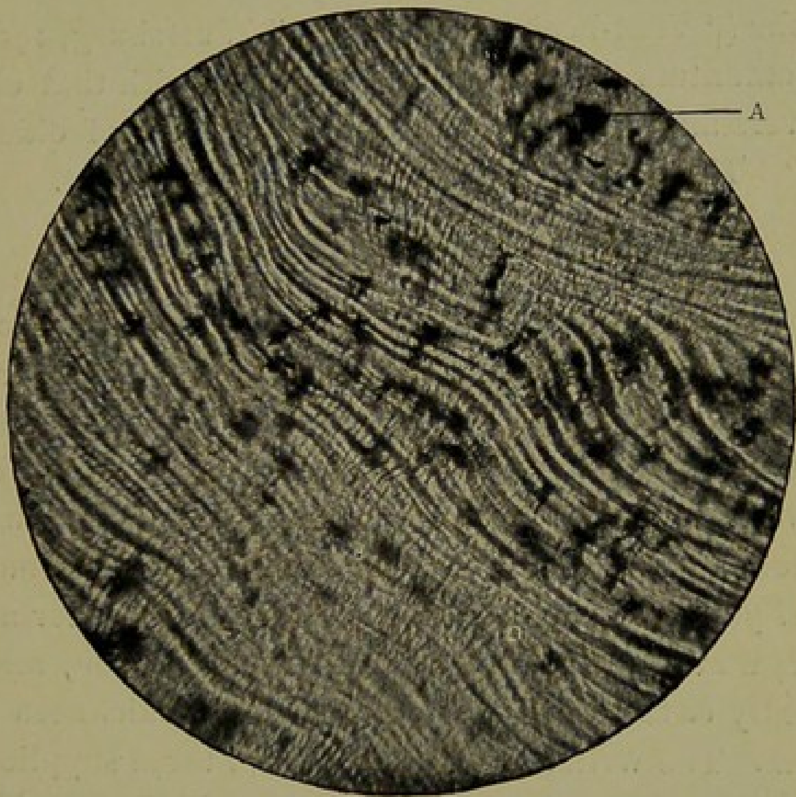


Fig. 68.—Transverse section of an adult premolar near apex, to shew the varying disposition of the lamellæ. The incremental lines follow the surface of the dentine. "As the centre of the area is approached, this regularity is much interfered with, some of the lamellæ being discontinued, others greatly thickened, while the field, taken in its entirety, suggests anything but regularity in the laying down of the different strata. Magnified 60 times. A. Granular layer of Tomes. Photomicrograph by Norman Broomell.

marked off from the rest of the matrix, at times, and running in a parallel direction to the long axis of the root, they give rise to a lamellated structure. (Fig. 65).

In young cementum the lamellæ correspond in number over all portions of the root, the only difference being that they are much thinner at the cervical than at the apical region: in adult cementum their width is greater, and they are usually more numerous in the latter than the former situation.[1] (Norman Broomell.)

The term "Incremental lines" was introduced by Salter, ("Dental Pathology and Surgery," 1874), and includes the laminations sometimes found in enamel (but not the brown striæ of Retzius, or Schreger's lines), the contour lines of Owen in dentine, and the layers of stratification in cementum.

P. Stohr ("Text-book of Histology," Wurtzburg, 1901) says that "Cementum coincides in its structure with that of bone, but Haversian canals are found only in that of older individuals." This is probably an erroneous statement.

(iii) *Perforating Canals and Fibres*

In close juxtaposition to the band of homogeneous tissue which borders the dentine, and running at right or acute angles to it, in adult normal cementum, there can be commonly seen thick bundles of connective tissue fibres and broad irregular canals. In this way the homogeneous layer is bounded internally by the granular layer, externally by groups of perforating canals and fibres. The former are few and irregularly curved in an outward direction, and may occasionally extend half-way through the thickness of the cementum. The writer has found some of them supplied with tiny filamentous branches. The latter on high magnification are seen, in sections prepared by Weil's process, to consist of myriads of bundles of blackish strands. They are short and thick, and remind the observer of the odontogenetic fibres of dentine matrix. Their outer extremities may enter the canaliculi. (Fig. 69).

Black considers them, and seemingly with sound scientific reasonableness, to be the calcified or semi-calcified remains of the "principal fibres" of the periodontal membrane.

Sharpey's fibres, penetrating from without, may be noted

[1] "The Histology of Cementum." *The Dental Cosmos*, Vol. xl., p. 706, 1898; also Broomell's "Anatomy and Histology of the Mouth and Teeth," p. 432, 1902.

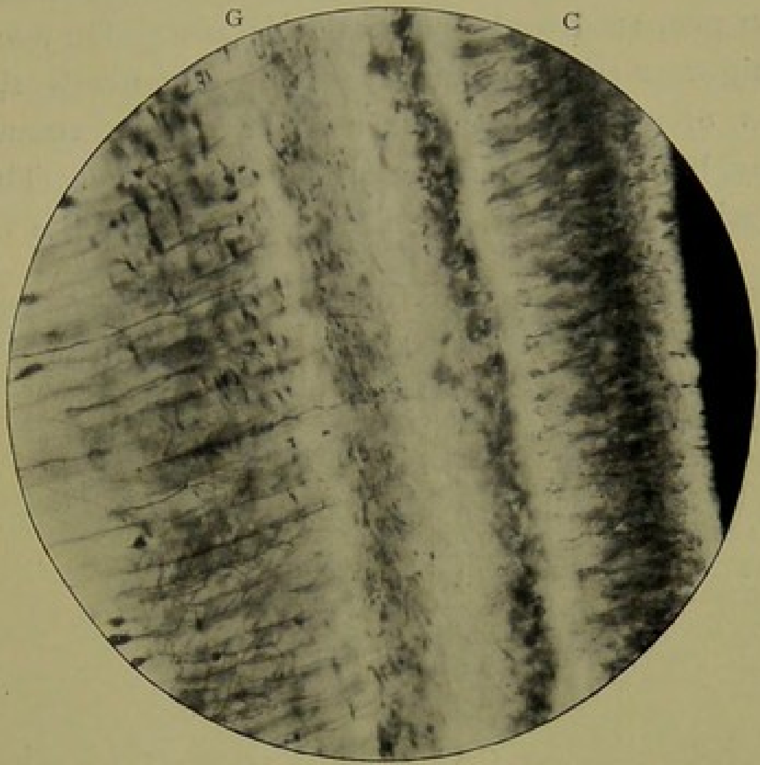


Fig. 69.—Longitudinal section of cementum. Prepared by Weil's process. Shews the perforating canals and fibres. Magnified 420 times. C. Cementum; G. Granular layer; H. Homogeneous layer; D. Dentine.

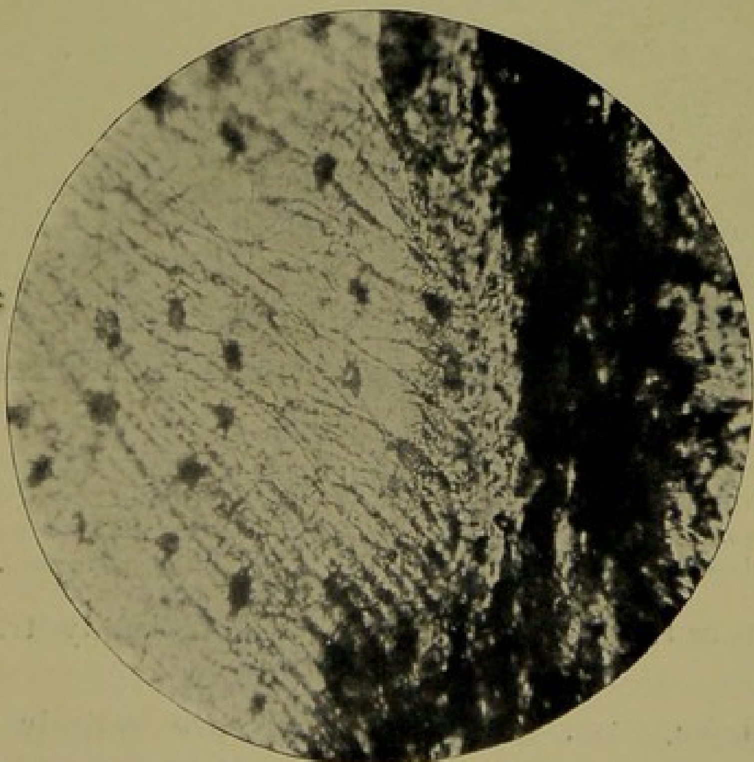


Fig. 70.—Sharpey's fibres of cementum. Magnified 800 times. Unstained. C. Cementum slightly hyperplasic.

in some sections of cementum where the hard and soft parts have been prepared and preserved *in situ*. They are very short straight or slightly curved bundles of fibrils, the main characters of which agree with white fibrous tissue, while some may be of the nature of elastic tissue. They are identical with the perforating fibres in the lamellæ of bone.

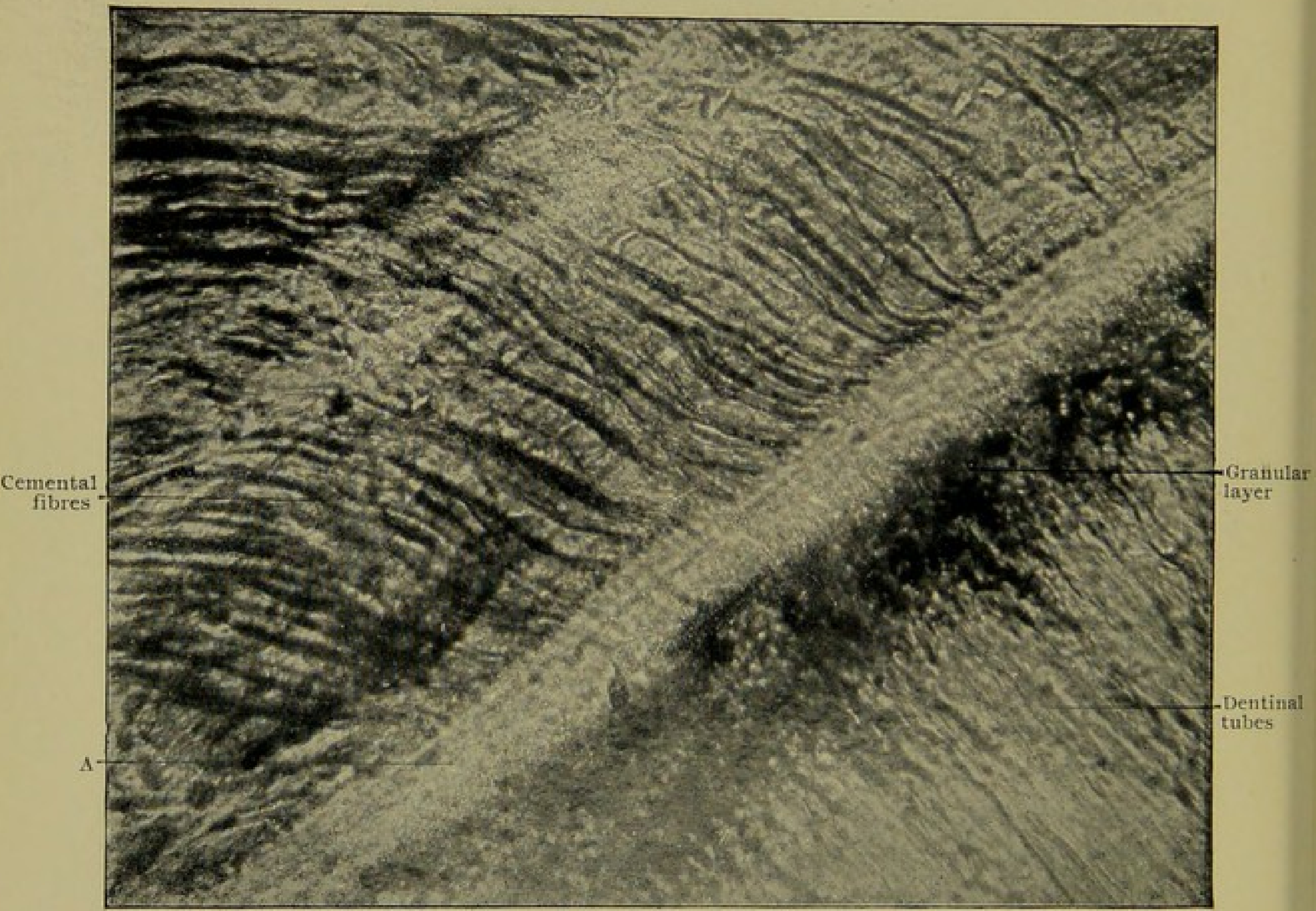


Fig. 71.—Perforating fibres passing from the outer margin of the first-deposited cementum outwards "until the next incremental line is reached, at which point they gradually disappear, but recur in the succeeding lamellæ." Magnified 1,000 times. A. Primary or oldest layer of cementum. Photomicrograph by Norman Broomell.

In cementum they occupy the interiors of slightly truncated canals.

As will be seen, Sharpey's fibres are entirely distinct structures compared to the perforating fibres described above.

Normal cementum is non-vascular; but there would seem to be, in the majority of cases, fine protoplasmic fibrils which traverse the boundary line between dentine and cementum.

Norman Broomell, in the excellent study already mentioned, would recognise in the tissue under consideration three zones or layers, not always discernible but fairly constant. The inner, first-formed, is granular, unbroken, and continuous with the granular layer; the intermediate con-

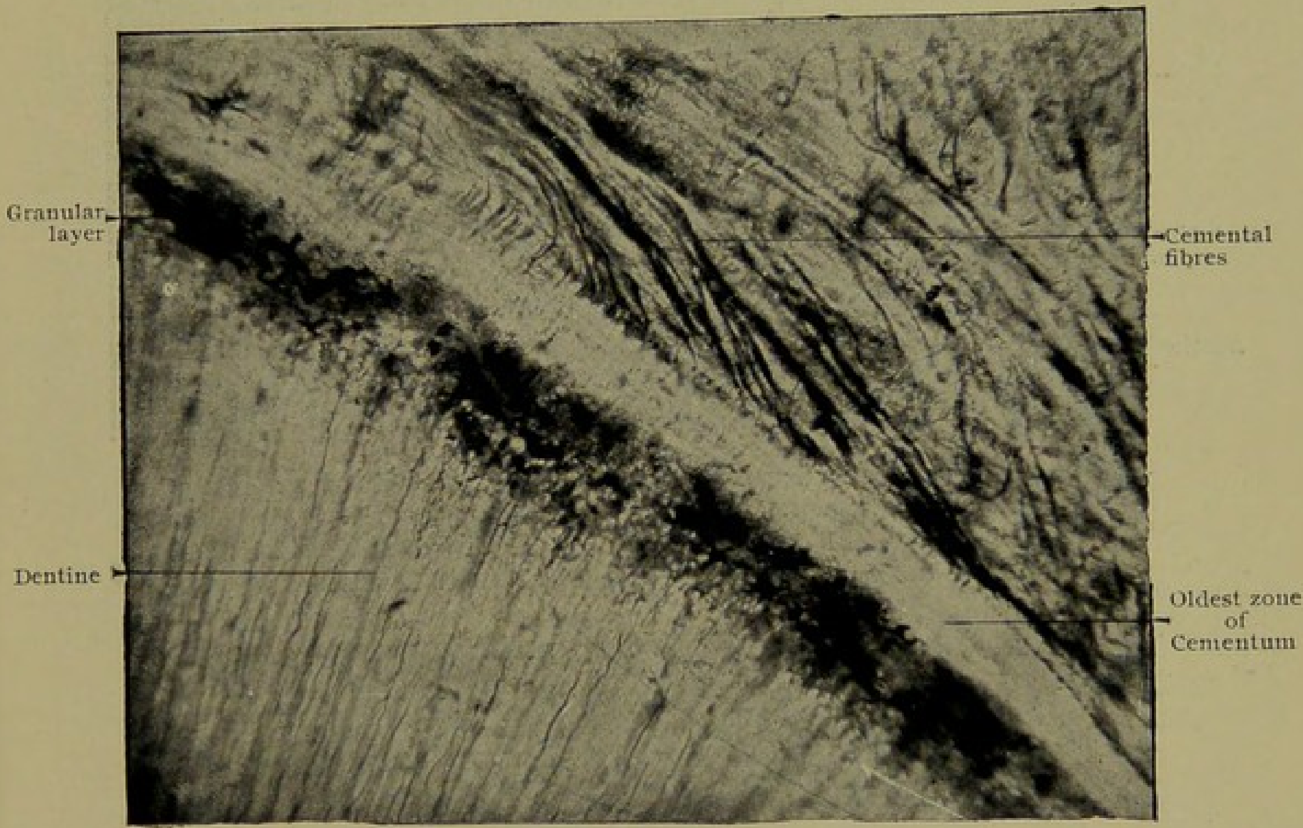


Fig. 72.—Fibres passing in a direction almost parallel to the surface, and towards the apex of the root. Magnified 300 times Photomicrograph by Norman Broomell.

tains many lacunæ; and the outer or youngest exhibits many sinuous incremental lines. As the tissue becomes more fully calcified the lacunæ disappear, and the zone possesses many of the histological characters of the oldest layer. Tomes describes this last layer in thick cementum as a "glassy film, denser than the subjacent portions," and considers it closely similar to the globular formations characteristic of dentine in an early stage of development.

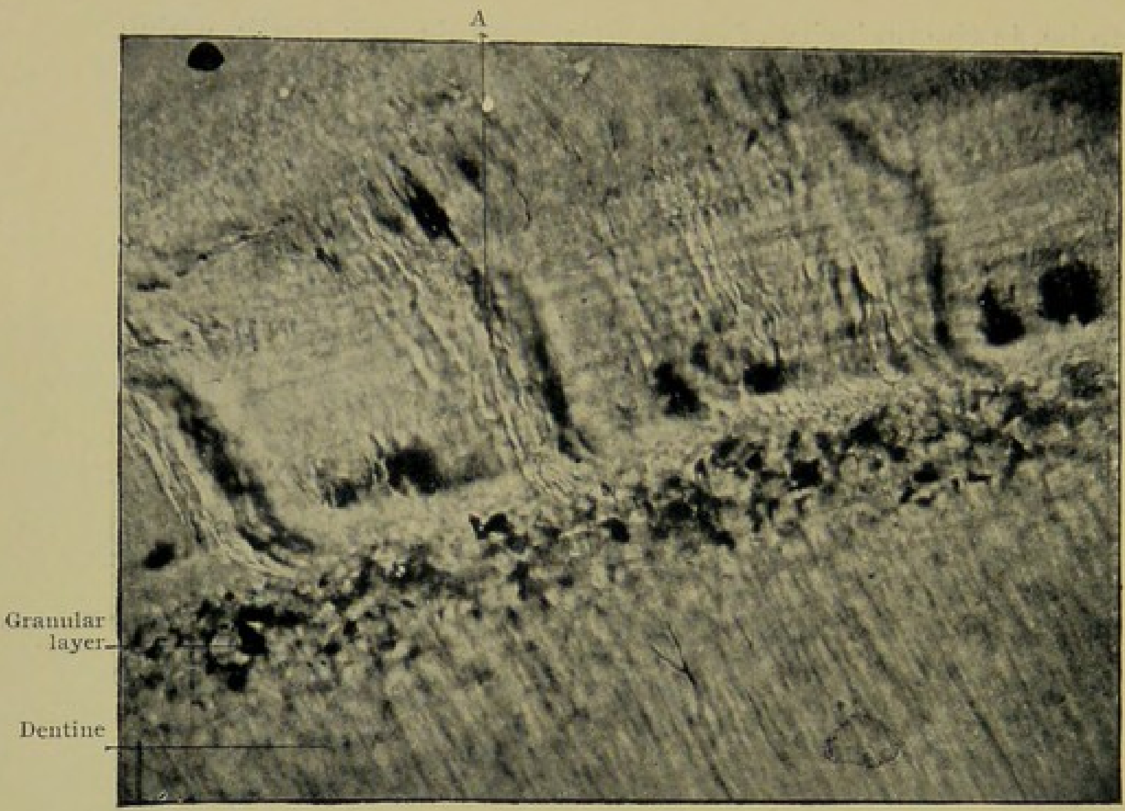


Fig. 73.—Fibres springing from the granular layer of Tomes, at regular intervals, and penetrating the cementum at right angles to the incremental lines. Magnified 500 times. A. The circumferential fibres of Broomell. Photomicrograph by Norman Broomell.

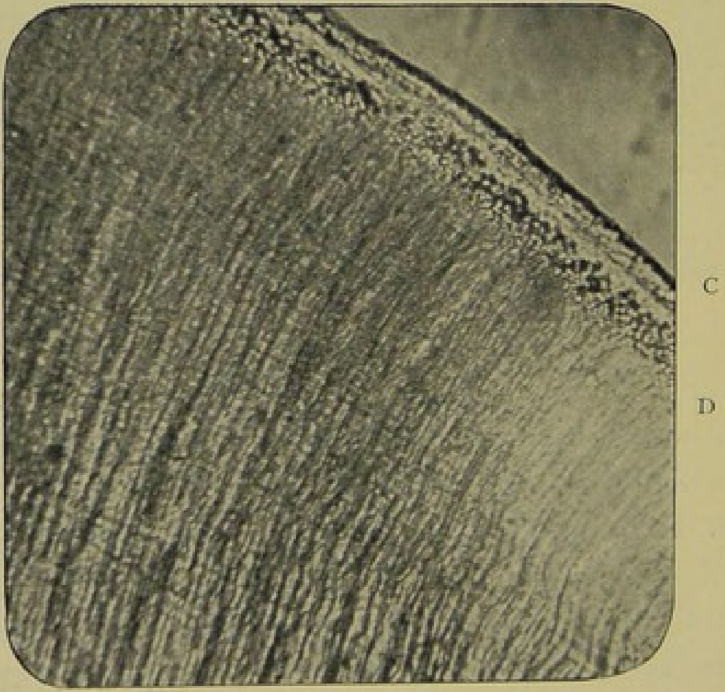


Fig. 74.—Structureless cementum of a deciduous tooth. Prepared by grinding. Unstained. Magnified 200 times. D. Dentine; C. Cementum.

Underwood, in "Aids to Dental Anatomy and Physiology," p. 49, 1902, says :—"The outermost layer of cementum is structureless : . . . when young, globular forms may be traced in its substance."

It is, however, perfectly obvious that he still inclines to the belief that normally this tissue contains lacunæ and canaliculi.

Cementum in deciduous and supernumerary teeth is relatively thinner than that of the permanent series. It is nothing more than a very narrow, structureless band. (Fig. 74).

CHAPTER VI

THE HISTOLOGY OF THE MAXILLARY AND MANDIBULAR BONES[1]

MICROSCOPICAL ELEMENTS IN : (i) Bone of Canine fossa ; (ii) Interdental septa ; (iii) Hard Palate ; (iv) Wall of Antrum ; (v) Angle of Mandible ; and (vi) Alveolar process.

The hitherto published descriptions of the minute structure of the osseous framework of the lower face and jaw,—such structures as are, in a word, in direct anatomical relationship and continuity with the teeth of man,—have necessarily been given only very infrequently ; but in addition to this, the descriptions which have appeared in text-books and journals have taken for granted that the histology of these particular bones corresponds with that of tabular and irregular bones in general.

To make this contribution complete, a few forewords are necessary and advisable.

GENERAL CHARACTERISTICS

Origin.—The manner in which the mandible is developed is twofold, cartilaginous and membranous. It is only necessary to briefly mention the following centres of ossification which have been described by Bland-Sutton in *Trans. Odonto. Society of Great Britain*, 1883 :—1, "*Dentary*," placed

[1] This chapter appeared originally in the pages of *The Dental Cosmos* and is here reproduced through the kind courtesy of the publishers of that journal.

below the future mental foramen ; 2, condyle ; 3, coracoid process; 4, angle; 5, *mento-mechelian*, at the chin, and 6, a *splenial* centre. The first five having become fused by an osseous network, the last-named appears immediately above Meckel's cartilage and the mandibular nerve, on the under aspect of the developing jaw. This centre of ossification extends downwards, and joins the *dentary*, after atrophy of Meckel's cartilage. Along the splenial centre the tooth germs are developed. Centres of ossification begin in the membrane on the outer surface of Meckel's cartilage ; also in the membrane in the inner surface of the sockets of the teeth. Each maxilla is developed from centres which arise in membrane.

Distribution.—Both forms of bone, known as compact (smooth, dense, and ivory-like) and cancellated or spongy (rough, open, and soft) are met with in the jaws. The former is found covering each surface both of maxillæ and mandible, the latter constituting the intervening tissue, which in the case of the lower jaw is similar to the diploë of the cranial bones. The compact forms a somewhat thicker shell or crust on the external and internal surfaces of the mandible than on any portion of the maxillæ.

HISTOLOGY

Before considering the special histology of the bones of the jaws, a brief description of the structure of osseous tissue generally must be given.

Bone of the jaw, as bone elsewhere, consists of a calcified fibrous ground-substance or matrix arranged as lamellæ around spaces of varying shape, size, and contents which everywhere penetrate it in all directions. Of these the following are to be noted : (a) Haversian systems, (b) lamellæ, (c) periosteum, and (d) Sharpey's fibres.

(a) An Haversian system consists of an Haversian canal, several lamellæ, with numerous lacunæ and canaliculi.

Interpenetrating everywhere are short longitudinal passages or tubes which in cross section appear as rounded or oval apertures, and, longitudinally cut, like short, straight, or slightly curved spaces of fairly regular diameter throughout. These are the Haversian canals. The largest may measure 100μ in width, the smallest 20μ, the average size being about 50μ.

They are surrounded by lamellæ,—thin bands of bony material arranged concentrically round each canal. Dark and light alternate, the difference in the refraction being due to the fact that the opaque lines are occasioned by the calcified fibrils running longitudinally, and the clear zones by their running transversely. In consequence, the ends only of the fibrils are cut across. (See Fig. 81).

Situated between these lamellæ are bone-lacunæ with their canaliculi. The first are flattened branched spaces, which may measure 14μ in their greatest diameter. (Stirling, "Outlines of Practical Histology," 1893). In dried specimens they look like myriads of tiny, dark, fusiform specks arranged with fairly uniform regularity between the lamellæ, and fully connected with each other and with the Haversian canals by means of many long, narrow tubes or canaliculi which cross the lamellæ. Each cavity is filled with or contains a bone-cell with a large oval nucleus, as first described by Virchow. These are homologous with those of ordinary connective tissue. The wall of each lacuna is formed of some substance which resists the action of decalcifying reagents in a similar manner to the sheaths of Neumann in dentine.

The contents of an Haversian canal, in the recent state, comprise several capillaries, small arteries and veins, a bundle of nerve-fibrils, and a few lymphatic vessels, all imbedded in fine connective tissue, which is surrounded externally by a tough lining membrane possessing properties identical with those which obtain also in the membranous lining of the walls of the lacunæ.

(b) In addition to the concentric lamellæ, others arranged parallel to the surface of the bone, are called "circumferential" or "peripheric"; while a third set, when found between the Haversian systems, are commonly spoken of as "intermediary." Their structures differ in no particular from the concentric lamellæ.

(c) The periosteum can be well studied microscopically in sections where the hard and soft parts have been retained *in situ*. Bony periosteum consists of two layers,—an outer, made up of white fibrous tissue, and an inner, of the same with fine yellow elastic tissue fibres in addition. In developing bone, osteoblasts,—small, cubical, nucleated cells,—are also present in this inner layer.

(d) Sharpey's perforating fibres are noticed in thin strips of decalcified bone near the surface. They thus run in from the deep surface of the periosteum and pierce the peripheric lamellæ in a perpendicular or oblique direction. The fibrous bundles are of varying lengths, and taper gradually to their free extremities. They are fasciculi of fibrils, probably of white fibrous tissue; though it has recently been shown that many of them are elastic fibrils. When they do not become calcified they shrink and leave tubes in the channels in the dry bone. Sharpey also first demonstrated the presence of decussating transparent fibrils which constitute the main part of the lamellæ. (See Fig. 81). In this way, in bone, Sharpey's discoveries include both perforating and decussating fibres, the former being bundles of fibrils, the latter an exceedingly delicate network of fibres. In dental histology Sharpey's fibres are the fibres which run from the periodontal membrane into the cementum; while his homologous fibres in dentine matrix were originally seen and described by von Ebner[1] and later by J. Howard Mummery.[2]

Turning now to the minute structure of several typical portions of the bones of the jaws, it will suffice to point out their distinguishing features.

(i) *Bone of Canine Fossa*

In vertical lateral sections of the bone of a young subject (age ten and a half years), it is found that the greater part of

[1] "Handbuch der Zahnheilkunde," Vienna, 1890-91.
[2] *Philos. Trans. Royal Society of London*, 1891.

Fig. 75.—Vertical section of the bone of the canine fossa; from a dried specimen. Magnified 45 times. Unstained. Shews its general histological features. The dark masses are crowds of lacunæ, the lighter portions the ground substance.

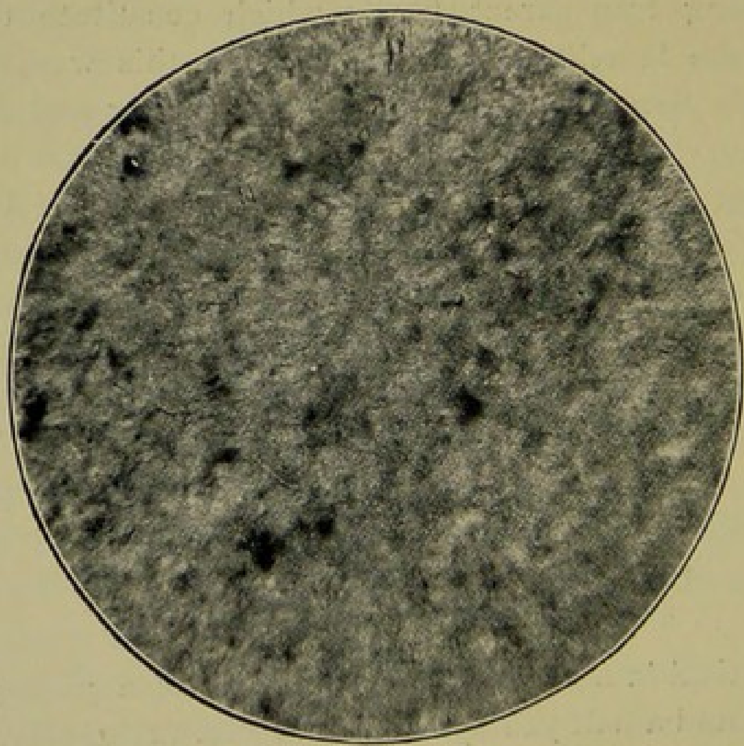


Fig. 76.—Granularity of the osseous matrix of the floor of the canine fossa. Magnified 750 times. Unstained. A few canals can be seen at the sinister corner.

the tissue is composed of a dense osseous substance, but very scantily supplied with Haversian systems. Large areas of bone are quite devoid of either lamellæ, lacunæ, or canaliculi. (Fig. 75). The matrix is distinctly coarsely granular (see Fig. 76), and has in it an indefinite number of short canals, the majority of which do not always communicate with lacunæ. These tiny tubular spaces, probably in the recent state, contain connective tissue fibrils, as they are too minute for the conveyance of blood-cells or even serum. They are

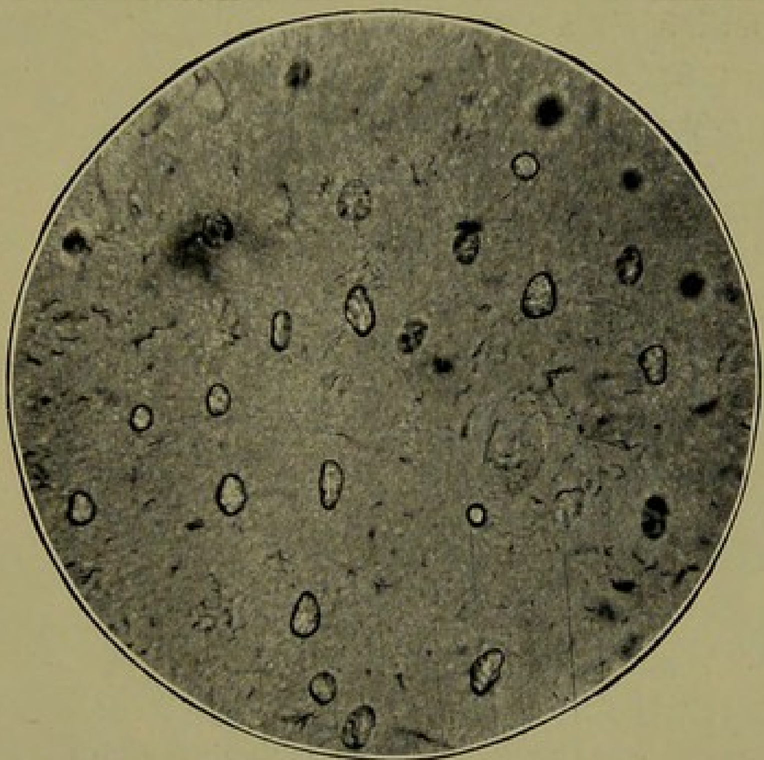


Fig 77.—Inermous lacunæ from a dried specimen of the floor of the canine fossa. Magnified 750 times. Unstained. In the matrix a few short canals can be seen.

most marked and most numerous in the neighbourhood of the lacunæ, the canaliculi of which they somewhat resemble. Varying in length, their diameter measures about 1μ Several are shown in the photomicrograph Fig. 76.

The Haversian lamellæ, when they do occur, are but feebly marked. They do not present the usual microscopical characteristics of other bones, being very irregularly disposed in position and in shape, size, and constituents.

The lacunæ are massed together without order or regularity. Many are spherical in shape and absolutely unlike those of well-constructed compact bone, the majority being provided with short coarse offshoots, though great numbers are quite inermous. This last fact is of great interest, and probably has also some pathological significance. These lacunæ, as is well shown in Fig. 77, do not possess, and they probably never did possess, canaliculi; their outlines are sharply defined rounded or oval contours, and under low

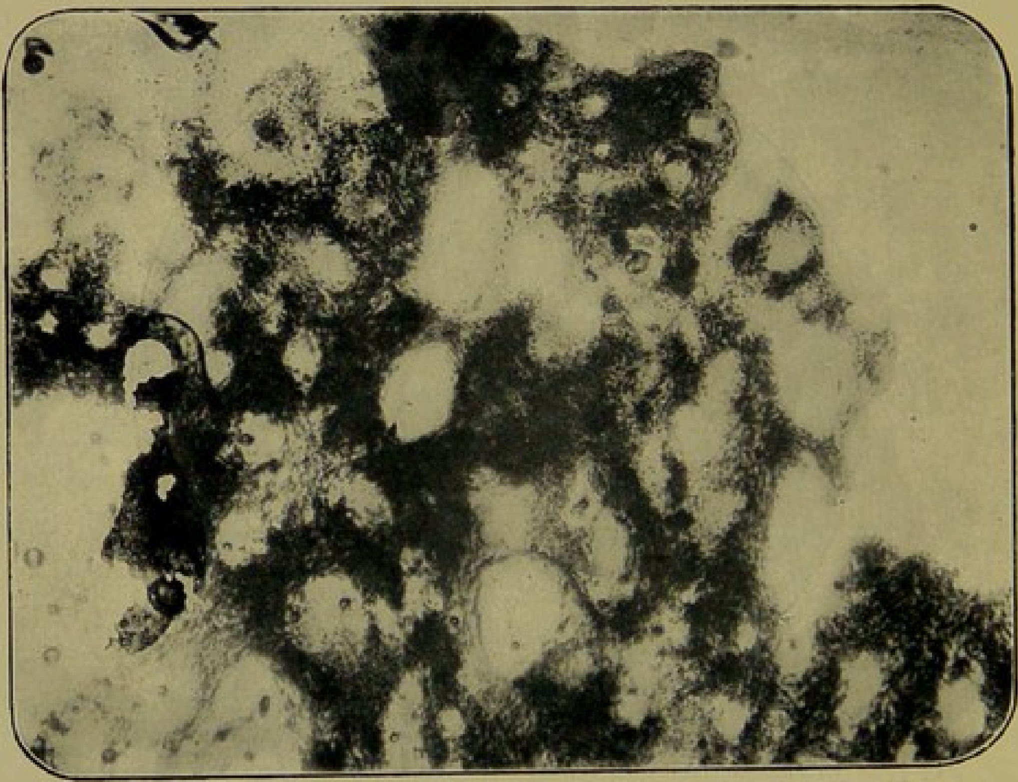


Fig. 78.—Vertical section of the bony septum between two maxillary premolars. Magnified 40 times. Unstained.

magnifications rather simulate dentinal tubes cut transversely.

In addition to the granular matrix, the substance of the bone, thin though it is, contains numbers of broad channels of great length, which may perhaps, during life, act as venous carriers of the blood or give passage to lymphatics. Possessing no histological or physiological interest, they occur sufficiently commonly in this situation to warrant a passing reference.

(ii) *The Interdental Septa*

These are composed of cancellated bone the lattice-like character of which differs in no material degree from spongy bone elsewhere. The lamellæ are arranged, as a rule, in lines parallel to the edges of the large openings in the bone. The lacunæ are very numerous; a few are inermous, but by far the greater number possess canaliculi. (Fig. 78).

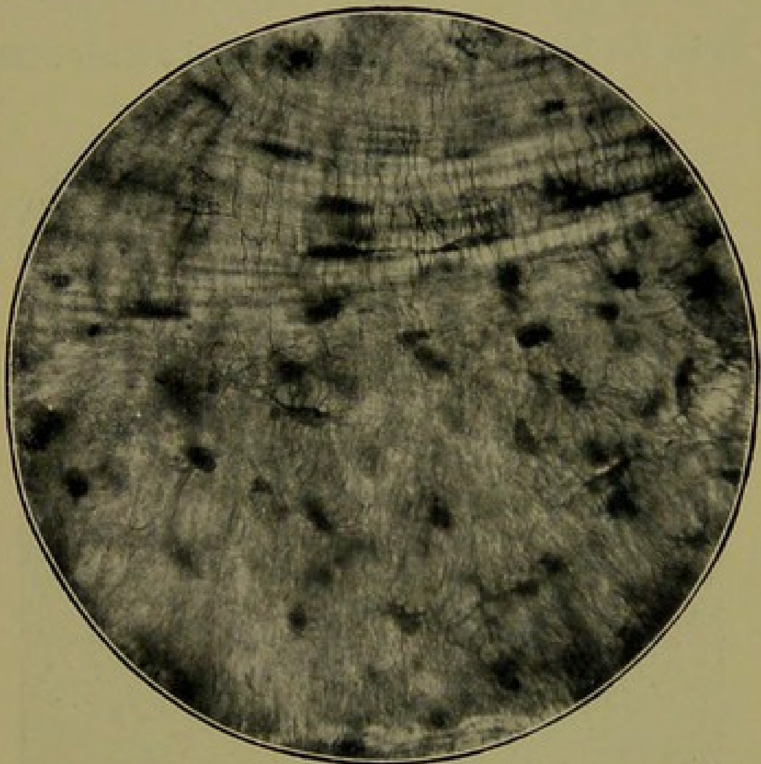


Fig. 79.—Sagittal section of the substance of the hard palate. Magnified 250 times. Unstained. The photograph exhibits the fusiform shape of the lacunæ in the lamellæ, and the rounder spaces elsewhere; also the connective tissue stroma of the matrix.

In the recent state, the large open spaces in the bone are filled with quantities of red medullary tissue, viz.—delicate branching, retiform tissue supporting the marrow cells of Kölliker, and small coloured nucleated cells many of which undergo sub-division by karyokinesis.

(iii) *Hard Palate*

Vertical antero-posterior sections of the roof of the mouth at the articulation of the palatal process of the maxillary with the horizontal plate of the palate bones, near the sutural line, all reveal the characteristics of dense osseous tissue thickly crowded with lacunæ and canaliculi (Fig. 79), and also several longitudinal spaces of large dimensions filled with marrow. The long axes of the lacunæ are more or less parallel to the long axes of the cancelli.

(iv) *Nasal Wall of Antrum of Highmore*

Here, as in the bone which constitutes the floor of the canine

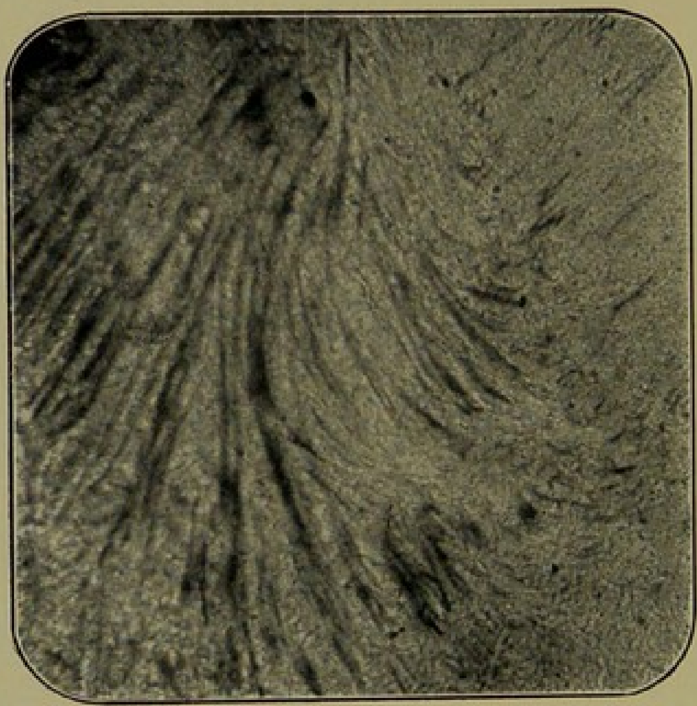


Fig. 80.—Radiating connective tissue fibres in the matrix of the bone of the wall of the maxillary sinus. Magnified 250 times. Unstained.

fossa, the matrix is very coarsely granular, and contains in places long markings, which are evidently the remains of the connective tissue stroma. (Figs. 80 and 81.) The lacunæ, which are exceedingly scanty, do not present the usual characteristics, being spherical or oval when viewed from above. (Fig. 82). Some are concavo-convex as seen in side section. Again, the canaliculi are but very indifferently formed.

(v) *Angle of Mandible*

Examination of the structure of vertical transverse sections exhibits, best of all, the pervious parts of the bones,—the regular disposition of the Haversian systems, and the peripheric and intermediary lamellæ. The first are not very numerous, and are seen mainly in cross section. The peripheric lamellæ are comparatively long, and the line of demarcation between the individual lamellæ very marked.

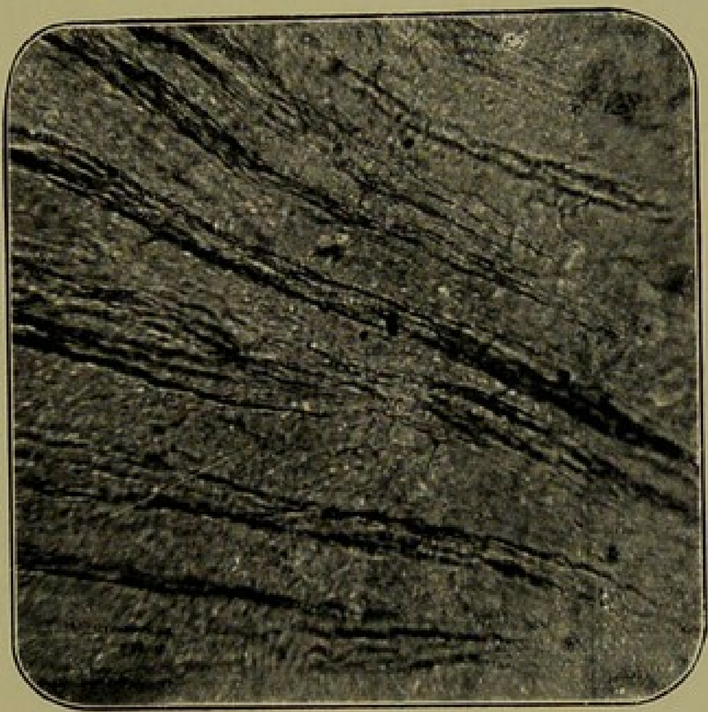


Fig. 81.—Perforating fibres running lengthwise through the matrix of the bony wall of the maxillary sinus. Magnified 800 times. Unstained. The cut extremities of descussating fibres appear as white, round dots.

(Fig. 83). Strong lines of calcified connective tissue fibres can be observed, here and there, closely welding together the intermediary lamellæ even in bones of adult life (age thirty-five years). Internal to the free surface of the jaw, the cancellated tissue follows very much the lines already laid down.

Vertical lateral preparations of the same, show absence of Haversian systems, but multitudes of lacunæ and canaliculi, and many radiating bands of calcified fibres.

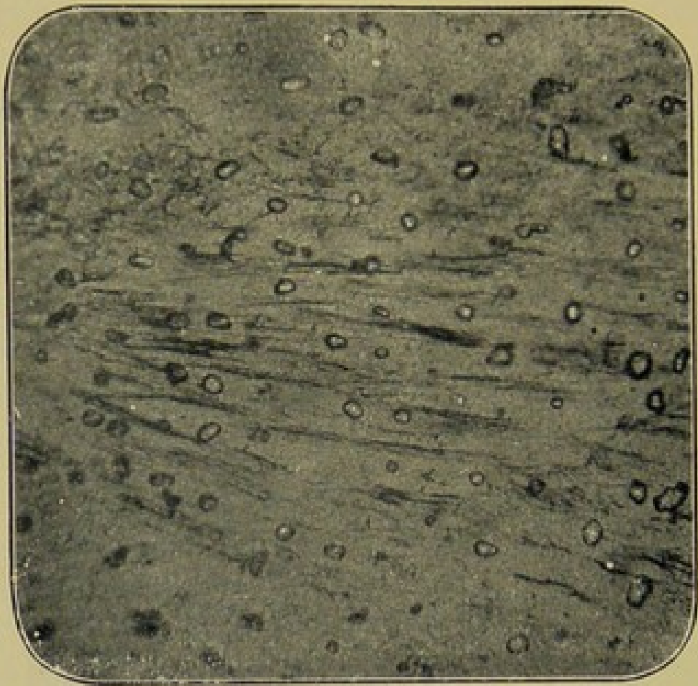


Fig. 82.—Inermous lacunæ amongst perforating fibres. Bone of antral wall. Magnified 250 times. Unstained.

Fig. 83.—Vertical section of the angle of the mandible; from a dried specimen. Magnified 50 times. Unstained. The section shews the general structure. At the upper part of the figure the long peripheric lamellæ are seen at the free edge of the bone, with intermediary lamellæ between the Haversian systems. At the lower part of the figure the commencement of the cancellous diploë-like portion is separated from the external surface by the dense layer of dark compact bone.

Fig. 84.—General structure of the bone of the alveolus; from a recent specimen. The cancellous spaces and contents are too darkly stained to show any structure. Magnified 40 times. Stained with fuchsin.

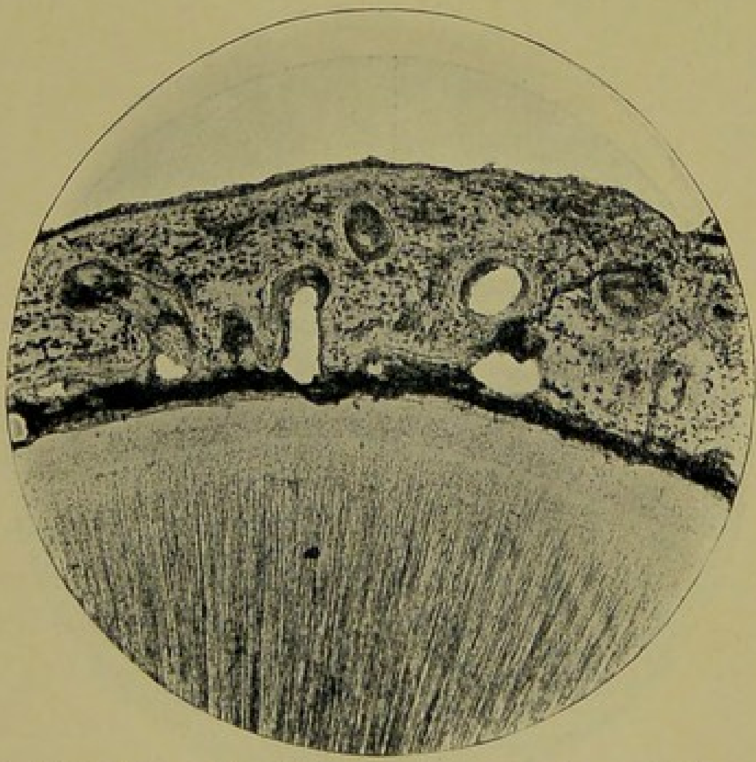


Fig. 85.—Transverse section of the alveolus *in situ*; from a dried specimen. Magnified 40 times. Stained with borax-carmine. In the upper part of the photograph is the free edge; below, the dentine and cementum, with the periodontal membrane intervening.

Fig. 86.— Perforating fibres of the alveolus, passing into the periodontal membrane. Magnified 800 times. Unstained.

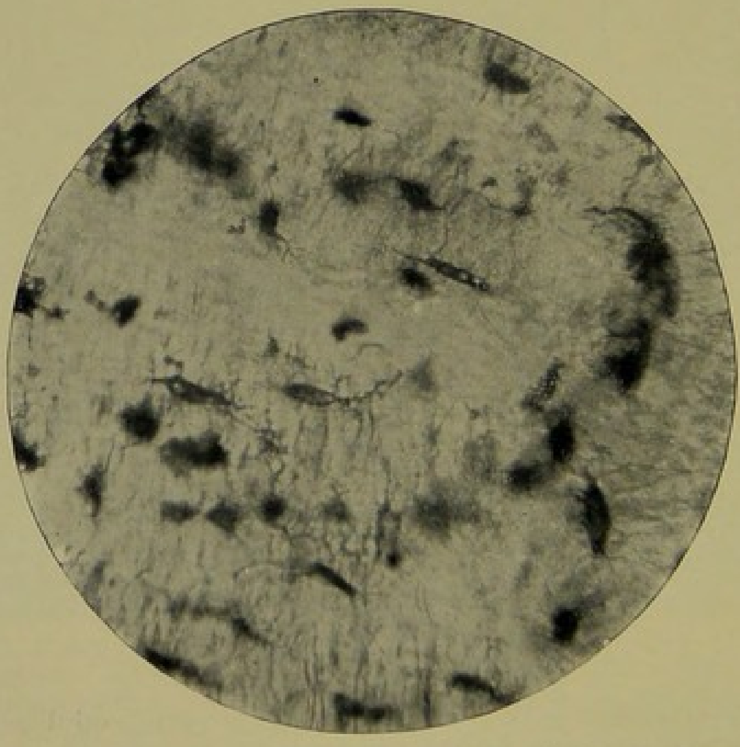


Fig. 87. Lacunæ and canaliculi in the bone of the alveolar process. Magnified 250 times. Unstained

(vi) *Alveolar Process*

Here are found all the appearances of soft cancellous bone, with Haversian systems and lacunæ well marked. (Figs. 84 and 87). The cancelli run longitudinally in the same direction as the long axes of the teeth. Osseous tissue is dense externally (see Fig. 85); and the perforating fibres are very strong and of great length. (Fig. 86).

CHAPTER VII

STRUCTURAL MODIFICATIONS OF THE ENAMEL, DENTINE AND CEMENTUM

MICROSCOPICAL ELEMENTS IN THE ENAMEL OF: (i) *Rodentia*; (ii) *Sirenia*. (iii) TUBULAR ENAMEL. (iv) PLICI-DENTINE; (v) VASO-DENTINE; and (vi) OSTEO-DENTINE. CEMENTUM.

Students of comparative anatomy need not be reminded that that subject is full of interest with regard to the modified forms of teeth, not only in number and shape but also in size and function. It is not surprising, then, that the minute structure of the masticatory organs of the lower vertebrates not infrequently differs very remarkably from that of man. As was hinted in Chapter III., enamel may be found, in some instances, clear and structureless, in others, presenting a most complicated pattern. Here will be briefly considered the chief variations in the histology of the enamel, dentine and cementum met with in the vertebrates. Tomes' "Manual of Dental Anatomy" will ever remain the standard work, and to this and to Owen's "Odontography" readers are referred for elaborated details.

ATYPAL VARIATIONS OF ENAMEL

Among *Mammalia* the order *Rodentia* supplies many instances of modification in structure of this tissue. These variations may be a provision on the part of nature to render the free surface and incisive margin of the teeth particularly strong. Taking the Families in their proper anatomical order, brief reference can only be given to the histology of the enamel of (i) the *Muridæ*, mouse, rat, &c. ; (ii) *Castoridæ*, beaver ; (iii) *Soricidæ*, squirrel ; (iv) *Hystricidæ*, porcupine ; and (v) *Leporidæ*, rabbit, hare. In *Rodentia*, generally speaking, the large incisors are frequently pigmented a deep orange colour. According to Tomes, the colour is situated in the substance of the enamel itself.

Enamel invests the anterior and lateral aspects of the teeth and is thicker in the former than in the latter situation.

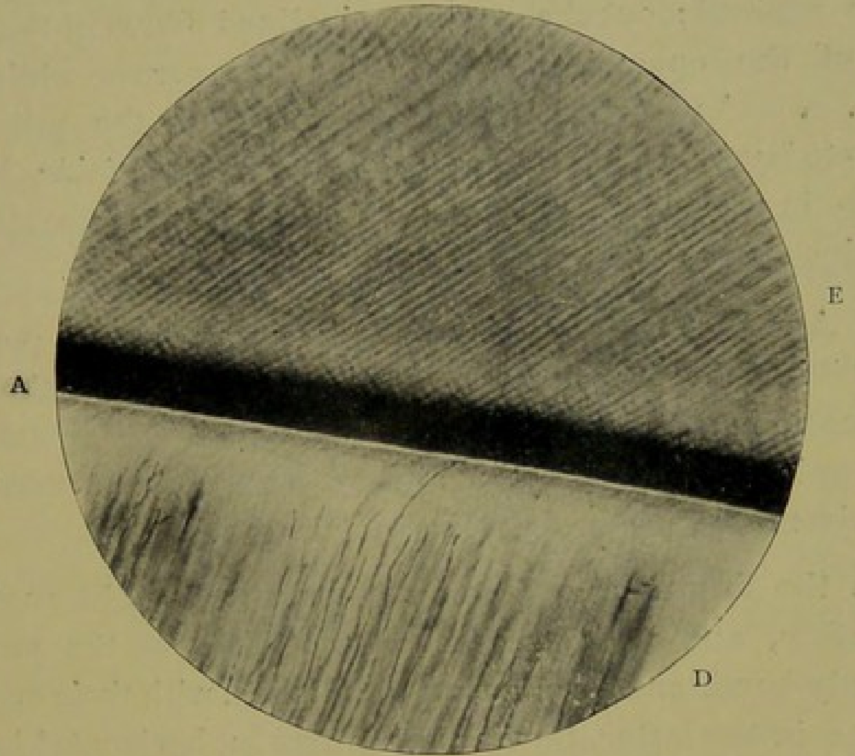


Fig. 88.—Vertical section of a persistently-growing scalpriform tooth of a rodent. Prepared by grinding. Stained with borax-carmine. Magnified 240 times. Shews striation of enamel rods. E. Enamel ; D. Dentine ; A. Amelo-dentinal junction.

(i) In the *rat* the straight columns are arranged in a parallel direction, and are placed at an acute angle with the surface of the dentine. This is seen in the accompanying photograph (Fig. 88). Each rod is not only very striated but is also deeply indented, and by making serrations with its neighbours renders the tissue remarkably dense and difficult to fracture.

(ii) The enamel of *beaver* exhibits a lattice-like arrangement of the rods. *Longitudinally* cut, the enamel rods are "inclined upward towards the apex of the tooth, at an angle of 60 deg., then, after passing through about half the thickness of the enamel, they turn up abruptly again, so that they are approaching parallelism with the dentine, here making an angle little less than 30 deg. with it. It follows from this that no *transverse* section can show very plainly the direction of the prisms in both parts of their course. The most instructive transverse section is one cut parallel with the layers near to the dentine; this will plainly show the successive layers passing to the right and to the left just as in the squirrel; but the yet-more-inclined fibres of the outer half of the enamel will then be cut across obliquely. . . . . As regards the decussation of the prisms of ultimate layers, it is similar to that of the *Soricidæ*, but it differs in the laminæ being slightly flexuous instead of pursuing perfectly straight lines." (Tomes).

(iii) An apparent division into inner and outer portions is exhibited in the enamel of the *squirrel*. Here, the rods are continuous through all the thickness of the tissue, but, running in different directions when viewed either vertically or horizontally, produce a complex pattern.

"In the former they leave the dentine at right angles to its surface, and after traversing two-thirds of the enamel, suddenly bend, and form an angle of 45deg. with their original course: in the latter, they are arranged in horizontal layers, each layer a single prism in thickness. In alternate layers the prisms pass to the right and to the left, crossing those of the next layer at right angles, and thus making a pattern of squares in the inner two-thirds of the enamel. In the outer third, where the prisms bend abruptly upwards, those of superimposed layers no longer pass in opposite directions, but are all parallel; in fact, no longer admit of distinction into alternate laminæ." (Tomes).

(iv) Individually flexuous rods are found in the enamel of the *porcupine*, the courses of which are not confined to one plane. At the periphery of the tooth the rods run in a parallel direction.

(v) Parallel, slightly curved enamel columns are constant in the teeth of *hares*.

In the order *Sirenia*, of which the *manatee* is an example, the enamel rods run in a perfectly straight course, and are not flexuous. This is therefore a very simple type.

Simpler variations still are found in *Pisces*. Some Families, *e.g.*, eel, hake, &c., have a homogeneous type of enamel which exists as a tiny free structureless point on the dentine. The majority of fishes, however, probably possess a system of tubes which pass either partially or wholly through the enamel.

Tubular Enamel

GENERAL CHARACTERISTICS

Definition.—As the expression implies, the enamel, instead of being a solid mass of rods and basis-substance, presents a tubular structure.

Origin.—The tubes are produced through the failure of calcification of the central zones of the rods formed by the ameloblasts of the enamel organ.

Distribution.—A class characteristic of Marsupials (except the wombat), but found also in some examples of *Pisces*, *e.g.*, *Sargus*, barbel, porbeagle shark, and certain *Insectivora* (soricidæ) and *Rodentia*, such as jerboa, &c.

HISTOLOGY

The chief point of interest is the presence of a system of tubular canals in the substance of the tissue. These may be very extensive and numerous, or very short and few; and be confined to the inner or cortical aspects of the enamel or in its intermediate portions.

It has already been shown that in human enamel dentinal tubes often cross the amelo-dentinal junction, to end either cœcally or else in the enamel-spindles. But in addition to these, comparative anatomy furnishes many instances where other tubes occur. Dentinal tubes pass across the boundary and run into the enamel in marsupials (*e.g.*, kangaroo).

In many fishes, the passage of these tubes from the dentine takes place, but the canals grow smaller in calibre as they approach the enamel cortex, which, however, they do not reach. Tomes describes and figures (*op. cit.* pp. 33 and 34) enamel from the tooth of a fossil shark in which the tubes

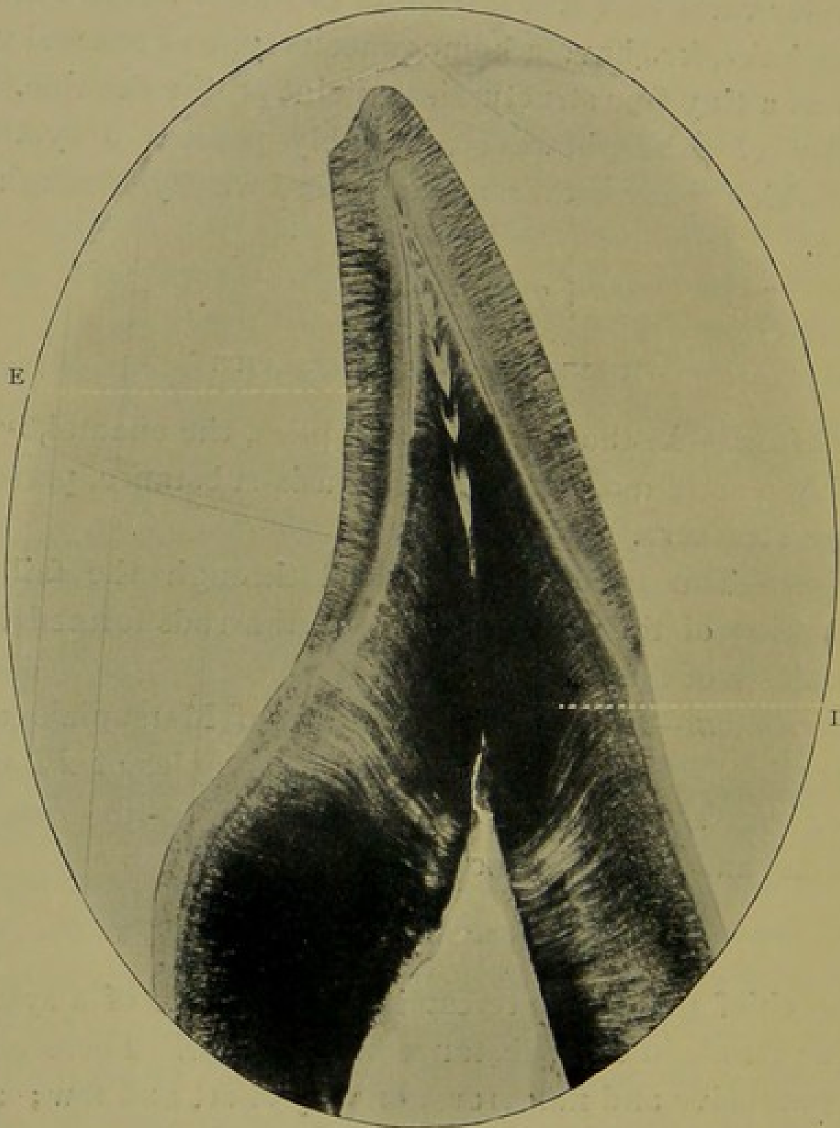


Fig. 89.—Sagittal section of Incisor-like tooth of *Sargus Ovis*, shewing tubular enamel. Prepared by grinding. Unstained. Magnified about 10 times. E. Enamel; D. Dentine.

pierce both the inner and outer zones. In *Sargus Ovis*, and *Cestracion* they likewise penetrate from the surface.

The tubes are found in the longitudinal axes of the enamel rods, not in the basis-substance; and their courses are generally fairly straight and parallel. In *Sargus*, nevertheless, after peripheral penetrations and running at right angles with the surface, they suddenly bend at an obtuse angle with their course. (See Fig. 90).

It is difficult to offer a satisfactory explanation of the presence of these enamel tubes, but the opinion expressed by Tomes is, no doubt, correct.

Thus (p. 37) he writes :—" If all enamel, in its development, passes through a tubular stage, then these are merely

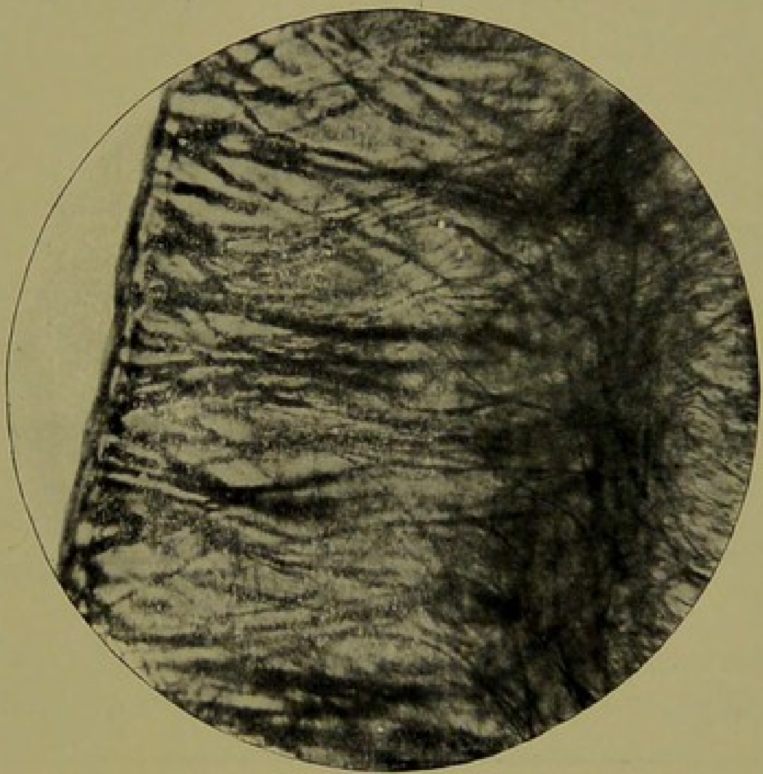


Fig. 90.—Same as preceding. Magnified 240 times.

arrests of complete development and perpetuations of a stage which is transitory in placental mammals."

Paul's views are not in accord with those of Tomes. In an article in *The Dental Record*, p. 496, 1896, this author observed :—

" If we admit the general principle that all spaces or tubes in enamel are between and not within the prisms, then the structure of genuine tubular enamel seems less difficult to understand. It is clear that any imperfect approximation of enamel cells must leave spaces between the prisms which can only be filled with an indefinite intercellular substance, or possibly by further prolongations of dentine matrix, and in neither case is it likely that such interprismatic matter would become calcified; because on the one hand, it is too far removed from the influence of the odontoblasts, and on the other, because the calcifying energy of the ameloblasts is almost entirely expended upon their own internal petrifaction. I would therefore suggest that tubular enamel is

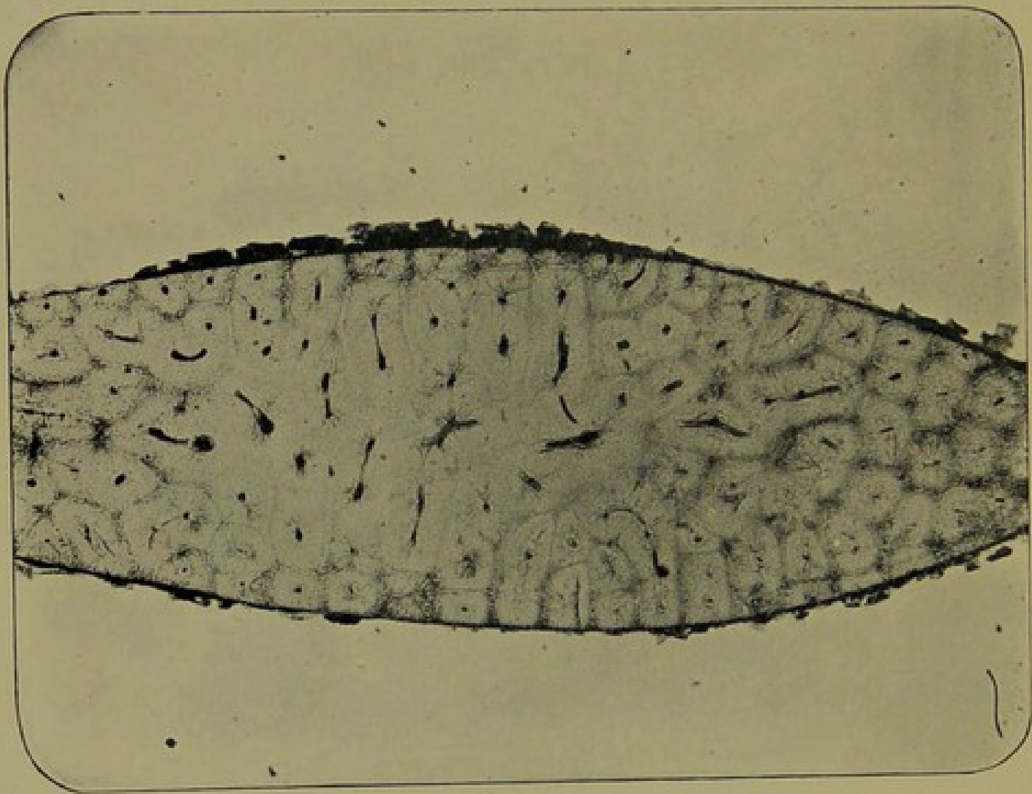


Fig. 91.— Transverse section of a rostral tooth of *Pristis*. Prepared by grinding. Stained with coloured collodion. Magnified about 10 times.

an enamel in which there is an excessive amount of intercellular substance only imperfectly calcified, and much as it looks like tubular dentine, it is really formed on an exactly opposite plan. The one is a negative and the other a positive picture. In dentine the cells occupy the tubes, and the intercellular substance becomes the solid calcified matter; in enamel the tubes are represented by the intercellular substance, whilst the cells become the solid calcified matter."

But it must be confessed that Paul's remarks seem hardly quite apposite in this connection, based as they are on the probably incorrect hypothesis that odontoblasts form dentine matrix. The syllogism he uses is faulty, inasmuch as the premises are not generally accepted, and are open to a different interpretation.

VARIETIES OF DENTINE

Tomes has classified Dentine as Hard, or unvascular dentine, sufficiently described in Chapter IV., plici-dentine, vaso-dentine, and osteo-dentine. This is considerably more scientific than that found in the writings of Owen, who somewhat confuses the two last-named varieties. Thus the older palæontologist described vaso-dentine as being composed of coarse channels containing cells, vessels, and nerves of the pulp—obviously the osteo-dentine of the later author. By limiting the expression vaso-dentine to those forms in which blood-vessels *only* permeated the dentine, Tomes has cleared away many conflicting conceptions.

Plici-dentine

(*Phon.* Plissi-denteen : *plĭco*—I fold)

Definition.—"An ordinary dentine with its surface folded up and wrinkled into a greater or less degree of complexity." (Tomes).

Histologically considered, the dentine is hard, and unchannelled except by tubes which radiate, as usual, more or less at right angles to the pulp cavity.

If a pulp chamber be merely indented externally, or if portions of the dentine are somewhat invaginated, or the pulp itself, instead of being simple in outline, has several prolongations, no longer does a cylindrical pulp cavity result but one with folded outlines.

This obtains in the teeth of the *Selache maxima* (Basking shark), or *Ichthyosaurus*.

In *Lepidosteus* the upper part of the tooth consists of a simple single pulp chamber, with plicated walls, while at its base there are several pulp chambers running longitudinally,

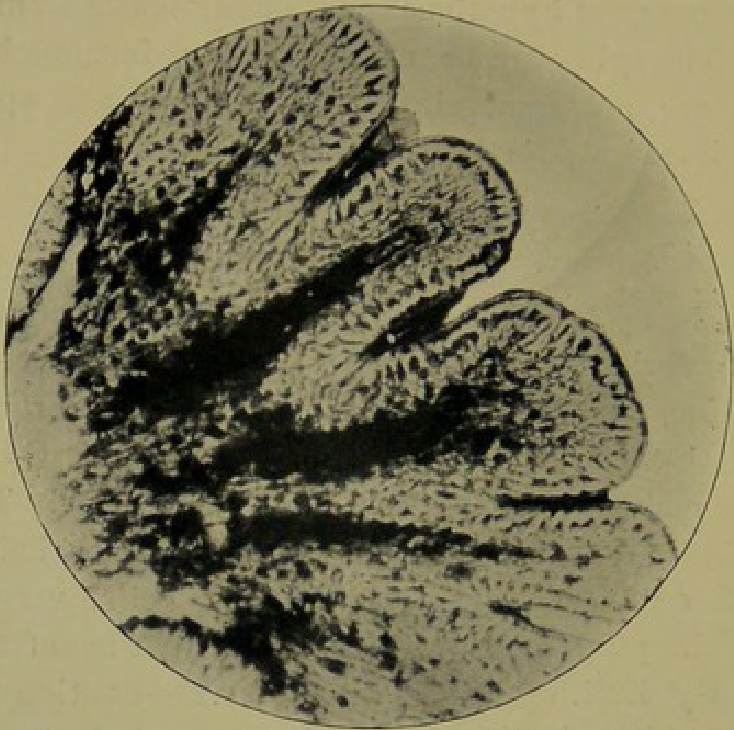


Fig. 92.—Transverse section near base of tooth of *Anarrhicas lupus*. Shews the plicated outlines of the dentine. Magnified 45 times. From a specimen in the collection of Sidney Spokes.

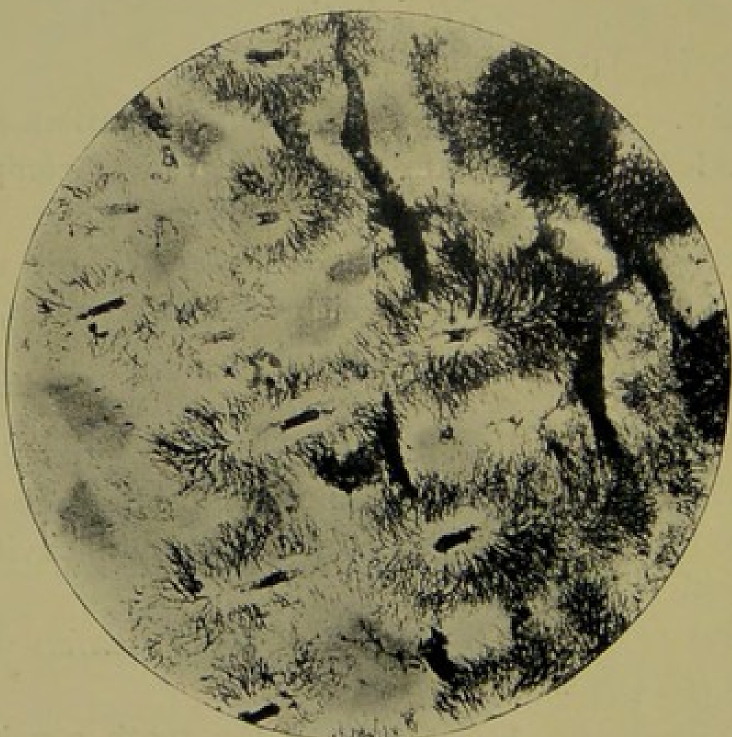


Fig. 93.—A form of Plici-dentine. Transverse section of tooth of an extinct crocodile (*Teleosaurus*). Prepared by grinding. Unstained. Magnified 240 times.

and variable in size, each always having radiating dentinal tubes. The peripheral pulp cavities run in straight lines in a centrifugal direction. And so also in *Anarrhicas lupus* (Fig. 92).

If these straight lines become twisted or curved or branched, a much more complex pattern is produced, as in the extinct reptiles *Labyrinthodon*, *Leptognathus*, and *Dendrodus Biporcatus*; also an extinct Crocodile.

Fig. 94.—The same as the preceding. Longitudinal section. Magnified 240 times

Many teeth are composed of groups of vertical denticles or primary pulp canals with radiating dentinal tubules. The periphery of each system occasionally blends almost imperceptibly with those of neighbouring denticles. Thus a pretty pattern is seen in both horizontal and vertical sections. The teeth of the rostrum of *Pristis*, of an extinct hippopotamus, *Myliobates*, *Zygobates*, and others reveal this. In the first condition each dentinal system is permeated with fibrils from the central pulp. The dentine is hard and unvascular, but not plicated.

Vaso-dentine

Another variety of this dental tissue, in which, broadly speaking, there are no tubules as such, is vaso-dentine. As the term implies, it is a vascular dentine. Extending outwards through the matrix is a series of moderately sized canals or

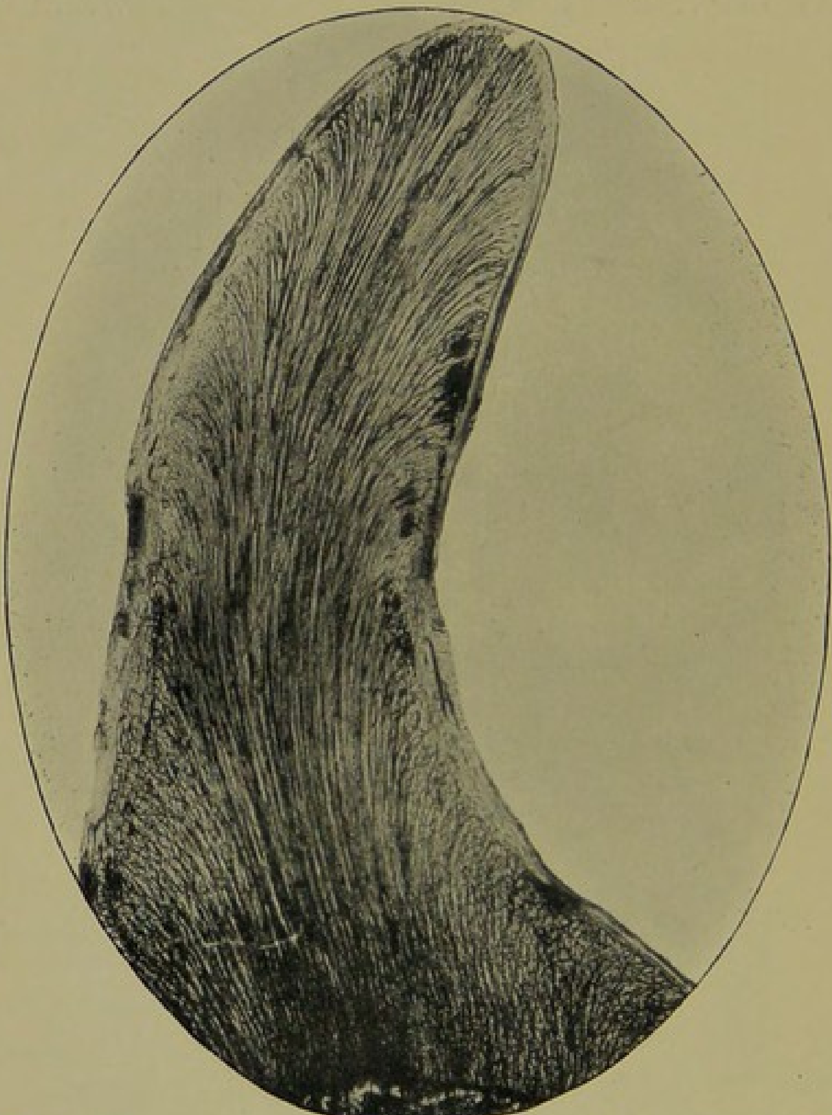


Fig. 95.—Sagittal section of an intermaxillary tooth of *Anarrhicas lupus*. Prepared by grinding. Unstained. Magnified about 10 times. The mass of the tooth is occupied by vaso-dentine.

channels of nearly uniform calibre throughout, each filled with a capillary from the pulp.

The channels run in the same direction as the tubes in hard dentine—that is, radially. A little below the free surface of the tooth their distal extremities are formed by loops, the convexities of which are outwards. Dried sections sometimes show thorn-like processes, running laterally from the vascular canals. (See Fig. 96).

The matrix of the dentine itself is slightly laminated.

Vaso-dentines are found in many fishes—hake, cod, *Sargus*, flounder, haddock, &c., in the former of which the canals are numerous, in the latter scanty. The dentine of

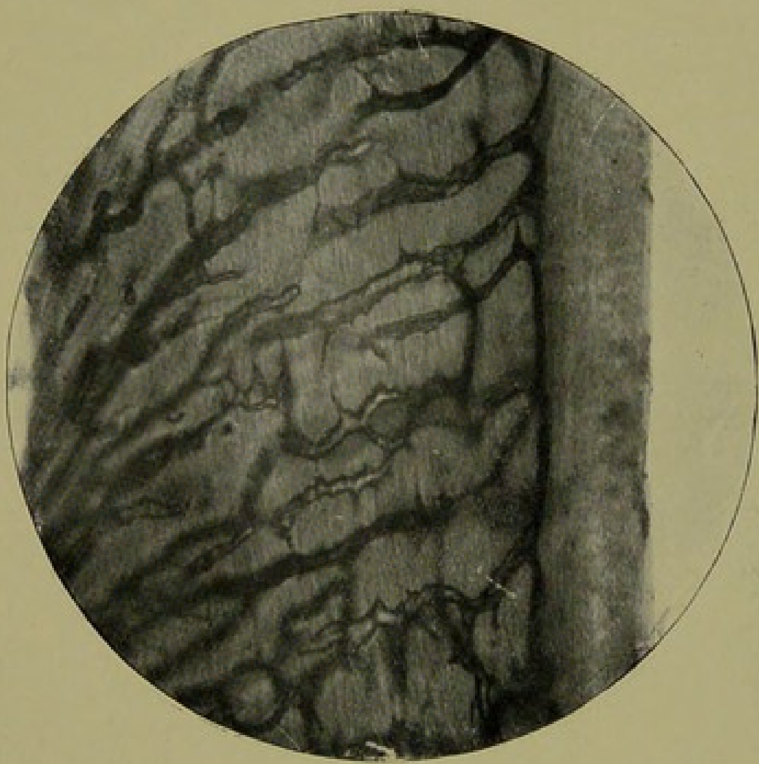


Fig. 96.—Vertical section of tooth of *Merlucius vulgaris* (Hake). Prepared by Weil's process, with the substitution of Golgi's method of staining. Magnified 250 times. Shews the vascular channels in the dentine, with their so-called "thorns,' and the laminated matrix of the dentine.

the first-named is tubeless. The teeth of manatee and *Megatherium* possess vascular canals as a normal characteristic.

Osteo-dentine

In its general histological configuration, osteo-dentine closely approximates to that of compact bone, but the intermediary and peripheric lamellæ are wanting. Its irregular spaces are analogous to the Haversian canals of true bone. They contain, however, in this case, not medullary tissue, but pulp with round osteoblastic cells lining the walls in young developing specimens.

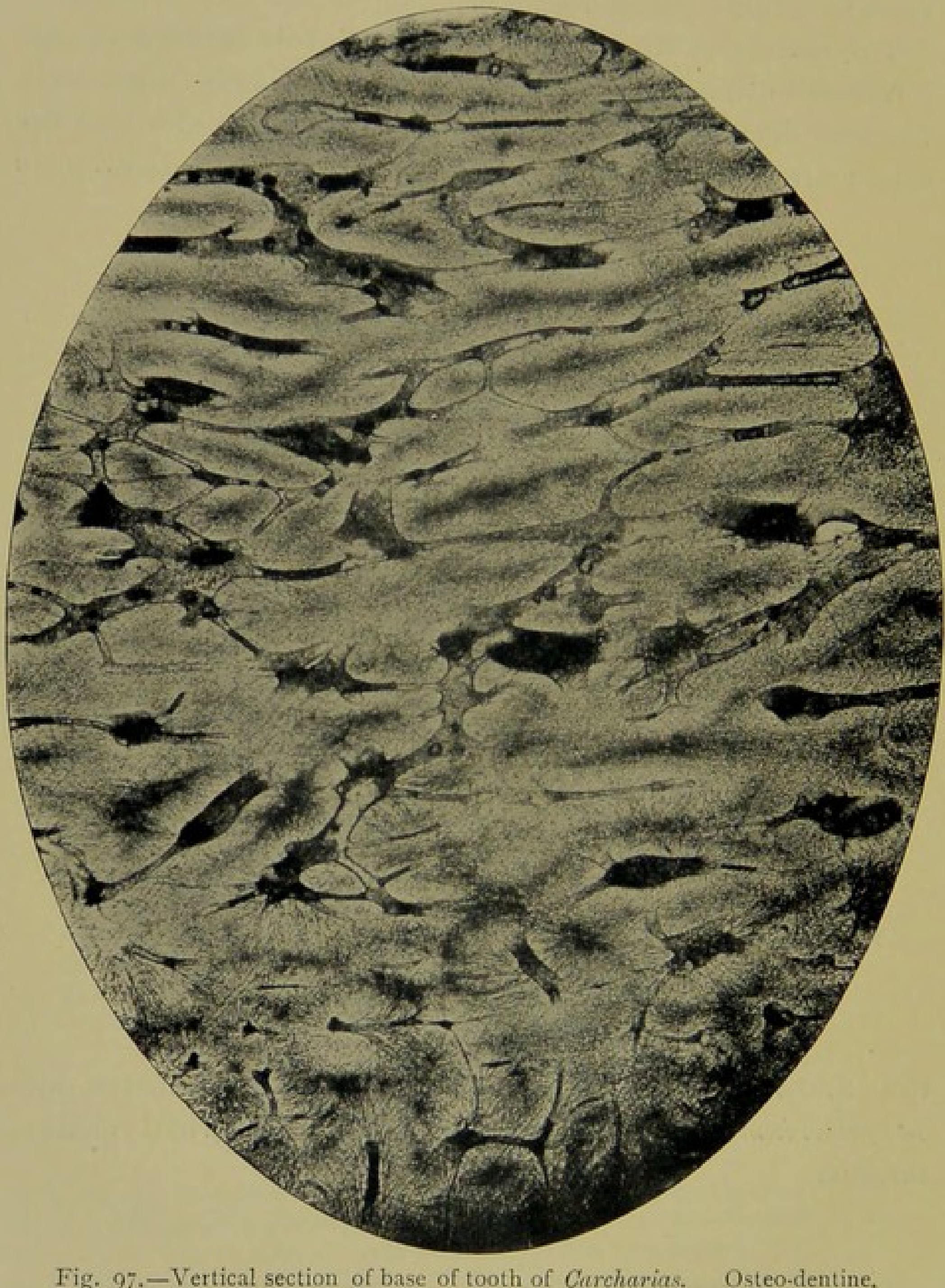


Fig. 97.—Vertical section of base of tooth of *Carcharias*. Osteo-dentine. Magnified 50 times.

Osteo-dentine is found in the teeth of fishes, of which it may form the whole or part, as in the photomicrograph (Fig. 97).

In typical instances, when longitudinally cut, it is made up of more or less parallel trabeculæ, which extend through the substance of the tooth, traversing the pulp tissue and dividing it into great numbers of pulp cavities. There is no very

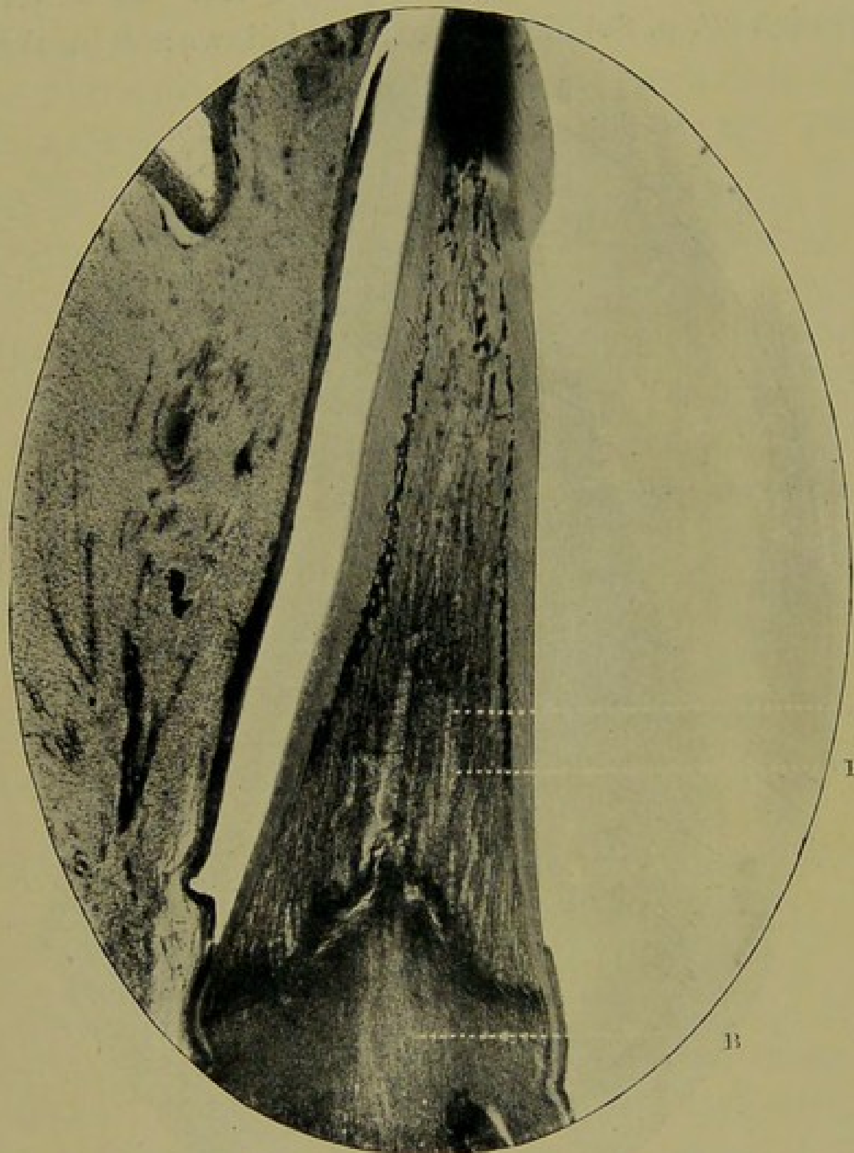


Fig. 98.—Longitudinal section of ankylosed tooth of *Esox lucius* (Pike). Prepared by the Author's process. Stained with Ehrlich's acid hæmatoxylene. Shews osteo-dentine. The full growth of the osteo-dentine is incomplete, a few elastic rods remaining in the centre of the tooth. Magnified about 10 times. A. Apex of tooth composed like the periphery of the dentine ; B. Bone of attachment ; E. Elastic rods, or uncalcified trabeculæ ; P. Pulp *in situ* ; M. Soft issues of the mouth.

regular tube system, otherwise the result of this sub-division into minor pulp cavities would be a flat form of plici-dentine in which the denticles are placed side by side in a regular and uniform manner.

In the osseous matrix lacunæ are sometimes found, and the dentine is more or less permeated by minute canaliculi. Many variations from this type exist. The structure of the teeth of *Lamna* (Porbeagle Shark) may be cited as an example. Tomes (*op. cit.* p. 80) describes it as follows:—"In the osteo-

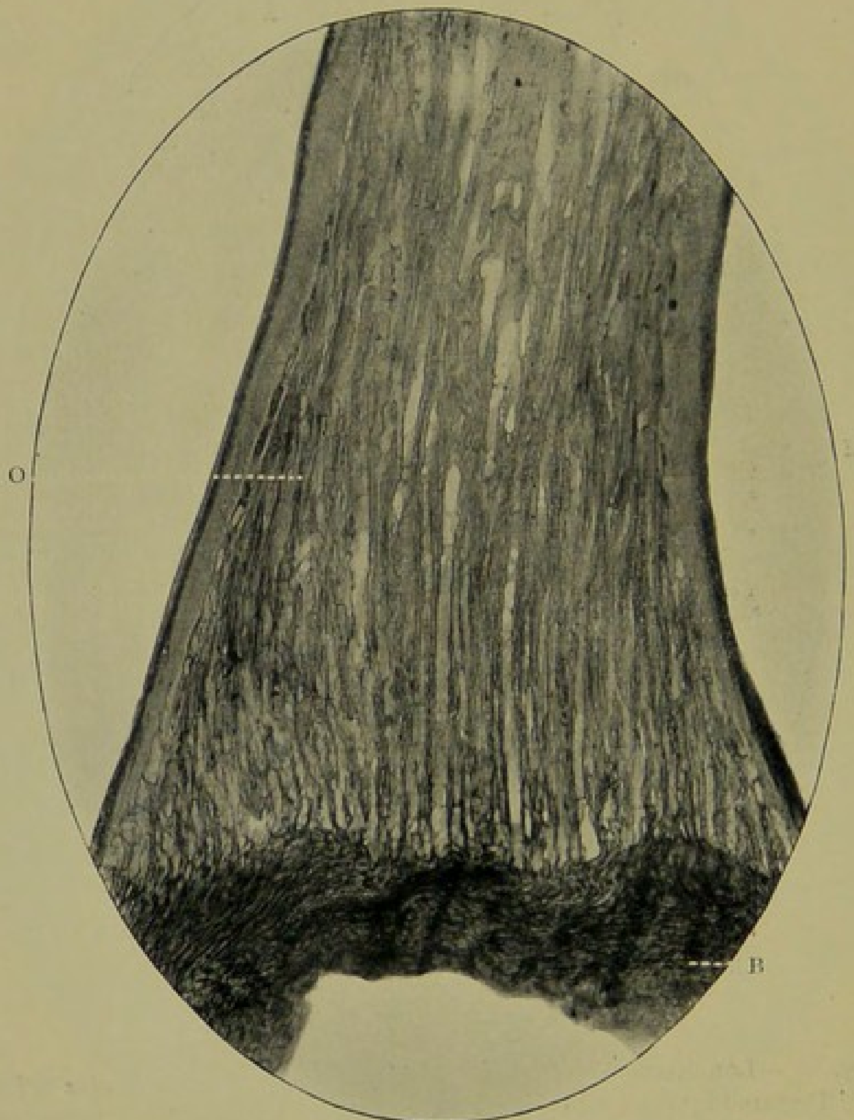


Fig. 99.—Vertical section of tooth of *Esox lucius*. Prepared by decalcification. Pulp tissue not retained *in situ*. Stained with borax-carmine. Magnified 40 times. O. Osteodentine; B. Bone of attachment.

dentine medullary canals of varying size run, with a direction, roughly speaking, parallel to the long axis of the tooth, anastomosing with one another; and from their sides wavy bundles of fine tubes radiate but do not run far; that is to say, its dentinal tubes do not radiate from any one central pulp chamber, but form an indefinitely large number of canals."

Recent Classification of the Varieties of Dentine

Dr. Röse, of Leipzig, has recently attempted a new classification of Dentine, and his communications to dental science, in these as in other matters, are always interesting. Thus he distinguishes :—

(i) Pure or Ortho-dentine, a term suggested by von Kupffer.

(ii) "Trabecular," or rod-like dentine.

(iii) Osteoid dentine.

(iv) Bone dentine.

(1) *Pure dentine* is a hard tissue with a smooth surface, of unilateral growth, being developed under an epithelial sheath or enamel organ.

This includes the following sub-divisions :—

(*a*) *Tubular dentine, i.e.*, normal tissue containing the canals for the reception of protoplasmic cell processes.

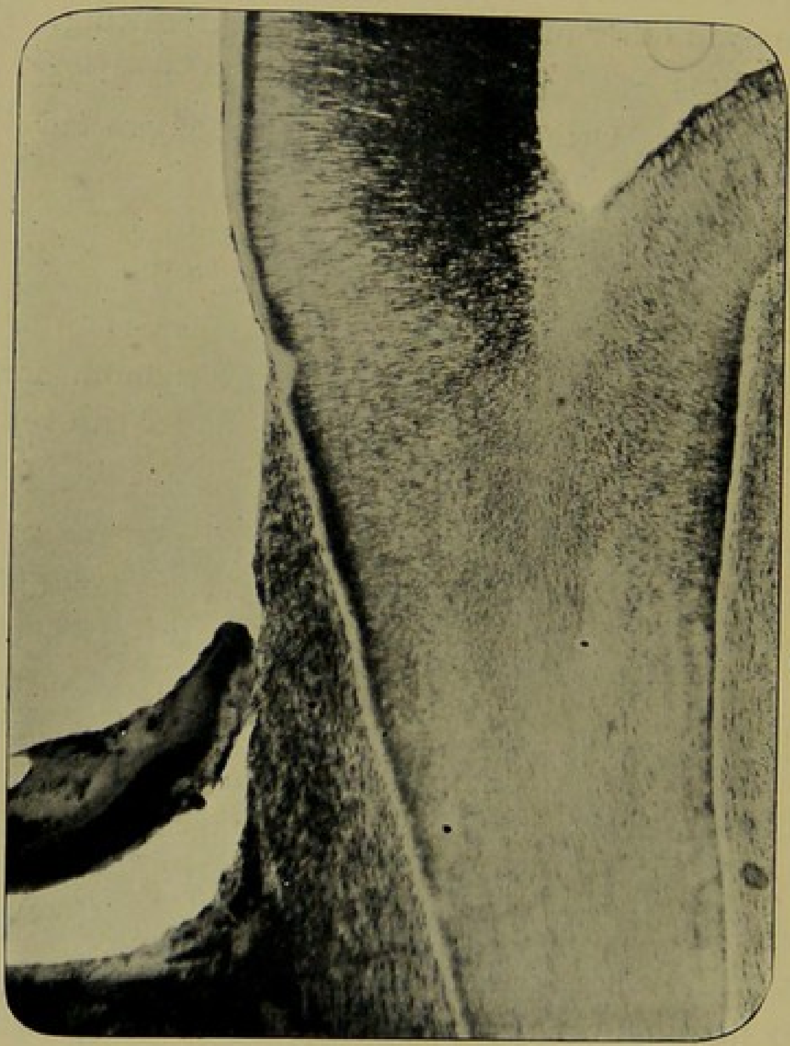
(*b*) *Vitro-dentine, i.e.*, tubeless and structureless, with no protoplasmic filaments whatever.

(*c*) *Vaso-dentine, i.e.*, containing blood-vessels.

(ii) *Trabecular dentine,* corresponding to the "osteo-dentine" of Tomes, is a new term introduced by Röse, who defines it as "a hard tissue with numerous short protoplasmic-bearing dentinal canals, capable of increase of growth in all directions, but *not* growing immediately beneath, or in dependence upon an epithelial sheath."

This variety is probably formed similarly to intra-membranous ossification of bone. Thus, in the interior of the pulp cavity, at an early period of development, arise rod-like tracts of closely-aggregated round cells. Within these tracts or columns, the first rudiments of structureless dentine are laid down exactly after the manner of the formation of the first layers of compact or cancellous bone. Single columns grow and increase in length and diameter. They thicken at the expense of the pulp tissue, become fused in places, and exhibit fine-tubed dentinal systems. Ultimately with the completion of the growth of the tooth, instead of there being one pulp cavity, there are many wide tubular canals con-

E



C D

Fig. 100.—Vertical section of the cervical region of a molar tooth of *Didelphys Virginiana* (Opossum). Prepared by grinding. Unstained. Magnified 45 times. D. Dentine; E. Enamel; C. Normal lacunated cementum.

taining pulp tissue radiating in every case in a centrifugal manner.

The first formed parts of the rods are structureless, and these are designated by this author as *vitro-trabecular dentine.*

(iii) *Osteoid dentine* is a hard tissue growing in all directions; contains no protoplasmic enclosures; sometimes forms pure bone tissue; sometimes trabecular dentine.

(iv) *Bone dentine*, or *Osteo-dentine*, is a transitional form, between bone on the one hand and dentine on the other; contains both bone corpuscles and dentinal tubules, each carrying a protoplasmic fibril.

MODIFICATIONS OF CEMENTUM

Little need be recorded about this. It is sufficient here to point out that the normal cementum of some of the Marsupial mammals (*e.g.*, the opossum, see Fig. 100), does contain prominent well-shaped lacunæ and canaliculi. Not only are the spaces of fairly uniform size, and the canaliculi of regular calibre and length, but the arrangement in layers or series is wonderfully parallel. Deposition of the tissue with inclusion of cemental corpuscles has, doubtless, proceeded without deviations from the original and earliest formed layer. The cementum, therefore, forms naturally a thick coating to the roots of the teeth, and comparison with the lacunated hyperplasic cementum of the teeth of man cannot fail to have a striking and convincing effect on the mind of the astute and experienced observer.

CHAPTER VIII

THE DENTAL PULP

MICROSCOPICAL ELEMENTS :—(i) Odontoblasts ; (ii) Pulp cells proper ; (iii) Fibrous stroma ; (iv) Basal layer of Weil ; (v) Arteries, Veins, and Capillaries ; (vi) Medullated and Non-medullated Nerves.

GENERAL CHARACTERISTICS

Definition.—The soft, vascular, and sentient organ which occupies the central portions of teeth, being naturally bounded, on all sides, by dentine, which thus constitutes its cavity.

Origin.—In Man and *Mammalia* it is the ultimate formation of the dental papilla, which is itself derived from the stomodoeal parietal mesoblast (somatopleur).

Distribution.—All the calcified teeth of fishes, reptiles, and mammals have pulps.

Macroscopical Appearances.—A soft, thin, flattened, whitish organ, with, occasionally, lines of pink running in a longitudinal direction if removed from its bony cavity before *post-mortem* changes occur.

Its measurements in upper permanent adult teeth are as follow :—

Greatest average width, sagittally and midway between apex of root and incisive or morsal edge: First incisors, 1·5 mm. ; canines, 2·5 mm. ; first premolars, 3·5 mm. ; second premolars, 3·8 mm. ; and molars, 5 mm.

Greatest average length: First incisors, 19 mm. ; canines, 19·5 mm. (in a coronal direction, 23 mm.) ; first premolars,

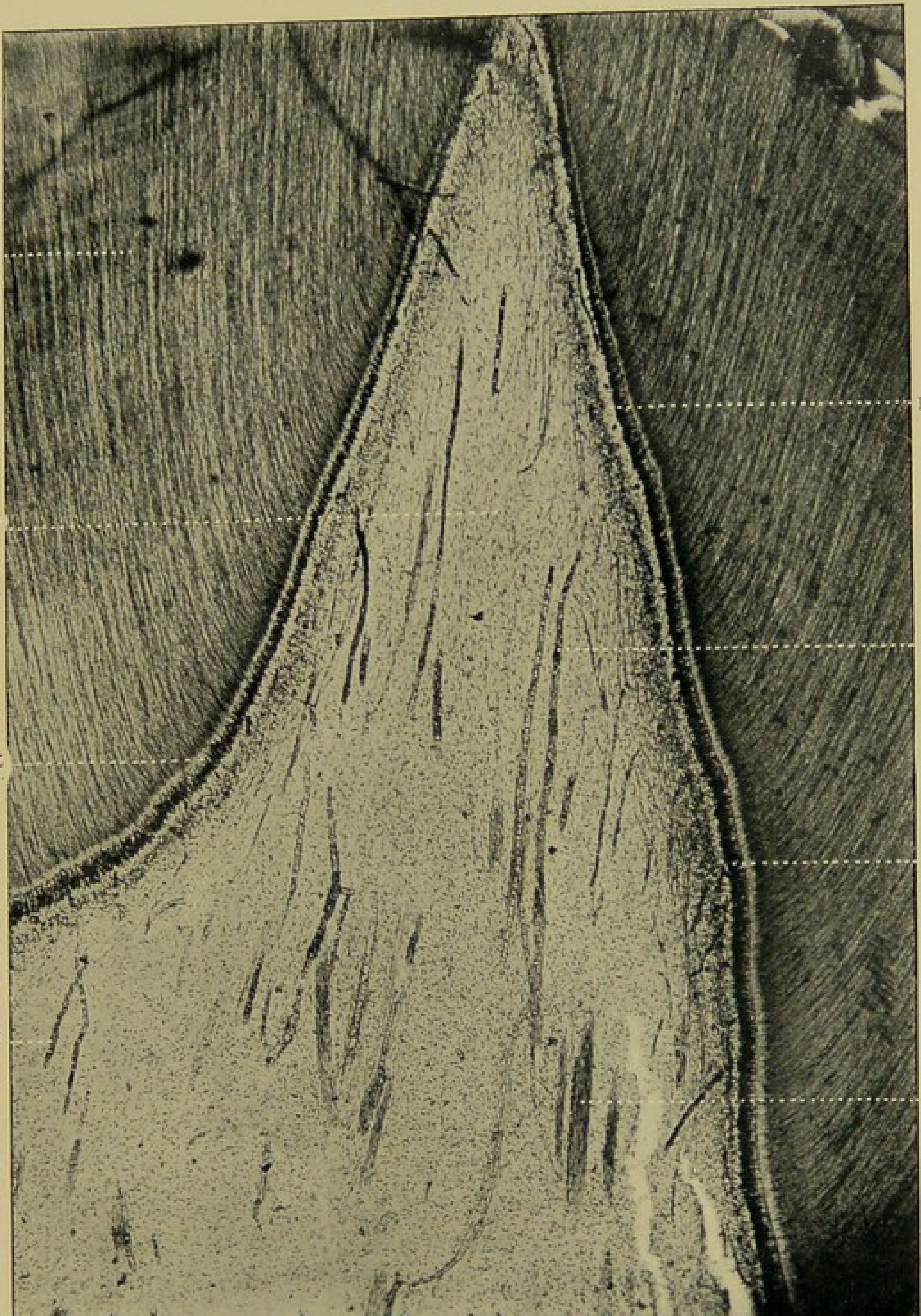


Fig. 101.—Longitudinal section through the cornual region of a young adult molar, the dentogenetic zone of which is on the point of calcification. The pulp is *in situ*. Prepared by the Author's process. Stained with Ehrlich's acid hæmatoxylene. Magnified 80 times. D. Dentine ; P. Pulp tissue in cornu of tooth ; D.Z. Dentogenetic zone ; O. Odontoblasts ; B.L. Basal layer of Weil ; B. Blood vessels ; N. Nerve bundles.

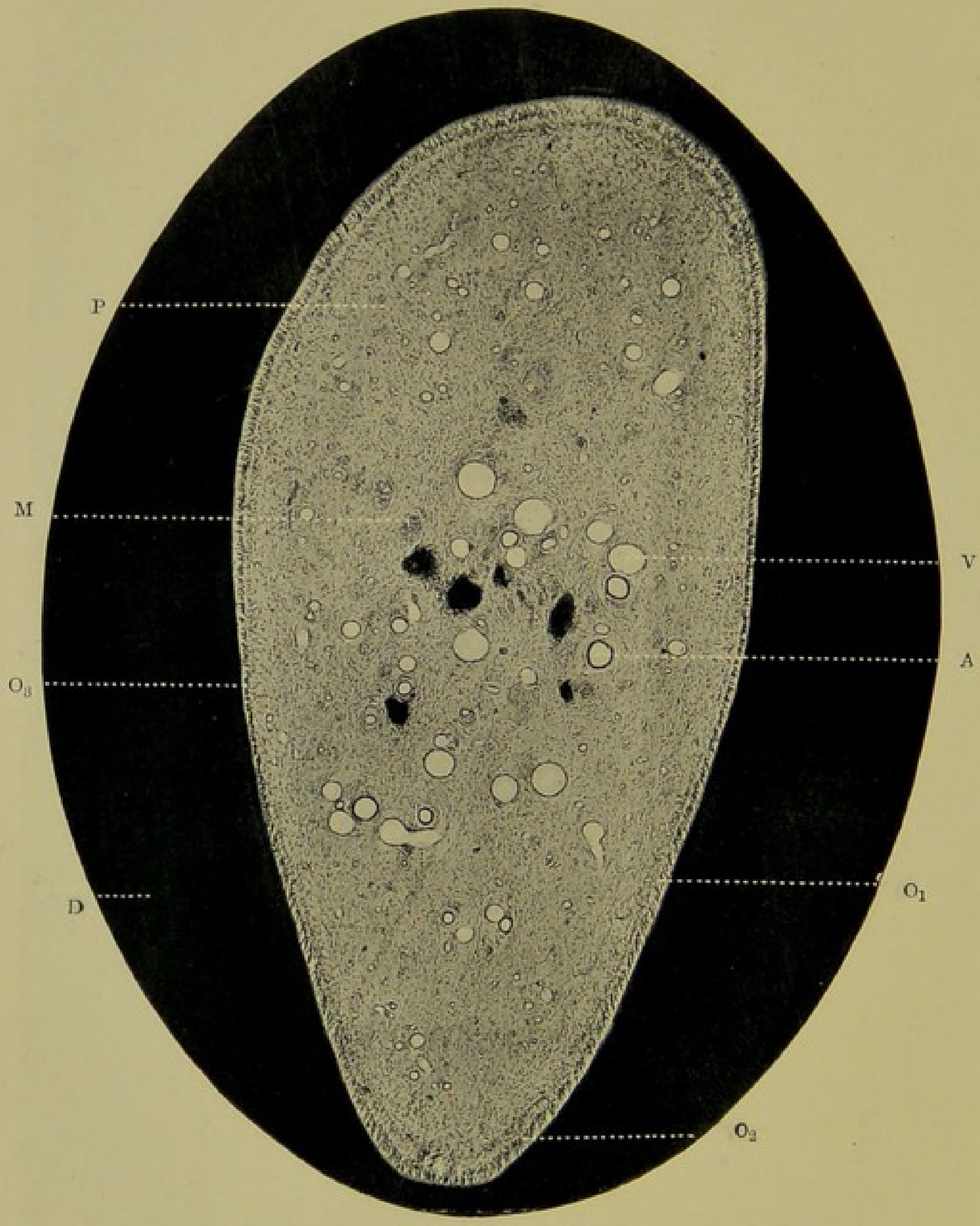


Fig. 102.—Transverse section of an adult canine, with the pulp *in situ*. Prepared by the Author's process. Stained with rubine. Magnified 45 times. D. Dentine; P. Pulp tissue proper; O_1, O_2, O_3, odontoblast layer; A. Artery; V. Vein; M. Medullated nerve bundle.

The narrowest diameter of the pulp in the section of which Fig. 102 is a photomicrograph, measured 1·5 mm.; the widest diameter 3·35 mm.

17 mm.; second premolars, 15 mm.; molars about 15 mm.; third molars, 11·5 mm.

For purposes of description it is advisable and convenient to arbitrarily divide the pulp as well as the pulp chamber into the (i) coronal region—the most distal portion which

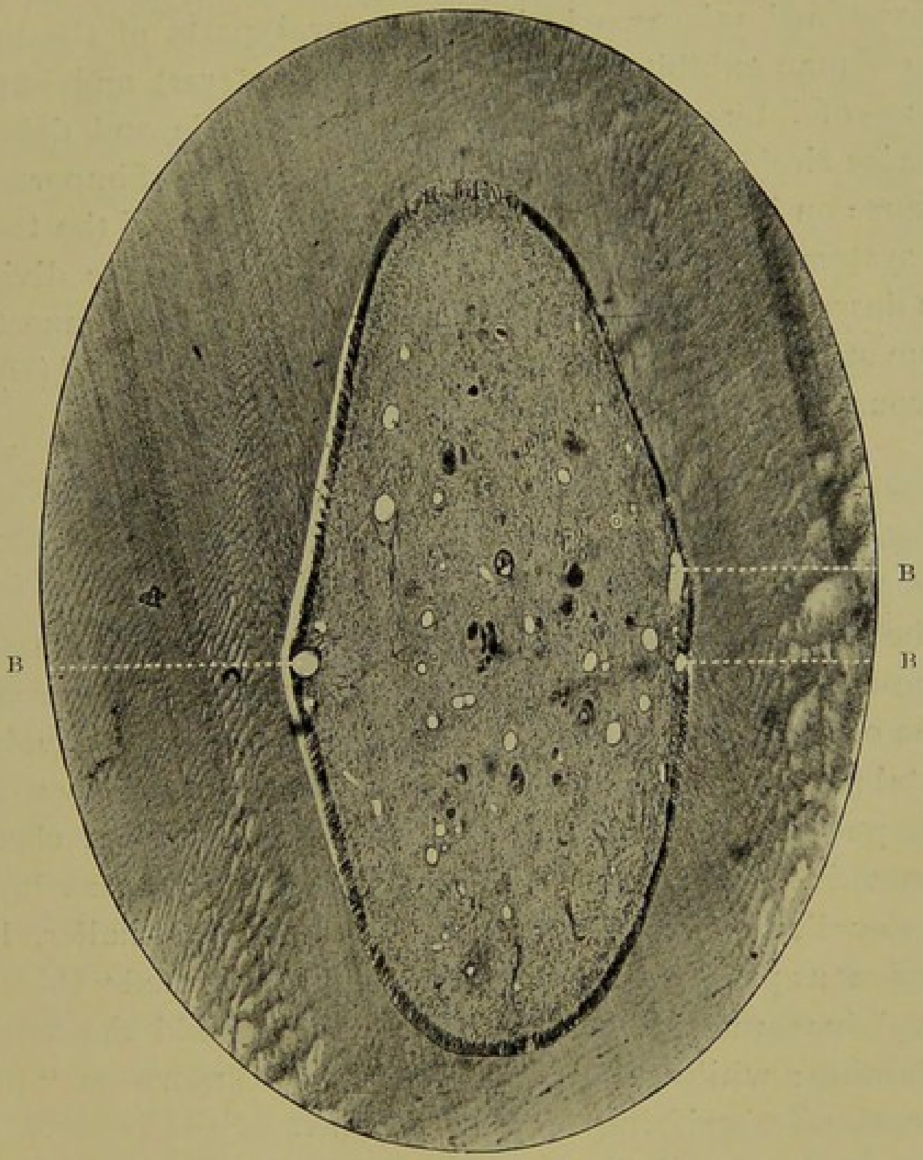


Fig. 103.—Similar to the preceding figure, but stained with Ehrlich's acid hæmatoxylene. Magnified 45 times. B.B.B. Blood vessels in the basal layer of Weil.

projects into the crown of the tooth; (ii) the cornual region indicating one of the pointed or rounded extremities of the coronal region; (iii) the cervical; and (iv) the radicular regions—that is, at the neck and in the roots of teeth respectively.

HISTOLOGY

The dental pulp is a delicate connective tissue[1] consisting of ramified cells imbedded in a slightly fibrous stroma and granular transparent basis substance, and is plentifully supplied with blood-vessels and nerves.

Examined microscopically the several parts of the tooth pulp of man exhibit objects of profound interest and importance—of interest because so many debatable and debated theories circle around the cells and nerves, and of importance because on its integrity depends the life-history of the tooth. To systematically study them, the subject may be divided into descriptions of (A) its cellular elements, (B) its connective tissue stroma or framework, (C) its vascular supply, and (D) its nervous system.

A

The Cellular Elements

The cells of the dental pulp fall naturally into two classes: of these the former is the more important when full growth of the organ has taken place; the second during its developmental periods. A cursory examination of an adolescent or adult pulp shows that two kinds of cells stand out clearly distinct from each other—the peripheral prominent layer, the so-called odontoblasts, and the central, smaller, less conspicuous pulp cells. The *latter* should be termed "Odontoblasts," inasmuch as it is their function to build the matrix of dentine; while the *former* might be known as "pulp corpuscles," signifying different work. See footnote on page 49, also the Appendix.

As bearing upon this point the statement of Röse, of Leipzig, may be recalled. He says (*loc. cit.*): "The odontoblasts of pure dentine have, like the formative cells of 'trabecular' dentine, quite the appearance of osteoblasts. If one wishes further to distinguish odontoblasts from osteo-

[1] It is said to be similar to the jelly-like connective tissue of the early embryo, which in the case of the umbilical cord persists, and is called the jelly of Wharton.

blasts, and chooses not to make use of the commonly-employed term 'scleroblasts' introduced by von Klaatsh, new and concise definitions must be introduced. It would be commendable in the future to define only those dentine-forming cells that range themselves along an epithelial sheath as 'odontoblasts,' quite indifferently, whether one refers to multangular cells below or cylindrical cells above. Hence the word 'odontoblasts' belongs only to those formative cells of true dentine. The formative cells of 'trabecular' dentine and bone tissues, which have never had any connection with an epithelial sheath should, on the other hand, be defined as osteoblasts."

(1) *The Cells of the Membrana Eboris of Kölliker or the Odontoblasts*

All along the periphery of young or mature pulps, arranged like a palisade in a single row, is a collection of large, columnar epitheloid cells. This layer is most marked at the coronal portion of the pulp, and becomes appreciably less distinct at the cervical portion, while in the region of the root it is practically invisible. It is most clearly seen in the developing teeth of kittens and other embryos, as well as in complete sagittal longitudinal sections of young and adult human pulps, although in the latter the columnar character of the layer has disappeared. In transverse sections, too, this layer is visible, and it is not difficult to say with accuracy from which portion of the pulp the particular section has been taken. A closer inspection reveals the fact that the *membrana eboris* is composed of cells —the so-called odontoblasts, a term suggested by Waldeyer in 1870, and generally adopted since that time. In young pulps it consists of a single row of cells; in adult specimens several rows. These cells are of the utmost interest and moment. They will be described with regard to shape, size, relationships, structure, processes, and analogies.

(*a*) An odontoblast, generally speaking, in its very earliest phase of development, is represented by a large oval nucleus,

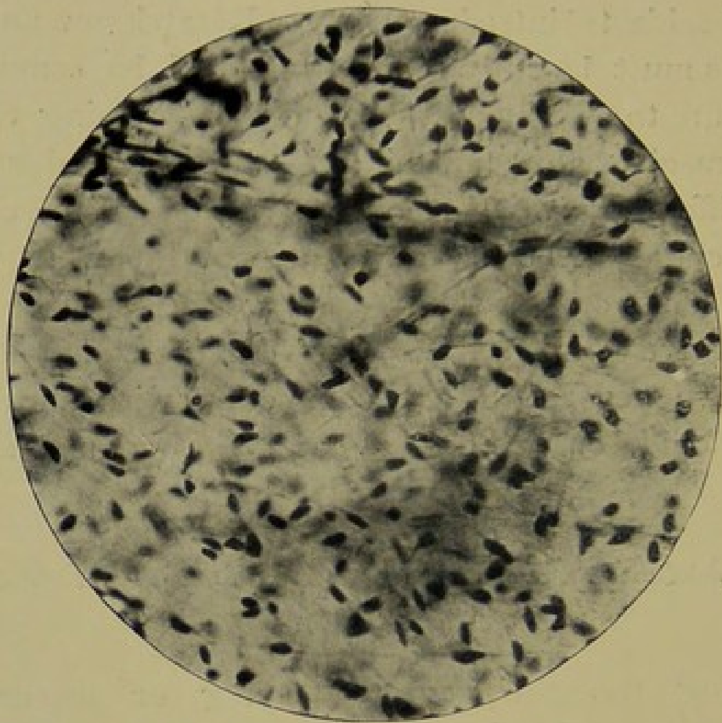


Fig. 104.- The structure of the pulp tissue. Prepared by Weil's process. Magnified 250 times

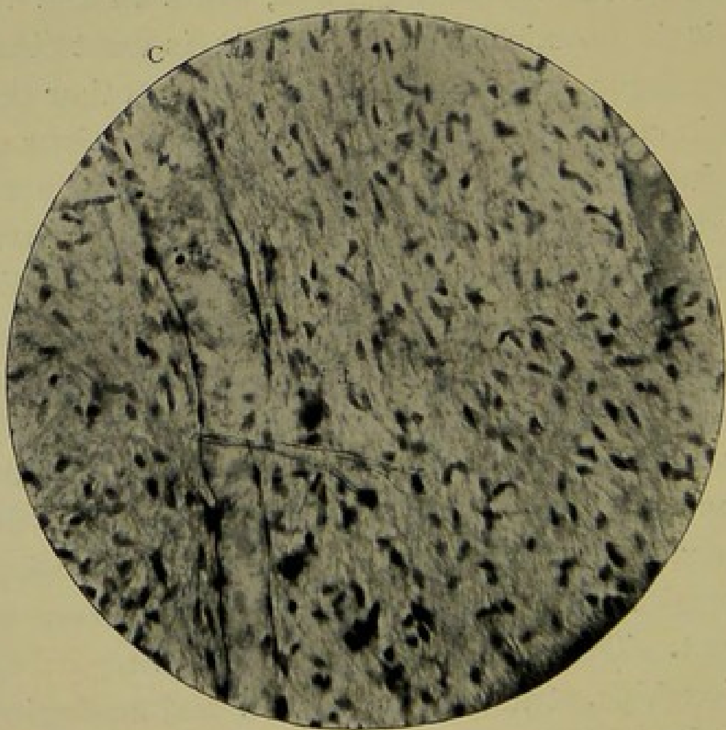


Fig. 105.—Same as the preceding. Prepared by the Author's process. Magnified 250 times. C, A Capillary.

Fig. 106.—Odontoblasts on the surface of the pulp. Prepared by fixing and hardening in formalin and alcohol, and cutting on an ether-freezing microtome. Stained with chloride of gold. Magnified 250 times. To shew the enormous length of the dentinal processes of the cells.

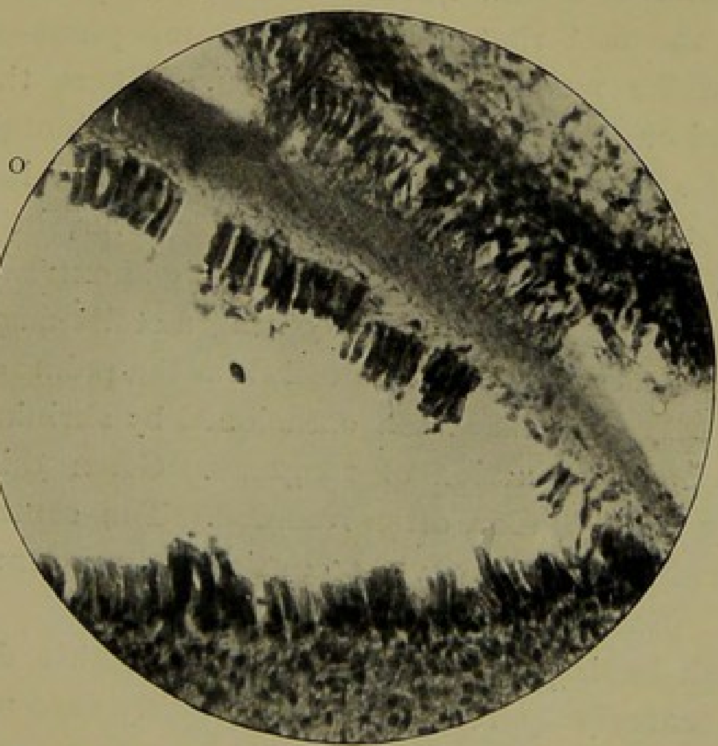


Fig. 107.—Young odontoblasts from a developing tooth germ. Magnified 250 times. o. Odontoblasts.

devoid of visible protoplasm (Paul).[1] It may be recognised without difficulty, when about one-fourth its normal size. "It then consists of a large oval nucleus situated at its extreme base, with a short pyramid of protoplasm reaching towards the surface, and displacing the fibres of the surface pulp cells on either side. At this time it possesses no dentinal fibre, merely ending in a blunt point, though no doubt some delicate invisible protoplasmic processes are given off."

Later on, but while still young, and during its period of greatest activity, an odontoblast is a large bipolar, nucleated, epitheloid cell, more or less columnar in *shape*. This varies considerably in the same specimen, and ranges from that of a mere thin cord with bulbar terminations to that of a pear or banana, as Underwood[2] has recently likened it. Many cells are carrot-shaped, many caudate. Some are short and thick, some long and thin; some have, as is well known, square dentinal ends, others rounded extremities. But it would appear that those found in fully-grown pulps are more or less pyriform in shape, while those in older specimens are reduced often to a thin fibrous bundle. A point worthy of notice is the fact that cells in the same plane—the same section—differ much in conformation. Where the pulp is constricted or flattened laterally, there the odontoblasts are thick and short; in the place where the pulp is broadest, however, they are long and thin. Moreover, in the latter situation, in adult pulps, they have enlarged extremities, that near the dentine sometimes presenting a stellate appearance, with the processes leaving the cell from the points of the star. Most probably this has been occasioned by shrinkage of the cells through the action of reagents. Often this dentinal extremity is triangular, often rounded. The central portion or body of the cell is very considerably attenuated and cordlike. (See Fig. 108).

In teeth having cylindrical pulp cavities this diversity in shape is scarcely appreciable, and probably does not exist.

1 "A Contribution to the Histological Study of Dentine." *Trans. Odonto. Soc. of Great Britain*, p. 129, 1899.

2 "Aids to Dental Anatomy and Physiology," p. 25, 1902.

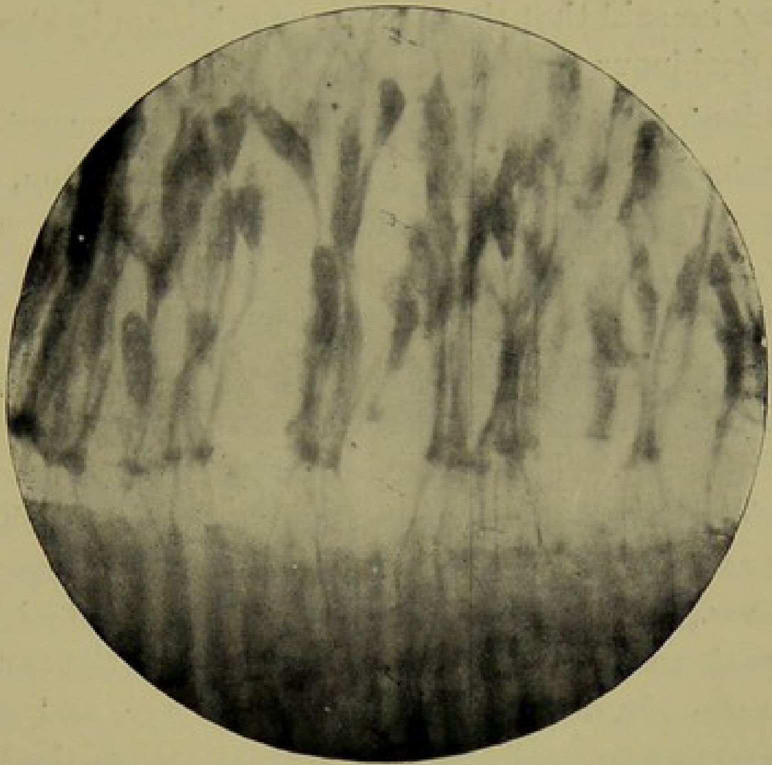


Fig. 108.—Similar to Fig. 102. The odontoblasts marked O_2 in that photograph. Magnified 750 times. To shew the peripheral processes extending into the dentinal tubes as the dentinal fibrils.

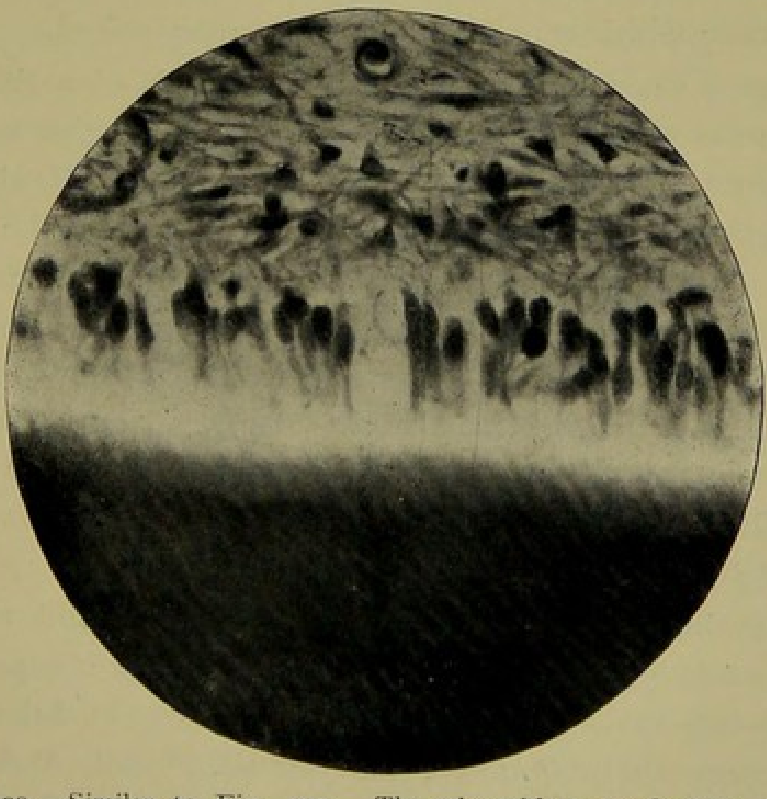


Fig 109.—Similar to Fig. 102. The odontoblasts marked O_3 in that photograph. Magnified 750 times.

It may be said that the same remarks apply also to fully-formed deciduous teeth.

An odontoblast is said to have no limiting membrane.

Pathological conditions, such as inflammation, suppuration, or calcareous degeneration of the pulp do not seem, at first, to affect the shape of the odontoblasts: this rule obtains in all normal and abnormal examples.

(β) With regard to *size*, odontoblasts vary considerably, the coronal cells being larger and more marked than the radicular cells of the pulp. This change in size corresponds in a measure to the length and width of the tubules, with which they are closely associated. The largest cells in an embryonic tooth-germ—viz., those under that part of the dentine which is covered by enamel, and called, for the sake of brevity, the coronal part of the pulp—have a diameter of 10 to 15μ, and if they be compared to adult cells in the same situation, the latter will be found to vary from 25 to 30μ in length, with a breadth of about 5μ. Waldeyer[1] gives the size of adult odontoblasts, but does not compare them with developing cells—a point of importance which seems to have been overlooked.

It seems reasonable to suppose that this diversity of size would account for the increase of calibre of the fibril (and therefore tubule) as it approaches the pulp. Paul (*loc. cit.* p. 134) mentions that at the period of time when the dentinal matrix has reached a depth of $\frac{1}{20}$ mm., the odontoblasts are very long, but remain about 7·7μ in width. In the ox they may attain the length of 50μ. According to Kölliker, the stratum of the *membrana eboris*, in an adult pulp, measures from 41μ to 83μ in thickness; the odontoblasts themselves being 25μ long, and 4μ to 4·5μ broad.

(γ) *Relationships* to surrounding structures:—

The author, in a paper written in 1889, showed that these cells are not packed closely together, but are separated by wide visible spaces, which in certain cases are filled with a "homogeneous substance, and small, round, and angular

[1] Stricker's Histology, Vol. 1, 1870, p. 476.

cells." It is necessary to add that this is the case in developmental pulps, there being only a slight amount of intercellular tissue in most adult specimens. There are visible also in many instances, fine delicate fibrils stretching into the dentine between the odontoblasts, in addition to the already-mentioned structures. These fibres are not nerves, but form what may be termed the "supporting fibres" of the pulp. Reference to this point will again be made later on. (Page 143).

The long axes of the odontoblasts are approximately in the same direction as that of the tubules—a fact well brought out in transverse sections of pulp cut *in situ*, and best observed in its narrowest part.

In some sections, the cells are separated some distance by a gap, in which a capillary loop may lie quite close up to the dentine, and also pulp matrix—viz., delicate intercommunicating fibres. And in young pulps, in which dentine matrix is still being produced, many of the cells have attached to their distal ends lines of "transitional tissue" which Paul calls "collars." An odontoblast collar or shoulder is thus often seen, and was described by the earlier investigators as a lateral or median process of the cell. Mature cells have it not, only those of earlier stages of growth exhibiting it. A collar nearly always adheres to the dentine matrix, but very often to the cells themselves; is more highly refractile than any other part of the cells; and is the only portion in which they are in mutual contact. It is important to notice, however, that a collar is not part and parcel of the odontoblast. It is pierced by its dentinal process. It is probably derived from the pulp matrix, and really consists "of a delicate network of pulp fibrils woven about the necks of the odontoblasts upon which the secretion of the latter is poured and solidifies to form the dentine matrix." This is the interpretation supplied by Paul, but while the author agrees with the histological appearances just described, he cannot see his way clear to accept Paul's exposition or statement as to the lime-bearing functions of the odontoblasts.

(δ) In *structure*, the odontoblasts possess a coarse degree of granularity, which does not disappear on the addition of a weak acid, and is apparently unaffected by glycerine, and certain other chemical re-agents. The distal ends of the cells *when young* are apparently clear and homogeneous, the granularity being confined to the lower four-fifths. In transverse section, this granularity is due to either (i) a coarse, deeply-staining reticulum or spongioplasm, or to (ii) the presence of numerous translucent globules (? of first-formed calcoglobulin). The author has failed to see the clear zone in adult odontoblasts, and considers that the spongioplasm becomes

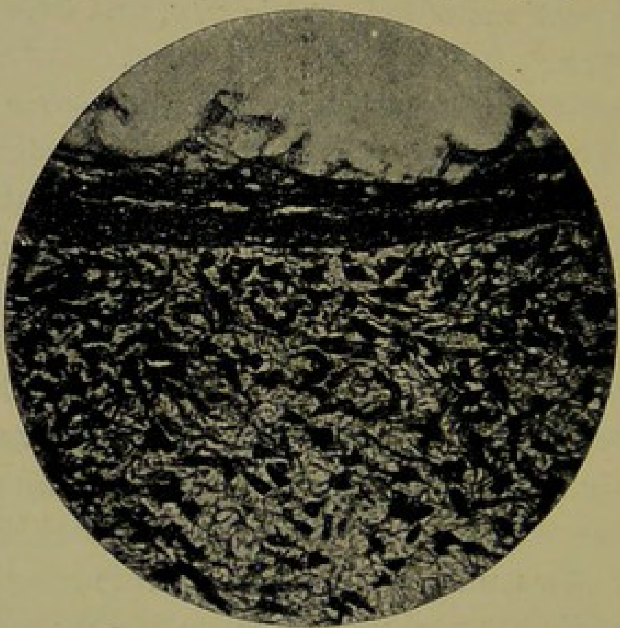


Fig. 110.—Section of tooth germ before the surface cells of the pulp have undergone any differentiation. Magnified 250 times. Photomicrograph by Paul.

coarser through thickening of the nodes of the network as time goes on, and the amount of the hyaloplasm is proportionately diminished. Hence he again differs from Professor Paul in his belief that the clear zone is due to calcoglobulin.[1]

The nucleus of an odontoblast is large, oval, and prominent,

[1] In this connection a remark by Professor Schäfer ("Quain's Anatomy" vol. I., part II., p. 174, 1898), is of profound significance: "It would seem that the presence of certain inorganic substances, and especially calcium, is essential to the life, and therefore to the functions of protoplasm; but in what manner the lime may be combined with the organic basis of the living material, remains as yet quite undetermined."

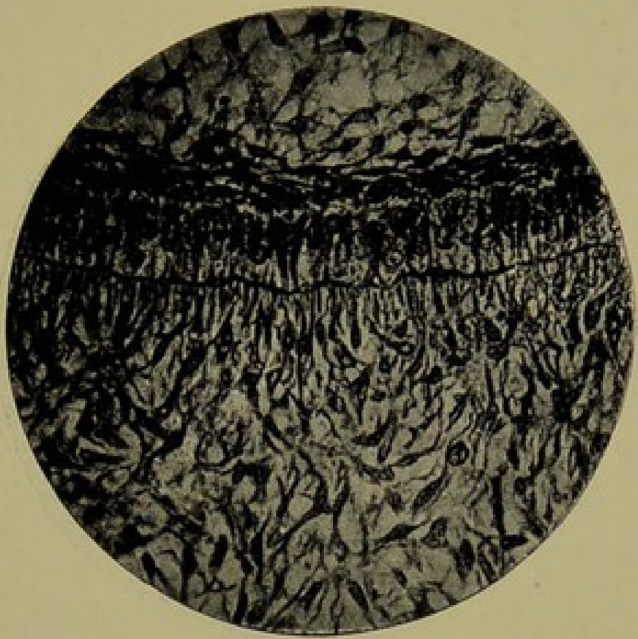


Fig. 111.—A later stage than Fig. 110. Shews surface pulp cells becoming arranged in a fairly regular layer, with their chief processes directed towards the ameloblasts. Magnified 250 times. Photomicrograph by Paul.

Fig. 112.—Shews complete evolution of surface pulp cells. They have produced a superficial fibrous layer, and their nuclei are now in a "resting" state. The odontoblasts have not yet appeared. Magnified 250 times. Photomicrograph by Paul.

Fig. 113.—Shews the line of "transitional tissue" along the top of the odontoblasts. At one place it stretches across a gap between two cells caused by the intervention of a blood-vessel undergoing degeneration Magnified 250 times. Photomicrograph by Paul.

Fig. 114.—A very thin section of odontoblasts, shewing the pulp fibres investing them, and ending in the "transitional tissue" forming the shoulder or collar of each cell. Magnified 340 times. Photomicrograph by Paul.

and is situated at the basal extremity of the cell. Its wall is well-defined, and its chromoplasm pronounced. Occasionally nucleoli may be found. The nucleus is usually placed at the centripetal end of the cell as has been already stated; but Paul has shown that it may be found in the middle, and occasionally quite at the distal end, where its long axis lies transversely to the cell. In this latter case, however, it must not be forgotten that the odontoblast itself is very short, or has been cut obliquely so as to appear short. If a cell was lying a little out of the level plane of its neighbours, in a vertical section, the nucleus would probably appear higher in the body of the cell than usually obtains. Paul thinks that it exhibits an exhausted condition, and has ceased to grow. An odontoblast may have two nuclei in the same cell, a "condition by no means uncommon," and, rarely, atrophied nuclei have been observed by Paul in the dentinal fibre, just beyond the transitional tissue. These appearances are interpreted by him as being due to coalescence of two odontoblasts, the lower cell reïnforcing and rehabilitating the degenerated upper odontoblast.

(ϵ) The *processes*.—These cells are remarkable for their polar offshoots, which may be classified as (i) central or basal; and (ii) peripheral or dentinal.

Of these, the first named are most easily observed in sections prepared by Weil's or Decalcifying processes, when ordinary stains are used, but the latter cannot be so clearly demonstrated unless, as Howard Mummery has suggested, a special method of staining with iron and tannic acid is adopted. Carmine and rubin and a few anilin dyes show them also.

The peripheral poles of the odontoblasts, then, stretch into and enter the tubules of the dentine, and are here called dentinal fibrils. In some cases they are bifurcated: several fibrils may emanate from one cell; and nothing else can be seen entering the tubule. Boll[1] has counted as many as six processes belonging to one cell.

[1] "Untersuch. der Zahnpulpa." *Archiv. für Mikrosk. Anat.*, p. 73, 1868.

It is no difficult task to demonstrate the basal offshoots of the odontoblasts. They are exceedingly thin and may intercommunicate with each other. This, however, is not at all satisfactorily proved. They present no varicosities of surface, are not swollen or twisted, and take the stain less deeply than other portions of the pulp tissue. They are invisible in young developing cells. Special stains, such as Golgi's, Stroebe's, or methylene blue have failed up to the present time to trace back these central poles to the terminations of the nerves of the pulp.

According to Magitot,[1] the basal processes of the odontoblasts are continuous with the branches of large reticulate cells, situated as a layer, beneath them. These latter cells are placed in direct line with the nerve terminations. (See diagram, p. 169). In this manner, the sensibility of the dentinal fibril is accounted for. Recent workers have not, however, corroborated Magitot's views, and his deductions, in the light of more modern research, would seem to be incorrect.

In the dental pulp of the ox, these basal processes assume a large size. If an incisor is removed from the jaw of an ox, immediately after the animal has been slaughtered, and then broken longitudinally in a vice, the basal poles may be demonstrated in a few minutes, while still fresh. A small piece of the *membrana eboris* is removed and teased in salt solution; while carmine or chloride of gold clearly stains the long process.

Aitchison Robertson[2] has studied these offshoots in the ox, and he reports that "odontoblasts were seen which had become separated from the other cells, and had drawn out along with them their internal or root process. This was in some cases of great length, and could be traced for some distance into the pulp. In other cases, part of the dentinal fibre still remained attached to one extremity of the separated odontoblasts, while from the other extremity, the long internal root process was seen extending into the pulp."

[1] *Journal de l'Anatomie de M. Charles Robin*, Paris, 1881.

[2] "On the Relation of Nerves to Odontoblasts, and on the Growth of Dentine." *Trans. Roy. Soc. of Edinburgh*, p. 323, 1891.

The processes sometimes measured even twelve times the length of the odontoblast cell, and in some instances passed into groups of nerve fibres, amongst which they apparently ran for some distance before they acquired a medullated sheath. This author significantly observes :—" I am convinced that the central processes of the odontoblasts become con-

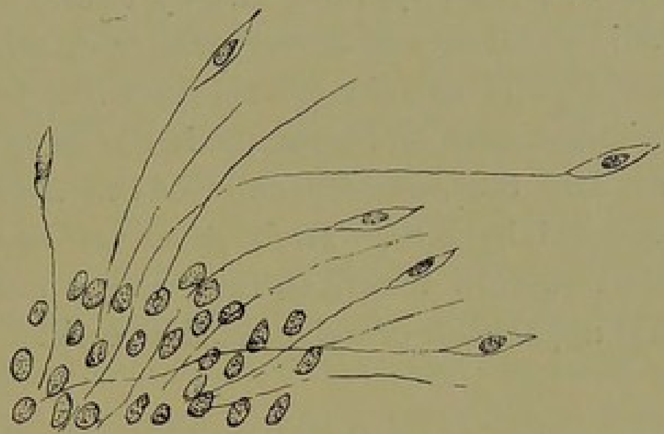


Fig. 115.—Portion of surface of the pulp teased in potassium anhydrochromate solution. Shews the very long central process belonging to each odontoblast and entering the substance of the pulp. The odontoblast has fallen off in many cases, and leaves the central process projecting like a fine hair or nerve fibre. After Aitchison Robertson.

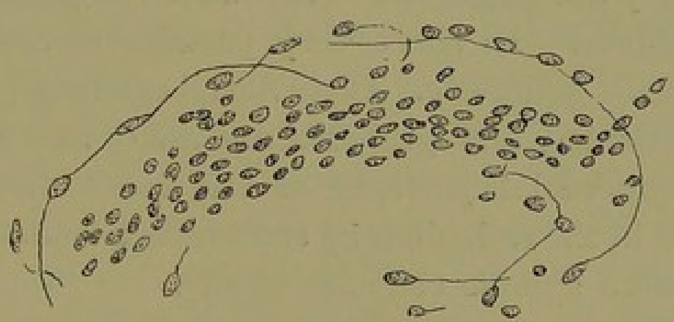


Fig. 116.—Apparent direct continuation of the root process of the odontoblasts with the axis cylinder of a nerve. After Aitchison Robertson.

tinuous with the nerve fibrils. . . . The long central process seems to become the axis-cylinder of a nerve fibre, which gradually acquires a primitive sheath in which the medullary or white substance slowly accumulates, till an ordinary medullated nerve results. . . . It is very difficult to say whether all the odontoblasts send in their long processes to join the nerve fibres."

It is a histological fact that odontoblasts possess processes running towards the pulp; but it has not been proved, in spite of Robertson's work, that they are the direct continuation of the pulp non-medullated nerve-fibres.

Their existence is doubted by Hertz ("Untersuch. über den feineren Bau und die Entwicklung der Zähne," in Virchow's "Archives," Bd., 37, 1866) and by Paul.

(ζ) There is a certain amount of *analogy* existing between the odontoblasts, and certain epitheloid cells, found in the olfactory regions of man and animals, in the ganglionic layer of the retina, and the auditory cells of the *macula lutea* of the membranous labyrinth. Their processes are somewhat similar, their structure identical, their shape modified only by the mutual apposition of neighbouring cells.

(2) *The Other Pulp Cells*

The cells of the pulp proper, viz., those situated in the central portions of the tissue, differ in size and shape during the various stages of the growth of that organ. In developing teeth they are large, and have rounded angular or spindle-shaped outlines. In short, they partake of the nature of embryonic cells generally. Their nuclei are large, prominent, oval or lenticular, and granular, and are devoid of nucleoli. Near the superficial portions of the tooth they are very loosely held in the reticulum by the connective tissue stroma; and here, more spindle cells are visible.

In adult teeth, the pulp cells are chiefly stellate or angular in shape, with numerous branches. Their number is greater, as a rule, than the ordinary round cells; but cells of any description are comparatively few. The branches are long and multiplied, and interlace with one another, giving the pulp the appearance of a mucoid tissue. Fewer cells exist in the radicular region of the pulp. A few insignificant-looking odontoblasts are found; but the mass of the pulp seems composed of bundles of thick and thin connective tissue fibres, running in all directions.

The morphology of the individual cells is best studied in fresh pulps which have been teased-out in physiological salt solution, and suitably stained.

B

The Connective Tissue Stroma

Extending throughout the pulp in every direction, like an exceedingly delicate net, is the connective tissue stroma or scaffolding in which the cells are imbedded. This framework serves two purposes, as an imbedding material for the pulp cells, and as a support to sling up the soft delicate organ in its bony casing, in much the same way as marrow is supported in the medullary cavities of bone. The fine fibres do not enter the dentinal tubules, but they are often seen attached to the matrix of the dentine, where, most likely, they become the odontogenic fibres.

In the sub-odontoblast region of the pulps of adult teeth the basal layer of Weil is seen. This, first described by the late W. A. Weil, of Munich,[1] in his monograph on the Dental Pulp consists of a distinct clear layer of fibres with a great scarcity or even absence of cells. In describing it, he wrote: "The layer contains no cellular elements or nuclei; it appears rather as a web of extremely fine fibrils, which do not run perpendicularly through the layer, but running obliquely towards the deeper layers, interlace with one another in a crosswise direction. . . . It may be said, with perfect security, that they arise from the projecting basal ends of the odontoblasts. It is, however, surprising that these offshoots do not follow the axial directions of the odontoblasts, but turn sideways to one direction or another, and thus form the crossings."

The basal layer measures at the coronal part of the pulp 0.025 mm. in diameter, and gradually thins away and becomes diminished in size, until it no longer exists in the radicular region.

[1] "Zur Histologie der Zahnpulpa." Leipzig, p. 55, 1887.

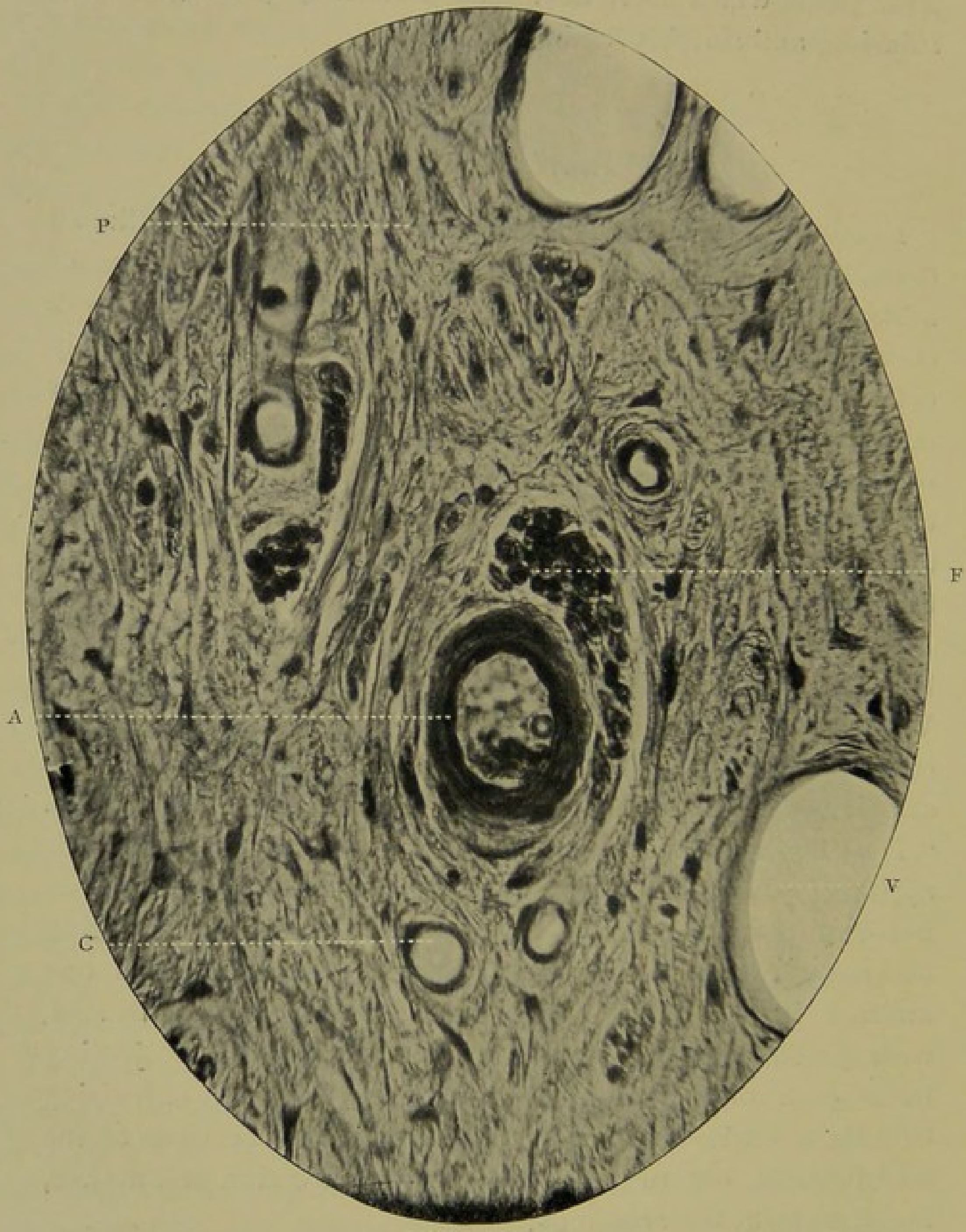


Fig. 117.—The dental pulp. Prepared by the Author's process, and stained with Ehrlich's acid hæmatoxylene. Magnified 750 times. A. Artery; C. Capillary; V. Vein; P. Pulp tissue proper; F. Fasciculus of medullated nerve fibres.

This statement is corroborated by Partsch,[1] of Breslau, and deserves great attention.

Further, Howard Mummery[2] refers largely to this in a recent paper, where he says:—"According to my experience the layer is not visible in young teeth in the situation of the rapidly-depositing dentine at the open, uncompleted end of the root." And it may be added, that the author has repeatedly observed it in the mature pulps of deciduous and permanent teeth as well as in certain pathological conditions; but never in young growing teeth. Professor Paul has, however, noticed "a clear zone of tissue just beneath the most actively growing young odontoblasts." He declares:—"It seems to me, after many careful examinations, that the appearance is not due to the presence of a specialised tissue, but is simply owing to a rarefaction of the pulp preceding the active extension of the odontoblasts, which are of course progressing inwards through the pulp matrix."

Regarding the exact nature of the basal layer, it is a difficult matter to decide. It is certainly fibrous; but whence the fibres come and go, and whether the whole layer is an artificial product or not is as yet undecided.

Weil himself considered that the fibres were undoubtedly continuous with the odontoblasts, and might thus be a means of communication between them and the nervous system of the pulp. He never was able to prove, however, that these delicate fibres were non-medullated nerves. Repeated attempts at differential staining to ascertain if they were of a nervous character have failed. A stray capillary may cross the layer and get into the spaces between the odontoblasts. Howard Mummery does not believe that all the fine fibres are in continuity with the odontoblasts; many of them penetrate through the layer and enter the dentine matrix.

Its existence as a true histological structure is doubted by Ebner and Röse.

von Ebner says:—"The odontoblasts are attached to the

[1] *Deutsche Monatsschrift für Zahnheilkunde*, p. 322, 1892.

[2] *Journal of British Dental Association*, p. 779, 1892.

dentine by means of the dentinal fibrils—they cannot, therefore, when the inner portions of the pulp shrink up (through the action of reagents used in the Koch-Weil balsam process) be very well torn away; but the layer immediately under the odontoblasts will seek to approach the centre of the pulp, and before it comes to a rupture, the tissue elements which form the connection of the odontoblast layer with the pulp lying beneath, will be very strongly stretched. These tissue elements are chiefly fibres, and in this way a

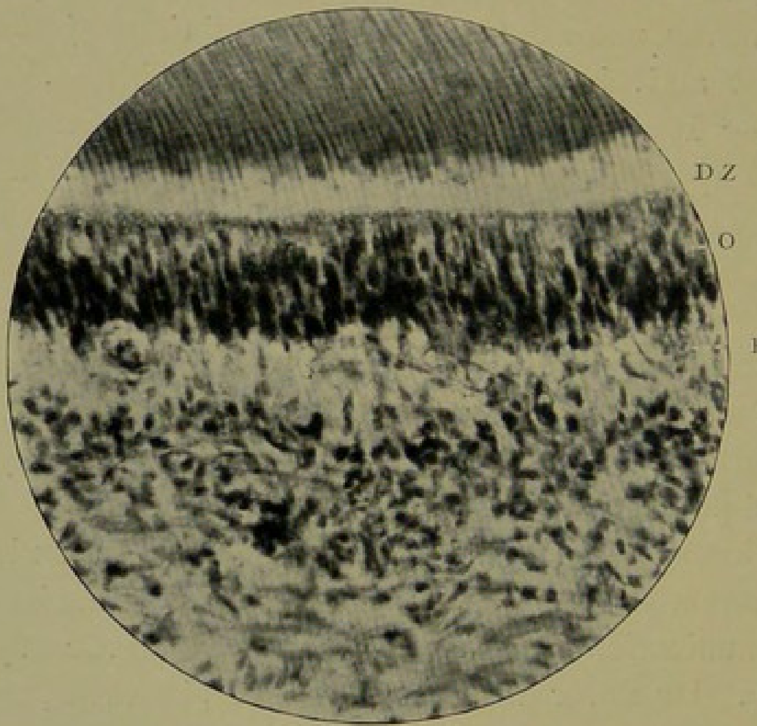


Fig. 118.—The pulp *in situ*. Prepared by the Author's process, and stained with Ehrlich's acid hæmatoxylene. Magnified 250 times. B. The basal layer of Weil; O. Odontoblasts; D.Z. Dentogenetic zone.

layer of fibres can be artificially produced which before was non-existent. . . . Dr. Weil shows that from the tissue of the pulp, rich in cells, which is found beneath the *membrana eboris*, numerous fibres penetrate toward the odontoblasts. But that these fibres, in life, exist as a special basal layer cannot be proved by Dr. Weil's method."

And thus also Röse.

But Howard Mummery considers that the facts of the non-distortion of blood vessels in the layer, as also its absolute disappearance at the growing extremity of the roots of teeth with large apical foramina must be taken into account, and disprove the theory of shrinkage of the pulp.

C

The Vascular Supply

The pulp is freely vascularized by branches which are derived from the Superior and Inferior Dental and Infra-orbital divisions of the Int. maxillary artery.

They enter the teeth through the apical foramina of their roots, generally as one large trunk, or as three or more small ones. Shortly after their entrance into the pulp, the vessels branch repeatedly, become smaller in calibre, until near the surface they form a simple capillary network which may measure 8μ to 12μ in width.

During the period of development the vascular system covers a large area of the dental papilla. The main arterial trunk, proceeding in a longitudinal direction through the centre of the tissue, diminishes in diameter very gradually, till near the edge of the dento-genetic zone, when it almost suddenly and rapidly becomes narrower, and is ultimately lost in a dense capillary plexus. The branches have the peculiarity that very often they issue at or about right angles with the main vessel. (See Plate I.)

In adult pulps, this angular method of division is not so evident; the larger vessels are located chiefly in the axial portion, whence numerous branches pass in all directions.

In the cornual regions many anastomatic capillary loops have their convexities directed towards the dentine. As a rule, these capillaries extend as far as the basal layer of Weil; but occasionally, as has been already mentioned, one or more may cross, and get between the odontoblasts. (Fig. 103).

The arteries vary in size, in different pulps, but a main trunk may measure about 83μ in width, while the diameter of the lumina of the capillaries is roughly about 8μ.

The former are accompanied, not only by their respective veins, but also by fasciculi of medullated nerves, which run side by side, sometimes so closely that nothing but a few connective tissue fibres and cells intervene between the outermost portion of the external coat, or *tunica adventitia*, of the artery, and the perineurium of the latter.

Properly-stained horizontal sections of pulps reveal in a most beautiful manner both the approximate number of blood vessels and also their differences in structure. In typical canine pulps, cut crosswise through the cervical region, the author has counted 10 of the former. The typical veins, several of which were just macroscopically visible, exceeded this number by 14, while the capillaries were practically countless.[1]

Histologically considered, the vessels of the pulp differ very considerably.

The Arterioles.—Structure.—The wall of each small artery consists of three coats, viz., the *tunicæ intima, media* and *adventitia,* the first-named being indistinguishable, except under high magnifications, and the *media* being very marked.

(i) *Tunica intima.*—Here are found, forming the lining of the lumen of the vessel, a flattened layer of thin, singularly elliptical epithelial cells (endothelium), each having a round or oval nucleus. When the blood corpuscles have not been retained *in situ* in the section, the cells may be sometimes seen to project into the lumina. External to the endothelial lining is an attenuated double wavy line, continuously circling the artery. This is known as the elastic layer of the inner coat, and it is made up of numerous longitudinal, closely-arranged yellow elastic fibres. (ii) The *Tunica media* is composed entirely of plain muscular tissue, which makes this coat the thickest and most prominent of all. It is arranged circularly round the vessel, and its component parts are made up of unstriped muscle fibres with elongated nuclei. The elastic tissue of the larger arteries is wanting

[1] These figures are introduced in this connection, in order to supply the reader with some idea as to the numbers that may be computed, *i.e.*, to demonstrate that the arteries of the pulp are not counted in hundreds, but in tens. It is obvious that the numbers given are never constant.

in this coat in the vessels of the pulp. (iii) The *Tunica adventitia*, consisting of areolar or connective tissue fibres and corpuscles, with nuclei placed in the long axes of the cells, represents the outer coat of the artery. These fibres and cells, too, run circularly round the vessels and blend intimately with the connective tissue fibres of the pulp.

The Veins differ from the arteries in the fact that the size of the middle coat is greatly reduced, and the endothelial cells are shorter and broader. Otherwise they resemble the arteries. In sections, they are easily differentiated from the other blood-vessels in having a very much greater diameter. They are non-collapsible in the pulp, and retain the rounded outlines of their walls. This is doubtless due to their strong support by means of the stroma which permeates the pulp tissue.

The walls of the *capillaries* are exceedingly delicate, being formed by a single layer of endothelium, which is a continuation of the endothelial lining of the arteries, on the one side, and the veins on the other. The smallest capillary walls may consist of only two or three of such cells, which, in this case, are curved to form the interior of the tube. The nuclei are marked and the chromoplasm pronounced. (See Fig. 117).

There are no traces of any lymphatics in the dental pulp. Yet Bödecker (*op. cit.* p. 251), says that he has seen vessels "composed of large, flat, slightly protruding endothelia," and containing "a finely-granular coagulated albumen, scanty granular corpuscles, and a very limited number of blood corpuscles."

D

The Nervous System

As eliciting the closest attention on the part of many thinkers and writers, as presenting a truly fascinating and profoundly interesting field of speculation, as affording ample opportunities for most brilliant work in original research the study of the nervous system of the dental pulp may claim to be, of all dental histological subjects, of the first importance, instruction, and value. One is completely astonished at the mass of literature, old and new, which has been devoted to it. Its bibliography is manifold, and in itself would furnish, if gathered in one volume, most illuminating reading. Yet in spite of the earnest labours of one half-a-century, it is amazing to recall the fact that while so much is known about

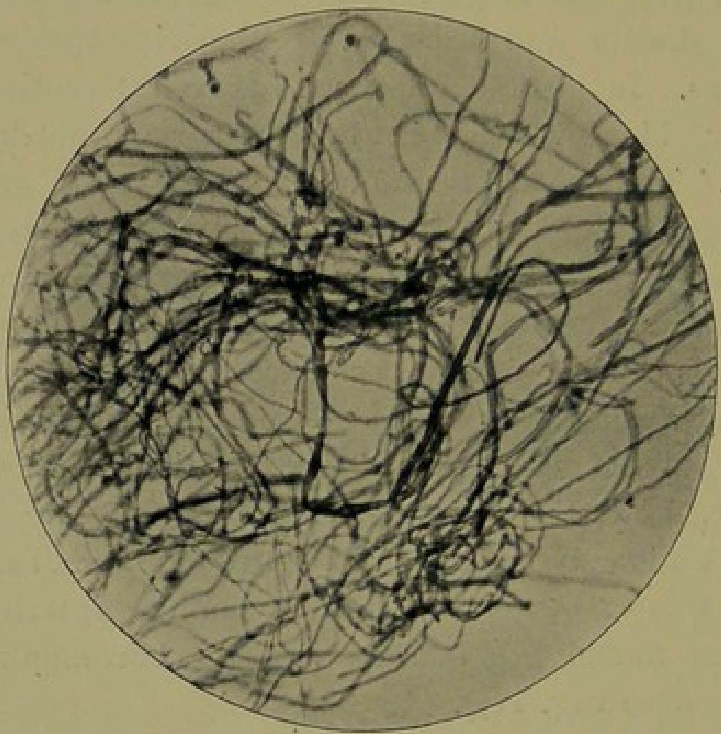


Fig. 119.—The plexus of Raschkow, teased out, and stained with chloride of gold. Magnified 250 times.

it, so much is still unknown—the actual methods of the peripheral distribution of the non-medullated nerves being buried in obscurity. True, that some of the earlier histologists solved most carefully *in suo modo* this particular and difficult problem; true, that modern methods of preparing the hard and soft tissues for microscopical examination have shed new light on it; it still remains to be noted that the anatomical data and physiological principles involved in the phenomena which give rise to pain in the teeth—the whole innervation of the pulp—the direct course by which nervous stimuli are conducted from the dentine or enamel to the sensory areas of the brain cannot be considered satisfactorily determined. But its capability of solution is unquestionable.

Here an attempt will be made to describe the chief recognised facts, and some arguments in this nebulous matter; and it will be convenient to consider these under the following headings:—The medullated nerves, their (i) method

Fig. 120.—Similar to Fig. 117. To shew six nerve bundles cut transversely. Prepared by the Author's process. Stained with rubine. Magnified 750 times. C.T.C. Connective tissue fibres and corpuscles. C. Capillary; M. One of the medullated nerve bundles.

of distribution, (ii) structure, and (iii) terminations in (a) fishes, (b) reptiles, (c) mammals.

(i) *Method of Distribution.*—Emerging from the "indifferent tissue" of the periodontal membrane, in company with the main arterial trunks, and entering the apical foramina of the teeth, the bundles of medullated nerves pass collectively into the pulp, in lines directly corresponding to its long axis. There are thus several funiculi colligated into sheaves; and without undergoing much appreciable diminution in numbers, they extend into the soft tissue, and maintain a more or less parallel direction with the outlines of the dentinal walls. The nervous trunks pass, like long, straight or very slightly wavy lines, in this way, for some considerable distance, and then begin gradually, as they approach the parieties of the pulp, to break up into smaller fasciculi; until, when close to the basal layer of Weil, the original bundles are represented only by two or more nerve fibres running side by side. In many instances, the bundles stretch up to the sub-odontoblast region, and then very suddenly burst forth in myriads of minute scopiform strands. (Röse and Gysi, "Portfolio of Microphotographs of Dental Histology," 1895). The result is the formation of an interlacing of fibres—the plexus of Raschkow. (See Fig. 119).

In every case the chief nerve fasciculi run alongside the larger blood-vessels, and in their areas of distribution follow them closely.

Towards their distal arborisation they become in places lobulated or varicose, a condition which, according to Schäfer[1], is occasioned by pressure or traction on them, causing the soft matter "to accumulate at certain points, whilst it is drawn out and attenuated at others." In addition to these occasional dilatations, and near their peripheral distribution they divide into branches—each component part participating in the division. By oft-repeated sub-division the fibres become much smaller.

(ii) In *structure*, the medullated or white nerve fibres differ not from those found elsewhere in the cerebro-spinal system of man, except in one particular, and that is with regard to size. The individual fibres in the pulp vary from 1.5μ to 3μ in diameter. Kölliker has measured them. His figures are:—In diameter, the large trunks in the radicular part

1 "Quain's Anatomy," Vol. I., part II., p. 309, 1898.

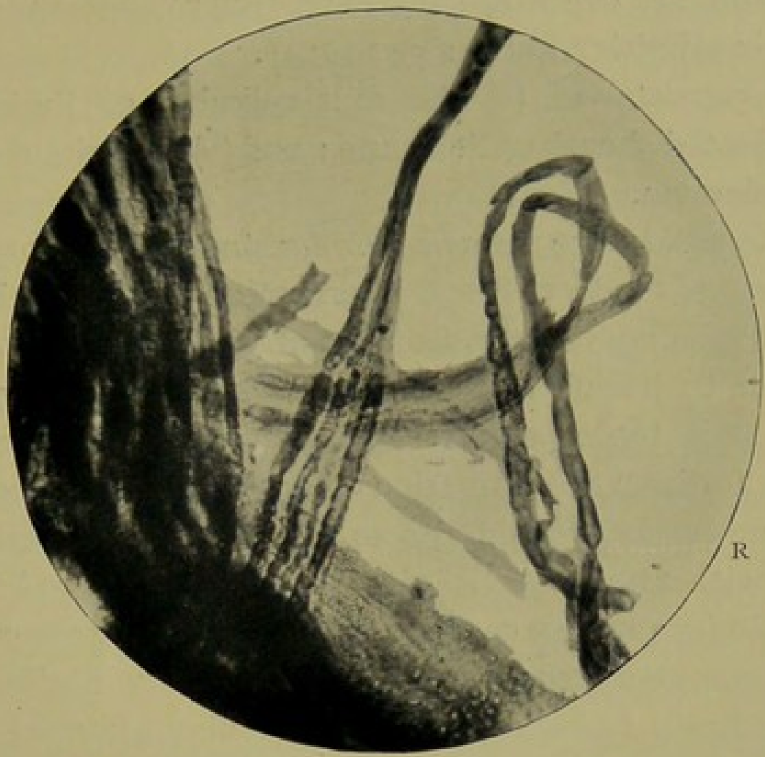


Fig. 121.—Medullated nerve fibres, teased out. Stained with osmic acid. Magnified 850 times. R, A node of Ranvier.

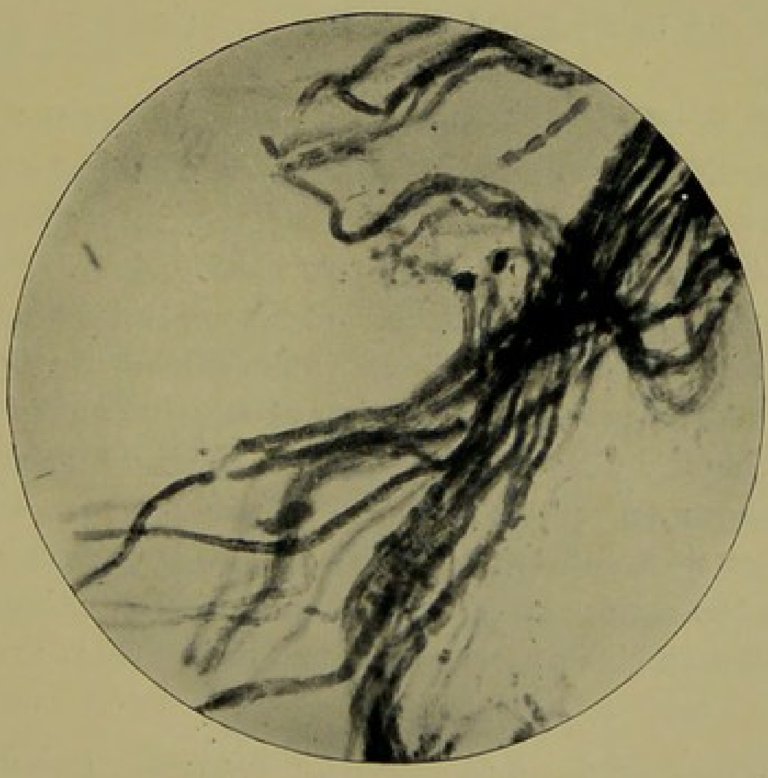


Fig. 122.—Similar to the preceding. Magnified 800 times.

of the pulp, are 62μ to 8μ; their constituent elements 3μ to 6μ; and their primitive fibres 2.5μ to 3.4μ.

Each consists of (α) the axis-cylinder of Purkinje; (β) the nucleated sheath of Schwann; and (γ) the primitive sheath or neurolemma.

(α) The axial fibre, or *axis-cylinder process*, or more shortly the *axon*, extends without interruption through the whole length of the nerve fibre, from its origin in the neurone in the cerebrum to its ultimate ramifications near the *membrana eboris*. It is to-day an almost certain fact that the axon is always a direct prolongation of a branch of a nerve cell, extending far away from its origin, but yet in perfect continuity with it. Max Schultze in 1837[1] observed that the axis-cylinder process consists not of a single cord or thread, but is a complex structure made up of many fibrils ("primitive fibrillæ") imbedded in fine granular material. Obersteiner told Gowers that he had counted as many as fifty such primitive fibrils in a single axis-cylinder, each fibril having a separate and distinct path of conduction. The writer has never seen these in the medullated nerves of the pulp; but there can be no doubt that they exist here in far fewer numbers.

(β) *The myelin sheath*, or white substance of Schwann, is easily identified in sections of the pulp when stained with osmic acid, the action of which is to render the fatty phosphorous matter of the myelin a dark grey or black colour.

The medulla is continuous, but presents here and there breaks in its continuity. These constrictions are known as the nodes of Ranvier. Occurring at nearly equal intervals, they divide the fibre into internodes. The white substance has undergone a certain amount of shrinkage at a node, and is quite transparent, but in addition there is present a finely granular stroma rendered evident through refraction by the fatty matters which are usually found in it. (Fig. 121).

[1] *Vide* Stricker's "Histology."

"The neurone and its relation to disease." *British Med. Journal*, Nov. 6th, 1897.

The nodes of Ranvier, when treated with various stains, exhibit other markings. In this way, a weak solution of silver nitrate reveals the crosses of Ranvier—in which the cement joining two internodes, and a small portion of the axon are affected, and also sometimes Fromman's lines—a cross-striation of the axon at the node; and a 1 per cent. solution of osmic acid, minute nodes on the primitive fibrils of the axon, with the black constricting ring of Ranvier placed outside (van Gedoelst).

Further subdivisions in the medullary sheath are found in the form of oblique slits passing outwards from the axon to the neurolemma. These are called "incisures," and are rendered apparent by the use of osmic acid and picro-carmine. They split up the internodal myelin into a series of short lengths or "cylinder cones," the bevelled end of one cone fitting accurately into the opposite similar end of the neighbouring cone.

In addition to these various histological structures in the medullated sheath of nerves, there exist also, when suitably stained, radial virgate striations, as well as a more-or-less-coarse reticulum.

(γ) *The primitive sheath or neurolemma* forms the external covering of white nerve fibres. It is an exceedingly delicate homogeneous membrane which passes over every node of Ranvier, and possesses in the mid-distance of an internode a large flat nucleus. At the node, the neurolemma is discontinuous with the axon, because of the intervention of the annular constricting band of Ranvier.

A horizontal section of the pulp stained carefully with osmic acid or hæmatoxylene or other stains displays the nerve bundles cut across. Collectively examined they show the endoneurium—fine connective tissue septa passing in between the individual nerve fibres, as processes of the perineurium which surrounds the fascicule itself. In the finest branches the latter is reduced to a mere connective tissue sheath.

(iv) *Peripheral Terminations of the Nerves*

In order to pave the way to some knowledge of the anatomical distribution of the free extremities of the nerve fibres in the dental pulps of man, it will be expedient and instructive to note how the nerves end in the pulps of the teeth of fishes, reptiles, &c.

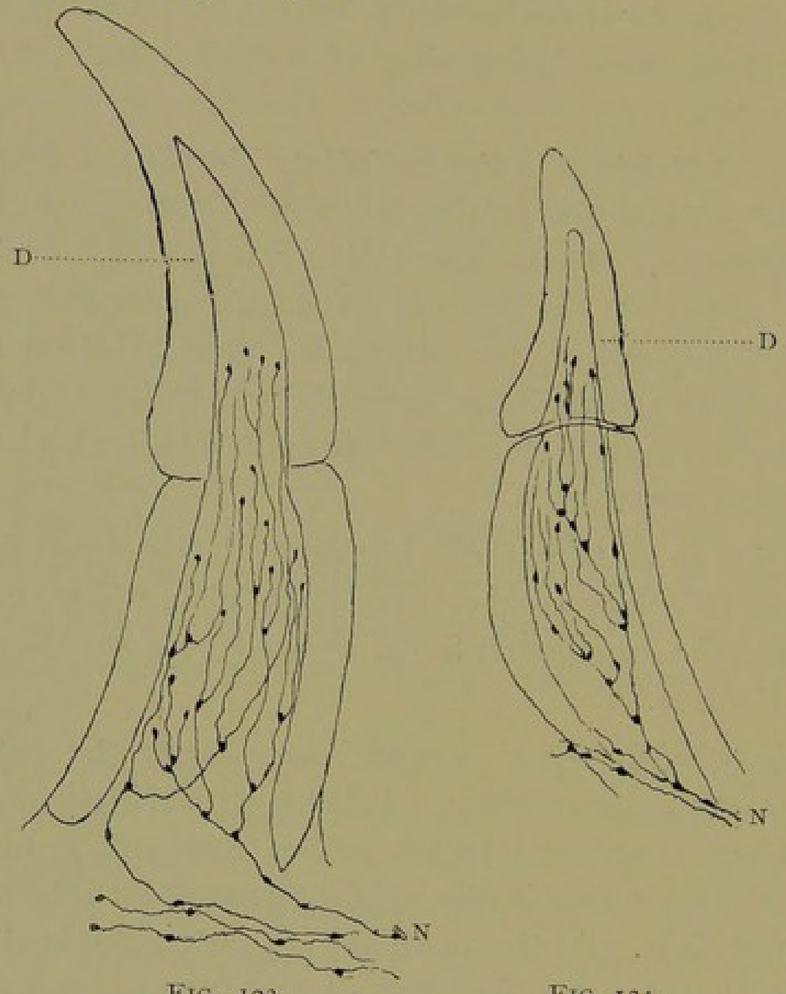


FIG. 123. FIG. 124.

Figs. 123 and 124.—Longitudinal sections of the teeth of *Gobius*. Golgi's stain. D. Dentine; N. Non-medullated nerve fibres, ending in free terminations, close under the dentine. After Retzius.

(a) *In Pisces*

Here the evidences as to the exact mode of the terminal arborization of the sensory nerve fibres are quite clear, thanks to the splendid labours of Gustav Retzius.[1] By Golgi's method of staining, he succeeded in positively demonstrating

[1] Biologische Untersuchungen," Neue Folge, iv., v. and vi., 1892, 1893, and 1894.

in the teeth of *Gobius* and *Gasterosteus*, anatomical conditions which agree in all essential points. Definite types of nerve-branching were observed.

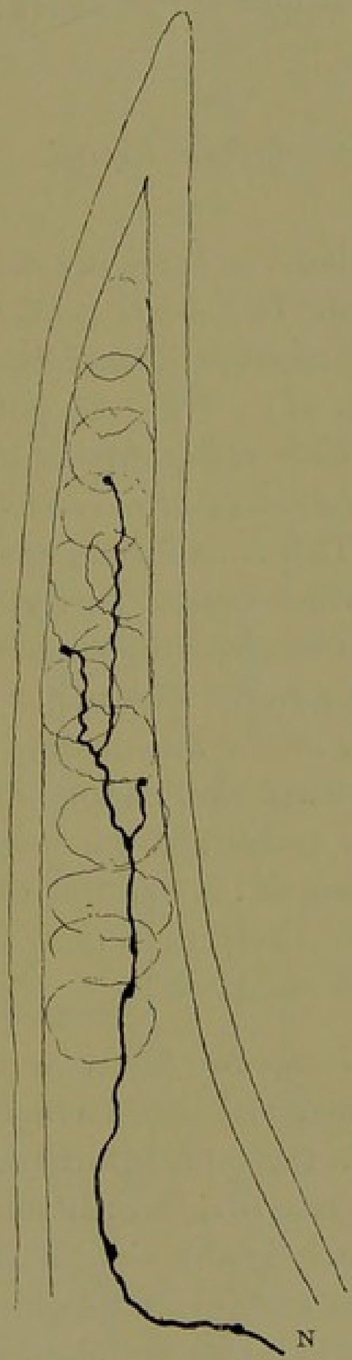


Fig. 125.—Longitudinal section of tooth of a larva of the *Salamander maculata*. Golgi's stain. N. Non-medullated nerve fibre. After Retzius.

The non-medullated nerve fibres arising from a dense plexus in the soft tissues in which the teeth are situated, pass into the pulp and spread out thickly to form free endings in that tissue, extending upwards towards the coronal region, and abundantly giving off lateral branches with free terminations. The extreme cornu of the pulp is not supplied with nerves. (For illustrations of this condition see Figs. 123 and 124).

(β) *In Reptilia*

Retzius was able here, to trace the nerves quite easily, still using Golgi's method. In *Lacerta agilis* he describes them as rising, in the first place, from the middle of the pulp. He writes (pp. 65 and 66, Vol. iv). "In the pulp may be seen the connective tissue which also contains blood-vessels, a black thread apparently consisting of nerve-fibres matted or closely pressed together. This thread rises upwards, and gradually gives off branches which extend partly towards the side, and partly upwards. These enter the odontoblast layer, and pass between the cells, as a rule, to the upper surface of the pulp, there to end directly under the dentine in free extremities, which here and there are swollen into knots. In transverse section these fibres penetrate the odontoblast layer, and reach the inner surface of the dentine, there to end free after a short ramification. The penetration of nerve fibres into the dentine was nowhere observed."

The larvæ of *Salamander Maculata* and *Triton Cristatus* provided suitable material for further tracing the non-medullated fibres. In these preparations, after their entrance into the pulp, the nerves divide dichotomously, and, branching upwards, end partly in the side of the pulp tissue, and partly close under the surface of dentine. The fine varicose branchlets rise about half-way up the tooth, but never pass to the upper end of the pulp (p. 41, Vol v.). "All branches end freely, spreading out in different parts of the pulp. Most of them apparently end close under the dentine or near its inner surface, but never penetrate into its substance or into its canals."

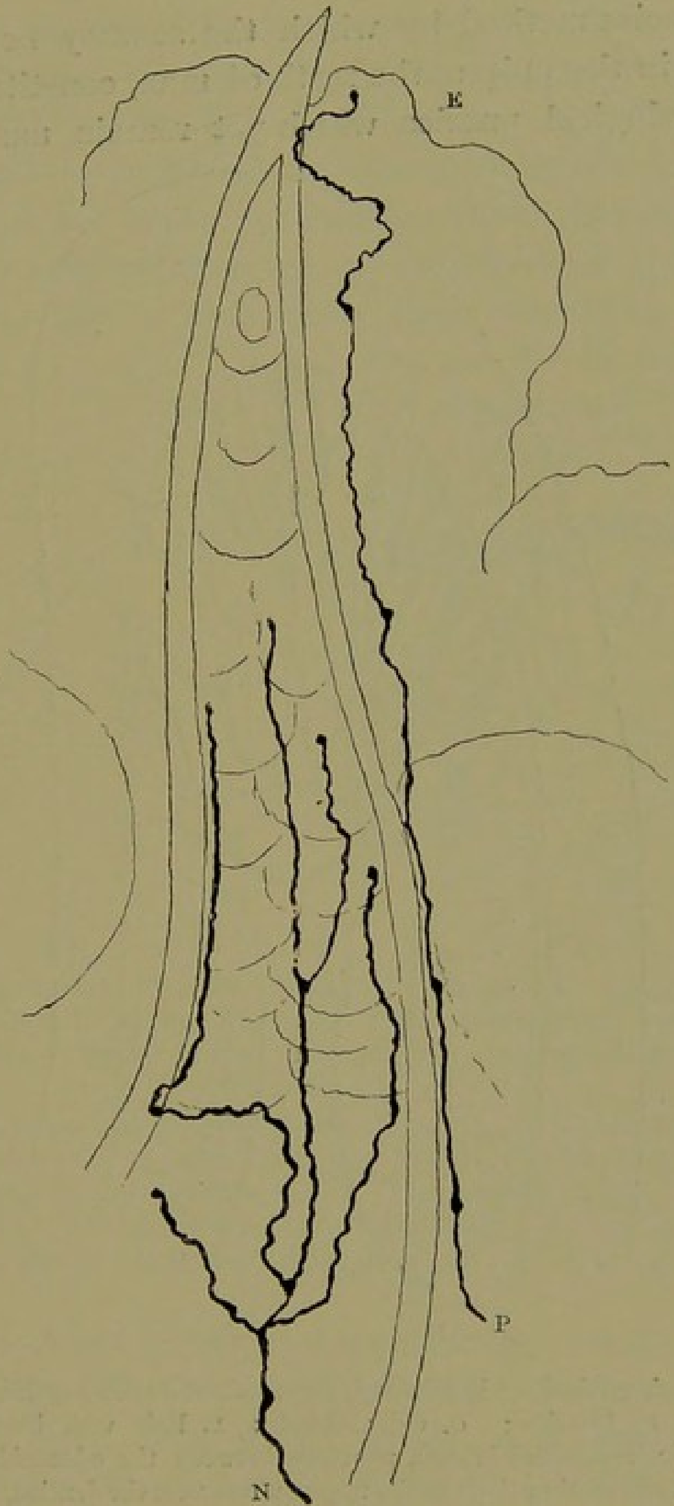


Fig. 126.—Tooth of larva of *Salamander maculata* with the surrounding oral mucous membrane. Golgi's stain. N. Non-medullated nerve fibre, branching and ending free in the pulp; P. Nerve fibre in the peridental tissues, ending free in E. the surface epithelium. After Retzius.

(γ) *In Mammalia*

The precise method by which the sensory nerves finally terminate in the pulp of the teeth of man, constitutes one of those histological puzzles which yet remain unsolved; and

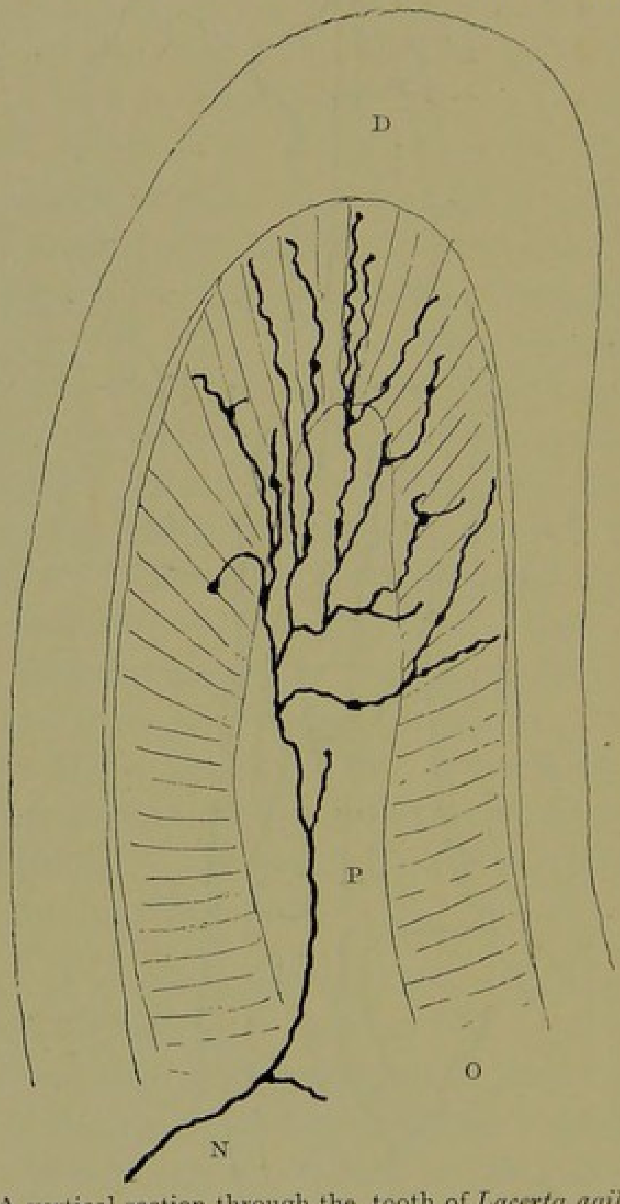


Fig. 127.—A vertical section through the tooth of *Lacerta agilis*. Golgi's stain. D. Dentine; O. Odontoblasts; P. Pulp with blood vessels and N. nerves which branch, penetrate between the odontoblasts, continue their ramifications to the upper surface near the dentine, and there terminate. After Retzius.

at the time of writing, it is absolutely impossible to give a clear and proved solution. As has already been hinted, the subject is too vast to do more than mention the chief modern theories connected with it.

1. In the teeth of *young mice*, Retzius in 1894 (*op. cit.* Vol. vi. p. 64) succeeded in staining the nerve fibres, not only everywhere in the pulp, from the beginning, near the blood-vessels, but also in tracing their branches into the odontoblast zone, and between these cells to the under surface of the dentine. "In vertical sections the fibres, like a string of tiny beads, stretch between the odontoblasts to the surface and there end free." They often bend round on reaching

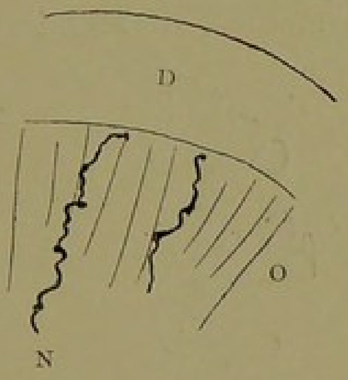


FIG. 128.

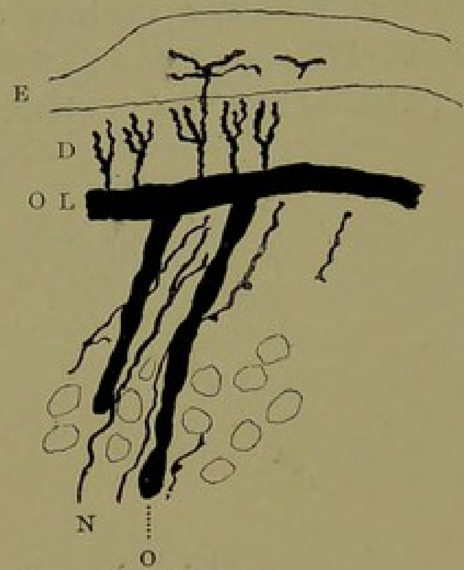


FIG. 129.

Fig. 128.—Transverse section of tooth of *Lacerta agilis*. Golgi's stain. D. Dentine; O. Odontoblast layer; N. Nerve fibre which passes free to the upper surface of the odontoblast layer and there terminates. After Retzius.

Fig. 129.—Vertical section of the upper part of a young tooth of a mouse five days after birth. Golgi's stain. E. Enamel with the ends of the dentinal tubes projecting into it; D. Dentine with stained dentinal tubes; O.L. Odontogenetic zone; O. Odontoblast; N. Non-medullated nerve fibre passing between the odontoblasts. After Retzius.

the surface, and run a little way tangentially. In a tangential section they can be partially traced under the dentine."

2. Franz Boll,[1] over thirty years ago, observed fine fibres (which he thought were nerves), by means of $\frac{1}{10}$ per cent. solution of chromic acid, in the pulps of *rabbits* and *guinea-pigs*. He used the persistently-growing teeth. He traced them to places between the odontoblasts, and

[1] "Untersuchungen über der Zahnpulpa." *Archiv. für Mikroskop. Anatomie.* Vol. iv., p. 73, 1868.

even between the dentinal processes of the odontoblasts which had been detached from the dentine. Thus he believed that the nerve fibres extend into the dentinal tubules. The nature of the fibres first described by Boll was not at all certain, and did not present the gemmules or beads which Golgi's and methylene-blue methods of staining depict upon the axons.

3. Carl Huber[1], of the University of Michigan, made use of the mandibular canines and molars of *dogs, cats,* and *rabbits.* His most satisfactory results were obtained from the pulps of rabbits' molars. The method of staining he

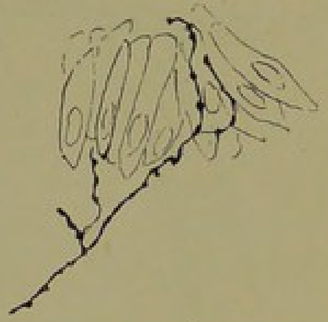


FIG. 130.

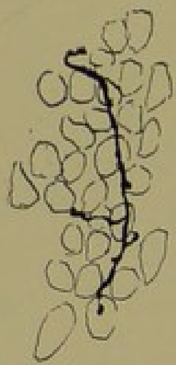


FIG. 131.

Fig. 130.—Vertical aspect of odontoblasts having between them two ultimate branches of a fine varicose nerve-fibril. From the pulp of a molar tooth of a rabbit. Prepared by staining with methylene blue fixing in ammonium molybdate and mounting in balsam. After Huber.

Fig. 131.—Similar to the preceding figure. Odontoblasts seen end on. The nerve termination lies over the cells. After Huber.

employed was 1 per cent. methylene blue in physiological salt solution injected into the common carotid during life. He describes the following interesting histological revelations :—" The medullated nerve fibres approach the lower portion of the pulp in one or several relatively large nerve bundles. On reaching the lower surface of the pulps, these larger bundles break up into numerous smaller ones, the latter consisting of eight to ten nerve fibres, although larger ones are frequently met with. In the fibrous tissue membrane which covers the under surface

[1] " The Innervation of the Tooth-pulp." *The Dental Cosmos,* vol. xl., pp. 803, *et seq.,* 1898.

of the pulp, and which is continuous with the periodontal membrane, these smaller nerve bundles form, as the result of frequent anastomoses, a plexus of medullated fibres. . . The smaller bundles of medullated nerves, coming off from the plexus, pass nearly perpendicularly up into the pulp, into

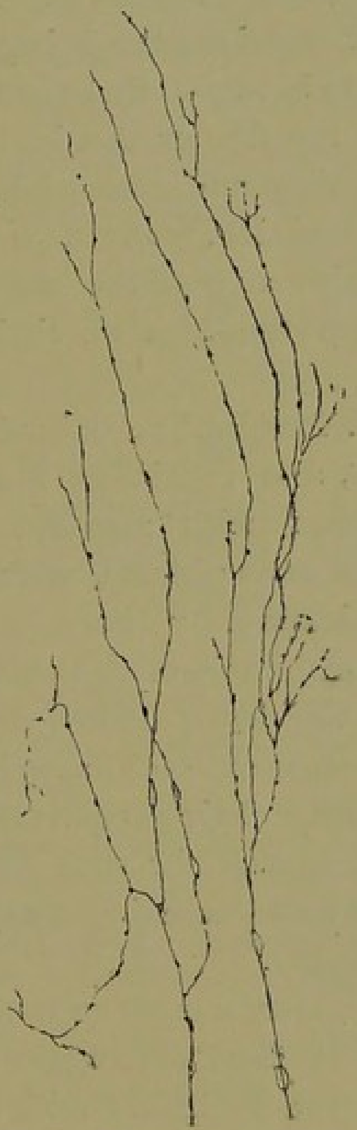


Fig. 132.—Non-medullated terminations of the nerves in the dental pulp of a dog. Stained with methylene blue. After Huber.

which they may be traced as small bundles of medullated nerves, two to eight or ten in number, to all levels of the pulps, some to the very tip. . . . On approaching the surface of the pulp, the medullated fibres lose their medullary sheath : the non-medullated terminal branches, after repeated division, form a plexus immediately under the odontoblasts.

They branch and re-branch into long, delicate varicose fibres." This plexus is that of Boll, and Raschkow, and others, but according to Huber, it is "a plexus only in so far that the varicose fibrils cross each other in various directions."

Huber's observations on the ultimate termination of the nerves corroborate those of Retzius. The fibrils given off from the plexus just mentioned as being present beneath the odontoblasts, pass up between these cells, and end, as fine beads, usually near the free or dentinal end of the odontoblasts. Sometimes they run tangentially. Huber says that they do not, in his opinion, make any connection with the odontoblasts, nor with any of the cellular elements of the pulp: and he scouts the idea of their entrance into the dentine.

4. Legros and E. Magitot[1] examined the dental pulps of the *calf*, *dog and cat*, and concluded that the terminal filaments are continuous with ramified cells, situated immediately below the odontoblasts, with which they are in immediate communication. "There is thus," according to these authors, "a direct chain of sensation transmitted from the nerve-ending to the dentinal fibril *viâ* the branched cells, and the basal processes of the odontoblasts, the bodies of these latter and finally their peripheral poles." (Fig. 137).

The most careful search for such cells in the pulps of *Herbivora* and *Carnivora* (including man) has been attended only by negative results.

5. Oscar Römer[2], after a great deal of labour and experiment, and following on the lines suggested by Morgenstern, used the teeth of three-weeks-old *kittens*, and adopted the intra-vitam methylene-blue stain. He enunciated the following, *inter alia*:—

(i) The nerves of the pulp penetrate, as non-medullated filaments, the spaces which intervene between the odontoblasts, reach the zone between

[1] "Morphologie des follicle dentaire chez les Mammiferes." *Journal de l'Anatomie et Physiologie*, 1879.

[2] *Loc. cit.*

these cells and the dentine, and here pass into the interior of the odontoblast processes, that is to say, in Kölliker's dentinal tubules.

(ii) The chief mass of the nerve filaments radiate out of the cornua of the pulp into the dentine; while the other zones of the dentine of the crown appear to be poorer in nerve branches, and the dentine of the root entirely nerve-less.

(iii) A greater part of the dentinal tubules widen out at the enamel-dentine boundary, into curious

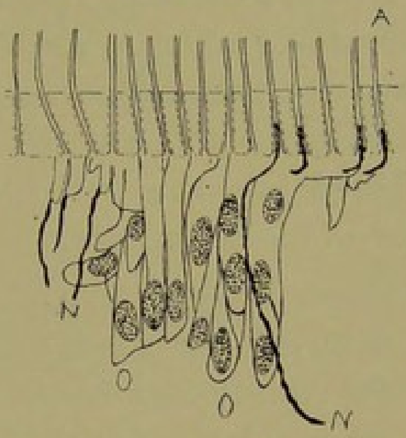


Fig. 133.—Diagram of a section through the tooth-germ of a kitten, three weeks after birth. Prepared by the Intra-vitam method of staining with methylene blue; fixing in ammonium molybdate, formalin, and subchloride of platinum; decalcifying in acetic acid, and embedding in celloidin. Shews Römer's conception of the passing of the non-medullated nerve fibres into the dentinal tubules. A. Dentinal tubes; O. Odontoblasts; N. Fine nerve fibril going upwards out of the pulp, between the odontoblasts to the dentinal tubules in the dentogenetic zone. After Römer. *Cf.* Figs. 54 and 140.

partly spindle-shaped, partly club-shaped formations which are chiefly arranged in very great numbers around the apices of the dentinal cusps, and in which, in well-preserved sections, small roundish or larger oval corpuscles are perceptible, which are often arranged in rosary-like rows, and, with gold chloride, take an intense stain; and

(iv) The small corpuscles in the interior of the spindle-shaped enlargements of the dentinal tubes may be regarded, with great probability, as terminal corpuscles of sensitive nerves in the dentine, analogous to the terminal corpuscles of the sensory nerves of the skin and the papillæ of mucous membranes.

This author, representing the latest researcher in the subject (1899), out of forty-seven drawings in his monograph gives, however, only two figures depicting the passage of nerves into the dentinal tubules. One is magnified 250 times, and the other an amplification of the first, 750 times (*vide* Tafel iv., Figs. 16 and 17). In spite of their measurements, (0.25μ to 0.3μ), of Römer's indefatigable zeal, his earnestness and his precautions, the author is unable to agree with the interpretation placed upon the appearances presented by the sections, and must distrust the drawings accompanying the text, being thus forced into the belief that the Strassburg professor is in error in his deductions.

6. Aitchison Robertson (*op. cit.* p. 823) in the pulps of the *ox*, when treated with 0.6 per cent. solution of potassium anhydrochromate for twenty-four hours, found long central processes to the odontoblasts, which he believed became continuous with the nerve-fibrils. He says (p. 324), "The long central process seems to become the axis-cylinder of a nerve fibre which gradually acquires a primitive sheath, in which the medullary or white substance slowly accumulates till an ordinary medullated nerve results." His drawings, reproduced in Figs. 115 and 116, unfortunately convey nothing to the enquiring mind, and certainly if they are correct, his assumption is still unproved.

7. Kölliker in 1860 (*op. cit.* p. 300) in the teeth of *man*, observed that the primitive fibres, which are given off from a rich plexus, "form very evident loops," but he did not consider them the ultimate terminations.

8. In specimens of full-term fœtuses, presumably *Human*, Bödecker[1] using gold chloride, positively asserts "that an indirect connection of the two" (dentinal fibrils and nerve

[1] "The Anatomy and Pathology of the Teeth," 1894.

endings) "is established by the intervening reticulum of living matter."

It must not be forgotten, however, that this author believes that the dentinal fibrils arise *between* the odontoblasts, whose rôle it is to furnish the basis-substance of the dentine. But

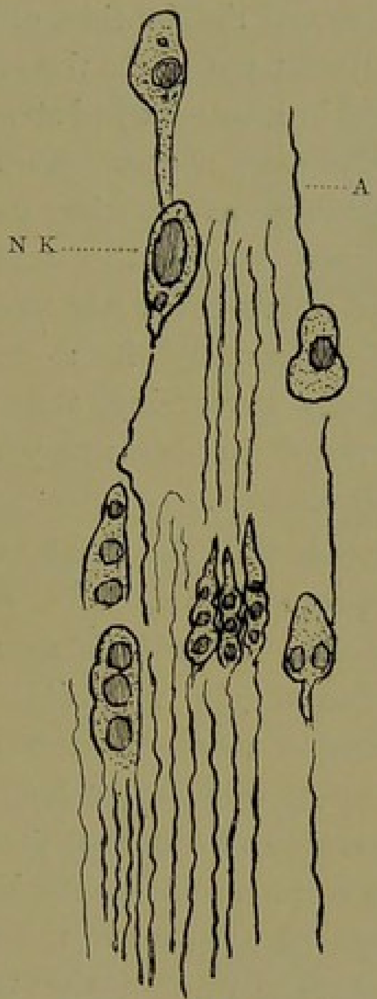


FIG. 134.

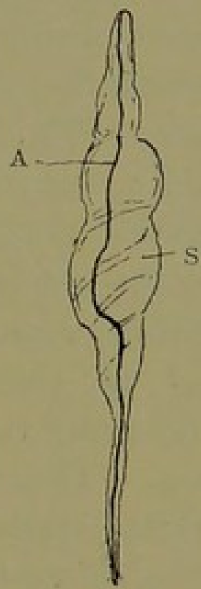


FIG. 135.

Fig. 134.—Longitudinal section of the dentine of a young Human tooth. Stained with osmic acid. A. Axon; N.K. Nerve corpuscle. After Morgenstern.

Fig. 135.—Nerve ending in enamel of a young tooth. S. Nerve corpuscle; A. Axon. After Morgenstern.

this, as well as many other matters of which Bödecker has written, must be accepted with the greatest caution. His views are so heterodox, and do not conform in any degree with the accepted hypotheses and observations of a great number of reputed histologists of various nationalities.

9. Morgenstern[1] describes in the teeth of *man*, bundles of axis-cylinders surrounded by their medullary sheath passing into the dentine or enamel. In the former tissue they traverse tubules, some of which are smaller and others larger than the ordinary tubules. Each canal has in it two axons, and they terminate either (i) at the cortex of the dentine, or (ii) at the amelo-dentinal junction, or (iii) even pass into the enamel. In the first-named locality they end in knob-shaped structures which may be ellipsoid or pyriform in shape. (Fig. 134). In enamel they may end variously, as in the dentine, in elongated nucleated structures where the axon (α) passes through the entire so-called nerve-corpuscle to end at its periphery (Fig. 135), (β) terminate on a nucleus of the said nerve-corpuscle, or (γ) traversing the entire nerve corpuscle, may wind itself round one or many nuclei, and end on the last or furthermost nucleus.

His chief argument lies in the fact of the black colouration found in Golgi-stained preparations, and he has adduced no proof that what he has described as nerves *are* nerves. Thus he writes (page 383 *op. cit.*) "The nerves which appear in the dentine when treated by the silver method, show black filaments of very varied length and thickness. Their intense black colour, and different peculiarities—characteristic of nerves—leave no doubt of the identity of these fibres with nerve filaments. In regard to the wealth or number of nerves, probably no one part of the tooth is materially distinguished from another. There is, however, probably a distinction in regard to the mode of their division and termination. It is the dentinal canaliculi which for the most part contain the longer nerve filaments: there occur, however, many more nerve filaments than are in the dentinal canaliculi proper, which run between these, and in the same direction, in approximately the same direction, and in quite a different direction. The same direction as that of the

[1] "Uber das Vorkommer von Nerven in der hartern Zahnsubstanazen." *Deutsche Monat. für Zahnheilkunde*, p. 436, 1892; also *Deutsche Monat. für Zahnheilkunde*, p. 111, 1895.

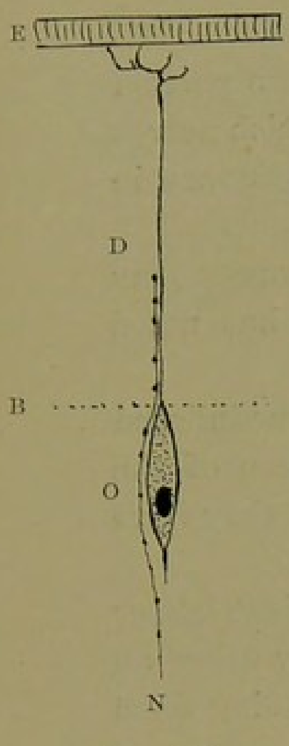


FIG. 136.

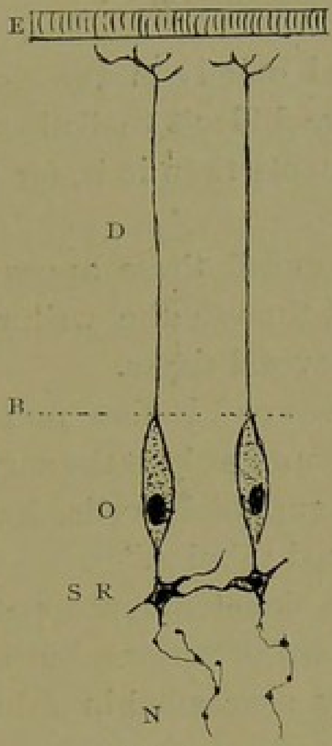


FIG. 137.

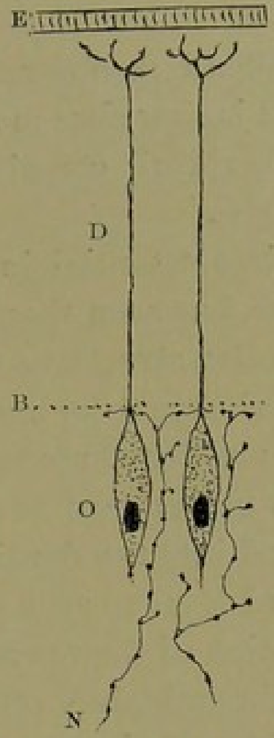


FIG. 138.

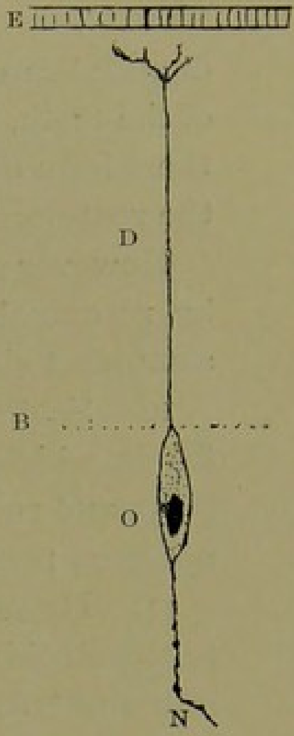


FIG. 139.

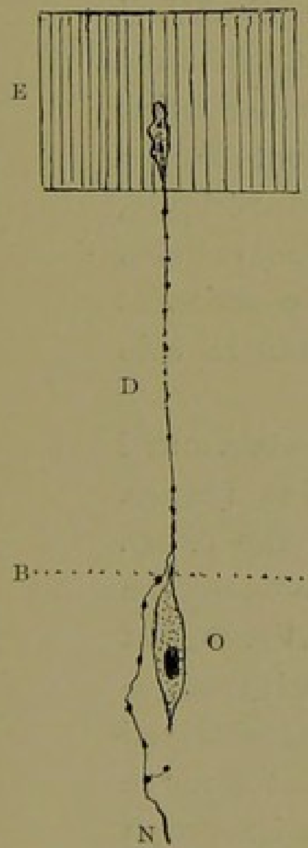


FIG. 140.

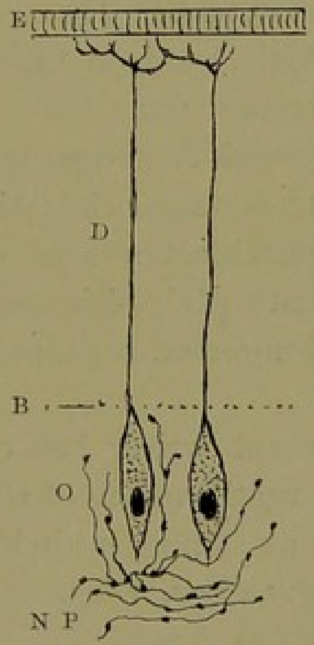


FIG. 141.

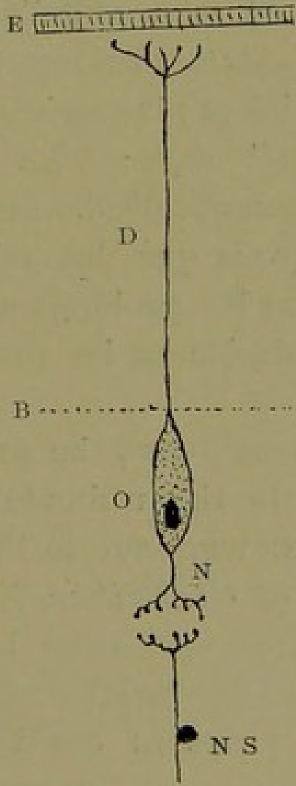


FIG. 142.

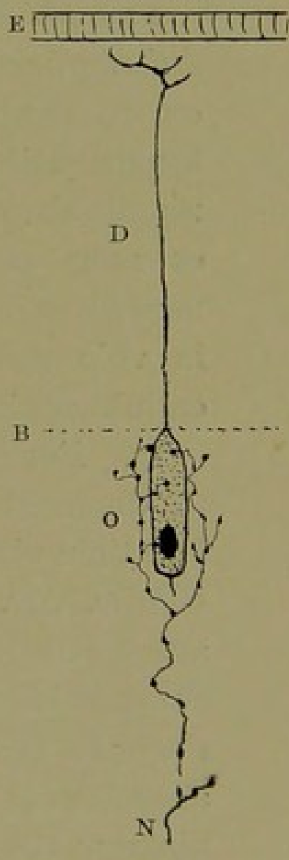


FIG. 143.

Figs. 136 to 143.—To shew in a diagrammatic manner the various conceptions as to the method of termination of the non-medullated nerve fibres in the pulp. Fig. 136, according to Boll; Fig. 137, according to Magitot; Fig. 138, according to Retzius; Fig. 139, according to Aitchison Robertson; Fig. 140, according to Römer; Fig. 141, according to Huber; Fig. 142, according to Pont; and Fig. 143, according to the author. E. Enamel; D. Dentine; B. Limit of pulp tissue; O. Odontoblast; N. Non-medullated nerve fibre termination; N.S. Neuron in spinal cord; S.R. Stellate cells connected with the odontoblasts. N.P. Nerve plexus of non-medullated fibrils.

dentinal canaliculi is observed chiefly in the crown portion of the teeth, it is therefore more difficult to distinguish nerves there from other fibril constituents than it is, for instance, in the root portions."

However circumstantial in detail these appearances may be, no one else has seen them, though the writer has noted somewhat similar structures several times.

10. Schäfer[1] says "the nerves end in fine non-medullated fibrils, which are distributed abundantly at the surface of the pulp, and run up between the superficial cells, but they have not been traced into the dentinal tubules."

11. Howard Mummery has devoted much patient labour to the elucidation of the nerve arborisations, but by using an iron and tannin stain, has only succeeded in following them to the odontoblast region.

12. M. Pont in a contribution to the *Trans. of the III.rd. International Dental Congress,* Paris, 1900, on "La cataphorése en art dentaire et plus spécialement dans les cas de dentine hypersensible" says: "La description des odontoblastes rapelle absolument celle des neurones sensoriels périphériques, et nous croyons que les odontoblastes sont des cellules nerveuses dont les prolongements périphériques constituent la voie cellulipète et les prolongements pulpaires la voie cellulifuge."

13. For many years, the present writer has endeavoured to demonstrate the ultimate ramification of these nerves. His then views were set forth at some length in the *Trans. Odonto. Soc. of Gt. Britain*, November, 1893. Some of the arguments are reproduced in the Appendix. Since that communication appeared, he has still confined his investigations to the pulps of the teeth of man, and has obtained abundant evidences of the presence of non-medullated nerve fibres at the periphery of the pulp. The photomicrograph Fig. 119 represents a teased preparation of the medullated fibres, which go to form a component part of the plexus of Raschkow. It was made thus:—A recent tooth, unaffected

[1] "Quain's Anatomy," vol. III., part iv., p. 31. 1896.

in any way by morbid influences, on being carefully split in the jaws of a vice, is found to have covering the inner surface of the dentine a moist, colourless, almost invisible film. Removal of this and staining with suitable reagents revealed a tangled mass of medullated nerve fibres. The staining reagents used were not especially appropriate for non-

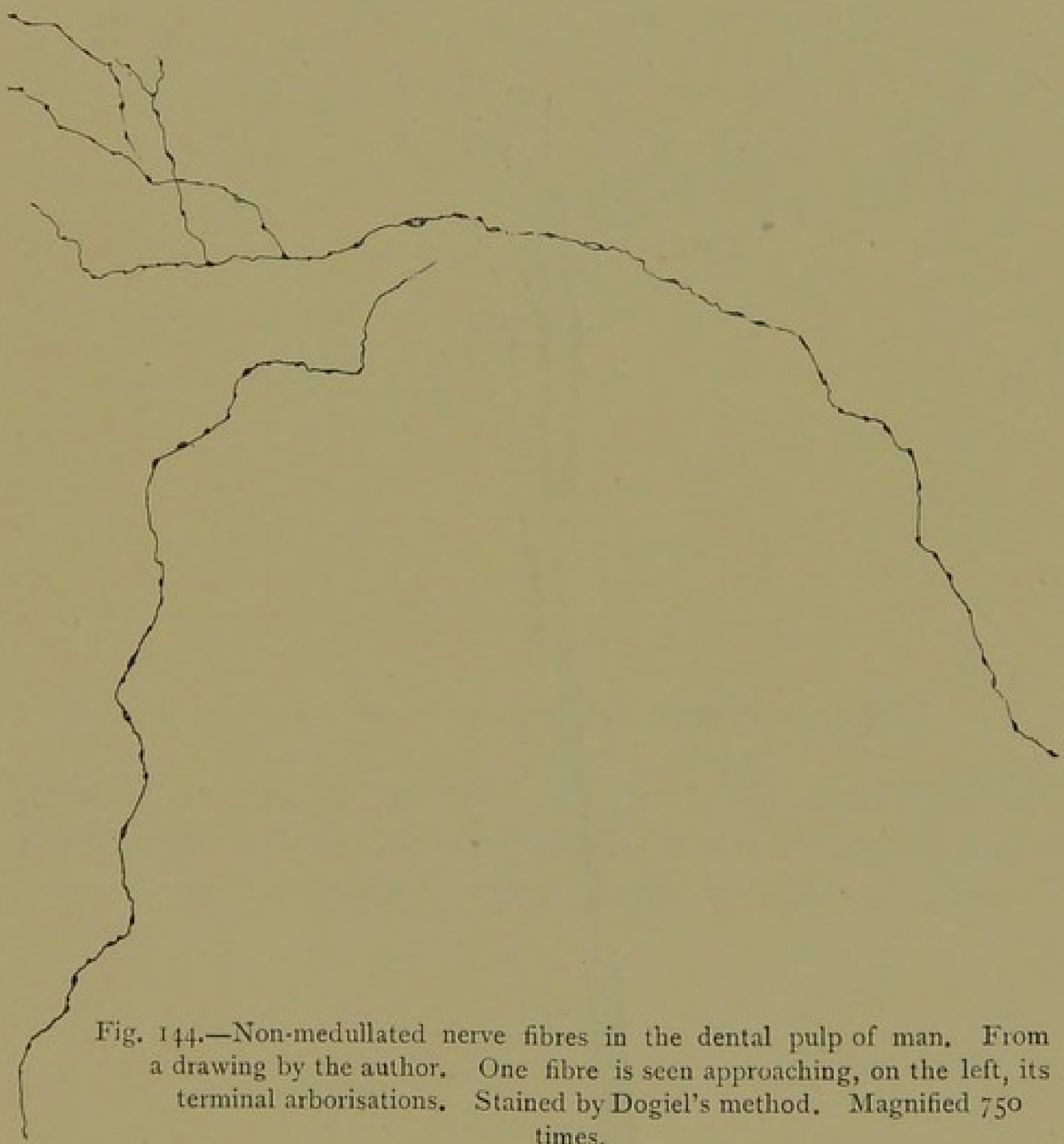


Fig. 144.—Non-medullated nerve fibres in the dental pulp of man. From a drawing by the author. One fibre is seen approaching, on the left, its terminal arborisations. Stained by Dogiel's method. Magnified 750 times.

medullated fibres. In other parts of the tissue numerous nerves of the latter class could be readily stained by using a $\frac{1}{16}$ per cent. physiological solution of methylene blue, "fixing" in picrate of ammonia, and mounting in glycerine.

As the result of his researches, the author has the strong

Fig. 145.—Longitudinal section of the pulp of a human incisor tooth. Stained by Ford Robertson's modification of Heller's stain. Magnified 40 times. Shews the general arrangement of the medullated nerve bundles. From a section prepared by Storer Bennett.

conviction that these fibres terminate in a basket-work of varicose fibres embracing and often closely attached to the cell walls of the individual odontoblasts. The sensory

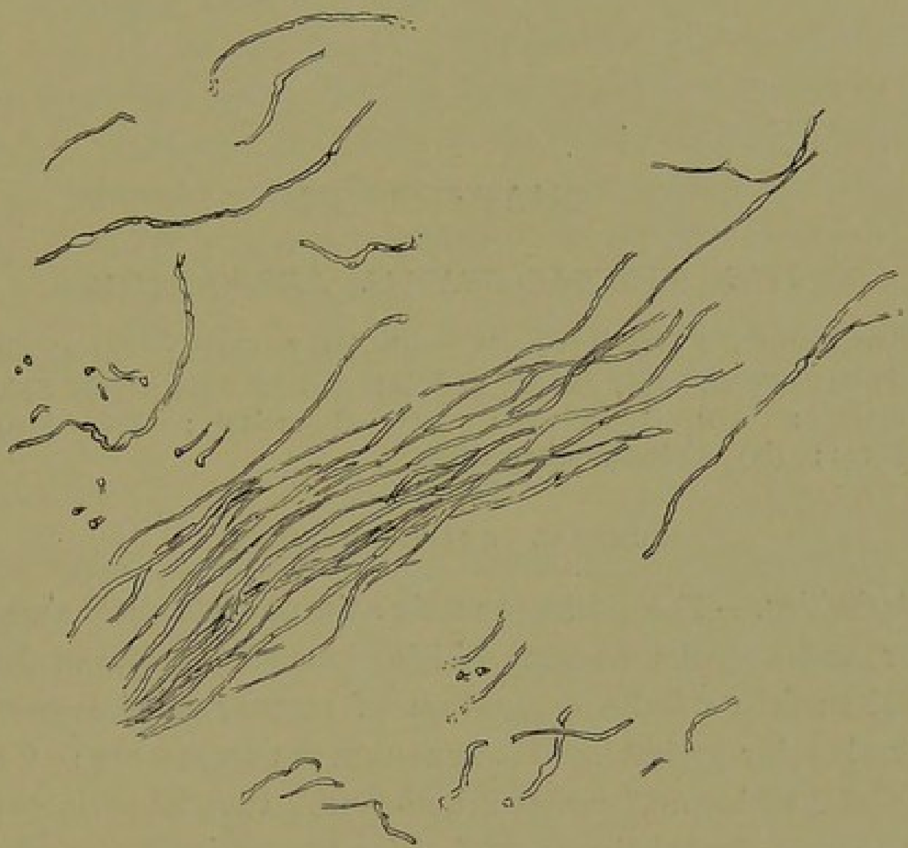


Fig. 146.—The same as the preceding. Magnified 250 times.

currents are traced, in this way, from the amelo-dentinal junction through the dentinal fibrils, odontoblasts, arborisations of non-medullated nerves to the medullated fibres of the pulp.

CHAPTER IX

THE ALVEOLO-DENTAL PERIOSTEUM

MICROSCOPICAL ELEMENTS :—(i) "Principal" fibres ; (ii) Connective tissue fibres ; (iii) Blood vessels ; (iv) Nerves ; (v) Epithelial masses ; (vi) Osteoblasts ; (vii) Osteoclasts ; (viii) Sharpey's fibres ; (ix) Calcospherite spherules.

GENERAL CHARACTERISTICS

Definition.—The thin connective tissue with extensive vascular and nervous systems which intervenes between the external surface of the cementum of teeth and the bone of their alveolar sockets. Its synonymous terms are :—"Periodontal membrane," "root membrane," "dental periosteum," or "alveolo-dental ligament." The expression "Periodontal membrane" is, for the sake of convenience, used here and throughout this work.

Origin.—It is derived from the outer layers of the dental follicle.

Distribution.—It exists in all teeth attached to the jaws by gomphosis articulation, viz. : those of man and most mammals, crocodiles, and a few uncommon fish. The teeth of the vast majority of fishes, and some reptiles, are fixed by either ankylosis hinge or membrane. In these the periodontal membrane is wanting.

The gingival portion of the periosteum, according to Stohr,[1] is called the "annular dentinal ligament."

Macroscopical Appearances.—A white dense membrane covering over the roots of teeth, it varies in thickness in different

[1] Stohr, "Text-book of Histology," Wurzburg ; p. 218, 1901.

individuals, in different teeth in the same mouth, and at varying periods of life. It is thickest in childhood and thinnest in senility. In measurement, in adult age, it ranges from 0·2 mm. to 0·3 mm. in width, and from 8 to 20 mm. in length. These are average statistics: in the localities where it dips into bays or recesses of the alveolar process, the width is proportionately increased. Its microscopical nature is best studied when the tissue is retained *in situ*, easily accomplished in sections prepared by fixing and hardening the soft part first in formalin, or Müller's fluid, and afterwards decalcifying with hydrochloric or other acids, and finally cutting on an ether-freezing microtome.

HISTOLOGY

The several parts of the minute structure of the periodontal membrane may be described as follows:—(i) The fibrous elements; (ii) Cells; (iii) Blood vessels; (iv) Nerves; (v) Calcospherite spherules.

1.—*The Fibres*

The fibrous elements are grouped into two separate and specific divisions, which, however, are indistinguishable anatomically:—(A) The "principal" fibres,[1] and (B) The ordinary and less important connective tissue fibres.

A

The principal fibres of which the greater part of the membrane is composed are of the white connective tissue variety, no elastic fibres whatever being present (Black). Many are fasciculi of delicate wavy fibrils gathered together to form coarse, strong bands; but more commonly they run in loose bundles. At the neck of the teeth they pass immediately outward from the cementum,—the fibres generally lying fairly parallel to each other,—to be inserted into the fibrous mass

[1] A term first suggested by Black in "Periosteum and Peridental Membrane," 1887, to whom a great deal of our knowledge of the histology of this tissue is due.

of gum tissue. Nearer the radicular portion, the fibres merge into the connective tissue fibres of the periosteum of the alveolus, from which they cannot be readily distinguished. In the apical space they are very irregular, or may be almost absent, this portion of the socket of the tooth being filled with small cells, and few fine fibres (the "indifferent tissue" of Black), with abundant room from the passage of blood-vessels and nerves. The apical space may measure 0·5 mm.

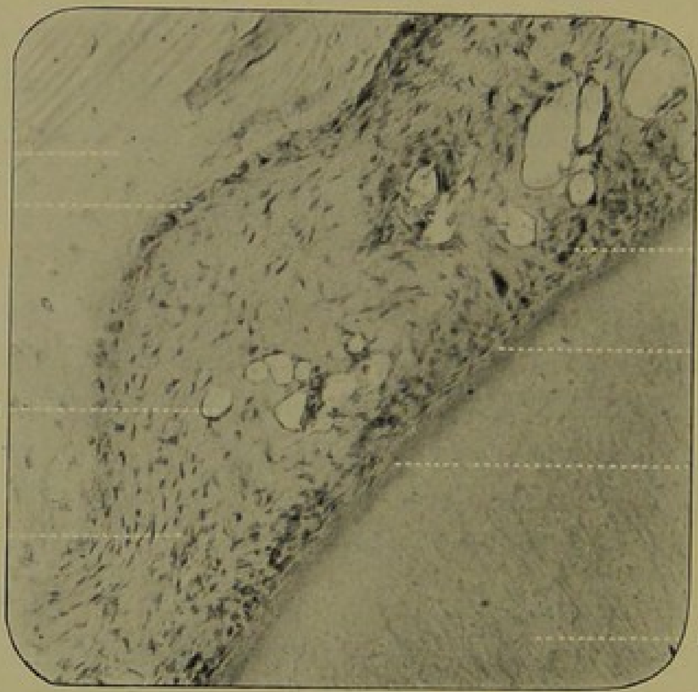


Fig. 147.—Transverse section of the periodontal membrane of man *in situ*. Prepared by the Author's process. Stained with Ehrlich's acid hæmatoxylene. Magnified 250 times. M. The root-membrane with its fibres and cells; B. Its blood vessels; and E. Its epithelial gland-like bodies. D. Dentine; C. Structureless cementum; A. Bone of the alveolus; O_1, Osteoblasts on the wall of the alveolus; O_2. Osteoblasts on the surface of the cementum.

in depth. At the surface of the gum the fibres course in wavy lines directly outwards, *i.e.*, at right angles to the long axis of the tooth, and then suddenly upwards to be inserted into the gum; at the neck of the tooth near the alveolar margin they are inclined root-ward, and are inserted into the bone or periosteum. At the mid-distance—otherwise the alveolar portion of the membrane,—they run squarely across; but near the apex of the root, they assume a crownward direction. At the apical region itself they radiate from the cementum to the bone.

The fibres which arise from the cementum are finer than those inserted into the alveolus, and are continuous with Sharpey's fibres of the cementum ; and the large ones, as a rule, break up into delicate bundles of fibrils.

They all pursue a rather sinuous course, being deviated from straight lines by the presence of the vascular and nervous zones in the central portions of the membrane.

B

The ordinary fibres are found among the foregoing. They are the common type of connective tissue fibres with nuclei and tissue corpuscles. They are arranged diagonally to the principal fibres, and are usually difficult to distinguish, on account of their feeble staining properties.

2.—*The Cells*

The cellular elements are of several varieties.

(*a*) The lamellar connective tissue corpuscles are spindle-shaped, nucleated, ramified, and very prominent. They are called "fibroblasts" by Black. They are freely distributed to all parts of the membrane.

These cells, or corpuscles, differ in no essential particular from the ordinary cells or corpuscles of connective tissues generally. Thus, they are nearly always of the *flattened* or *lamellar* pattern. They are frequently affixed to the surfaces of the peripheral fibres; may extend between several fasciculi ; and are most commonly joined by means of branching processes, which in this manner form delicate reticula throughout the tissue between the principal fibres.

They are composed of clear granular protoplasm, and their nuclei are oval or fusiform in shape. They may be well shown by staining the membrane *in situ* with chloride of gold immediately after extraction, stripping from the surface of the cementum, and teasing-out pieces thus removed in a plane parallel to the periphery of the root.

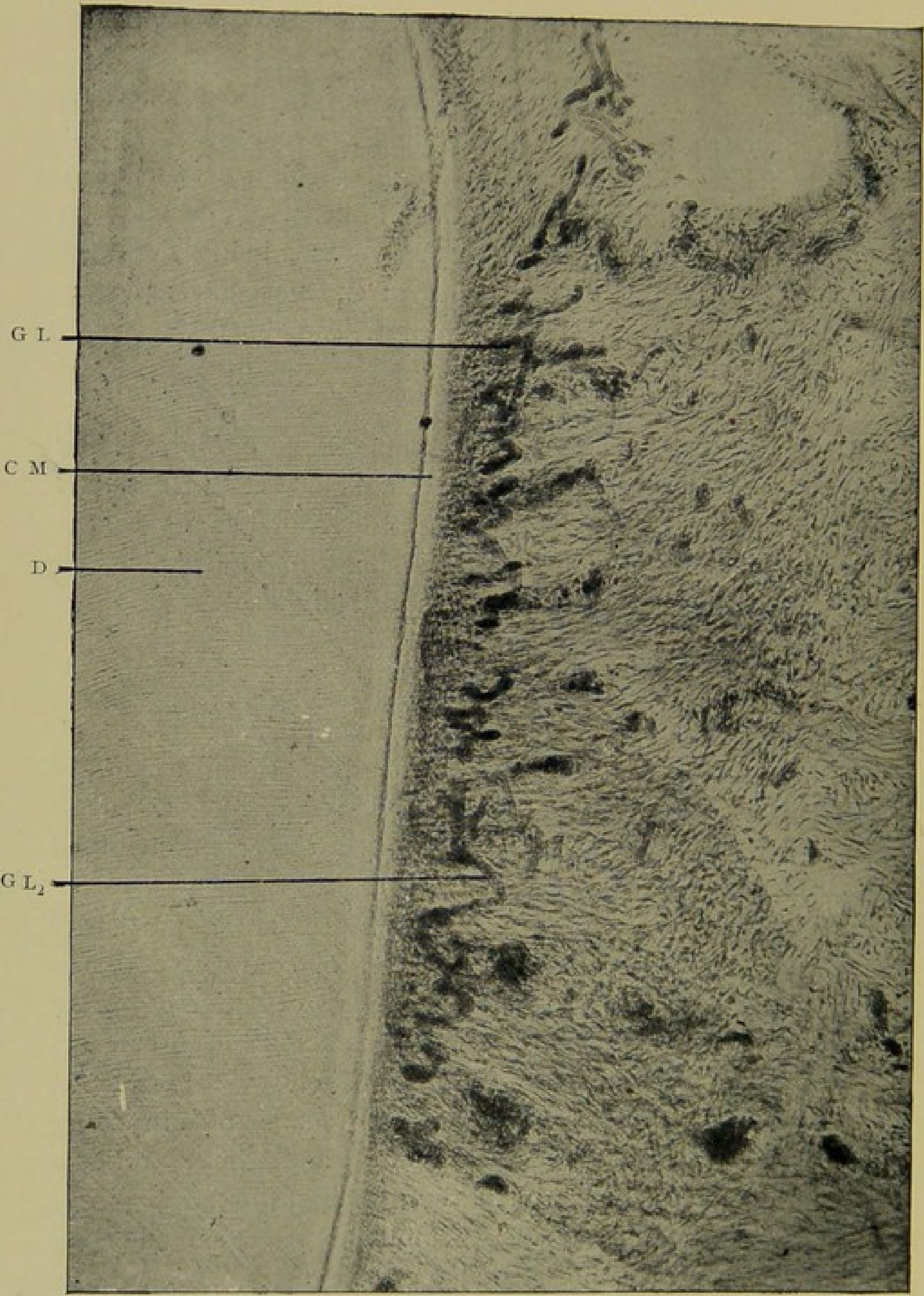


Fig. 148.—A small area of a transverse section of the root of a tooth, and a portion of the periodontal membrane, shewing glands. D. Dentine; C.M. Cementum; GL. and GL². Tubular glands (?) winding among the fibres of the membrane. Photomicrograph by permission of G. V. Black.

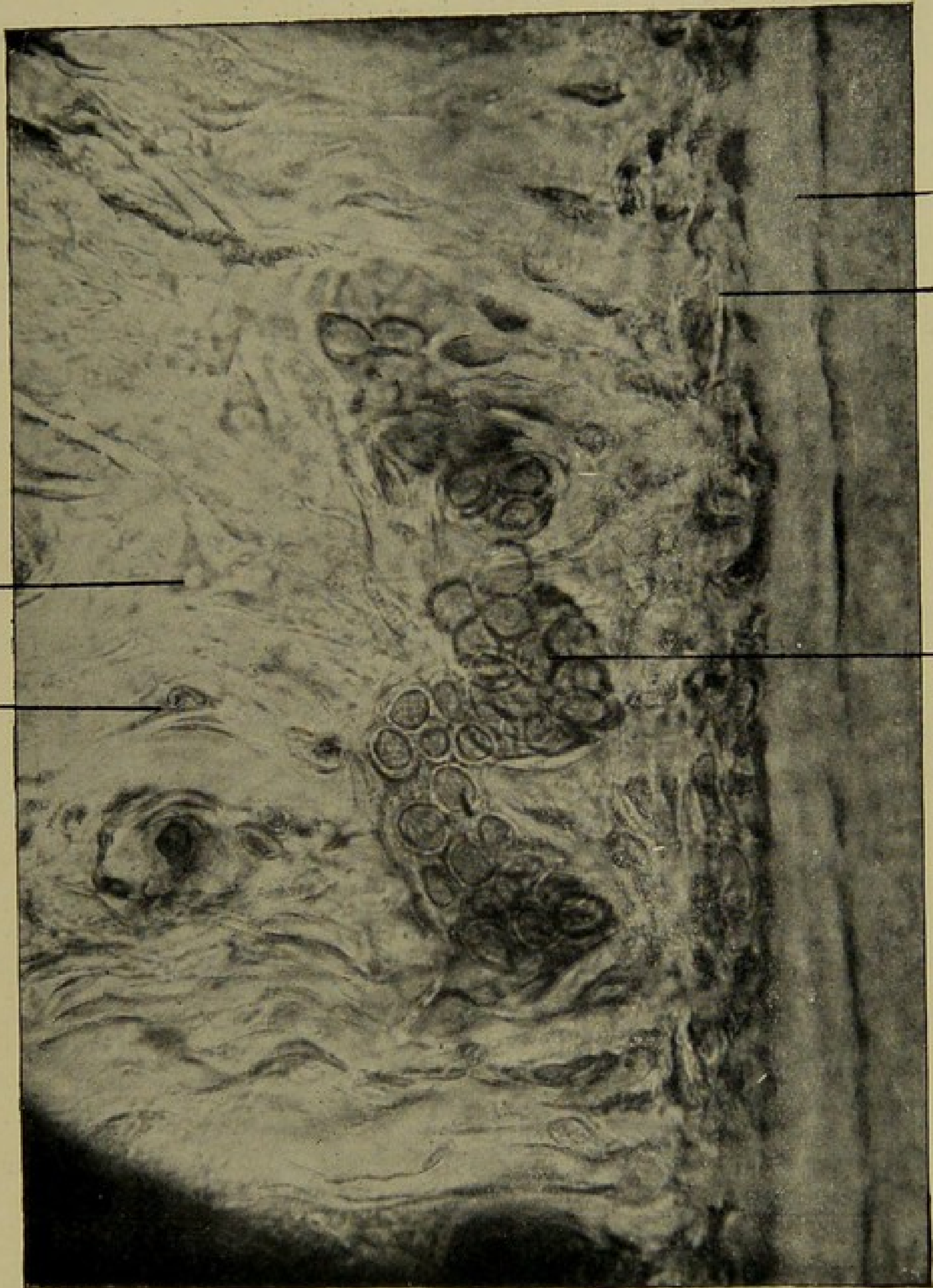


Fig. 149.—Epithelial bodies in the periodontal membrane. C.M. Cementum; C.B. Osteoblasts lying between the fibres of the membrane close to the cementum; G.L. Epithelial cells with nuclei; C.C. Connective tissue cells. Photomicrograph by permission of G. V. Black.

(β) Osteoblasts are flattened, cubical, or irregularly-shaped nucleated cells applied intimately to the external surface of cementum and bone. This irregularity in shape, in the former situation, according to Noyes ("American Text Book

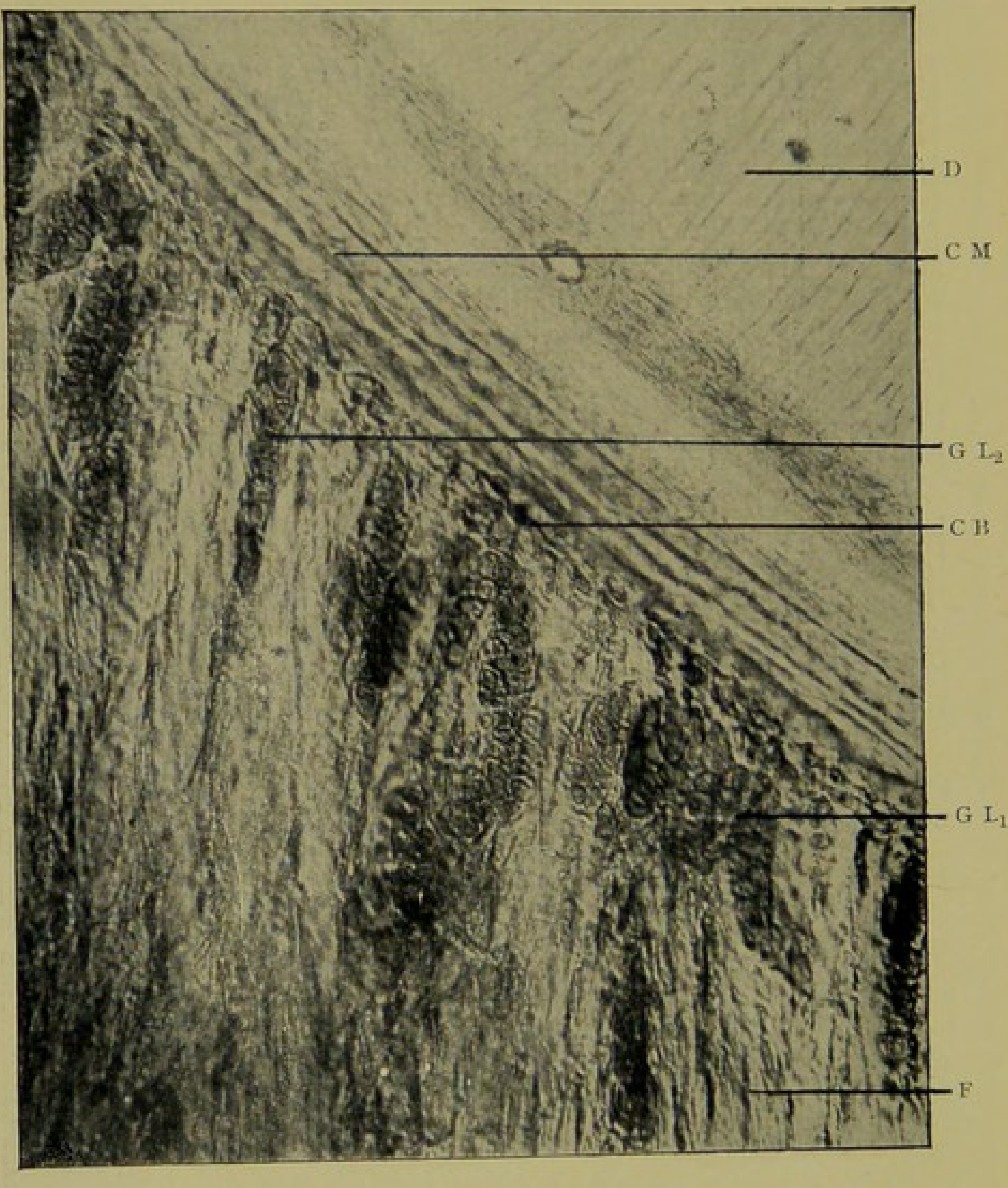


Fig. 150.—Shewing gland-like epithelial bodies lying between the large white fibres of the root membrane. D. Dentine; C.M. Cementum; C.B. Osteoblasts; GL1, GL2, Glands (?); F. Large white connective tissue fibres. Photomicrograph by permission of G. V. Black.

of Operative Dentistry, p. 144, 1901), is caused by these cells "fitting around the attached fibres of the membrane, so as to cover the entire surface of the membrane between the fibres."

They are called "cementoblasts" by Black, Noyes and others; but no points of morphological difference can differentiate them from those ordinary osteoblasts which are found in the inner layer of the periosteum of the alveolus.

(γ) Osteoclasts, or myeloplaxes, are multi-nucleated giant cells, oval in shape, being found where absorption of either bone or cementum is in progress. They measure 30μ in diameter, and are most frequently discovered in the bay-like recesses (the foveolæ of Howship) on the periphery of these hard tissues. In the periodontal membrane they lie in close contact with the surface, which they are about to absorb, and thus, while intervening in the interfibrous spaces, destroy or cut off the ends of the principal fibres, when they, as Sharpey's perforating fibres, are built into the bone or cementum.

(δ) Epithelial cellular bodies or "rests" are not infrequently observed in the inner portion of the periodontal membrane. They appear near the cementum, just outside the layer of osteoblasts, and are seen exceedingly well in horizontal sections. Very pronounced are they in the root membranes of the teeth of the sheep and pig, less so in man, except in the teeth of the young. Attention was originally attracted to these masses by Malassez[1] in 1885; and Black described and figured them in "Periosteum and Peridental Membrane," 1887; but in ascribing to them the rôle of lymphatics, he was probably incorrect, as no true lumina have ever been discovered, and their connection, if any, with the deeper-lying lymphatic system has never been traced. This worker has, however, modified his views on their functions and character in his latest addition to the literature of the subject. (*The Dental Cosmos*, p. 101, 1899).

Most probably, whatever be their functions, they take their origin from scattered, unabsorbed, or unatrophied remnants of the epithelial sheath of Hertwig, as was first pointed out

[1] "On the Existence of Masses of Epithelium round the Roots of Adult Teeth, in a Normal State." *Journal of the Brit. Dent. Association.*

by von Brunn[1], or from remains of the zahnleiste, which have persisted after disappearance of that structure.

Under magnifications of 250 or higher, their histological characteristics can be easily discerned in suitably stained cases.[2]

Situated between the principal fibres, and running generally in an outward direction, they assume the form of cords or tube-like collections of epithelial cells, each of which contains in the centre a large oval nucleus. Surrounding each "rest" is, apparently, a very delicate basement membrane. Cut obliquely, there is some trace of what might be a lumen; but the glandular nature—or otherwise—of these bodies as described by Black requires more investigation and confirmation before dogmatic statements as to their real character can be expressed.

Regarding the so-called gingival gland, Black writes as follows :—" This is a small lobulated mass of connective tissue cells lying close to the attachment of the gum to the tooth at the gingival line. It is mostly included within the prolongations of the epithelium of the gingival space, or that which covers the portion of the free margin of the gum lying next to the neck of the tooth. It has a strong glandular appearance. Its cellular elements are not epithelial, but are round connective tissue cells. These are in lobules, divided in part by delicate hyaline membranes, which often appear double in sections, occasionally giving the appearance of ducts. But close studies of them indicate rather that they are duplicatures of the membrane envelope. In part, the lobules are divided by epithelial bands from the prolongations of the epithelium of the gingivæ. A strong epithelial band from the gingival epithelium encircles the whole mass and parts it from the neighbouring tissues except at its base. In cross sections this epithelial band is seen to be a continuous sheet without break. Though definitely lobulated, this body does not seem

[1] *Archiv. für Mikroskop. Anatomie*, 1887.

[2] Hæmatoxylene is a useful reagent.

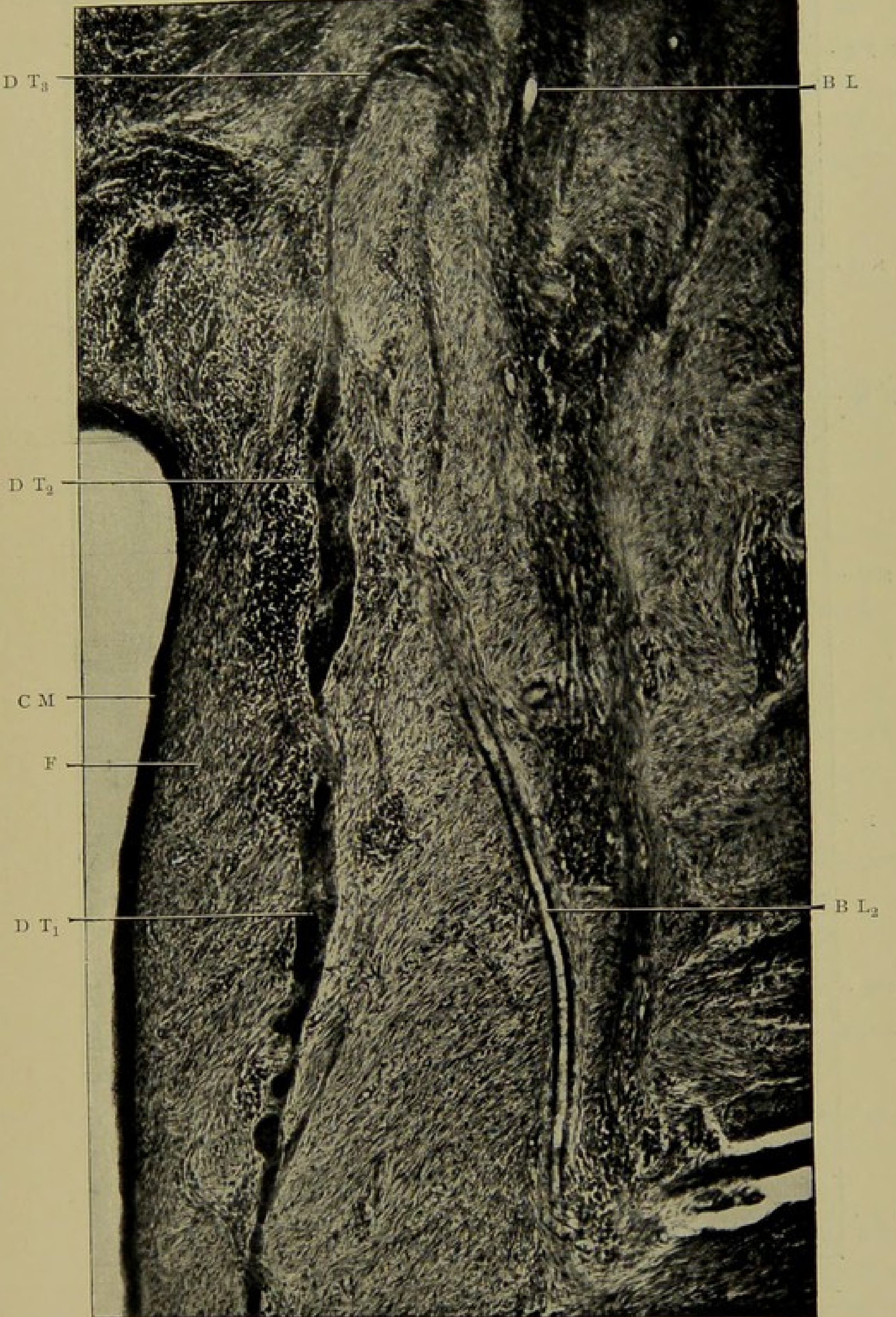


Fig. 151.—Supposed duct of glands of the root membrane, starting from a group of glands not shewn in the field. C.M. Cementum; D.T$_1$, D.T$_2$, D.T$_3$, Duct; F. Fibres of the membrane. B.L. Blood-vessels. Photo-micrograph by permission of G. V. Black.

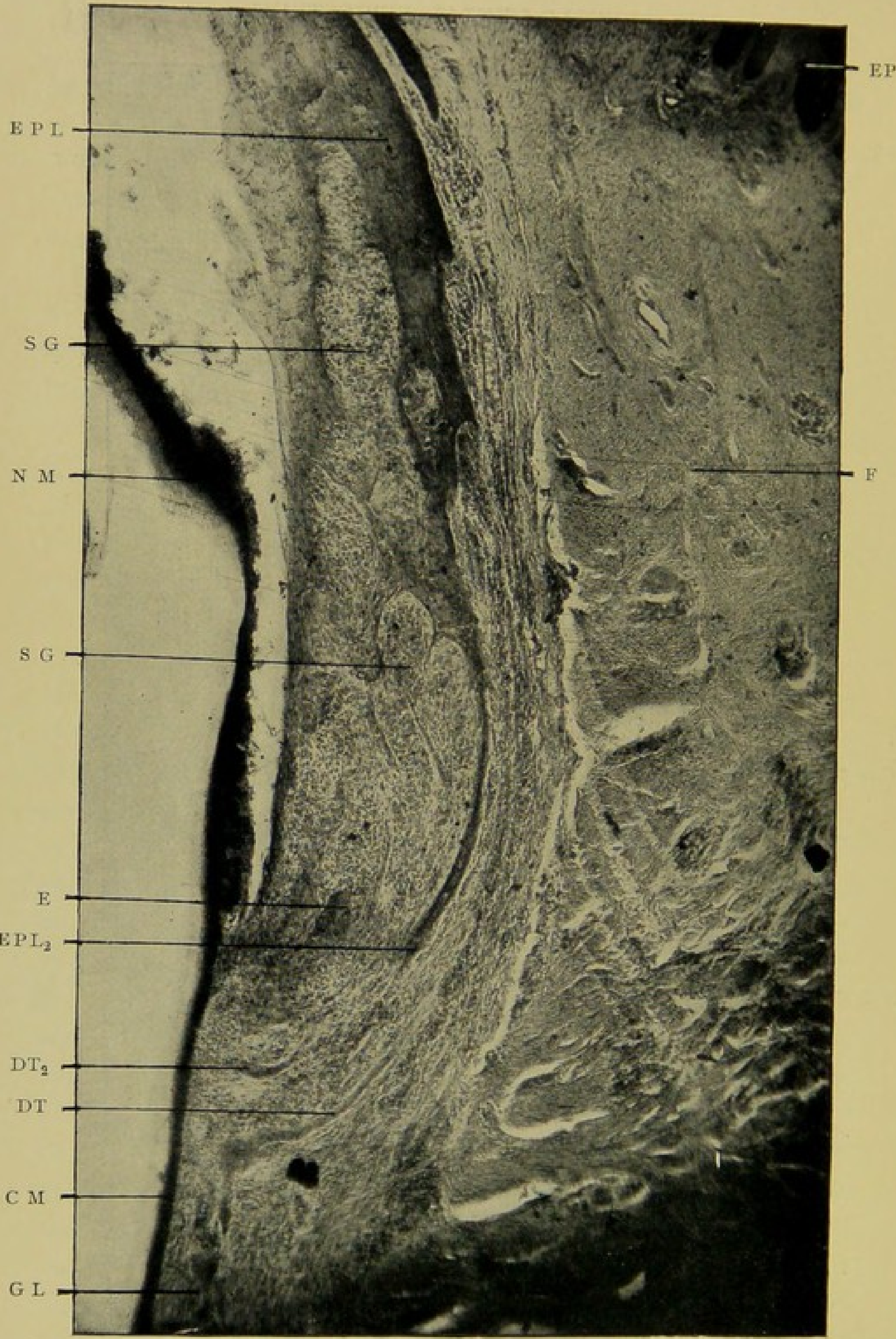


Fig. 152.—The so-called gingival gland. S.G. S.G. Gland; C.M. Cementum parted from the dentine; N.M. Nasmyth's membrane separated from the enamel by the acid used in decalcification; E.P.L. Epithelial column dividing the gland from the surrounding tissues; except at its base; E. Epithelial cells; E.P. Epithelium of outer portion of free margin of the gum; G.L. Glands of root membrane; D.T. Duct leading from glands towards the gingivus; D.T$_2$. Small loop of second duct. F Fibrous tissue of the gum. Photomicrograph by permission of G. V. Black.

to possess the character of a gland, and I should not suppose from an examination of this tissue that it had a glandular function. It encircles but a portion of the neck of the tooth, usually only the approximal portion, thinning away towards the buccal or lingual, so that in many of the lengthwise sections it may be very small or does not appear at all."

3.—*The Vascular System*

This lies in the central zone of the tissue and is exceedingly abundant. Arterial branches having a common origin with those of the pulp pass towards the crown from the apical space. Running thence, they branch, divide, and subdivide and are freely distributed through the body of the membrane, meeting and inosculating with the vessels of the gum and periosteum, and even occasionally of the Haversian systems of the alveolar bone.

The capillary network is scanty, the blood supply of the membrane being chiefly arterial and venous. Of the former the largest vessels, in horizontal section, may measure 0·05 mm. to 0·1 mm. in diameter.

The veins accompany the arteries.

4.—*The Nervous System*

The exact manner of the distribution and nature of the ultimate terminations or ramifications or anastomoses of the nervous supply of the root membrane is unknown: it is a branch of Dental Histology which has been practically ignored.

According to Noyes, however, "six or eight medullated fibres enter the apical region in company with the blood-vessels, and they receive other trunks through the walls of the alveolus and over the border of the alveolar process." (*Op. cit.* p. 155).

5.—*Calcospherite Spherules*

Tiny, almost structureless, rounded masses of calcoglobulin, called calcospherite spherules, may occasionally be found near the epithelial bodies. They are more constant in inflammatory conditions of the membrane. (*q.v.*).

CHAPTER X

A GROUP OF MINOR STRUCTURES. THE ABSORBENT ORGAN—THE DENTAL FOLLICLE—THE GUM—THE LINING MEMBRANE OF THE ANTRUM OF HIGHMORE

THE ABSORBENT ORGAN

MICROSCOPICAL ELEMENTS:—(i) Connective tissue stroma; (ii) Osteoblasts; (iii) Foveolæ of Howship.

GENERAL CHARACTERISTICS

Definition.—A delicate vascular structure spread over portions of the roots of the deciduous teeth of man, during the periods when they are about to be shed.

Origin.—From the outer layer of the dental follicle of the permanent teeth.

Macroscopical Appearances.—A thin, white, insensitive organ covering the excavated parts of the roots of temporary teeth loosened by the impending eruption of their permanent successors. It can be easily removed from the dentine, but is best observed and studied when retained *in situ*. It may also be seen as a soft reddish papilla over the crowns of the erupting teeth.

HISTOLOGY

Vertical sections exhibit a tissue composed of cells and blood vessels imbedded in a dense connective tissue stroma.

The cells are usually small and round, with round or oval prominent nuclei. On the surface, and fitting the foveolæ of Howship—large bay-like crescentic excavations in the dentine

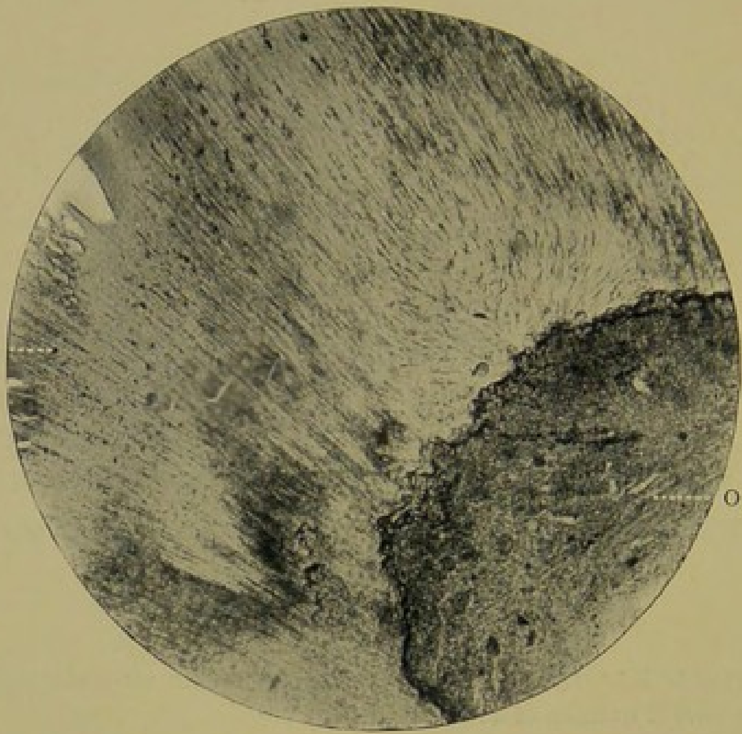


Fig. 153.—The absorbent organ. Prepared by the Author's process. Stained with Ehrlich's acid hæmatoxylene. Magnified 40 times. O. Absorbent organ ; D. Dentine of the deciduous tooth.

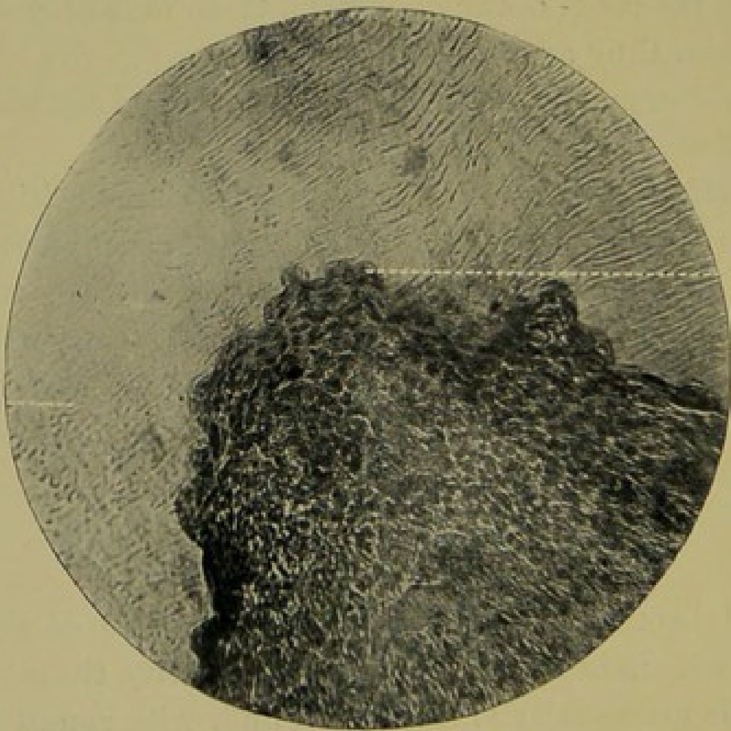


Fig. 154.—Same as the preceding. Magnified 250 times. H. A Howship's foveola with its giant-celled occupant. D. Dentine of the deciduous molar.

—are found large multi-nucleated giant cells which correspond in many particulars with osteoclasts. In fact, they may be considered to be nothing more nor less than these specially organised cells. The cells which make up the main mass of the organ are of the ordinary variety. They are not osteoblasts, in the general acceptance of the term, but may take on a lime-depositing function, as sometimes there are evidences in physiologically-absorbed roots of new depositions of dentinal matrix.

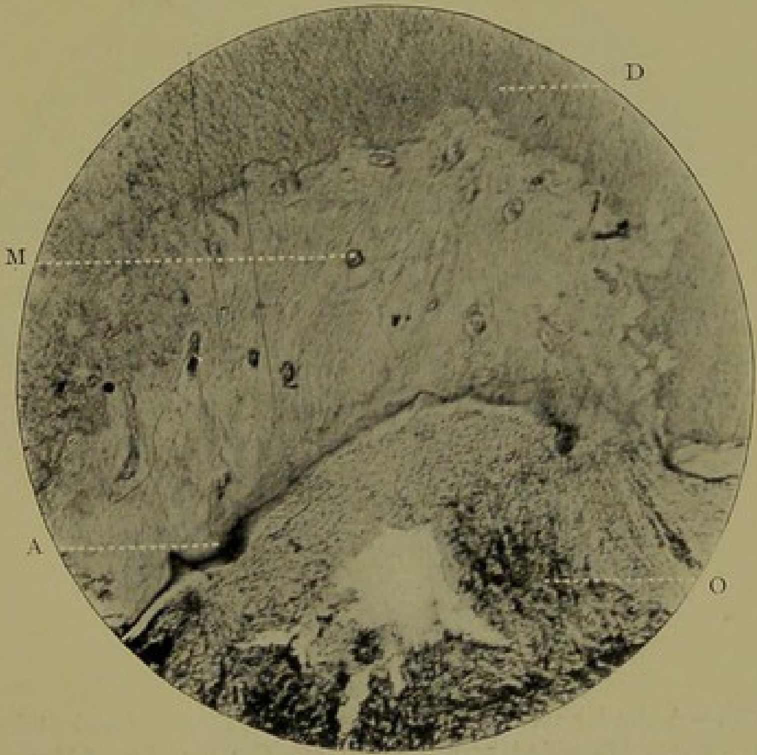


Fig. 155.—The absorbent organ *in situ*. Prepared and stained as in Fig. 153. Shews a deposition of dentine matrix (with a few scattered cells embedded in it) in the excavated portions of the dentine. Magnified 50 times. O, Absorbent organ; D, Dentine of deciduous tooth; M, Dentinal matrix containing nucleated cells; A, Albumenoid material undergoing calcification.

In the two accompanying photomicrographs, Figs. 155 and 156, it will be seen that a kind of hyaline matrix has been laid down, in the excavated portions of the roots of the deciduous teeth. This nearly homogeneous material may at times present nothing more than a coarse granularity, or, at times, shew a finely-fibrillated reticulum with large round nucleated connective tissue cells imbedded in its midst. Both forms closely recall those two kinds of adventitious dentine found in the pulp known as hyaline, and cellular. (*q.v.*) Here, again,is another remarkable instance of dentinal matrix being produced without the aid of the so-called odontoblasts.

The vessels are very numerous, but comparatively large nerves other than vaso-motor branches are probably absent.

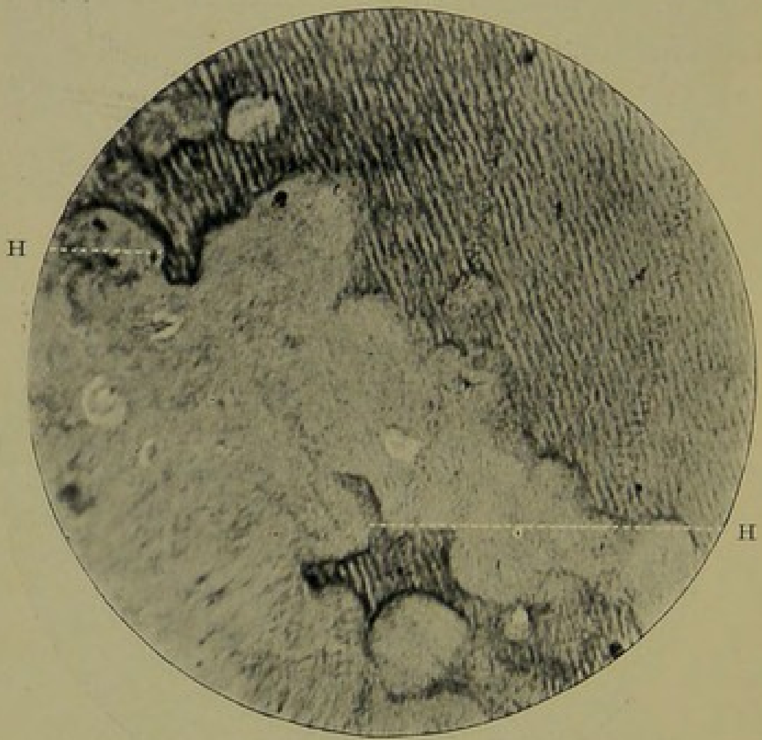


Fig. 156.—A similar section to the preceding. Prepared and stained as in Fig. 153. Magnified 250 times. H. The foveolæ of Howship filled with calcified dentinal matrix.

THE DENTAL FOLLICLE

MICROSCOPICAL ELEMENTS :—(i) Outer and Inner Portions ; (ii) Fibres ; (iii) Glands.

GENERAL CHARACTERISTICS

Definition.—A sac-like investment of fibrous tissue of the non-erupted teeth of man, and many animals, which disappears after histogenetic periods have passed.

Origin.—From the meso-blastic cells of the outer portion of the dentinal papilla.

Macroscopical Appearances.—A rather tough, pale membrane easily stripped off the surface of teeth which have not yet arrived at the proper time for eruption.

HISTOLOGY

It is composed of bundles of white connective tissue fibres, running in a complex and varied fashion and interlacing in all directions. The cellular elements, as well as the vascular

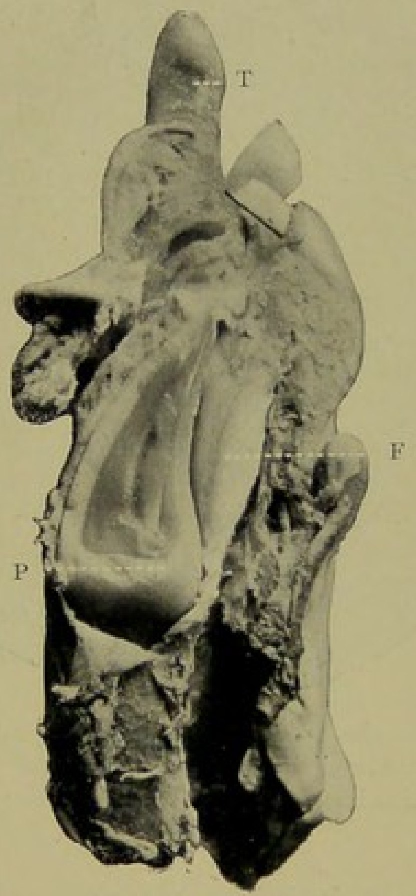


Fig. 157.—Sagittal section in the incisor and canine regions of mandible of a young heifer. Prepared by cutting through the jaw with a saw while in the recent state. Actual size. Shews (P) the permanent tooth in its (F) follicle; T. Fully-erupted temporary incisor.

supply, are scanty. The outer portion is less dense than the inner, but it cannot be removed as a separate layer from the latter, as neither is divided by a pronounced line of demarcation. The inner is dense, and is covered on its free surface, *i.e.*, the part directed towards the enamel and cementum with a flat layer of epithelial cells, which are manifestly part of the layer of polygonal cells of Nasmyth's membrane.

Running inwards towards this cellular layer groups of tubular epithelial glands wind between the fibres. They are simple bodies, though sometimes they may branch. Their lumina are very narrow, often most indistinct; but the epithelial cells which line the basement membrane are cubical in shape and have large prominent nuclei. They end in *culs de sac.* Their function is unknown, and their origin

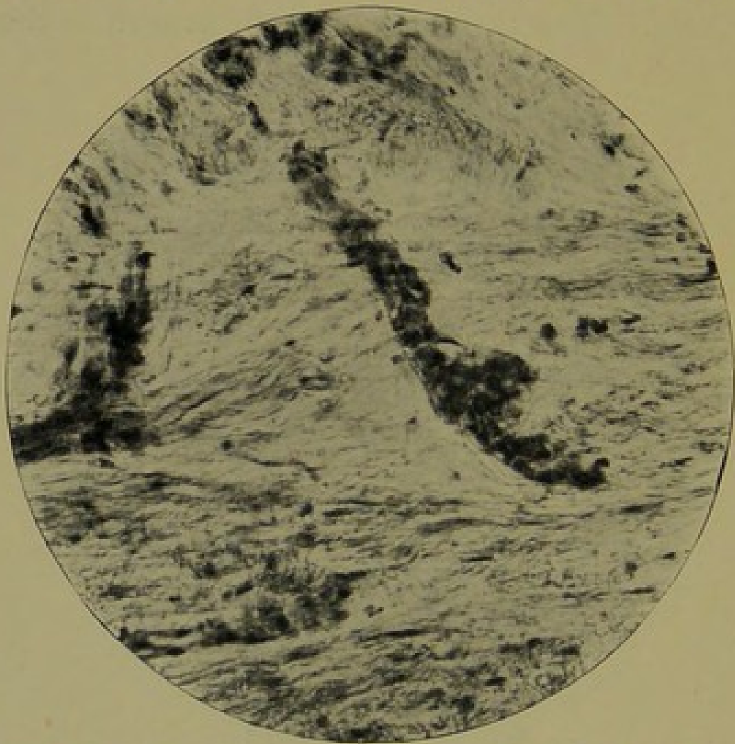


Fig. 158.—A tubular gland-like structure from the dental follicle of man. Prepared by "fixing," hardening, and cutting on an ether-freezing microtome. Stained with Ehrlich's acid hæmatoxylene. Magnified 250 times.

doubtful, although it is quite possible that they may be derived originally from "rests" of the epithelium of the zahnleiste.

THE GUM

Microscopical Elements:—(i) Epithelium of the mucous membrane; (ii) Simple and compound papillæ; (iii) Mucous glands; (iv) Fat lobules; (v) Bloodvessels; (vi) "Glands" of Serres.

GENERAL CHARACTERISTICS

Definition.—The soft dense tissue which clothes the alveolar processes of the jaws, being intimately connected with their periosteum, and surrounding the necks of the teeth.

Origin.—The superficial epithelial portion is derived from the stomodæal epiblast, the submucous tissue from the stomodæal mesoblast, both due to the backward involution of these parts of the blastoderm between the maxillary and mandibular processes of the head.

This involution deepens and extends further backwards, till a thin partition only intervenes between it and the cæcal extremity of the fore-gut. On the absorption of this, connection with the pharyngeal cavity is permanently established.

Macroscopical Appearances.—The gum is a smooth, firm, pale pink tissue round the necks of the teeth, continuous externally with the sulci between the lips and cheeks, and internally with the hard and soft palates, floor of mouth and root and sides of tongue.

HISTOLOGY

The minute anatomy of the gum may be conveniently considered under the following heads:—(A) The mucous membrane; (B) The submucous tissue.

A

The mucous membrane is essentially of a stratified epithelial character, consisting as it does of several layers. On the surface are squamous epithelial cells of large size, which overlap each other to some extent. Deeper, they become more cubical in shape, but the deepest of all are columnar in outline, and form the *rete Malpighii*, resting on an exceedingly thin basement membrane. In the lower layers the shape of the cells is modified by their mutual apposition. They fit each other very closely. The epithelium of the gum can be divided into the layers known as the *stratum corneum*,

Fig. 159.—Vertical section of the gum. Prepared similarly to Fig. 158. Stained with Ehrlich's acid hæmatoxylene. Magnified 50 times. A. Oral epithelium; P. Papilla of the submucous tissue; C. Connective tissue fibres interlacing in all directions; D. Scanty cellular elements; V. Blood-vessel; T.T. Parts of the section torn in cutting; B. Alveolar bone.

stratum lucidum, and *stratum granulosum*, as in the epidermis, and possibly there is eleiden or granular material deposited in the older, more superficial cells.

The deeper cells are more protoplasmic than the others, undergo repeated karyokinesis, and gradually push outwards the latter, which ultimately become lost by abrasion.

Many "spiny" cells, separated by systems of wide intercellular channels, are often noticed in the layers nearest to the *rete mucosum* or *Malpighii*.

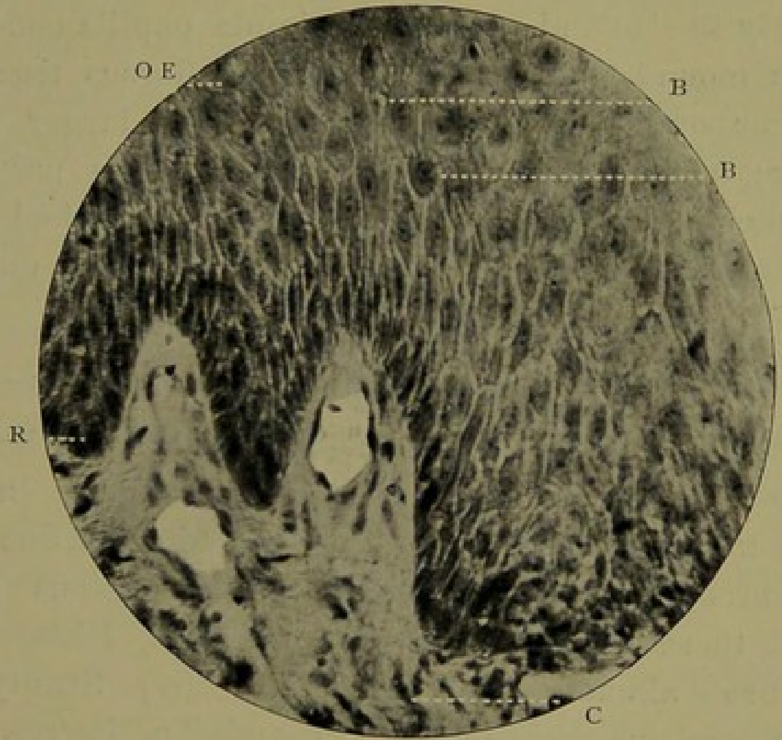


Fig. 160.—Vertical section of the oral epithelium. Stained with Ehrlich's acid hæmatoxylene. Magnified 250 times. O.E. Epithelium of gum (oldest cells); B.B. Intercellular bridges of the "spiny" cells; R. Rete Malpighii; C. Corium.

This last named consists of a very folded line of columnar cells, placed vertically on the surface of the papillæ, which are formed by the submucous tissue.

The epithelial mucous membrane is perforated here and there to allow the passage of the ducts of many mucous glands, which are present in the sub-lying region.

B

The sub-mucous tissue consists of dense bundles of connective tissue arranged throughout its substance. These are closely associated with the fibres of the alveolar periosteum, and at the necks of the teeth, with the "principal" fibres of the alveolo-dental periosteum. They pass outwards in fan-shaped fasciculi to the surface of the numerous papillæ.

The latter are large elevations of the submucous fibrous tissue. They form the base on which the cells of the *rete mucosum* rest, and between them are depressions which vary indefinitely in size and shape. A simple papilla consists of one large mound or elevation of vascular fibrous tissue, the term "compound" being applied to those larger ridges, which are further sub-divided by smaller ones passing in from without. The papillæ are visible to the naked eye, if, after removal of the epithelium by means of some dissociating fluid, the free surface of the gum be examined.

Other constituents of the sub-epithelial tissue are:—

(i) Small lobules of fat cells—tiny oval vesicles (each cell being about 70μ in diameter)—of adipose material gathered together into clusters, and imbedded in a fine reticulum of areolar connective tissue; (ii) Mucous glands, similar to those described on page 201; (iii) Blood-vessels, which are abundantly distributed; (iv) Scanty nerve fasciculi; and (v) the so-called "glands" of Serres.

The last named (see Figs. 230 and 232), according to Tomes (*op. cit.* p. 102), are "small round aggregations of pavement epithelium, met with at a little depth, or even bedded in the surface." These have no known function, but are remnants of the dental formative organs. Bland-Sutton and R. R. Andrews[1] consider them to be histologically comparable to young enamel organs; but Sayre Marshall[2] erroneously describes them as lobulated glandular structures.

1 "American Text-Book of Operative Dentistry," p. 90, 1901.
2 "Principles and Practices of Operative Dentistry," p. 58, 1901.

THE MUCOSA OF THE ANTRUM OF HIGHMORE

MICROSCOPICAL ELEMENTS:—(i) Epithelium; (ii) Submucous Tissue; (iii) Glands.

GENERAL CHARACTERISTICS

The histology of this tissue seems to have escaped the notice of workers, who, generally speaking, have contented themselves by saying that it is continuous with, and similar to the Schneiderian mucous membrane of the nose.

Thus Tomes (*op. cit.* p. 549) says that it is ciliated, but differs from the lining membrane of the nasal fossæ, in that it is thinner and less vascular.

A knowledge of its minute structure is important because of its intimacy with the roots of the first and second maxillary molars, or pre-molars, and the fact that treatment of its diseased conditions not infrequently comes into the province of the work of the dental surgeon.

Regarding its anatomy, Sappey[1] describes it as being supplied with glands, which, in appearance, are much like the Meibomian glands of the eyelids. They are irregularly distributed, and much scantier than those of other mucous membranes.

Definition.—The lining membrane of the maxillary sinus, otherwise called the Antrum of Highmore.

Origin.—It is an outward involution of the epiblast of the olfactory fossæ, which themselves originate at a point below and in front of the ocular vesicle. It is said that it begins to develope about the fourth month of intra-uterine life.

Macroscopical Appearances.—A thin whitish tough membrane, very readily removed from the bone, and in places

[1] "Quant au sinus maxillaire, elles (the glands) répandent sur tous les points de ses parois avec une telle profusion, qu'il serait fort difficile d'en faire le dènombrement. . . . Ces glandes affectent, du reste, toutes les dimensions et toutes les formes possibles : il y en a de très considerables et de très compliquès, de moyennes, et plus simples, de petites, de très minimes, et enfin d'uni-utricular. Les unes revêtent la forme arrondie, d'autres la forme rameuse, d'autres les formes intermédiares. Elles sont surtout remarquables par la dilatation extrément fréquente de leur conduit, en sorte que sur un grande nombre, d'entre elles il existe un kyste, naissant, ou ayant déjà acquis une certain dèveloppment ou completèment developpé." —"Traitè d'Anatomie," Vol. III., Paris, p. 660, 1871.

thrown into slight rugæ. In old subjects (*æt.* 64) patches of pinkish material (inspissated mucus) may be seen. The thinness is not uniform, in health large territories may be found somewhat thicker than the rest. It is also slightly thicker over the situations of the glands.

It measures 0·7 mm. to 0·9 mm. in thickness. The whiteness is due to lack of blood supply, which is particularly scanty. The vessels come from the anterior and posterior ethmoidal branches of the orbital group of the ophthalmic artery. Bödecker, in this connection, says (*op. cit.*) "The blood vessels are principally derived from the mucous membrane of the nasal cavity, although some of the smaller branches arise from the posterior dental arteries through the alveoli."

Its toughness depends upon the large amount of white connective tissue fibres which go to make up the greater proportion of its bulk. Sections curl up very readily, and large pieces can be torn off the thin bony walls to which it is but loosely attachedby fibrous tissue.

HISTOLOGY

The lining membrane presents for microscopical examination—(i) An epithelial surface, (ii) sub-epithelialtissue, (iii) certain glandular structures, and (iv) its periosteal attachment.

(*i*) *The Surface Epithelium*

In common with the mucous membrane of the respiratory passages (except that of the olfactory region of the nose), the upper surface of the soft palate, the nasal region of the pharynx, and several other organs of the body, the epithelium of the antral mucosa consists of a transitional layer of ciliated columnar epithelial cells, situated side by side, and on and between several layers of variously shaped cells, the lowest stratum of which is placed on a delicate basement membrane. This covers the whole of the mucous membrane.

The layer of epithelium measures about ·02 mm. in depth in young subjects (*æt.* 25).

Each superficial cell is granular, narrow, more or less columnar in shape, and bears, at its free end, a number of long cilia, which are securely fixed to the surface of a clear disc. The attached basal extremity of the cell is generally pointed or dichotomous.

The intervening and deep-lying cells are pyriform or polyhedral, thus called, by some authors, "battledore cells," whilst the deepest cells are spherical. All have very pronounced oval nuclei, which in the case of the first-named is situated near the refractile disc.

Some authors consider that the younger spherical cells finally replace those possessing cilia; but probably this is not true, as they appear to contain mucigen, and to become ultimately distended into the shape of goblet-cells.

At intervals numerous goblet or chalice cells may be observed between their ciliated neighbours.

These are large poculiform bodies, with wide open mouths, which are directed inwards towards the centre of the antrum. Each contains mucigen and an indistinct small nucleus placed at its distal end. The mucus may entirely or only partially fill it; but sometimes it can be observed in sections, becoming extruded from the mouth of the cell.

(*ii*) *The Sub-Epithelial Tissue*

is very loose, and sparsely supplied with cells and blood-vessels, though glands are fairly abundant. It is made up of bundles of white connective tissue fibres, which, while in no sense compactly arranged, are still very tough. The writer has never noticed the presence of any elastic tissue fibres in this membrane.

(*iii*) *The Glands*

are of great interest. They are visible macroscopically in suitably-stained specimens, as pin-point spots more deeply coloured than the rest of the tissue. Seen in sections cut in a plane perpendicular to the surface of the bone of the antrum, they present the appearance of tubular glands; and this, no doubt, led Sappey to assert that they resemble the tube-like glands in the eyelids. Such, however, is not the case, for if sections be made in an oblique direction, or in a plane parallel with the surface of the antral bone, below the level of the epithelial layers, they are at once recognised as compound racemose bodies, consisting of well-defined lobules, and having single ducts, which open on to the free surface of the mucous membrane.

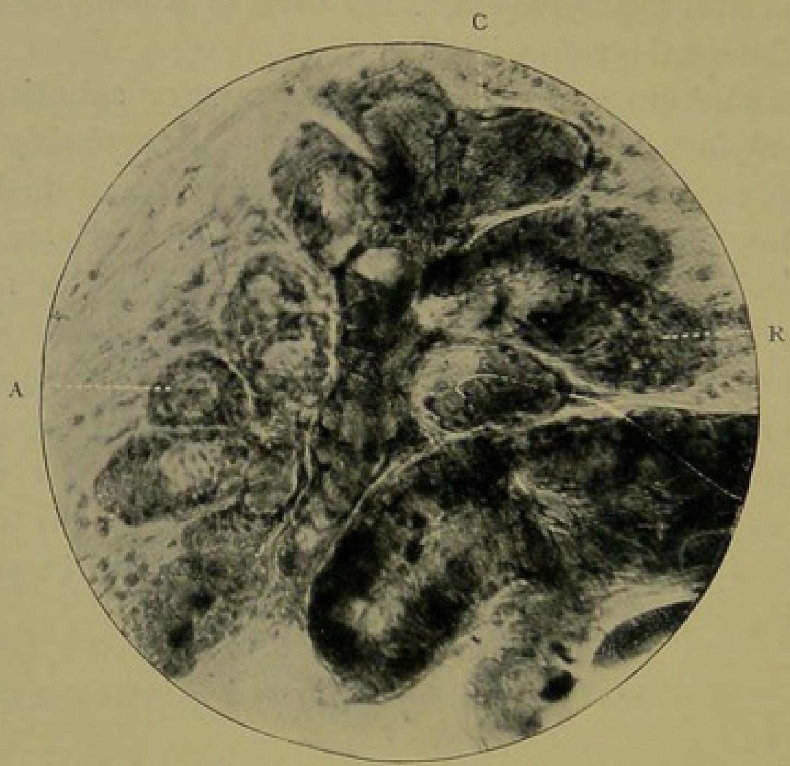


Fig. 161.—A mucous gland of the lining membrane of the Antrum of Highmore. Stained with Ehrlich's acid hæmatoxylene, counter-stained with eosine. Magnified 250 times. A. Mucous secreting cells in activity; R. The same after the period of activity is passed; C. Crescent of Gianuzzi.

The largest glands measure in length 0·8 mm. to 1·3 mm., and 0·2 mm. to 0·6 mm. in depth. The lobules assume varying shapes (see Fig. 161), and are held together by delicate strands of connective tissue. Each lobule possesses a small duct, which communicates with a larger excretory duct, and its constituent parts are composed of a number of alveoli or acini. Glands during rest, and after a period of activity, are clearly observed.

These latter consist of a basement membrane, on which rest, by means of their broad bases, five or six, or more, large polygonal secretory cells. Others often fill the acini, leaving but little room for lumina. Their translucent interiors are traversed by an exceedingly minute reticulum of fibrils, which includes in its meshes mucigen, small indifferent flattened nuclei being placed at the periphery of each cell. The crescents or lunulæ of Gianuzzi—groups of small crescentic granular nucleated bodies—may be found occasionally in places between the bases of the cells, more darkly stained than the other parts of the acini.

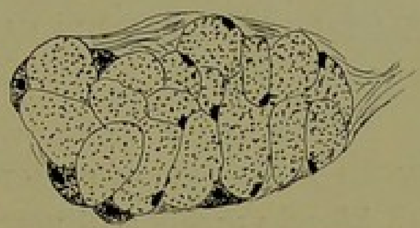


Fig. 162.—Diagram of Fig. 161 shews the secreting mucous cells about to begin their functions. Several crescents of Gianuzzi can be seen.

The ducts are short, straight tubes, of about ·02 mm. in length. In width at their orifices they may measure as much as 1 mm. At their junctions with the gland substance proper their diameters are less, as they are somewhat truncated. They are lined with a simple layer of small cubical epithelial cells.

(*iv*) *The Periosteal Attachment*

is due to the presence of strong bands of connective tissue which pass into the peripheric laminæ of the bone.

CHAPTER XI

THE ORAL CAVITY AND ITS ACCESSORIES

Microscopical Elements of the : (i) Lips and cheeks ; (ii) Tongue ; (iii) Salivary glands ; (iv) Hard and soft palate ; (v) Tonsils.

THE LIPS AND CHEEKS

These consist for the most part of muscular tissue, which is freely supplied with blood vessels and nerves. Loose areolar tissue, fat lobules, and great quantities of tiny glands make up the rest of their substance. Externally they are protected by skin, internally by mucous membrane. This is studded everywhere with myriads of vascular papillæ of microscopic size. In many papillæ nerve-end-bulbs are found.

"Labial" glands (small racemose bodies) have the free terminations of their excretory ducts directed to the inner surface of the lips, "buccal" and "molar" glands to that of the cheek, while small sebaceous glands occur in the outer part of the red border of the lips.

The mucous membrane of the mouth generally is lined with epithelium of the squamous stratified variety, many "spiny" cells lying in the deeper layers.

THE TONGUE

The tongue is a large soft organ, flattened from above downwards, situated in the floor of the mouth.

It consists mainly of muscles, extrinsic and intrinsic, the latter being those placed entirely in its substance. The fibres—striped and voluntary—exhibiting the usual features of muscular tissue generally, run in various directions, so that in any and every section some are cut longitudinally, others transversely, thus forming particularly attractive preparations for the microscope.

Greater interest than that of the histology of the muscles,

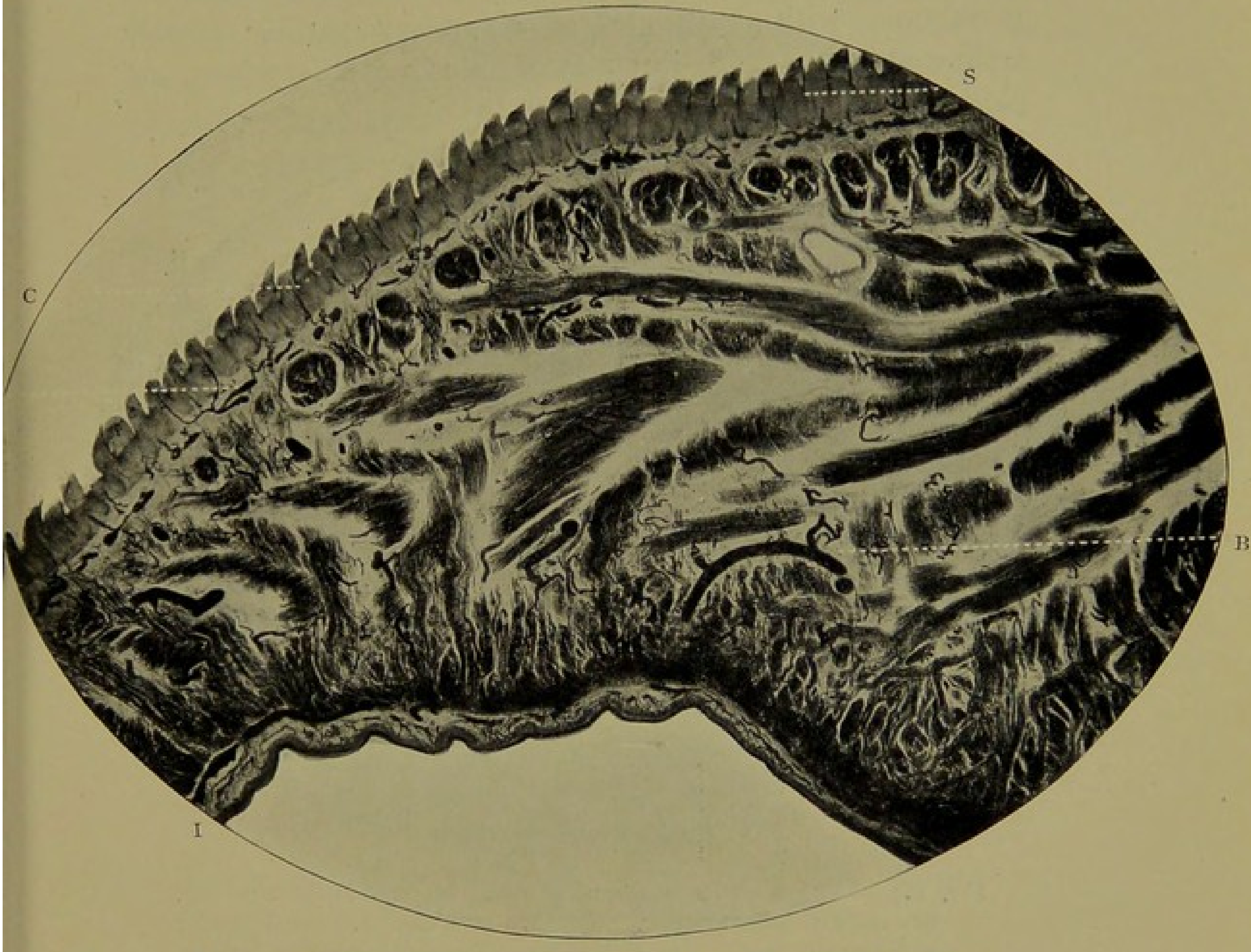


Fig. 163.—Coronal section of the tongue of a dog. Prepared by hardening in alcohol. Stained with hæmatoxylene and eosine. Magnified 12 times. S. Superior surface or dorsum of tongue; C. The epithelium of the conical papillæ; B. Blood-vessels injected with carmine; I. Inferior surface of tongue.

however, attaches to the mucous membrane and its abundant supply of eminences or papillæ of varying size and shape.

The anterior two-thirds of the dorsum presents on its surface, tip, and sides, where the mucous membrane is thin and closely adherent to the muscular layer beneath, enormous numbers of papillæ known as "conical," "fungiform," and "circumvallate." All are macroscopically visible, but microscopically of considerable interest.

HISTOLOGY

Each papilla is covered, like the rest of the oral mucous membrane, with multitudes of secondary papillæ closely embraced by the epithelium. It contains a capillary loop, and plexus of nerves.

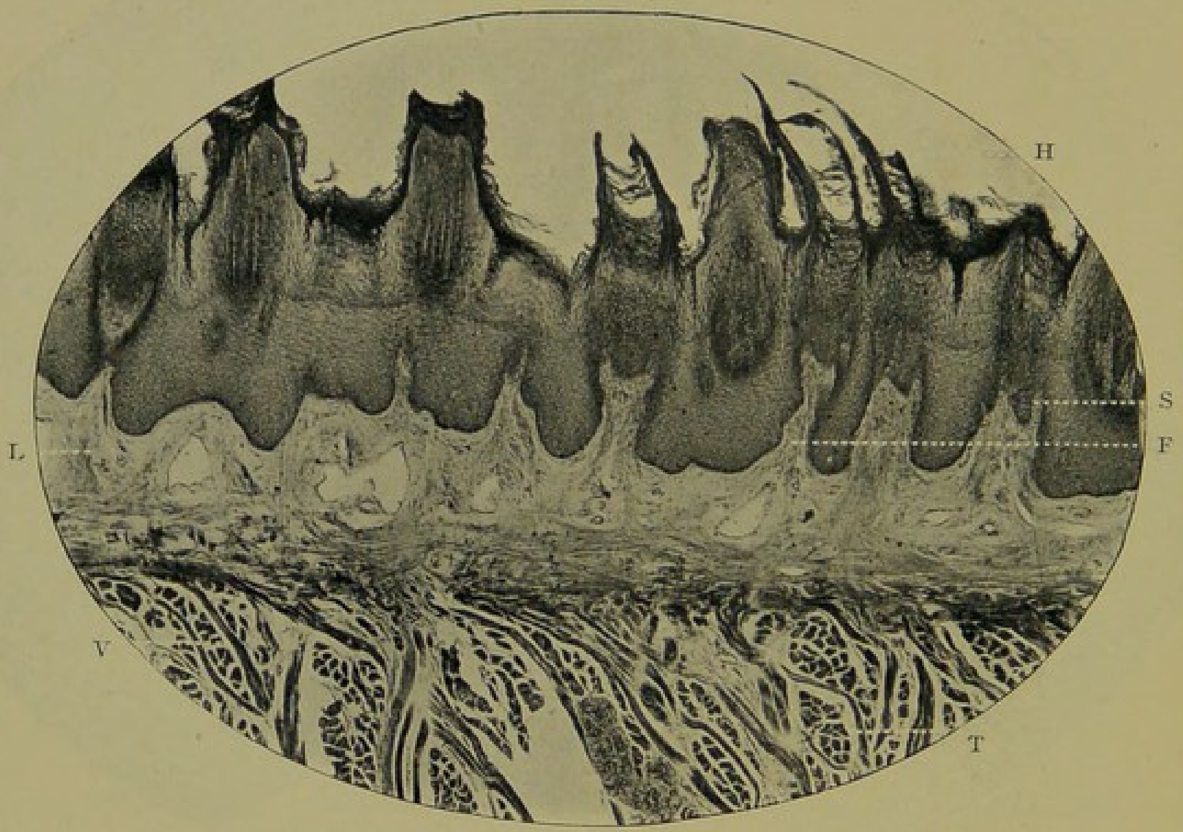


Fig. 164.—Vertical section of tongue of man. Prepared in the usual way. Stained wit hæmatoxylene. Magnified 70 times. F. Conical papilla; S. Secondary papilla; H. Epithelium of laminated structure between the papillæ, and extended into ciliiform processes over it. L. Lymphoid tissue; V. Muscle fibres cut vertically; T. Muscle fibres cut transversely.

As already stated, the papillæ are of three kinds:—

(1) *The conical papillæ* abound all over the dorsum, but are absent from the base of the tongue. In shape they are tiny elevations with tapering or cone-shaped extremities. They are the smallest of the three varieties, measuring, in man, to the base of the mucous membrane, 0·9 mm. to 1·0 mm. in length.

Their secondary papillæ are peculiar and unique in containing great quantities of elastic fibres, and being clothed by special epithelium of cornified nature, which "forms a separate horny process over each secondary papillæ, greater in length than the papillæ which it covers." (Schäfer)

When a bundle of these thread-like projections exists over the conical papillæ (which are often quite devoid of them), the term "filiform" is employed to designate the character of the papillæ. They are easily found on the surface of the tongues of cats and other carnivorous animals.

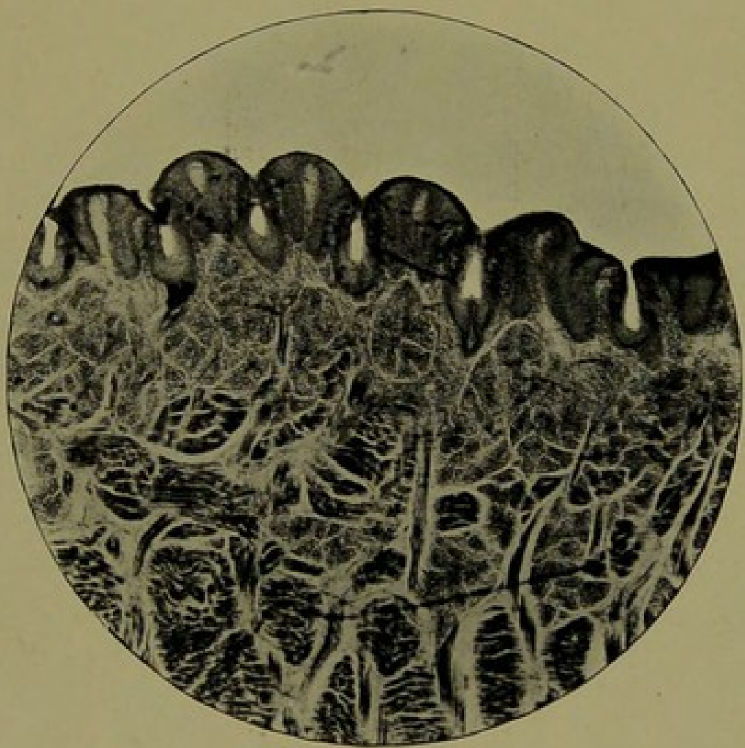


Fig. 165.—Fungiform papillæ with gustatory cells of tongue of rabbit. Stained with carmine. Magnified 30 times.

(2) The fungus-shaped elevations which beset the middle and fore part of the tongue are called *fungiform papillæ*. In the recent state they are of a bright red colour. Possessing blunt rounded extremities, they are attached by narrow foundations.

(3) Most interesting of all, are the *circumvallate papillæ*, so called from their environment. Each is placed in a poculiform depression of mucous membrane, and has a cone-shaped appearance, surrounded as it is by a trench or *fossa*, on the

outer free margin of which is a slight elevation of mucous membrane. This, completely circling the papilla, is the *vallum*, which is comparable to a rampart. Hence the name.

These papillæ are very few in number, sometimes not more than a dozen existing on one tongue. They are located on

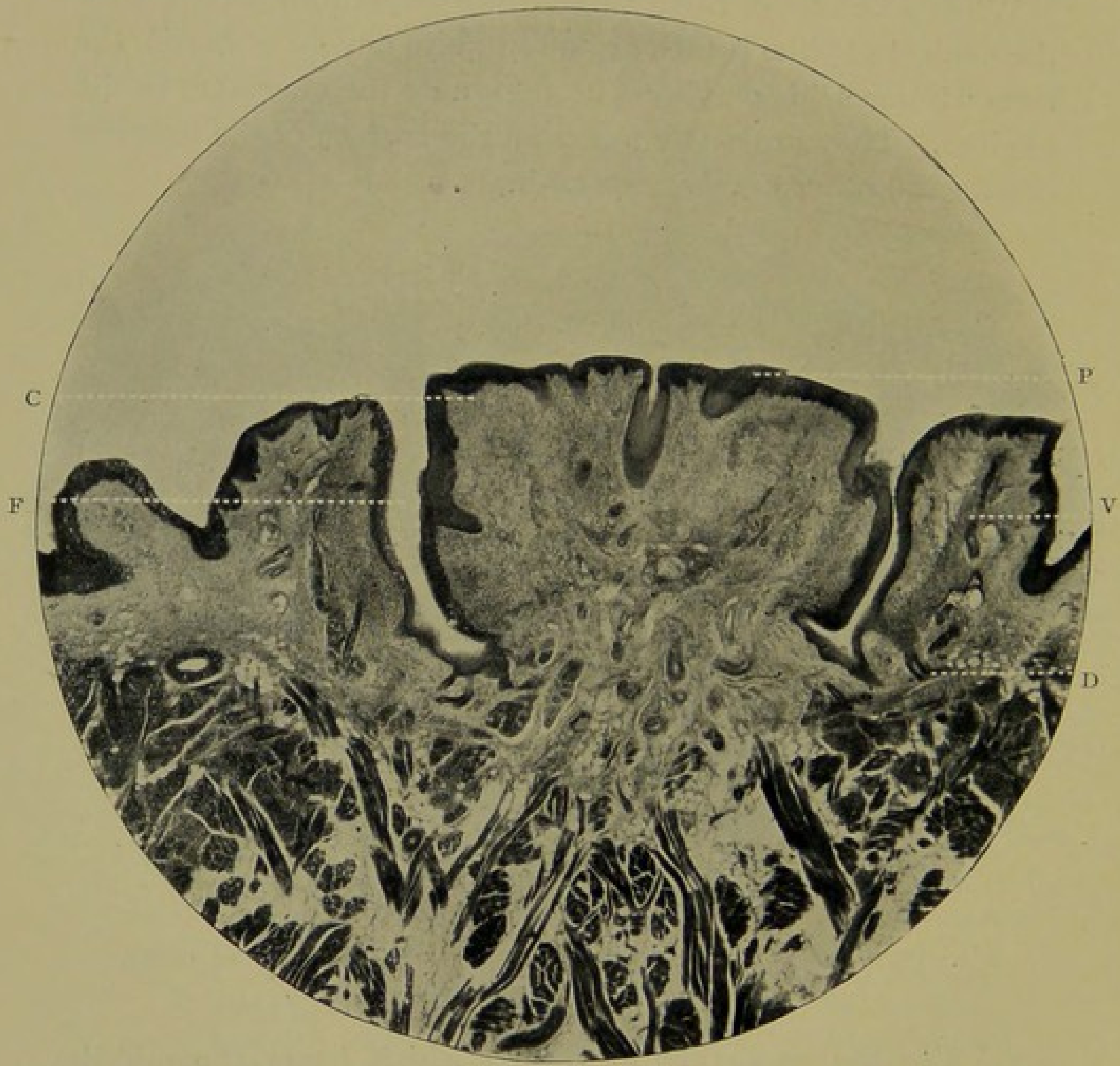


Fig. 166.—Circumvallate papilla of the tongue of man. Prepared in the usual way. Stained with hæmatoxylene, and counter-stained with eosine. Magnified 30 times. P. Circumvallate papilla (its epithelium); F. *Fossa*; V. Vallum; D. Duct of gland opening into base of fossa; C. Corium of papilla.

the posterior third of the organ, arranged in two rows, which meet together at a point, like the arms of the letter V. In width they may measure as much as 2·5 mm.; width inclusive of the vallum on either side 4·5 mm. In addition to the vascular and nervous supply of the corium, the stratified epithelium which is extremely thick, contains in it several "taste buds or goblets," both on the sides of the papilla itself and in the mucous membrane of the *fossa*. At the base of the *fossa*, which may measure 1·25 mm. in depth, the openings of the ducts of one or more glands can be seen.

"Taste-buds" are oval in outline, and consist of a collection of narrow and fusiform gustatory cells, all enclosed by a single

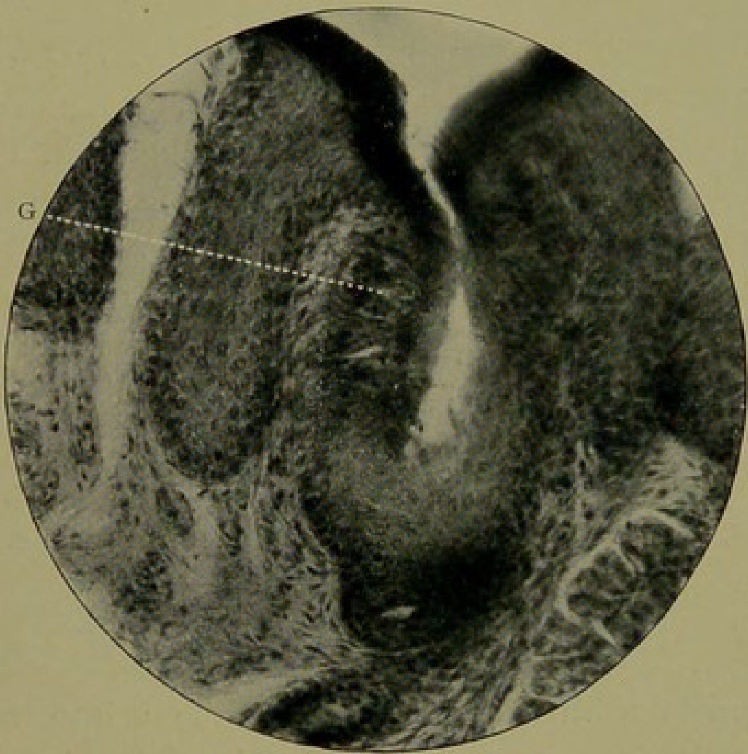


Fig. 167.—The gustatory cells in a fungiform papilla of the section photographed in Fig. 165. Magnified 300 times. G, Goblet or gustatory cells.

layer of broader fusiform cells, the *encasing cells*. A slight depression in the lingual epithelium over the goblet has at its base, a group of fine trichinous processes, which are the termination of these gustatory cells.

The base of the tongue contains many mucous glands. They are large and broad, their dimensions, in man, being 1·4 mm. in width, and even 3·0 mm. in length. They possess the usual histological features of mucous glands generally. (Fig. 168).

THE SALIVARY GLANDS

The parotid, sublingual, and submaxillary glands secrete saliva.

In man, the former is composed of alveoli of serous cells; the sublingual of mucous alveoli, and the latter of both, though the serous alveoli preponderate. According to its secretion, so do the histological elements of each gland differ.

HISTOLOGY

They are compound racemose glands (Fig. 171), consisting of an aggregation of lobules, each of which has a duct which, after branching, terminates, on the one hand in fine small branches into which the alveoli of the glands open, and on the other, in larger ducts which ultimately end by a free orifice on the surface of the mouth. Many blood-vessels ramify in a small amount of loose connective tissue, which forms the investment for the lobules, and for the gland itself. In the last situation, the capsule contains ordinary flattened cells, a few granular plasma-cells, lymph corpuscles, and occasionally a little adipose tissue.

Ducts

Histologists arbitrarily divide the ducts into an *intra-lobular part* and an *intercalary part*. The *intralobular portions*, larger than the rest, and near the free opening of the duct, are lined with epithelium of which the cells have the following characteristics:—They are large, columnar or conical in shape, with their truncated extremity directed towards the lumen: they have a centrally-placed spherical nucleus: they are granular at their inner and finely striated at their outer extremities. (See diagram, Fig. 172).

The fibrillated markings are well seen in the submaxillary gland.

The large ducts are covered with a coating of fibrous and elastic tissue, intermingled with a few small muscular fibres.

The *intercalary portions*, shorter and narrower than the preceding, extend to the alveoli, and are lined with clear flattened cells, possessing elongated nuclei, at their most distal part. As they approach the intralobular ducts, their

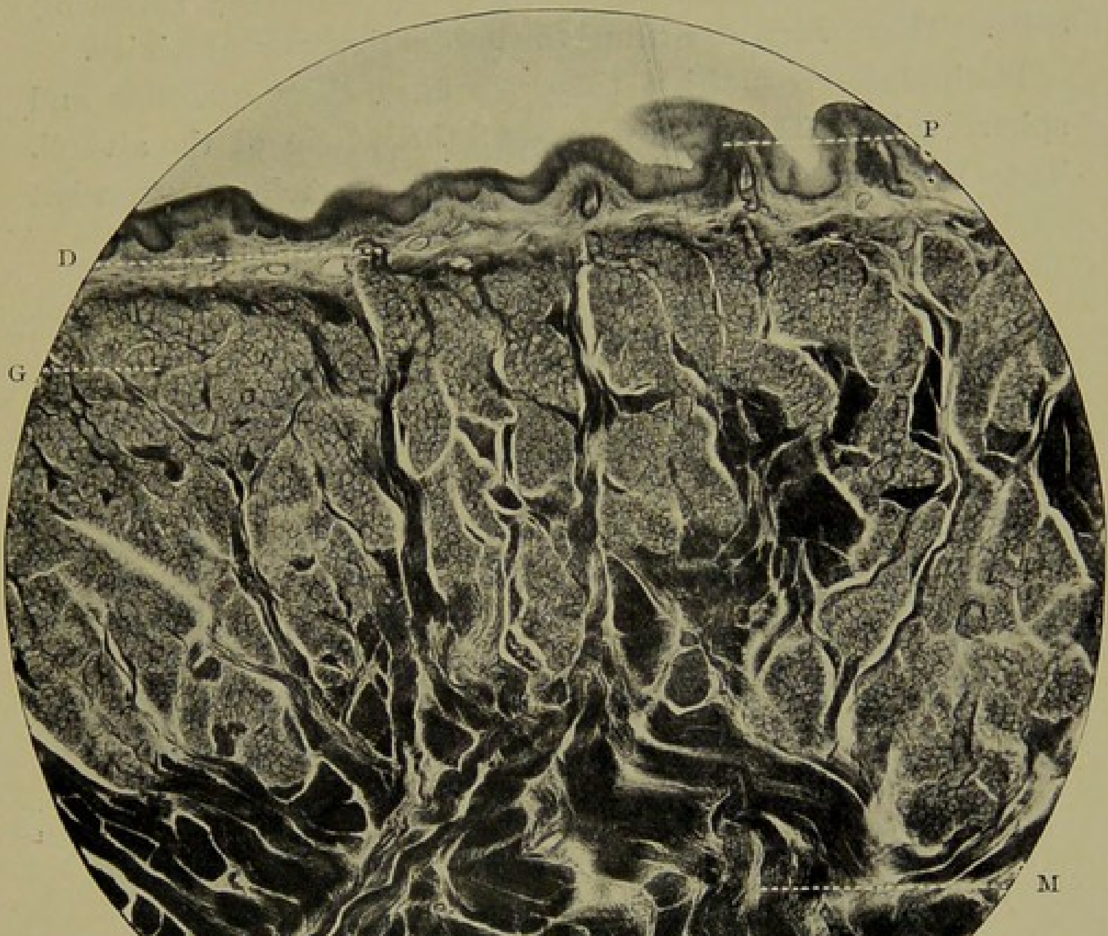


Fig. 168.—Vertical section through base of the tongue of man. Prepared by hardening in 3 per cent. nitric acid, and subsequently staining with methylene-blue. Magnified 25 times. G. Mucous gland; D. Duct of gland opening on to the surface; P. Conical papilla; M. Muscle fibres.

lumina are lined with cubical cells with small nuclei. (See Figs. 173 and 174).

Alveoli

Alveoli constitute the secreting part of the glands, and are of two kinds : (A), mucous, (B), serous.

A

Mucous Alveoli

Bounded by a delicate reticulated basement membrane, each alveolus is lined by a single layer of true secreting cells. These vary according to their activity or passivity.

In the latter condition they are large clear granular and spheroidal in shape, and nearly fill the whole of the alveoli. They take stains very indifferently. Each nucleus, somewhat

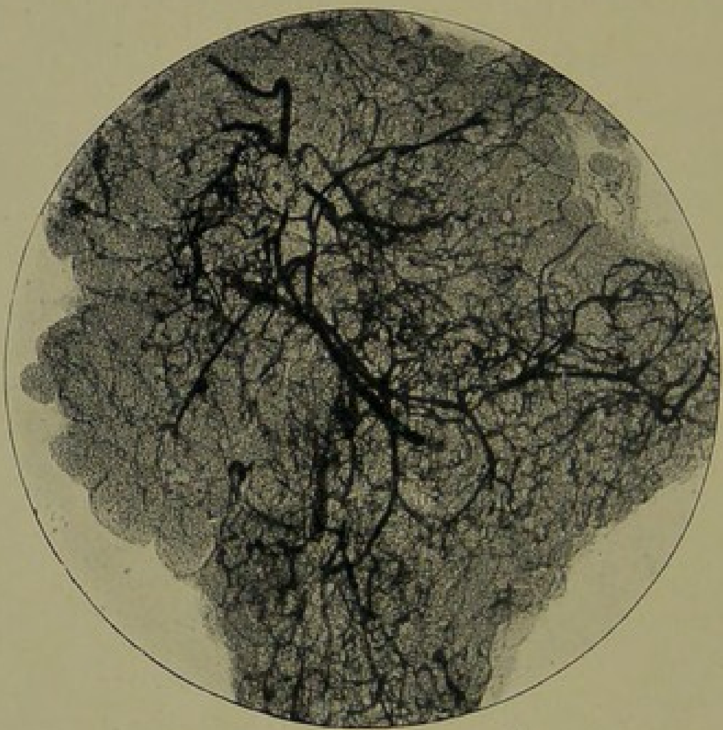


Fig. 169.—Transverse section of salivary gland of cat, stained with picric acid, blood vessels injected with carmine. To shew its abundant vascular supply. Magnified 30 times.

flattened, is placed near the basement membrane. The transparent appearance is due to the presence of mucin or mucigen.

In addition, there are also found certain marginal cells, the *crescents of Gianuzzi* (the *demilunes* of *Heidenhain* of some authors). They have semilunar outlines, are small, very granular, and stain deeply with the usual dyes.

In an active state, as the result of stimulation, the cells stain readily, become rather smaller and more granular, and the nuclei, now no longer compressed, occupy the central parts of the cells. (See Figs. 175 and 176)

B

Serous Alveoli

At rest, these cells, when properly prepared and stained, are granular, with their nuclei in their centres completely

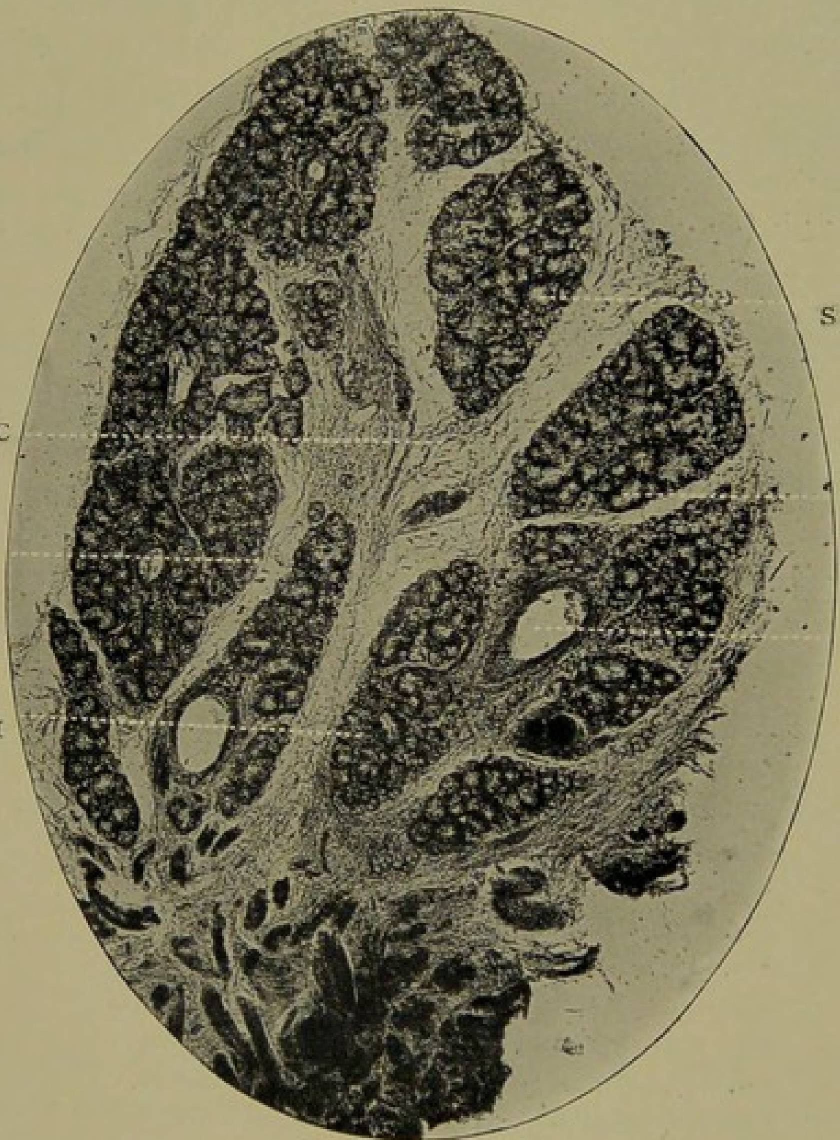


Fig. 170.—Submaxillary salivary gland of man. Prepared in the usual way. Stained with Ehrlich's acid hæmatoxylene. Magnified 20 times. Shews several lobules. S.S. Serous aveoli; M.M. Mucous alveoli; B. Blood-vessel; C. Connective tissue between the lobules.

obscured by the albuminous material in their protoplasm. The lumen similarly to that of a mucous alveolus is frequently totally occluded.

During a period of prolonged activity, the cells appear to be shrunken, a few granules have collected in their inner aspects, the nuclei are clearly revealed and easily recognised, and the lumen is large and patent. These changes are depicted in the accompanying diagrams (Figs. 177 and 178).

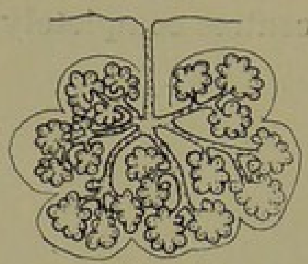


FIG. 171.

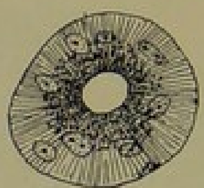


FIG. 172.

FIG. 173.

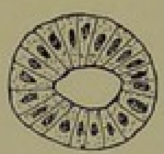


FIG. 174.

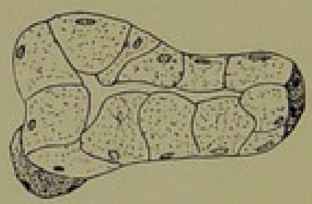


FIG. 175.

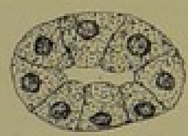


FIG. 176.

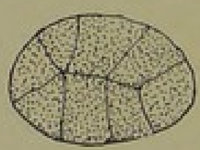


FIG. 177.

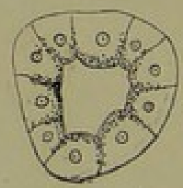


FIG. 178.

Fig. 171.—Diagram of a racemose gland.
Fig. 172.—Intralobular duct.
Fig. 173.—Mucous intercalary duct.
Fig. 174.—Serous intercalary duct.
Fig 175.—Mucous gland during a period of passivity.
Fig. 176.—Mucous gland during a period of activity.
Fig. 177.—Serous gland during a period of passivity.
Fig. 178.—Serous gland during a period of activity.

HARD AND SOFT PALATE

The histology of the osseous framework, and fibrous covering of the roof of the mouth requires but a brief survey, reference to its bony structure having been already made in Chapter VI.

HISTOLOGY

The surface is covered with a thin layer of periosteum, and stratified mucous membrane. Of the former nothing need further be said, its character being similar to that of the periosteum of bones generally ; the latter, however, thrown into folds (*palatal rugæ*) exhibits the same characteristics as in other parts of the mouth, except that in these ridges, as well as in the *papilla palatina* or incisive pad, the cells are larger, coarser, and more multiplied than elsewhere.

The vascular and nervous supplies are scanty, as is also the number of mucous glands.

The soft palate consists of muscular fibres, and a great number of glands all clothed with mucous membrane, which is covered on the anterior surface with squamous epithelium, and on the posterior surface with ciliated columnar cells. It measures approximately 10 mm. in thickness.

The uvula consists chiefly of compound racemose glands, and they abound in great numbers on the anterior surface of the soft palate where they form an almost complete layer under the squamous stratified epithelium.

THE TONSILS

The tonsils are soft, very vascular bodies placed between the anterior and posterior palatine arches or pillars of the fauces.

HISTOLOGY

They are composed of loose connective tissue of a soft character, the substance of which is permeated or infiltrated with lymphoid cells. Dense masses of these cells are collected here and there, and form the lymphoid follicles of the tonsil. The latter are large oval or round bodies having a breadth, in man, of 1·5 mm., and a length of 3·25 mm.

The framework of the follicles is a delicate stroma of fine retiform connective tissue, similar to the white fibres of areolar tissue. Hence it contains no nucleated cells as such, but trabeculæ of fibrous tissue surrounded by an open network of fibres more or less densely aggregated.

The cells contained in these are lymphoid cells, which resemble white blood corpuscles. They differ, however, in the

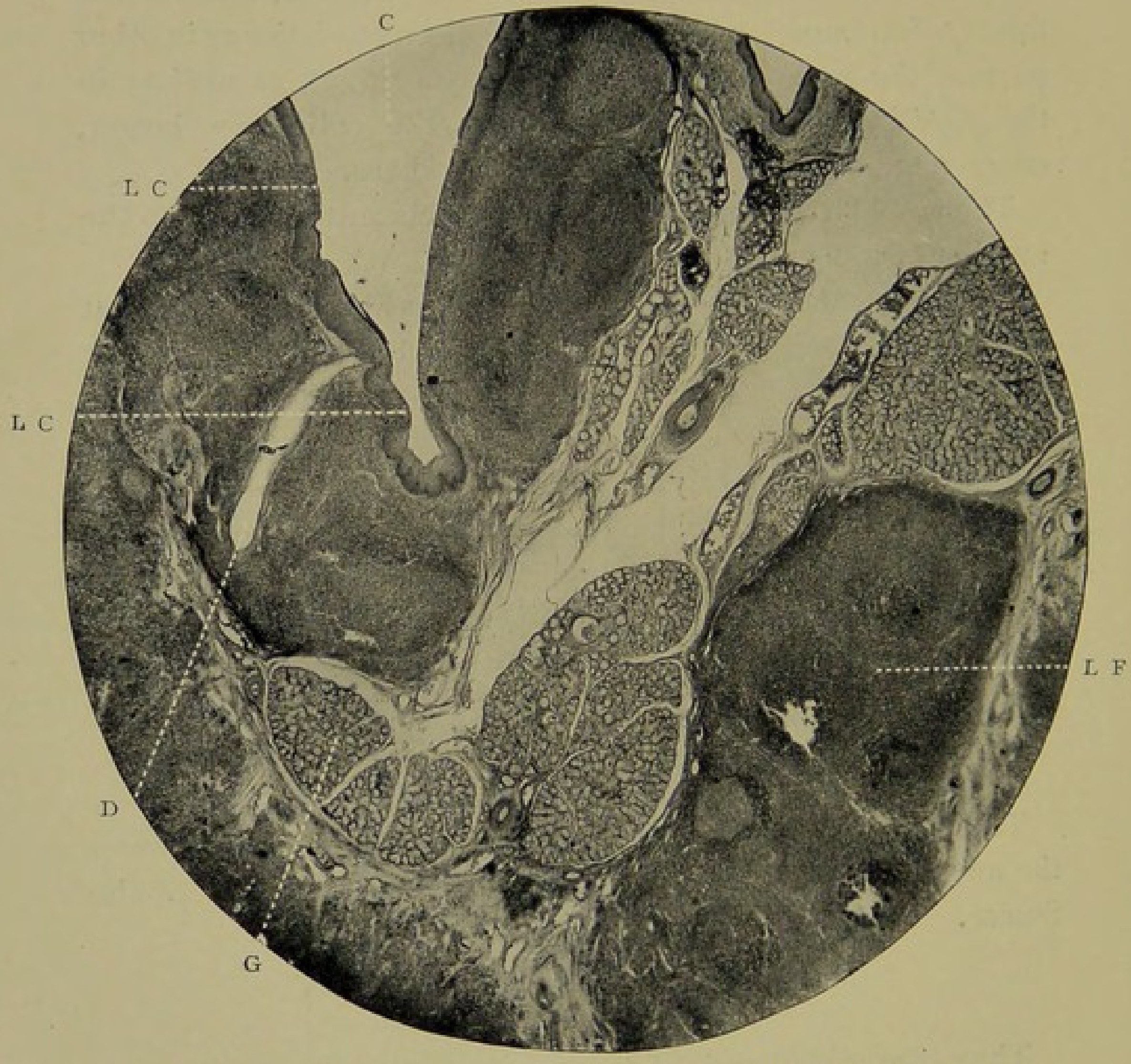


Fig. 179.—Vertical section of tonsil of man. Prepared by fixing and hardening Stained with hæmatoxylene; counter-stained with eosine. Magnified 60 times. L F. Lymphoid follicle; C. Crypt of tonsil; L.C. Lymph cells passing through the epithelium of crypt; G. Mucous gland; D. Duct of same, opening into the base of crypt.

facts that they have less protoplasm, and a relatively larger nucleus.

Stratified epithelium extends over the tonsil. Opening on the free surface of the organ are numerous crypts or clefts into which the stratified epithelium dips, being continuous all over except at the tiny orifices of a few mucous glands, the ducts of whose alveoli open on to the surface of the crypts.

Lymphoid cells pass through this epithelial layer or cells rom the follicles; become free and detached on the surface; and mixing with the saliva, appear as the so-called salivary corpuscles.

Part II

THE HISTOGENESIS OF THE TEETH OF MAMMALS
FISHES, AND REPTILES

CHAPTER XII

THE DEVELOPMENT OF THE TEETH IN MAMMALIA

MICROSCOPICAL ELEMENTS IN :—(i) The Enamel Organ ; (ii) Dentine Germ ; (iii) Dental Follicle. (iv) During later periods of the formation and growth of the enamel, dentine, and cementum ; and (v) Appearances in human embryos at half term.

For purposes of description it will be convenient to divide the series of phenomena which take place during the histogenesis of the deciduous teeth and surrounding structures, into :—

(A) The changes occurring in the jaws before and up to the period of formation of the dentine germ.

(B) The metamorphoses occurring in and around the tooth germ at the period of formation of the dentine germ.

(C) Subsequent stages of development.

A

Earliest Phases of Evolution

At a very early period of intra-uterine life in man, viz., about the 40th to 45th day, the embryo measuring about 12cm. in length, the first signs of change are noticeable.

(i) *Changes in the Epiblast*

Coronal sections through the anterior part of the embryonic head before this age show that there is a slight appreciable thickening of the stomodæal epiblast over the regions of the embryonic alveolar processes, that is, the promontories of tissue known as the maxillary processes of the embryonic face, which, having met the lateral plates of the fronto-nasal process, have continued their growth downwards and inwards, and joined the mid-frontal process to complete the alveolar arch and maxillary bone. In the mandibular arch the changes begin above the cartilage of Meckel, and at spots a little external to the primitive elevation of the tongue.

The contour of the rete Malpighii is undisturbed in its clear outline and flattened appearance.

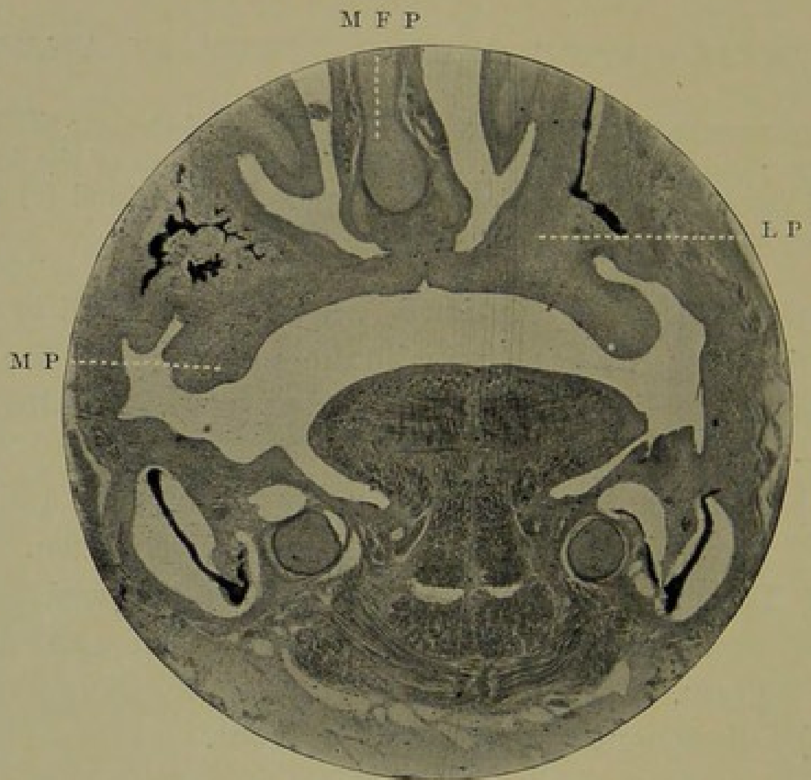


Fig. 180.—Coronal section through head of a human embryo, exact age unknown. Prepared as other soft tissues. Stained *en masse* with borax-carmine, and cut in paraffin wax. Magnified 20 times. To shew the development of the maxillæ. M.P. Maxillary process; M.F.P. Mid-frontal process; L.P. Lateral plates of fronto-nasal process.

The epithelial surface of the mouth is extremely thin and undeveloped, consisting of a few flat cells, while the rete Malpighii is almost indistinguishable from the rest of the epiblast. A great depth in the mucosa is noticed, and the bones which will ultimately form the crypts of the teeth are beginning to appear and stain deeply.

In the kitten, the start in the development of the bony alveoli is delayed at this time, and even later; but in man the osseous framework begins to assume a somewhat different shape, and is a prominent feature in specimens of an earlier date than the 40th day.

At this age, however, a marked metamorphosis in the epiblast can be observed.

(ii) *Formation of the Dental Furrow.*

Its free surface appears to be slightly indented ("*The primitive dental furrow*"), in most cases, and follows fairly

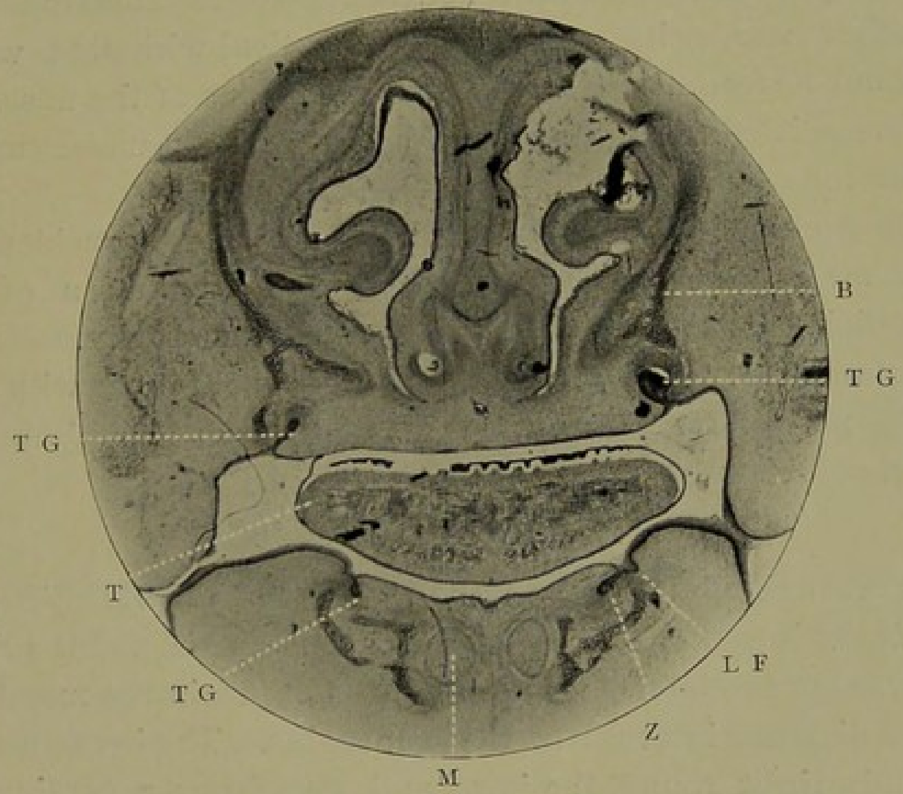


Fig. 181.—Coronal section through head of embryo of cat. Prepared and stained as last figure. Magnified 20 times. Represents the stage of development in man at about the 50th day of intra-uterine life. T.G. Tooth germ; Z. Tooth band; L.F. Lip-furrow; T. Tongue, M. Meckel's cartilage; B. Commencement of formation of bone of alveolus.

closely the lines of contour of the rete Malpighii. Over the palate in places, it is one cell thick, but over the floor of the buccal cavity, as well as its sides, and the sides of the roof, four, five, eight, or even nine rows of cubical or polygonal cells can be counted. The large size of their oval nuclei arrests attention. The cubical cells are set on what looks like a delicate line or basement membrane. A few small flat squamous cells are often found here and there, coherent to the surface epithelium.

As the epithelium approaches the place where the *primary inflection* is about to occur, it becomes thickened.[1] The nuclei become considerably elongated, and almost fill the cells which themselves have undergone some amount of lengthening.

The epithelial surface is clearly distinguishable from the underlying tissues, for two reasons :—It takes the stain more intensely, and its cellular constituents are crowded together. In other words, its appearance is identical with that which is about to form the Schneiderian membrane of the nose, the surface epithelium of the skin of the face, and the under surface of the tongue.

The epiblast would appear to be formed some considerable time after the mesoblast, that is, it is an involution of the superficial layer of the blasto-derm reflected backwards into the mesoblast. Its genesis is probably synchronous with that of the nasal fossæ, external skin, and mucous membrane of the cheeks.

(iii) *The Primary Epithelial Inflection*

In coronal sections of the maxillæ the *first epithelial involution* into the subjacent mesoblast begins at a spot a little external to the lateral margins of the tongue, in the mandible some distance internal to those margins. The invagination extends right round the jaws, and thus forms a continuous semi-circular band of cells enclosed by mesoblastic tissue. In vertical sections it looks like a narrow finger-like penetration of cells into the mesoblast: in side section it is seen to be a continuous flat band extending from the surface into the jaw.

(i) *Origin of the Lip-furrow and Tooth-band*

At the 40-45th day a splitting of this primary inflection occurs, not across, but in a longitudinal direction with it ; thus

[1] This epithelial thickening is greatest along the line of the future jaw on the surface of which it extends longitudinally, and is produced by sub-division and repeated multiplication of the deepest cells.

it becomes divided into two parts, an outer and an inner. The former is towards what will be the lip side, the latter towards the tongue. The former, known as the *labio-dental strand*, or *lippenfurche*, or *lip-furrow*, passes in a perpendicular direction, and ultimately produces the groove which is afterwards the furrow between the lips and the alveolar processes of the jaws : while the latter, known as the *common dental germ*, the *zahnleiste*, or *tooth band*, is penetrating the mesoblast in an horizontal direction, and becomes the layer of cells, in connection with which both the deciduous and permanent teeth are developed.

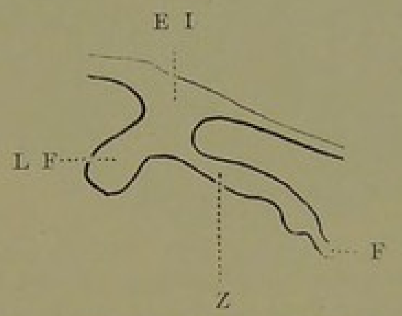


Fig. 182.—Diagram to shew method of cleavage of the primary epithelial inflection. E.I. Ingrowth of epithelium; L.F. Lip-furrow on outer or buccal side; Z. Tooth band on lingual side; F. Free growing end whence the permanent tooth germs will arise.

The opposing theories regarding the relations to each other of lip furrow and tooth band may be, here, briefly noted. Thus :—

(i) Röse[1] affirms that both have a common origin, as just described.

(ii) Baume[2] believes that the tooth band arises from the side of, or is merely a process of the lip furrow, an opinion shared also by

(iii) Xavier Sudduth,[3] who says :—" The lamina is only an offshoot from the side of the band, which becomes somewhat shallower, and in some instances disappears."

[1] "Archiv. f. mikros. Anatomie." Bd xxxviii., 1891, and "Anat. Anzeig," 1896.

[2] "Versuch einer Entwicklungsgeschichte des gebisses," in *Odontologische Forschungen*, 1882.

[3] "American System of Dentistry," p. 620, 1887.

(iv) Leche[1] holds that both are developed separately, but simultaneously.

At this time the tooth band possesses an attached edge or border, which is continuous with the surface epithelial cells, and a free edge or border, which penetrates more deeply inwards. It is from this free edge that the ten temporary tooth germs will be developed.

Still examining the coronal sections through the embryonic head, it is seen that each tooth germ is accurately directed

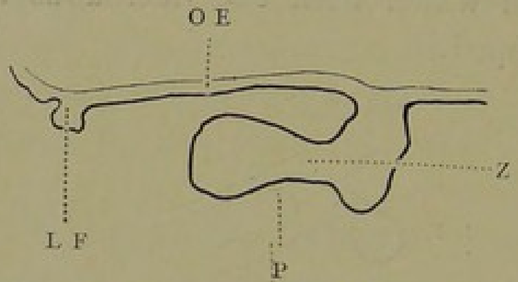


Fig. 183.—Diagram of a sagittal section through the germ of the first mandibular milk molar of a human embryo 30 mm. long. After Röse. O.E. Oral epithelium; L.F. Lip-furrow; Z. Tooth band; P. Site of future dentine germ.

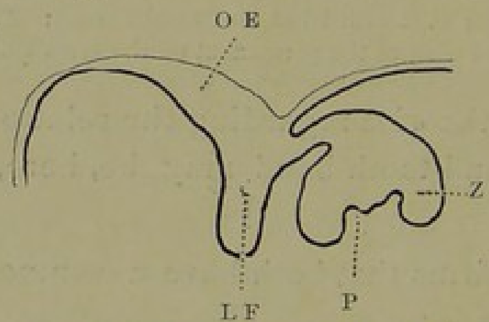


Fig. 184.—Diagram of a similar section to the preceding figure, but through the germ of the canine tooth of an embryo 40 mm. long. After Röse. The lettering as in Fig. 183.

towards the central portions of the developing alveolar bone: thus the direction of growth in the maxilla is upwards and slightly inwards, that in the mandible is downwards and slightly inwards. (See Figs. 181 and 185).

The cells lining the tooth band possess the same histological characteristics as those at its immediate junction with the free stomodæal epithelium; viz., long, cylindrical cells with

[1] "Morph. Jahrbuch" 1892, and "Bibliotheca Zoologica," 1895.

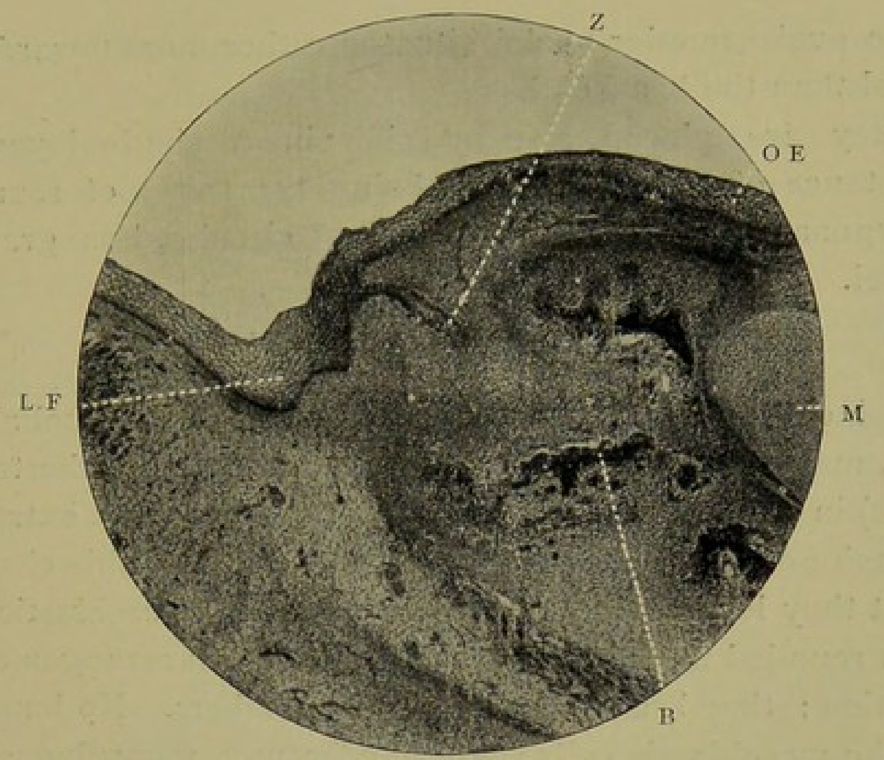


Fig. 185.—Coronal section of the mandible of an embryonic pig. Stained with hæmatoxylene. Magnified 45 times. Represents the stage of development in man at about the 50th day. Z. Tooth-band; L.F. Lip-furrow; O.E. Epithelium of mouth; M. Meckel's cartilage; B. Bone of alveolus.

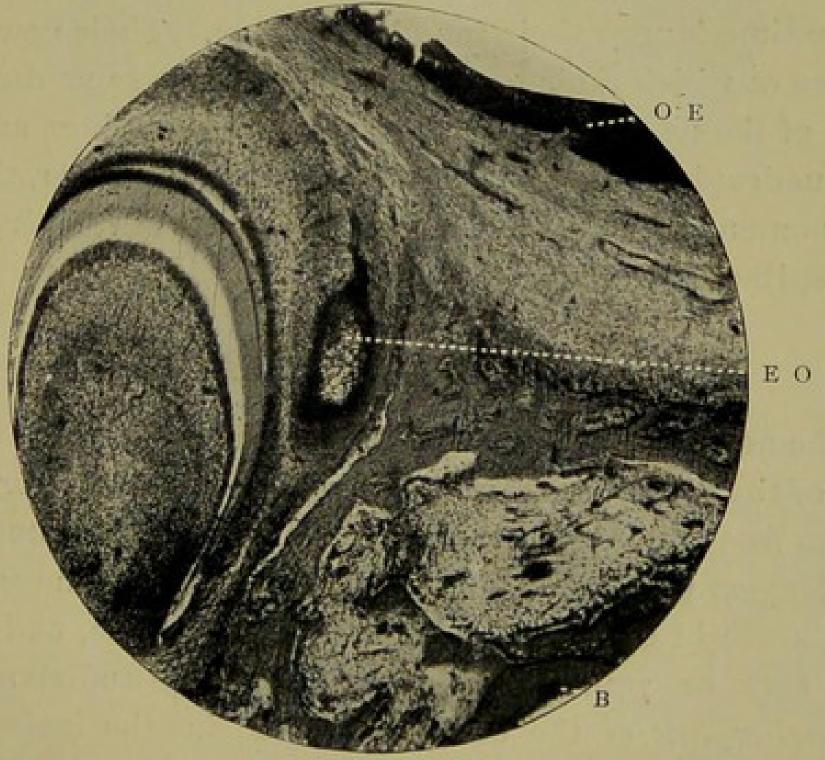


Fig. 186.—Further stage of growth. Magnified 45 times. The tooth germ in the centre of the field represents the stage of development in man at about the 60th day. E.O. First evolution of enamel organ. Lettering as in preceding photomicrograph.

large oval granular nuclei situated rather more towards the distal than the basal end.

They are placed side by side in a single layer, the substance of the tooth band being composed of round or polygonal less distinct cells having circular, less granular nuclei.

(v) *Changes in the Mesoblast*

Coincidentally with these alterations of the epithelial surface, many, *not all*, of the cells of the mesoblast (hitherto discrete) in the immediate proximity of the growing extremity of each germ undergo three distinct and remarkable changes. First they lose their identity as spherical mesoblastic cells with rounded nuclei; they undergo a fresh arrangement of position; they become multiplied in numbers. No longer do all the mesoblastic cells share like features regarding shape, the new change being that many become elongated, and therefore spindle-shaped and have fusiform nuclei. Those nearest the rete Malpighii of the tooth germ retain for some time longer their rounded outlines. Their new position is one in which their long axes take up the same direction as that of the up-growing tooth germ. Their numbers are trebled or quadrupled. It must not be forgotten, however, that these phenomena are only to be observed at the developing end of the epithelial germs.

(vi) *Evolution of the Enamel Organ*

The next step in development is concerned with the deepening of the tooth band and its lateral expansion *near*, but not *at*, its free end, into a bell-like structure. This takes place at its deepest portion, and on its labial side. At the superficial part a slight constriction begins to take place, and at about the 60th or 70th day in man, the first rudiments of the *enamel organs* of the deciduous teeth in the incisor region can be clearly discerned.

At certain spots, ten in number in either jaw, and separated at equal intervals along the continuous zahnleiste these campanular bodies are found. The intervening portion of the tooth band in its anterior part presently atrophies and finally disappears after the lamina has become cribriform, while it still remains continuous in the posterior or molar region. The primitive enamel organs become now specially organised and constituted.

Thus originate the earliest aspects of the enamel organ. In shape such an organ is primarily like a Florence flask or laboratory beaker, having a broad flattened concave base, and long

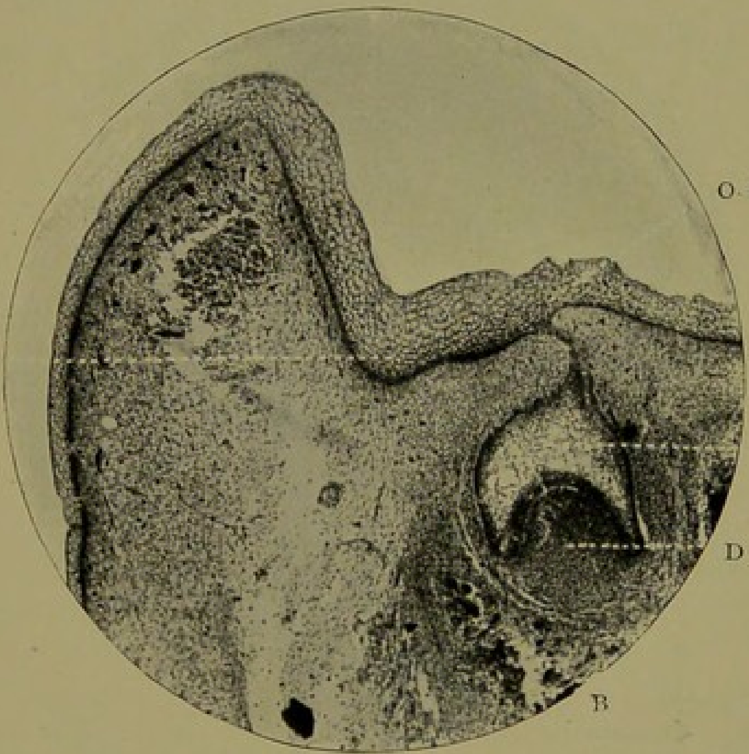


Fig. 187.—Further stage of development. Magnified 45 times. Represents the stage of development in man at about the 70th day. D.P. Rudiments of dentine papilla. Lettering as before.

narrow neck opening on to the free surface of the epithelium of the mouth. At first the outline of the enamel organ is smooth, but later on, the external part will become rather sinuous, due to several "tufts" or "papillary projections" from the subjacent tissue indenting the external epithelial layer of cells. Sometimes the tooth bands and the necks of the enamel organs also exhibit these as collections of polyhedral cells similar to those just mentioned. (See Fig. 212). Capillaries from the dental follicle are freely distributed to these "tufts." (See also Leon Williams's views).

In structure, the external cells still assume a cylindrical character; the deepest are more pronounced than those elsewhere, and they are still continuous with the oral rete Malpighii. The interior is filled with round cells, which however speedily develop long branched extremities, and exhibit, in a rudimentary fashion, the cells of the *stellate reticulum*. It is not yet determined how these internal cells become branched, or exactly in what way the *stellate*

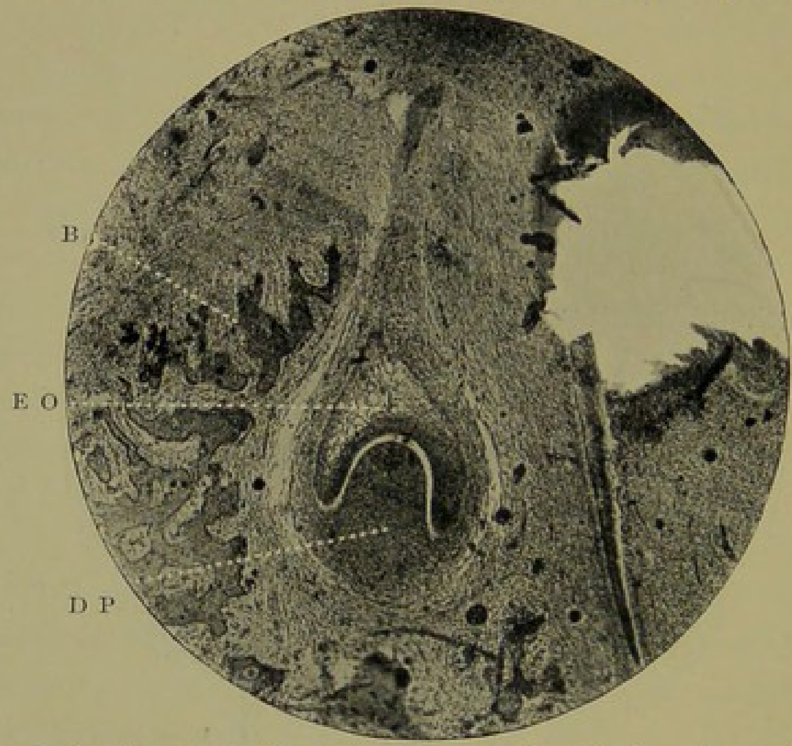


Fig. 188.—Campanular form of tooth germ, from the jaw of an embryonic kitten. Stained with hæmatoxylene. Magnified 45 times. Represents the stage of development in man at 70th day. Lettering as before.

reticulum is formed. Some observers, including Tomes, have thought that they represent cells undergoing retrogressive changes—conditions which point to their ultimate disintegration and atrophy;[1] but Leon Williams holds that they merely represent a sort of intercellular stroma. It is nevertheless certain that lengthy marked branching processes unite them together, their nuclei, in early stages of growth, being in no degree diminished in size, shape, or position.

[1] *Cf.* The degenerating cells in the cysts of epithelial odontomes, described in Chapter XXI.

All the central cells do not become changed into stellate bodies. Certain numbers, close to the deepest layer of the external epithelium, still retain their rotundity, and are ultimately the cells of the *stratum intermedium* which will presently assume their completed shape, viz., that of small polygonal rather branched cells, having connections externally with the stellate reticulum, and internally with the internal epithelium.

Rapid growth now occurs at the margins of each organ, and the whole structure resembles a bell with a handle.

The nearest mesoblast cells, about this time (70th day in man) begin to proliferate and to be more closely approxi-

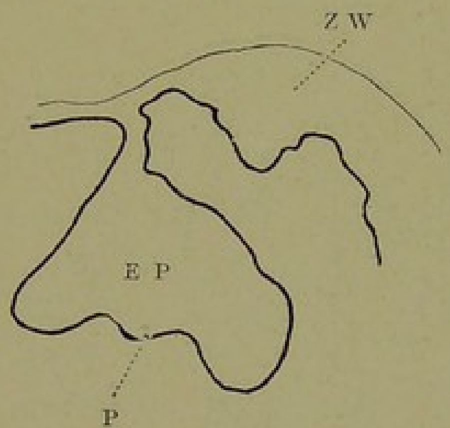


Fig. 189.—Diagram of a section through the germ of the first milk molar of a cow's fœtus, 47 mm. long. After Röse. Z.W. Zahn-wall characteristic of Ruminants; E.P. Enamel organ; P. Site of future dentine germ.

mated, and eight primitive dentine germs are noticed in the concavities of the enamel organs.

The alveolar crypts of the anterior parts have become increased in depth and importance, and begin now to assume a definite poculiform shape.

B

The Metamorphoses occurring in and around the Tooth germ at the period of formation of the Dentine germ

The elongation of the necks of the enamel organs, the transparency of its central portions, the density of the dentine papilla, and the first attempts in the formation of a sac or follicle or investing connective tissue sheath, are now observed (about 100th day).

While the neck of the enamel organ extends more deeply

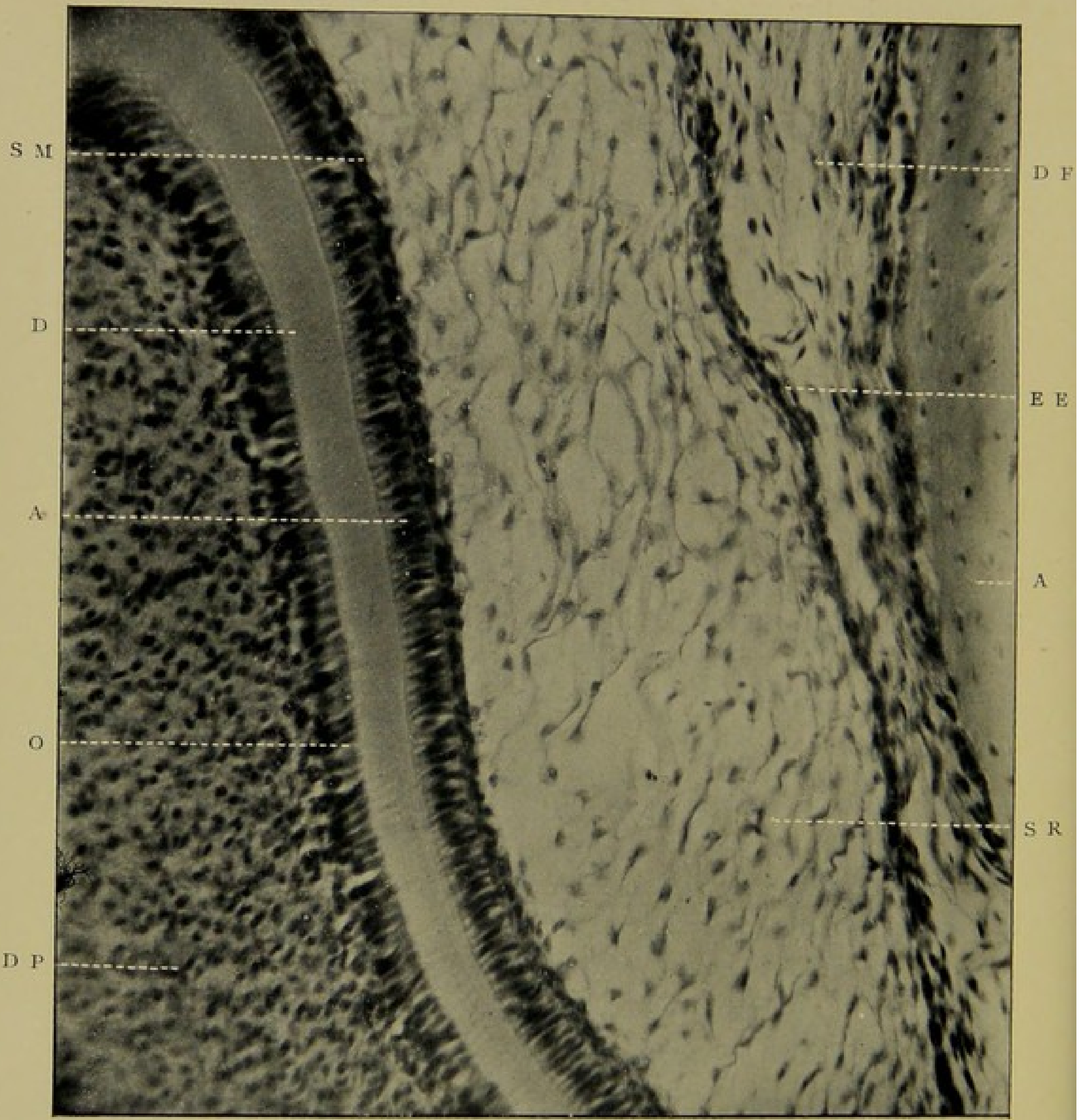


Fig. 190.—Structure of enamel organ. From jaw of a newly-born kitten. Stained with borax-carmine. Magnified 300 times. O. Odontoblasts; D. Dentine; A. Ameloblasts; S.M. Stratum intermedium; S.R. Stellate reticulum; E.E. External epithelium; D.P. Dentine papilla; D.F. Rudimentary dental follicle; A. Bone of alveolus.

than ever into the jaw, it becomes still further constricted, and practically occluded by the apposition of opposite rows of cells.

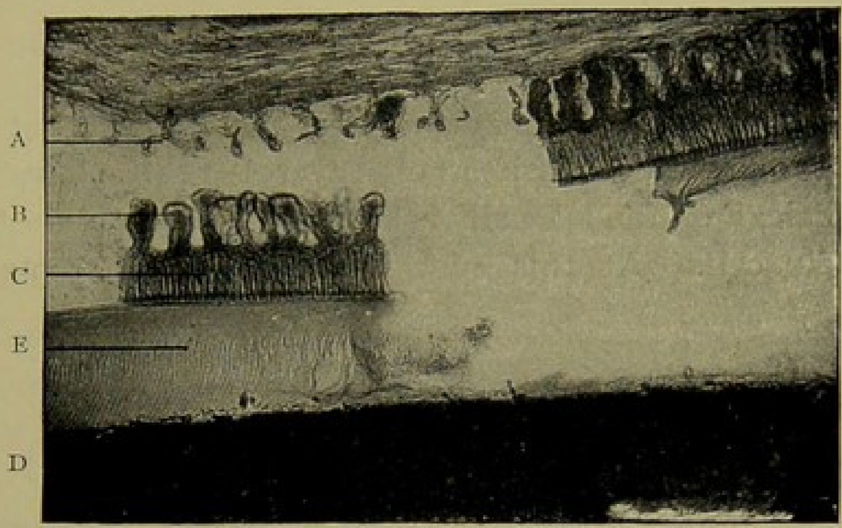


Fig. 191.—Section of incisor of a rat. Magnified 80 times. A. Capillary loops torn out of the secreting papillæ; B. Secreting papillæ after removal of capillary loops; C. Ameloblasts; E. Enamel; D. Dentine. Photomicrograph by Leon Williams.

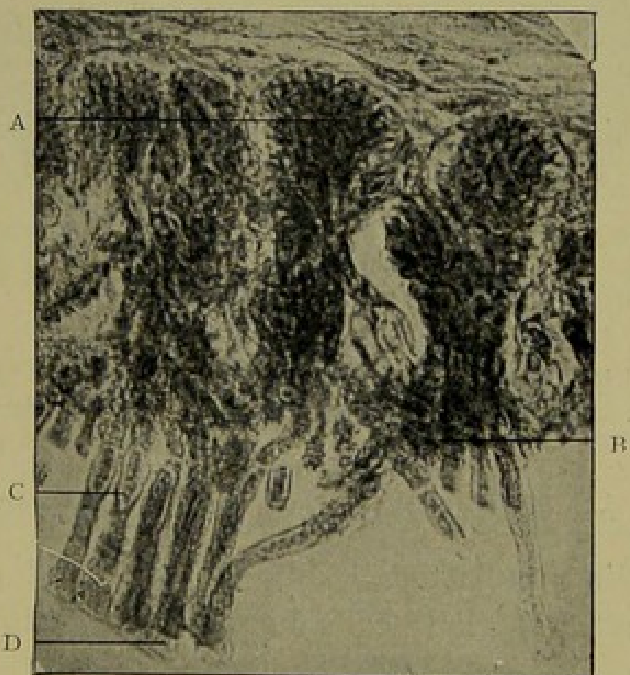


Fig. 192.—Secreting papillæ and ameloblasts from enamel-organ of rat. Magnified 600 times. A. Papilla shewing secreting cells; B. Shewing roots of ameloblasts passing into papilla; C. Ameloblasts containing oval nuclei; D. Plasmic strings and granules emerging from ameloblasts. Photomicrograph by Leon Williams.

The *stellate reticulum* is now near its fullest height of development.

(vii) *Structure of the Enamel Organ*

The periphery of the enamel organ, starting at the neck (at one side) consists of several rows of cubical or cylindrical epithelial cells, whose oval nuclei almost fill the whole cell. At this spot the most external stellate

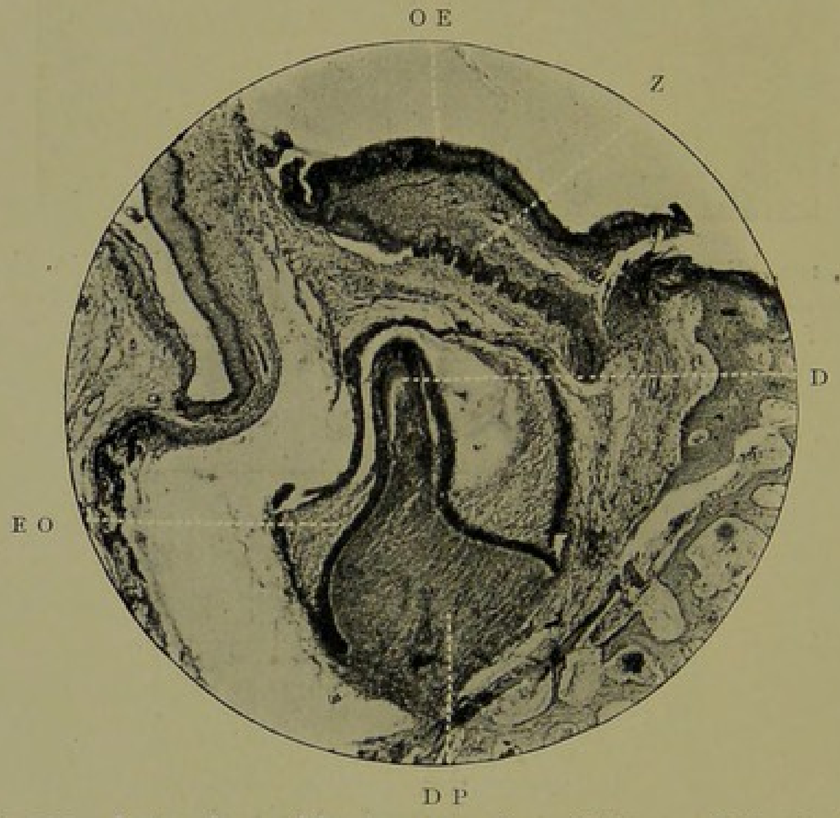


Fig. 193.—Later phase of development. Jaw of kitten. Stained with carmine. Magnified 65 times. Represents the stage of development in man at the 85th day. Z. Tooth band of permanent germ; E.O. Enamel organ; D.P. Dentine papilla of deciduous tooth; D. Earliest trace of formation of dentine; O.E. Oral epithelium.

reticulum cells are flattened and fusiform, and probably represent immature stellate cells, but their transition to the normal shape is sudden and pronounced.

At the deepest part of the enamel organ many ovally-nucleated cylindrical cells are seen, several layers thick. Passing over the convexity of the dentine germ they become aggregated more closely till as a palisading they are most elongated directly over the summit of the convexity.

Above these cells of the *internal epithelium* are now six or seven rows of rounded nucleated cells. It is possibly their function to recruit the former.

Thus beginning from without inwards, the enamel organ consists of (i) *external epithelium*; (ii) *stellate reticulum*; (iii) *stratum intermedium*; and (iv) *internal epithelium*. The latter, soon to be called ameloblasts or enamel cells, are placed side by side on what would seem to be a fine basement membrane. There is no commencement of deposition of enamel.

The cells of the stratum intermedium, according to Leon Williams, form a layer in which blood vessels are developed at a very early stage. This is well brought out in the enamel organs of Rodents. Here the layer seems to be "a highly differentiated secreting tissue." The ameloblasts are surmounted by epithelial papillæ, around and between which is a free distribution of capillary loops. The enamel-forming cells are seen to have an intimate relationship with the papillæ, each apparently having a root-like process which extends into and is lost within the papilla to which it belongs. "The diameter of each papilla is equal to about that of five or six ameloblasts, and each papilla may therefore be said to supply from twenty to twenty five ameloblasts." (Fig. 192).

The papillæ are supposed to originate in spindle-shaped cells.

(viii) *Changes in the Dentine Papilla*

Meanwhile the dentine germ is becoming highly specialized. The round nuclei of the cells crowd together, and apparently are imbedded at the enamel surface in a clear indefinable matrix. The cells are protoplasmic, minus branches; but most deeply of all they become fusiform with long branching processes, and are continuous with similar cells situated immediately outside the neck and the rotundity of the enamel organ. Furthest from the centre they are very narrow, and greatly separated from one another.

The alveolar bone is, at this time, extending towards the

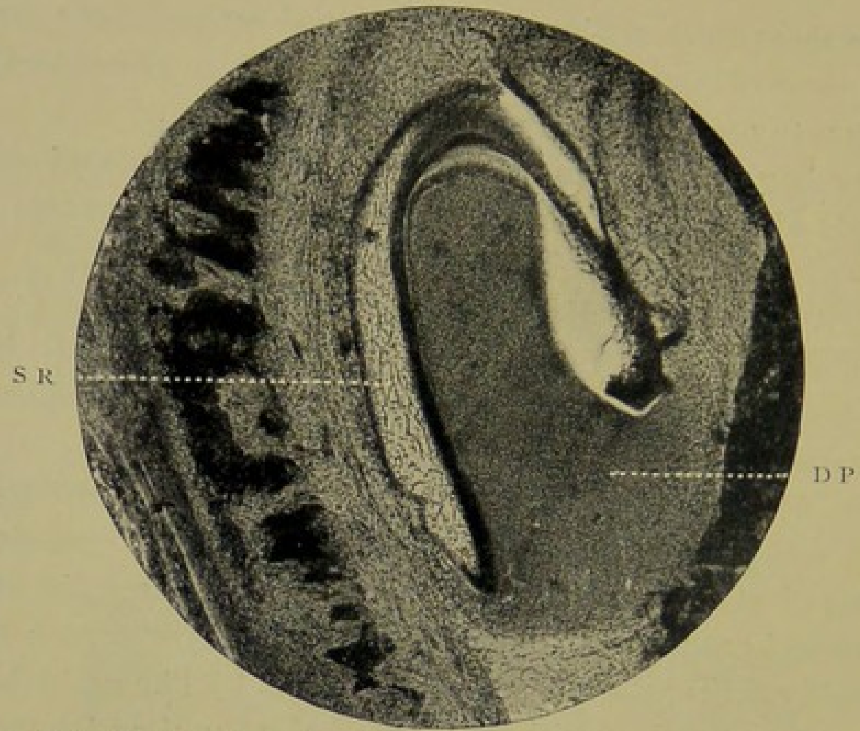


Fig. 194.—Further stage of evolution. Jaw of kitten. Stained with hæmatoxylene. Magnified 60 times. Represents the stage of development in man at about the 90th day. D.P. Dentine papilla; S.R. Stellate reticulum.

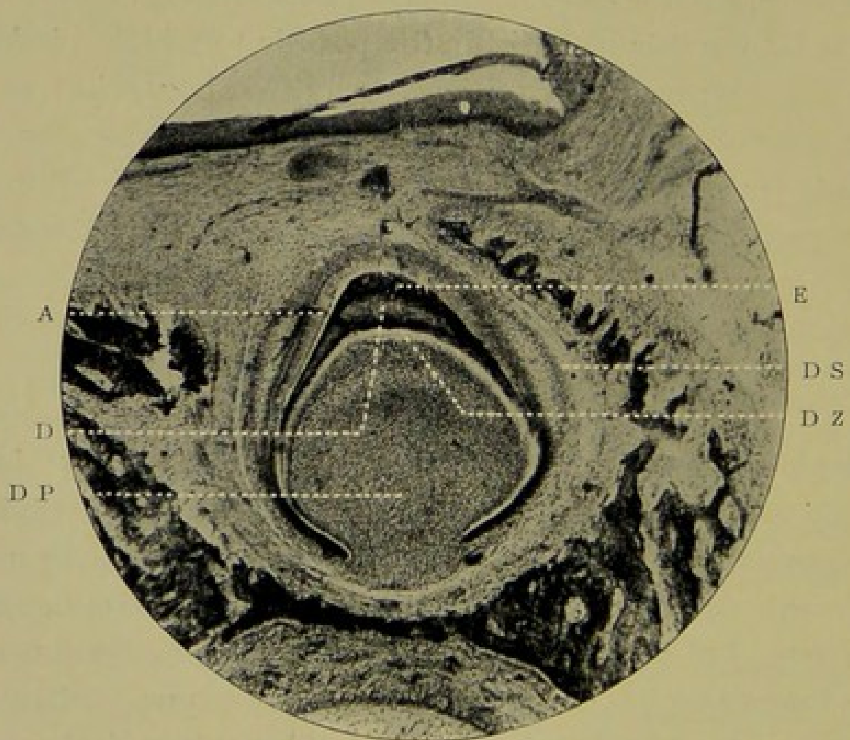


Fig. 195.—Same as preceding, further developed. Same magnification. Represents the stage of development in man at about the 120th day. E. First trace of enamel; D. Calcified dentine; D.Z. Dentogenetic zone; D.P. Dentine papilla; D.S. Dental sac; A. Ameloblasts.

surface, and is encroaching on the necks of the enamel organ.

Shortly after these changes have taken place, the neck of the enamel organ is attenuated to the thickness of two layers of cells; and a tremendous increase in the mass of the stellate cells occurs. The internal epithelium assumes the shape

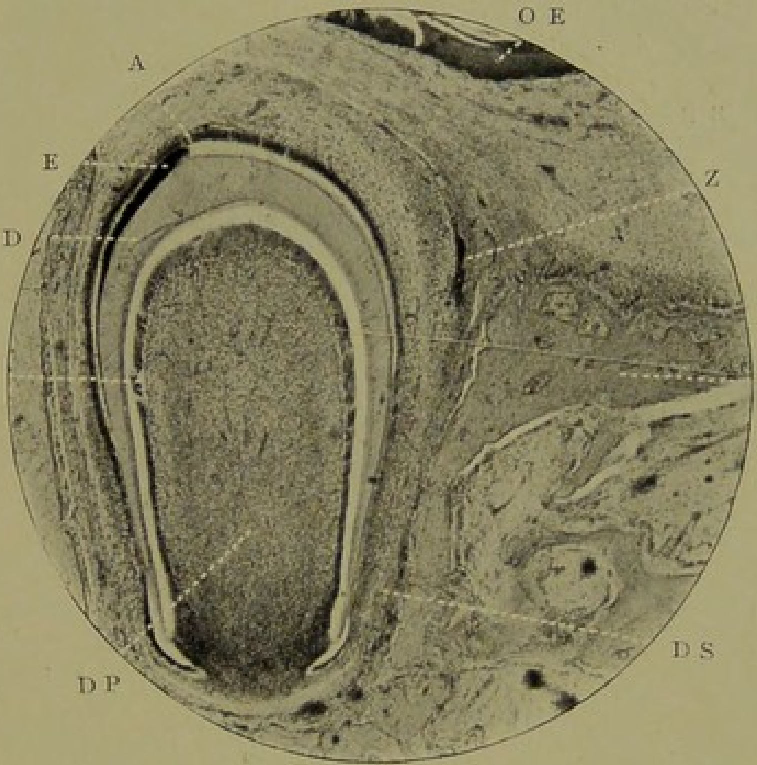


Fig. 196.—Further stage of development. Jaw of kitten. Stained with hæmatoxylene. Magnified 50 times. Represents the stage of development in man at about the 140th day. E. Early formation of enamel; A. Ameloblasts; D. Dentine; O. Odontoblasts; Z. Tooth band of permanent successor; O.E. Oral epithelium; D.P. Dentine papilla; B. Bone of jaw; D.S. Rudimentary dental sac.

of the ameloblasts; and some of the peripheral papilla cells that of the odontoblasts.

At the same time, about the 140th day in the deciduous incisors, the first deposition of formed dentine is seen, followed almost immediately by the darker line of enamel. The external and internal epithelia are still continuous.

C

Subsequent Embryological Changes

The tooth germ, at a later stage, is lodged in a deep, wide-mouthed gutter of bone. The cap of calcified enamel is surrounded by the layer of *ameloblasts*—long columnar protoplasmic cells having prominent nuclei at their distal growing ends. They measure about 5μ in width, and vary in

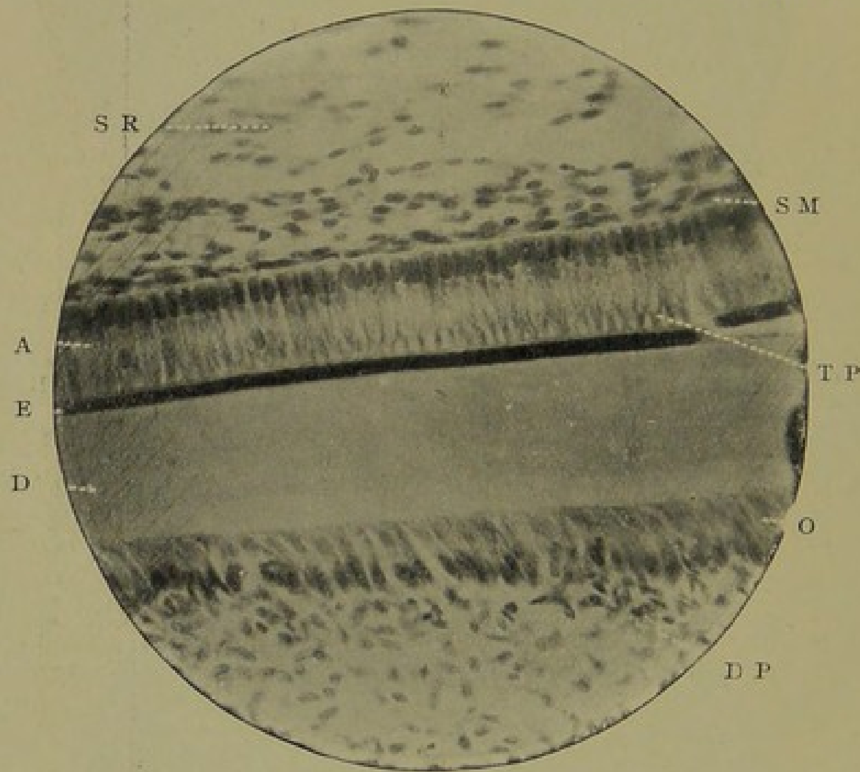


Fig. 197.—To shew early stage of formation of enamel and dentine. Prepared by the chromic acid method, stained with carmine, and imbedded in paraffin-wax. Magnified 320 times. D.P. Dentine papilla; O. Odontoblasts; D. Dentine; E. Enamel; A. Ameloblasts; T.P. Tomes' processes of the ameloblasts; S.M. Stratum intermedium; S.R. Nuclei of cells of stellate reticulum. Photomicrograph by Douglas Gabell.

length from 5μ to 15 or 20μ. At the base of the dentine germ they are cubical in shape, and here attain the former smaller dimensions.

In places where they are torn away from the periphery of the enamel they present tapering processes, "Tomes' processes." This end (viz., that directed towards the dentine), according to Tomes (*op. cit.* p. 160) is slightly enlarged, a fact demonstrated after treating an embryonic tooth germ with glycerine or other hygroscopic reagent. Each ameloblast is granular, and possesses also a delicate reticular structure. (See Fig. 219).

Many instances occur in which the cells appear to be

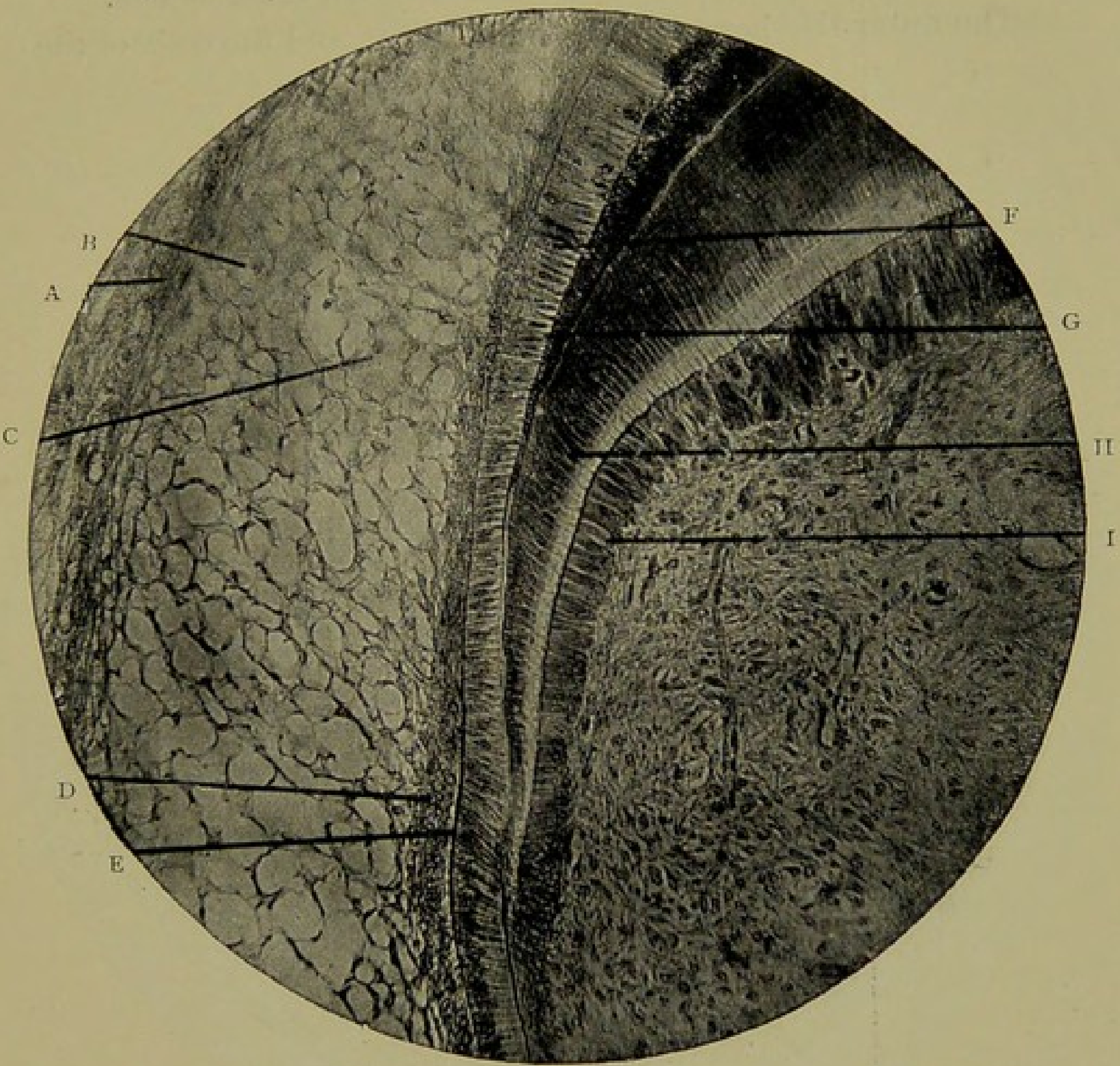


Fig. 198.—Section of developing tooth of human fœtus near the seventh month of intra-uterine life. Magnified 175 times. A. Outer epithelial tunic of enamel-organ in which secreting papillæ are developed; B. and C. Shewing large, round, granular, nucleated cells of reticulum of enamel-organ. The stellate appearance in this tissue is largely produced by shrinkage and the washing away of the cell contents. D. Stratum intermedium; E. Outer ameloblastic membrane; F. Ameloblasts; G. Inner ameloblastic membrane; H. Dentine; I. Odontoblasts. Photomicrograph by Leon Williams.

bounded at either end by lines of basement membrane. To these Leon Williams has given the names the "*inner* and the *outer ameloblastic membranes*."

The former had been previously described by Huxley, Raschkow and others as the *membrana preformativa*.

Both membranes are structureless basement membranes, and are adherent to both extremities of the ameloblasts.

The outer lies between the ameloblasts and the cells of the

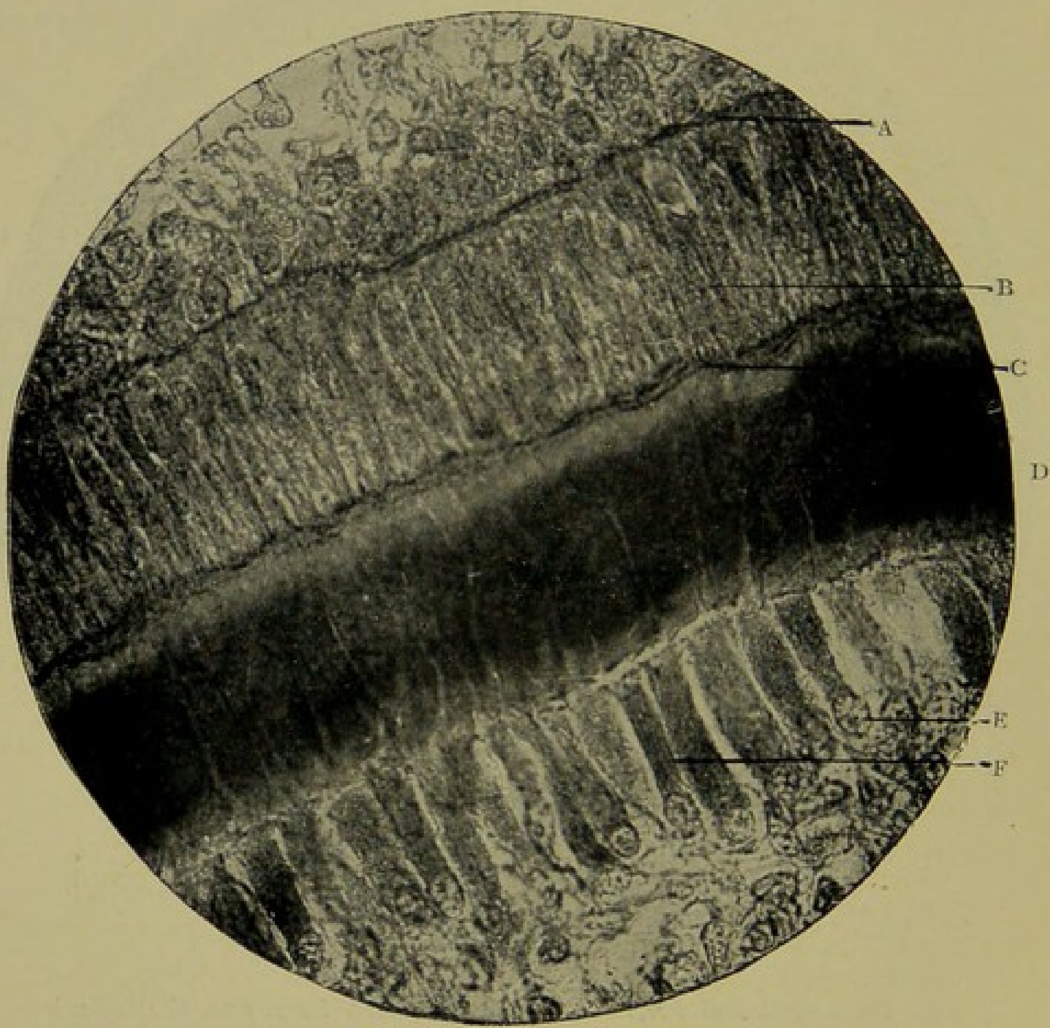


Fig. 199.—Section of developing tooth of embryo calf. Magnified 800 times. A. Outer ameloblastic membrane; B. Ameloblasts shewing net work pattern of plasmic cell-contents; C. Strings of plasmic net-work passing through inner ameloblastic membrane; D. Dentine; E. Reticular nuclei of odontoblasts; F. Net-work structure of odontoblasts. Photo micrograph by Leon Williams.

stratum intermedium; the inner between the ameloblasts and the formed enamel.

Leon Williams describes these membranes very carefully in his contribution to *The Dental Cosmos* for 1896, pp. 110 *et seq.*:—" It is impossible at present (1896) to speak definitely with reference to its (the outer membrane) origin, exact structure, or function. Its appearance at the ends of the cells and not between them would seem to argue against the suggestion that it is due to a condensation of the peripheral zone of the cells. But this view is supported by the fact

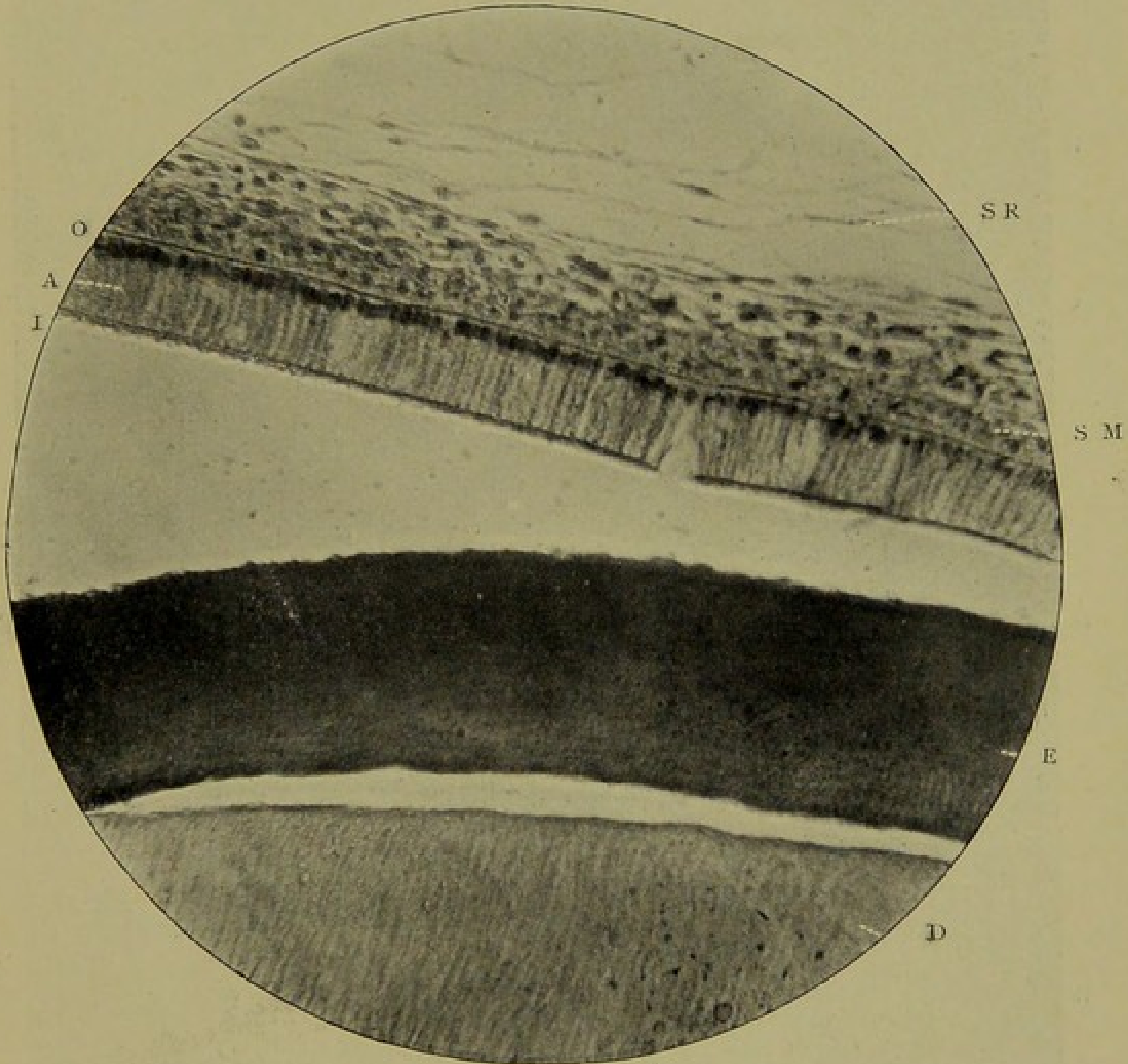


Fig. 200.—To shew arrangement of parts in the enamel organ. Stained with hæmatoxylene. Magnified 300 times. D. Dentine; E. Enamel; A. Ameloblasts; I. Inner ameloblastic membrane; O. Outer ameloblastic membrane; S.M. Stratum intermedium; S.R. Stellate reticulum.

that it is not seen during the earlier periods of the tooth germ; but only after the nearly or quite complete specialization of the ameloblasts." Under high powers it is composed of more than a single layer; and "it is possible that it plays an important part in the elaboration of material for enamel

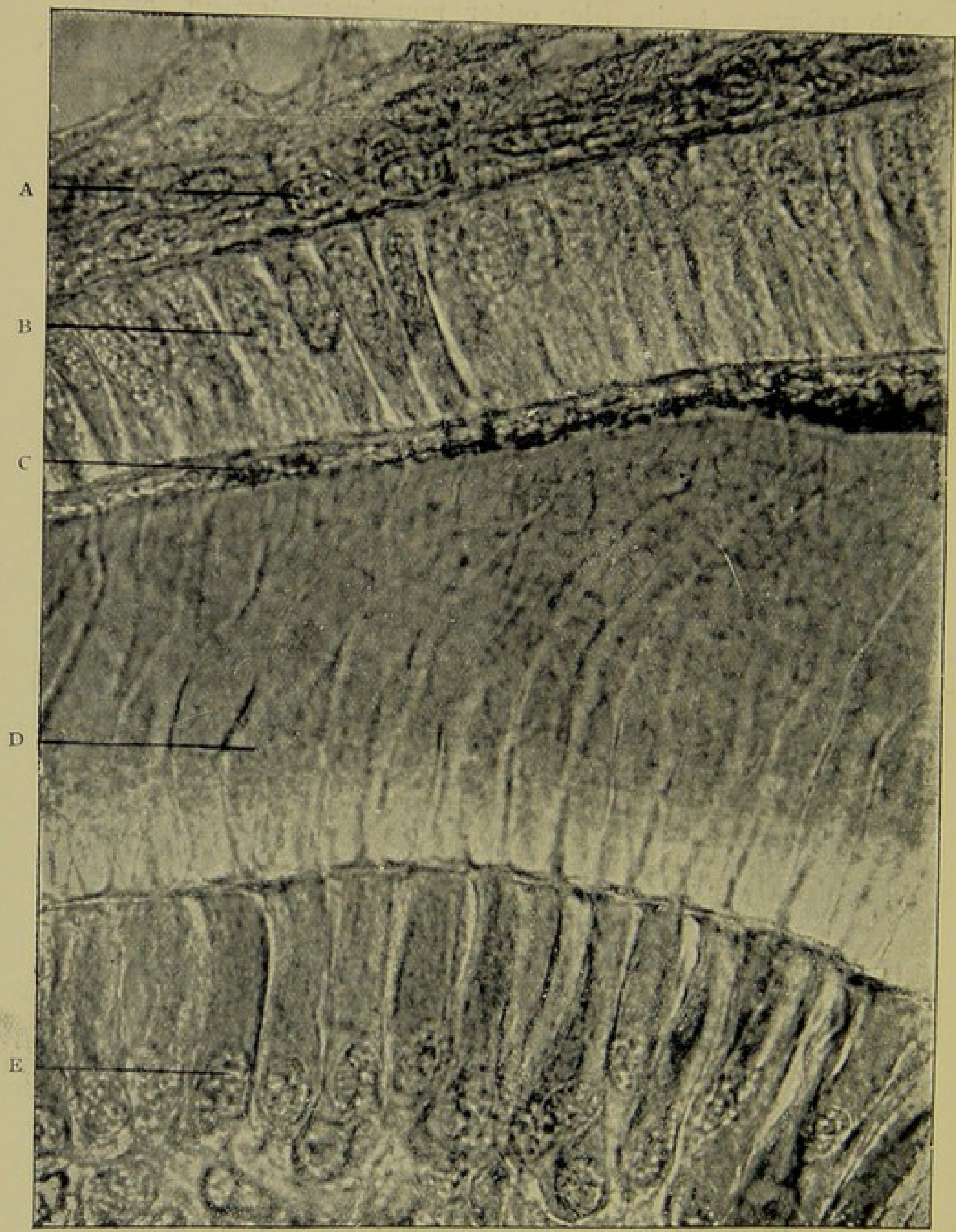


Fig. 201.—Section of developing tooth of human embryo. Magnified 1,000 times. A. Cells of stratum intermedium shewing structure of nuclei. B. Ameloblasts; C. Enamel-globules shewing radiating processes; D. Dentine; E. Odontoblasts shewing structure of nuclei. Photomicrograph by Leon Williams.

building. It varies considerably in thickness in different specimens, but persists throughout the entire period of enamel formation—a fact which would seem to give a decided negative to the theory that the ameloblasts are renewed from the stratum intermedium, as many writers on the subject have supposed."

The free surface of enamel has a pitted or honey-combed outline, whence the Tomes' fibres have been withdrawn; the rest is almost homogeneous.

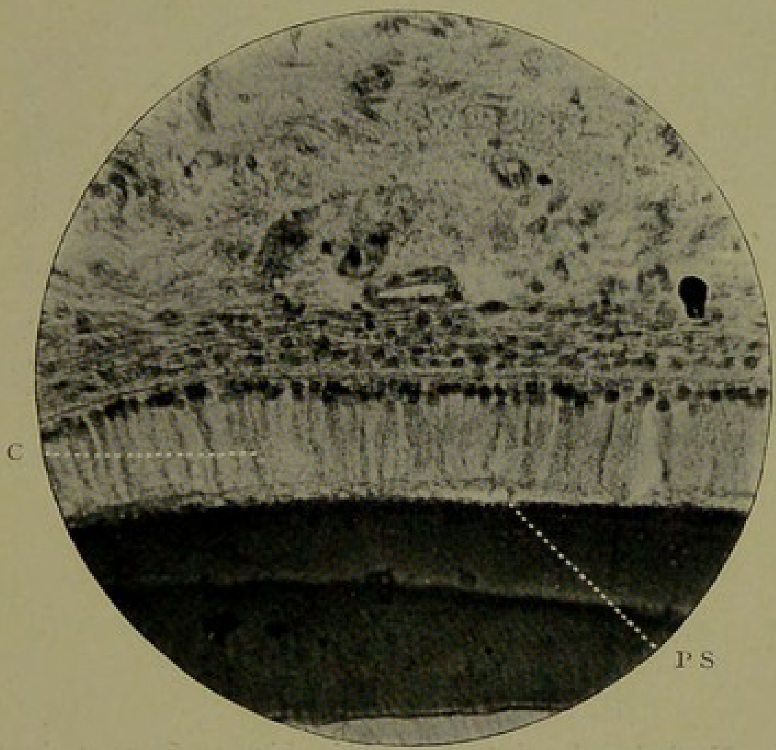


Fig. 202.—Similar to Fig. 200. P.S. Pitted surface of enamel; C. Calco-globular mass in an ameloblast.

Not so, however, the dentine, for traces of its tubular nature can, even at this early stage of growth, be easily observed in sections stained with Ehrlich's acid hæmatoxylene in its calcified (external), and less clearly in the formed but as yet uncalcified portions.

The superficial mesoblastic cells of the papilla, before the formation of the odontoblasts, are arranged with a certain amount of regularity, with their long axes pointing towards the ameloblasts. These in their growth become elongated, the result being, according to Paul (*op. cit.*), the formation of a definite superficial zone.

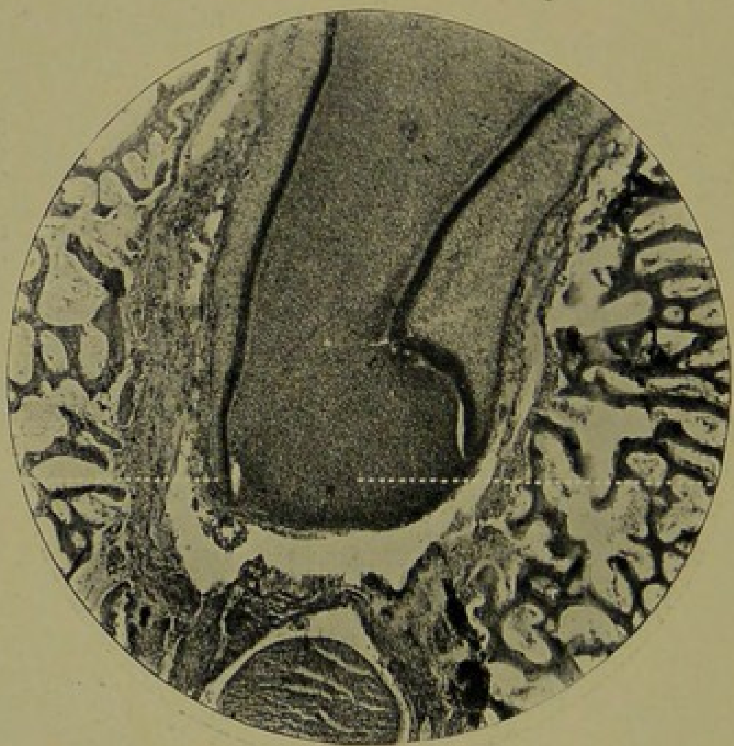
Their nuclei are "resting." (See Fig. 112).

Later on the odontoblasts themselves begin to appear among these superficial cells, the nuclei of which, passing from the resting stage, undergo atrophy.

The remainder of the papilla is made up of branched continuous cells.

Shortly after the fusiform connective tissue cells, which go

H



B

Fig. 203.—Vertical section through mandible of human fœtus at about the 160th day of intra-uterine life. Shews base of temporary canine tooth. Prepared as usual with soft tissues. Stained *en masse* in borax-carmine. Cut in paraffin-wax. Magnified 50 times. B, Base of dentine papilla; H, Epithelial sheath of Hertwig.

to make up the dental sac or follicle, have become continuous round the whole tooth-germ, the investing stellate reticulum begins to disappear. The first stage in its atrophy and absorption is the disappearance of the nuclei of these cells.[1] The external epithelial cells become somewhat separated, but connected still with the branches of the stellate

[1] The stellate reticulum persists longest in the intervals between the cusps of the molar teeth.

reticulum on the one hand and the elongated cells of the dental sac on the other. The ameloblasts reach their highest degree of development over the cusps of the dentine germ, and the enamel is being rapidly manufactured. The dentinal wall of the tooth germ is lengthening towards the base of

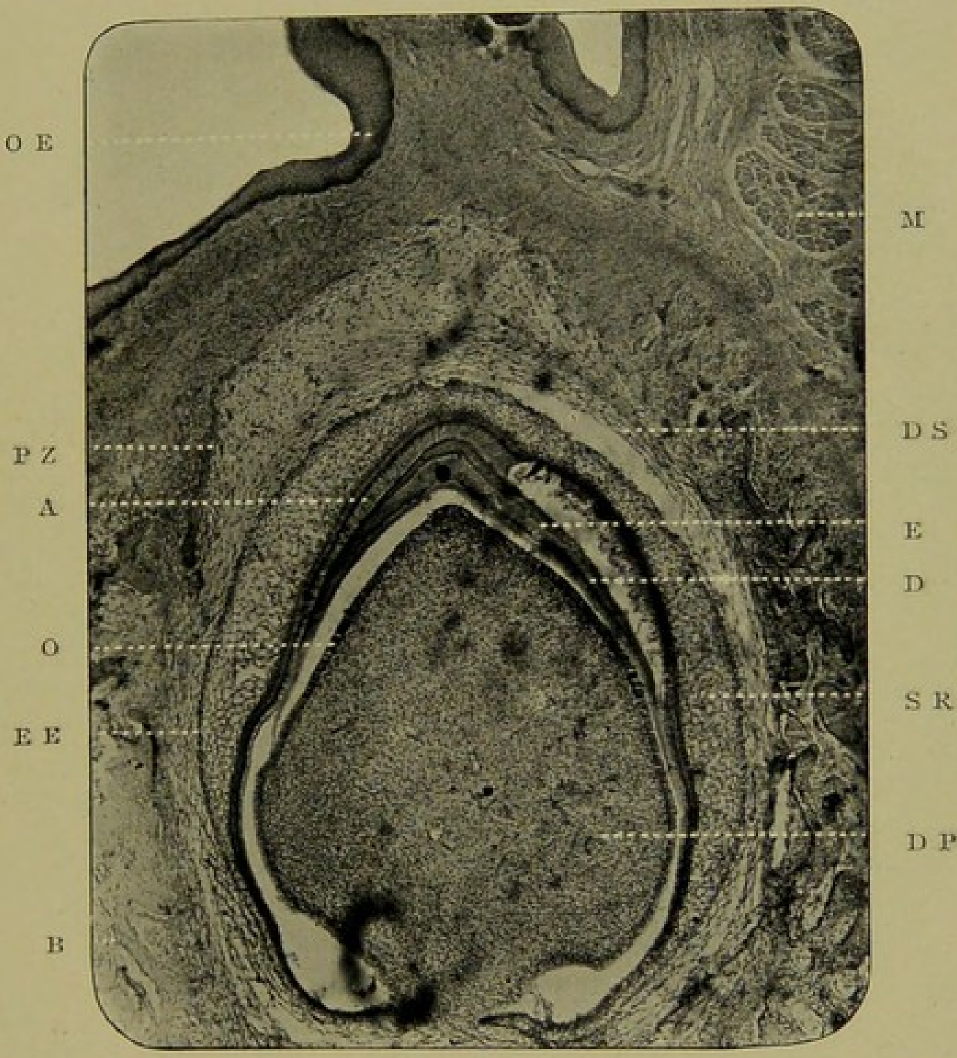


Fig. 204.—Vertical section through jaw of pup at birth. Prepared in the usual way. Stained with Ehrlich's acid hæmatoxylene. Magnified 45 times. Represents the stage of development in man at about the 140th day. O.E. Oral epithelium; A. Ameloblasts; E. Enamel; D. Dentine; O. Odontoblasts; D.P. Dentine papilla; S.R. Stellate reticulum; E.E. External epithelium; D.S. Dental sac; B. Bone of jaw; P.Z. Tooth-band of permanent tooth germ; M. Muscle fibres cut transversely.

the dentine germ, which shews signs of constriction by the approximation of the cells of the internal epithelium.

At the extreme point they suddenly curve upwards and outwards, and thus form the *epithelial sheath of Hertwig*.

The cells of the dentine germ possess the same histological characteristics, except those on the surface of the pulp,

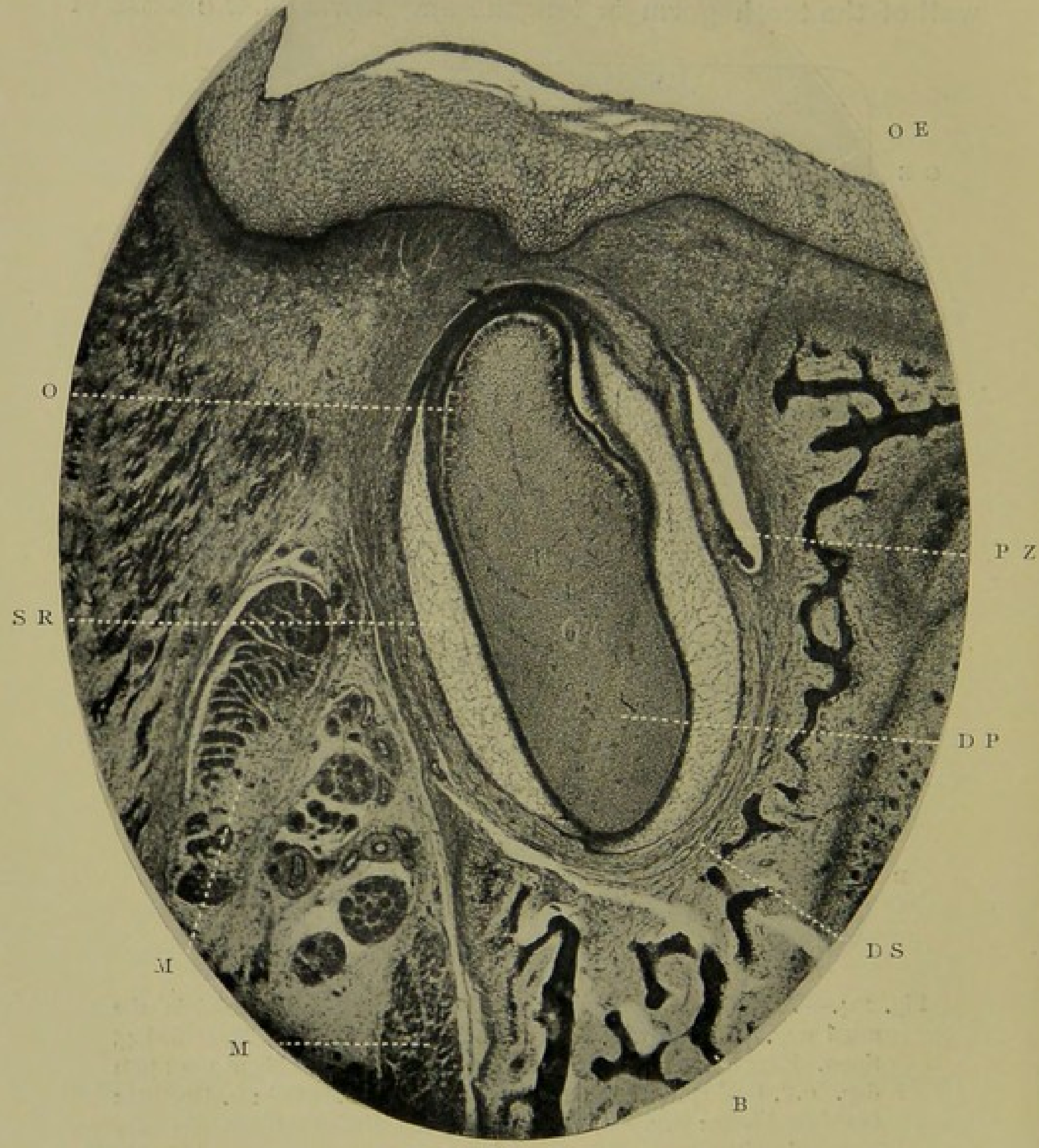


Fig. 205.—Coronal section through the maxilla of a fœtal pig. Prepared and stained as in last figure. Magnified the same. Represents the stage of development in man at about the 120th day. Lettering as in Fig. 204.

which, as the so-called odontoblasts, are clearly differentiated in size, shape, and staining properties from the other connective tissue cells.

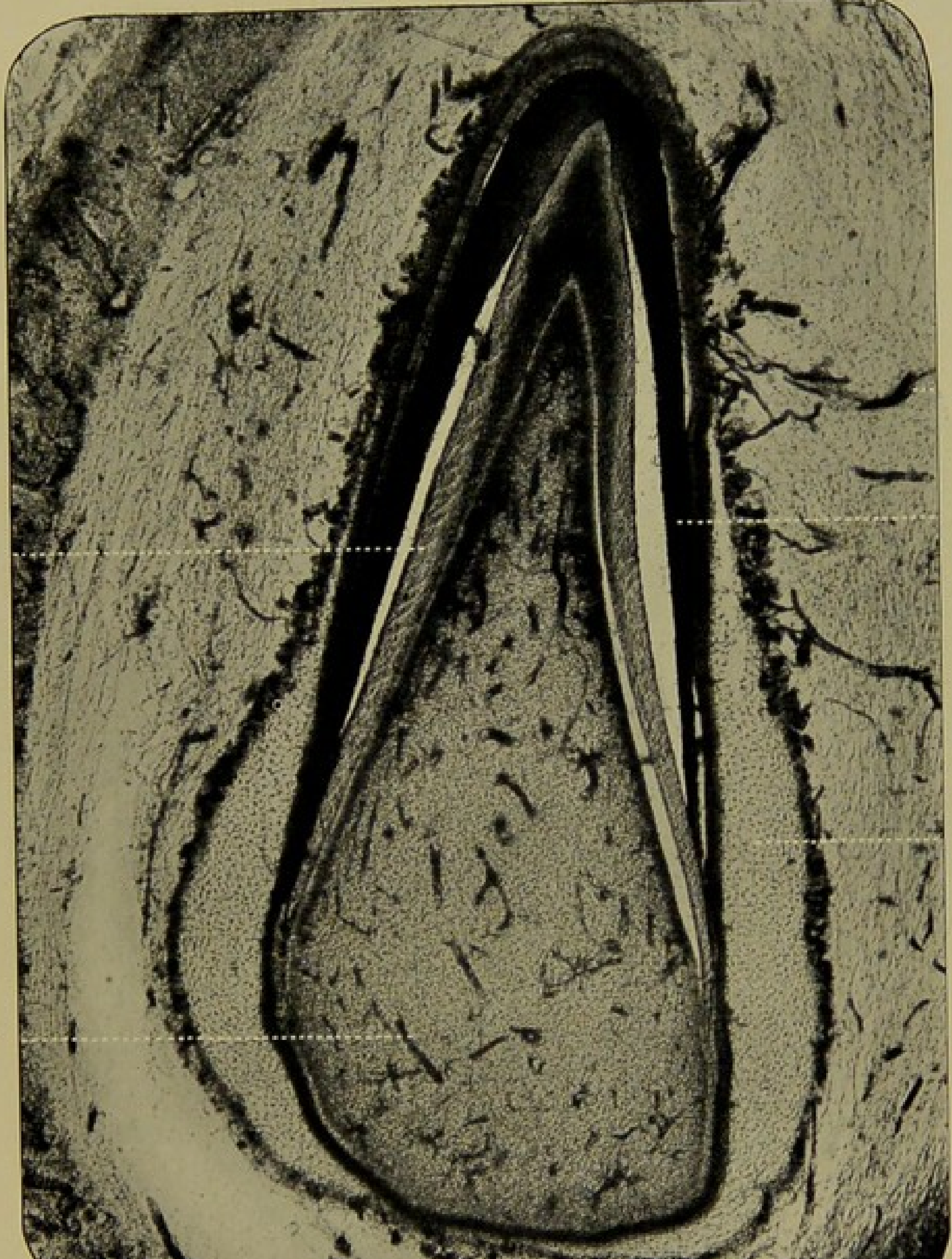


Fig. 206.—Coronal section through the mandible of a kitten. Stained with borax-carmine after hardening in formic aldehyde. The blood vessels are naturally injected. Represents the stage of development in man at about the 160th day. Magnified 65 times. E. Enamel; D. Dentine; S.R. Stellate reticulum; P.V. Blood vessels in the pulp; L. Loops of capillaries extending to the external epithelium of the enamel organ.

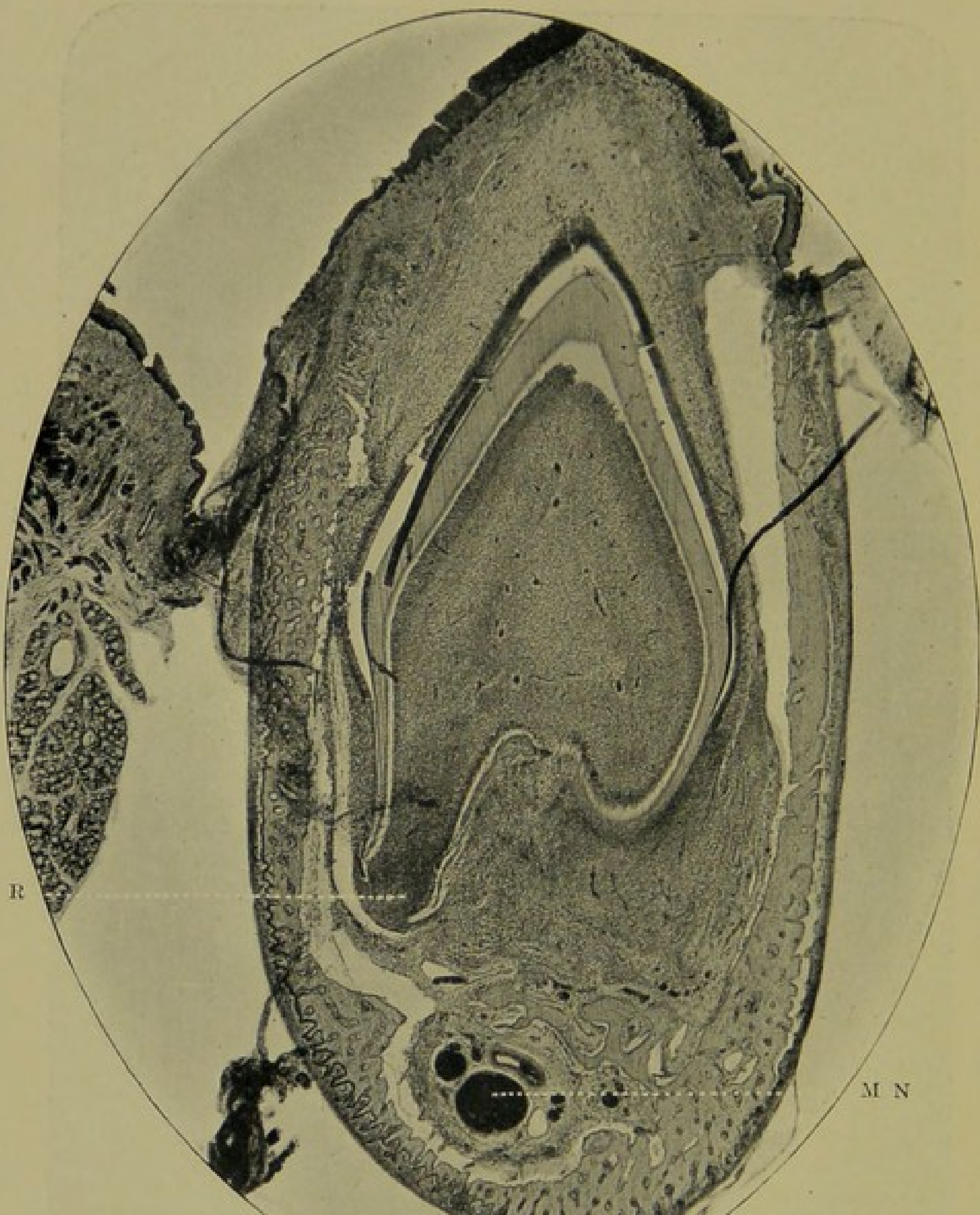


Fig. 207.—Vertical section of mandible of pup at birth. Stained with hæmatoxylene. Magnified 30 times. About same age as preceding figure. R, Early formation of a root; M.N. Mandibular nerve, with accompanying artery and veins.

(ix) *Evolution of the Permanent Toothgerms.*

About this period sections shew the epithelial inflection which goes to form the successional tooth, which is but the growing or free end of the zahnleiste, and not a budding from the neck of the enamel organ of the temporary tooth germs. Röse, of Leipzig, has proved this fact beyond doubt. This neck has now completely vanished.

Subsequently the tooth germ assumes the shape of the future tooth. The enamel organ has gone; the calcified dentine and dentogenetic zone surround the young pulp. The thickness of the enamel cap has increased; the regularly-arranged ameloblasts and *stratum intermedium* cells are very pronounced, and nothing intervenes between the oral epithelium and the *stratum intermedium* but a large amount of submucous tissue, composed of long branching fusiform connective tissue cells imbedded in a thin stroma, which also contains blood vessels, and at times, tiny masses of epithelium ("*glands of Serres*"). The latter are derived from the remnants of the fenestrations of the tooth band. The former seem to run right down to the condensed papillary tissue on the surface of the stellate reticulum, as if they were carrying special nutritive material to this region.

In the young pulp, the walls of the blood vessels and rudimentary medullated nerve fibres make their appearance, the first by the approximation and joining up of the branching process of the longer cells, running singly in a line, the second by the development of the cells in longitudinal bundles.

The vascularity or otherwise of the enamel organ is not yet determined, many competent authorities holding opposite opinions on this subject. Thus Lionel Beale, Leon Williams, Howes, and Paulton assert that a vascular network is to be found in the *stratum intermedium*, while Tomes, Paul, Andrews, Wedl, Sudduth, and Magitot affirm its non-vascularity.

(x) *The Blood Supply of the developing Dental Tissues*

In determining the relationship which normally exists between the vascular supply of the dental tissues and the tissues themselves, it is necessary to consider the origin of the blood vessels, their arrangement and mode of distribution, and the areas governed by them. Where great development is taking place there is free blood supply, and the more complex the organisation of a part—whether in anatomical structure or location or in physiological function—the more abundant anastomosis of capillary blood vessels is found. And this anastomosis is most important in controlling the growth of the tissue, as on it depends the hypertrophy, or atrophy, or normal conditions of the part. For should the blood stream be increased or accelerated, then overgrowth results ; while, on the other hand, should it be diminished or occluded, it is followed by shrinkage, atrophy, degeneration, and death.

Hence the blood supply of the hard and soft dental tissues is of vital importance ; when normal, the tooth undergoes the changes consequent on evolution, and, finally, is erupted in a perfect condition ; when abnormal, hypertrophies and atrophies of the whole or parts of the teeth are produced, and irregularities of external configuration, defects in quality of the organic and inorganic substances and other deviations from typical forms occur.

The most useful subject for the purposes of the examination of the capillary arrangement is an injected section, in which the functional activity of development is most progressive, and most clearly discernible—a section whose genetic cells are most busily engaged in producing the various dental and peri-dental structures—a section, in short, which exhibits the birth of the life-history of a tooth.

Here it is found that the tissues formed from each layer of the primitive blastoderm are supplied by separate sets of vessels. There is (i) an external or superficial, and (ii) an internal or deep network, the former being distributed to the tissues which are epiblastic in origin, including gum and certain parts of the enamel organ; the latter to those arising from the mesoblast, including dentine papilla, dental sac, and surrounding bone. Thus, the external set of vessels is distinctly separated from, and has no connection with, the internal deeper set, except at one part, viz., the periodontal membrane, where they meet and anastomose freely. (See Plate I.)

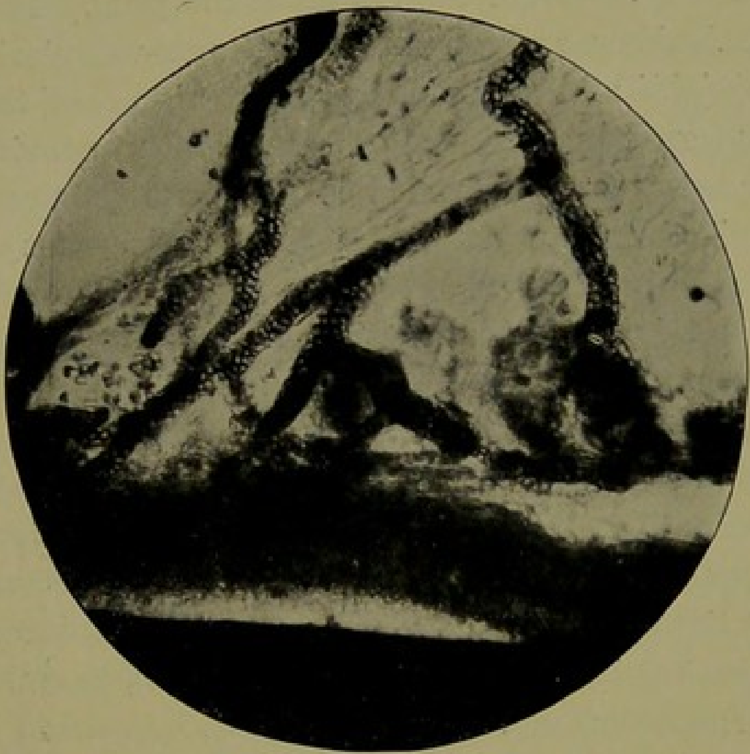


Fig. 208.—A portion of the blood supply of the stratum intermedium of the enamel organ of the section photographed in Fig. 206. Magnified 300 times. The staining was unsuited to reveal the structure of the ameloblasts: but it displays the blood corpuscles which have been retained *in situ*.

(i) *The external set* supplies the enamel organ and gum. On examination of the *enamel organ proper*, it is found that its external part is absolutely free from any closely-meshed network of capillaries. The layer of cells, forming the external epithelium and the thin branching cells of the *stellate reticulum* have no blood supply. One or two large non-branching vessels traverse the space occupied by the reticulum, from the thick gum and connective tissues lying external to the enamel organ. These, having advanced as far as the *stratum intermedium*, suddenly break up into numbers of small capillaries, and form a beautiful plexus which supplies the cells of this intermediate layer and the internal epithelium.

But the capillaries are placed very closely together over the layer of ameloblasts—a fact explained by the activity and importance of these cells in the formation of enamel and their consequent necessity for a large supply of blood.

Little need be said of the vessels of the gum. The *stratum corneum*, *lucidum*, and *granulosum* are non-vascularized : the *rete Malpighii* and fibrous connective tissue of the dermis differing greatly by being abundantly provided with numerous straight, long vessels which ramify in every direction. It is clear, therefore, that the nourishment of enamel organ and fibrous tissue of the gum emanates from the same source, and is quite differentiated from that of the other dental structures.

(ii) *The internal set* supplies the dentine organ, dental sac, and surrounding bone.

In the dentine organ, the pulp has by far the largest and most important system of blood-vessels. Here, one large vessel enters at the apical foramen of the tooth, and occupying its longitudinal axis, passes sinuously outwards, to end near the newly-formed dentine. As it proceeds, its calibre becomes somewhat diminished in size, and in a thick plexus of vessels its branches terminate beneath the odontoblasts, some running, in adult pulps, into the basal layer of Weil. There appears to be no definite regularity in the arrangement of the primary branches : they leave the large arterial trunk at a considerable angle—in some sections this approaches to, even if it does not exceed, a right angle. The secondary and other branches have a similar arrangement. The greater number of the minor distal branches run parallel to the dentogenetic zone under cover of the odontoblasts, between and around which their ultimate ramifications are distributed. These cells and the small round pulp cells which lie closely to them, have, therefore, an abundant supply of blood, brought about in a similar manner to that which obtains in the cells of the *stratum intermedium*, and internal epithelium.

The comparative size of these pulp vessels is much greater than that of the fine closely-set capillaries of striped muscle fibre; they bear a slight analogy to them, but none of the varicosities or spherical dilatations found on the walls of the latter are to be observed in the former.

The advantages of this peculiar method of arrangement—the sinuous primary arterial trunk, the branches coming off at right angles, the minute anastomosis beneath the dentine—are manifest at once. It is evident that they are thus distributed, first, to give as large an area of blood supply to the pulp tissues in as small a space as possible; and, second, to prevent shock or any other extraneous influence from acting injuriously on its delicate elements. In this manner, a flow of blood to the part is maintained—constant and uniform, two necessary factors in the production of perfect development, growth, and nourishment.

Included in the term "dental sac" at this period of the genesis of the tooth, are its products, the cementum and periodontal membrane.

It is difficult to determine absolutely whence and how the cementum is nourished. It would seem to come chiefly from the periosteal vessels. That trophic influences are exercised upon it to a certain but limited extent, is an undoubted fact, and it is equally certain that the dentine is not the medium by which they come. Hence it is fair to presume that the same vessels which supply the alveolo-dental membrane, vitalize the tissue by means of a protoplasmic exudation from their walls, which passes into it *viâ* the channels which contain Sharpey's perforating fibres.

Wedl[1] was the first to demonstrate that the dental periosteum has three sources for its blood supply, viz.: (a) from the gum, (b) from the pulp, and (c) from the adjacent bone of the alveolus.

[1] "Pathologie der Zähne," 1870.

In regard to the first, it has already been shewn that the external and internal sets unite in this situation, the vessels of the gum running deep downwards to anastomose with the internal set which supplies the dental sac. But also loops of capillaries from the main arterial trunk of the pulp, before it enters that organ, can be seen spreading outwards and joining the before-mentioned vessels. (See F. in Plate I.) And in addition, numerous offshoots from the capillaries of the alveolar bone run towards the cementum, and form thick plexuses with the other two. The periosteum is, therefore, most richly vascularized, and forms by its method of attachment the vascular bridge, so to speak, between the living tissues of the jaw and the living tissues of the tooth.

The vascularization of the bone of the alveolus calls for no further comment here, being identical with the blood supply of cancellous bone elsewhere.

Briefly, to summarise, it can be said with tolerable certainty that of the soft tissues, the pulp as being the most important nutritive agent, has the greatest, and the gum the smallest system of capillaries; while in the enamel organ the reticulate cells, and the external epithelium are destitute of any vessels whatsoever.

An examination of the section from a photomicrograph of which Fig. 206 is reproduced, shews, however, that while blood vessels do not actually anywhere pierce the stellate reticulum, yet long capillaries run freely everywhere immediately outside the external epithelium; and where this is closely applied to the *stratum intermedium* (the intervening stellate tissue being atrophied), the numbers and size of the capillaries are greatly increased. This must not be interpreted, however, as signifying vascularization of the enamel organ.

The cells of the internal epithelium must obtain a free blood supply from somewhere, for the purpose of manufacturing the calcific basis of enamel, and it is difficult to conceive of this physiological phenomenon occurring as a product of cells which have no contiguity whatever with the vascular system of the body.

The latest addition to the literature of the vascular supply of the teeth of man comes from the pen of Dr. W. Lepkowski, of Cracow. Following up original work on injected preparations of the teeth of the lower placental vertebrates, there appeared an interesting article on "The Distribution of the Blood vessels in the teeth of Man" in the "Anatomische Hefte."[1]

"In a foetus of seven months the alveolar artery provides one branch for each tooth-germ which is thus entered at its base. The artery directly before its entrance into the sac is still to be recognised as such, and can be easily distinguished from the veins accompanying it. Further on, the walls of the artery become so thin that even in stained preparations they can no longer be distinguished from the two veins accompanying it. The vessel now rises to the highest part of the pulp and there divides into a number of branches, which spread out in a fan-like fashion from the base to the apex of the tooth-germ. These branches are really capillaries. They proceed between the odontoblasts up to the dentine and there form broad loops which unite with each other. As has already been described in animals, there also spreads out in man, on the surface of the pulp between the odontoblasts, a broad net of capillaries, which is distinguished from the remaining woof running through the pulp by its breadth and density. An examination of numerous sections teaches one that the distribution of this capillary net is not, however, the same on the whole surface of the pulp. At the base of the tooth the vascular anastomosis is always denser and more interwoven than towards its apex, where the net becomes comparatively broader and looser. This arrangement of the vessels follows the arrangement of the odontoblasts. With low magnifying power there can be seen, in preparations stained with carmine, a broad band of odontoblasts at the base of the tooth-germ just where the vessels also are present in greater numbers; towards the top of the

1 "Die Verteilung der Gefässe in den Zähnen des Menschen," Weisbaden, 1901.

tooth-germ the breadth of the odontoblast layer decreases appreciably, and simultaneously the network of the vessels becomes looser. It can scarcely be doubted that both appearances are connected with each other. It is also easily to be explained why at the base of the tooth-germ the vessels and odontoblasts are more closely arranged than elsewhere; for it is on the base of the tooth that new substance is deposited, and the vessels and odontoblasts are chiefly concerned in this process. As this distribution of the vessels and cells can be seen in every preparation, we may consider this kind of arrangement as the rule in the formation of teeth. In reference to the mutual relationship between capillaries and odontoblasts, it may be mentioned that the former, as loops, reach, between the odontoblasts, up to the dentine layer. They take no direct share in the formation of the tooth-canals. On the other hand, we must assume that they convey the necessary material for the building up of the tooth and induce special activity of the odontoblasts. The dense distribution of the vessels at the surface of the pulp, between the odontoblasts generally, as also specially at the basal parts of the tooth-germ, points to this. . . . .

"If we compare the vascular systems in the various teeth of the same embryo, we obtain deviations according to the number of the roots and the form of the tooth crown. . . . . If we take a section through a single root tooth-germ—for example, a canine—we get, in the centre of the pulp, a bundle of vessels, which after their sub-division into finer ramifications provide for the entire pulp, and under the dentine spread out in a characteristic manner. In the germ of a two-cusp tooth there are present two bundles of vessels separated from each other. From this we get the impression, that the tooth had been developed from a number of single teeth corresponding to the cusps and roots. A series of sections obtained from the tooth-germ of a three-rooted molar favours the proposition still more. We see, therefore, in the first sections two bundles of vessels and two cusps. The vascular bundles enter separately at the base of the tooth-germ, and only in their ramifications in the tooth pulp do they become connected with each other."

As a carollary to this line of argument this author formulates the following highly interesting theory: "I believe that my results on the distribution of the vessels in developing molars speak in favour of the hypothesis advanced by various investigators, among them Dybowski and Röse ('Ergebnisse der Anat. und Entwickelungsgeschichte,' 1899), that the heterodont set of teeth of man and mammals has originated from a homodont dental apparatus. The individual cone-shaped teeth such as exist to-day in reptiles, becoming approximated through the shortening of the maxilla, fuse, so to speak, and form compound teeth, which according to their function and the development of the osseous parts surrounding them, in the course of time, receive their present shape. The witness for their descent from simple teeth is to be sought for in the rudiments of several cusps, and their separate vascular supply during their development. Not much reliance must be placed upon the number of roots with which they are provided. As already stated, this is as a rule reduced, perhaps in consequence of mechanical influences. Besides, as is known, there are often found four, five, or even six roots on molars. Their presence proves that corresponding to the number of cusps under favourable conditions they may continue to exist in their original type without reduction, of course, as rudiments, of the former homodont masticating apparatus.

"The vessels which externally surround the enamel-organ are connected with the pulp-vessels. The vessels originate in the inter-alveolar arteries which supply the cancellous bone substance of the maxillæ. They spread out in a dense woof at the surface of the enamel-organ, but do not, however, penetrate between the ameloblasts of the enamel-organ. To judge from microscopical sections they belong to the venous system. They surround the tooth-germ from the first rudiments of its development. Notwithstanding that they deviate from the method of arrangement of the pulp-vessels, they agree with the latter in so far, in a physiological sense, that they play an active part in the formation of the enamel, as the others have an active share in the formation of dentine. On thorough examination of the preparations, it is observed that at the apices of the tooth-germs where the enamel is thickest, the vascular net is also denser. The points correspond to the highest parts of the tooth. When the tooth crown is near its completion, the activity of the enamel cells gradually ceases, and the vessels supplying them slowly undergo retrogressive changes. Within the tooth, however, the formative activity of the odontoblasts and the blood vessels still continues, until the dentine of the crown and the roots has been built up.

"The disappearance of the vessels of the enamel-organ begins at the summit of the tooth, and proceeds in the direction of the root. In the stages of evolution, in which the tooth is erupted, the superficial vessels unite with those of the gum, those lying deeper surround the root and supply its newly-formed periodontal membrane. They spread out on the walls of the alveolus, and remain in this position, as long as the tooth exists. . . . Of the pulp-vessels, individual vessels or also bundles of them occasionally separate, perforate in places the dentine-layer and the enamel-layer and obtain connection with vessels surrounding the tooth-germ on the outside. Examples of such vascular connections I have observed in tooth preparations of the embryos of the lower animals, as also in those of man.

"On examining such sections one might be tempted to think of an analogy with the Haversian canals in bones. However, the vascular connections of the kind mentioned are too rare to be looked upon as quite normal formations. I believe I can explain in another way this vascular communication which arises but rarely.

"In later stages of development, and in adult man, one finds at the lateral surfaces of the teeth, and more especially on the molars, a funnel shaped constriction. In sections, made transversely through the tooth at the level of such a depression, one observes the dentine canals markedly condensed, as it were, as if there were present a scar in the dentinal tissue, which reached up to the pulp cavity.

"In my opinion these cicatricial formations in the developed tooth are related to the vascular communications just described. I myself during my researches on fully formed teeth have never seen any other formations than this cicatricial contraction, but Thiel mentions a case which tells in favour of my view. Scheff cites the same case in his 'Handbuch' when discussing hæmorrhage after extractions. After the extraction of the first upper bicuspid on the right side, considerable bleeding followed, which, on careful examination, was traced, from the wall of the alveolus, to a bundle of vessels which entered the tooth at the neck and ran transversely through the dentine up to the pulp. At the outset it is not to be assumed that the vessels in the case mentioned above originally perforated the fully-formed tooth, because the tooth substance in advanced life is too hard to allow blood vessels to penetrate, and, on the other hand, the vascular supply at that period, in comparison with that of a younger age, is too slight."

Lepkowski holds that: "If we compare the vascular distribution in the teeth of man with that of mammals, such as the pig, the horse, and the rabbit, we find, what was to be expected, that there are no appreciable differences. The course of the vessels, their distribution, the density of the vascular net at corresponding places, and its relationship to the tissues in course of formation, are the same here as there. The more pronounced differences are in the number of the vessels in the tooth-germ. In embryos of the animal species cited, there exists in the pulp, as also specially in the enamel organ, far richer vascular ramifications than in the corresponding teeth of human embryos. The explanation, to my idea, is not far to seek. There exist very considerable differences, first, in the relative size of individual teeth between animals and man (for example, the canine); and secondly, in the thickness of the layers of substance. In the dog the thickness of the enamel layer surpasses by far that of the human teeth. It is, therefore, quite natural that the tooth-germs of animals are provided more richly with vessels.

"Otherwise the vascular distribution from embryological periods up to the complete development of the teeth is, in its fundamental characteristics, analogous in man and animals. The observations also which I have made in regard to the relationship of vessels to the cusps and roots in human teeth may be similarly applied to the teeth of animals."

The subject is one of importance, and invites greater attention than has hitherto been accorded to it. It should not, however, be so difficult a matter to determine in these latter days; since the modern introduction into the methods of Dental Microscopy, of solutions of formic aldehyde, as a fixing and hardening agent, has shown that the natural injection of blood vessels by blood cells can be maintained almost exactly as during life.

(xi) *Final Stages of Evolution*

Later phases in the evolution of the teeth include the growth of enamel and dentine, the approximation, to the surface of enamel, of the external epithelium as the cellular layer of Nasmyth's membrane, and the complete organization of the dental follicle.

(xii) *Dental Sac*

As a thick investing fibrous belt this structure envelopes the whole of the tooth, except at the apex of its root. Each tooth has its own follicle: and each follicle has a separate entity. At first consisting, as has already been pointed out, of layers of flat fusiform cells, round cells begin to be formed within it. These move in an inward direction, and assume the shape and functions of ordinary osteoblasts. The result of their energization is to deposit cemental matrix, which, about the times of the completion of the crowns of the teeth, becomes intimately and securely applied to the external periphery of the dentine. These cells probably pour it out as a homogeneous ossifying flood.

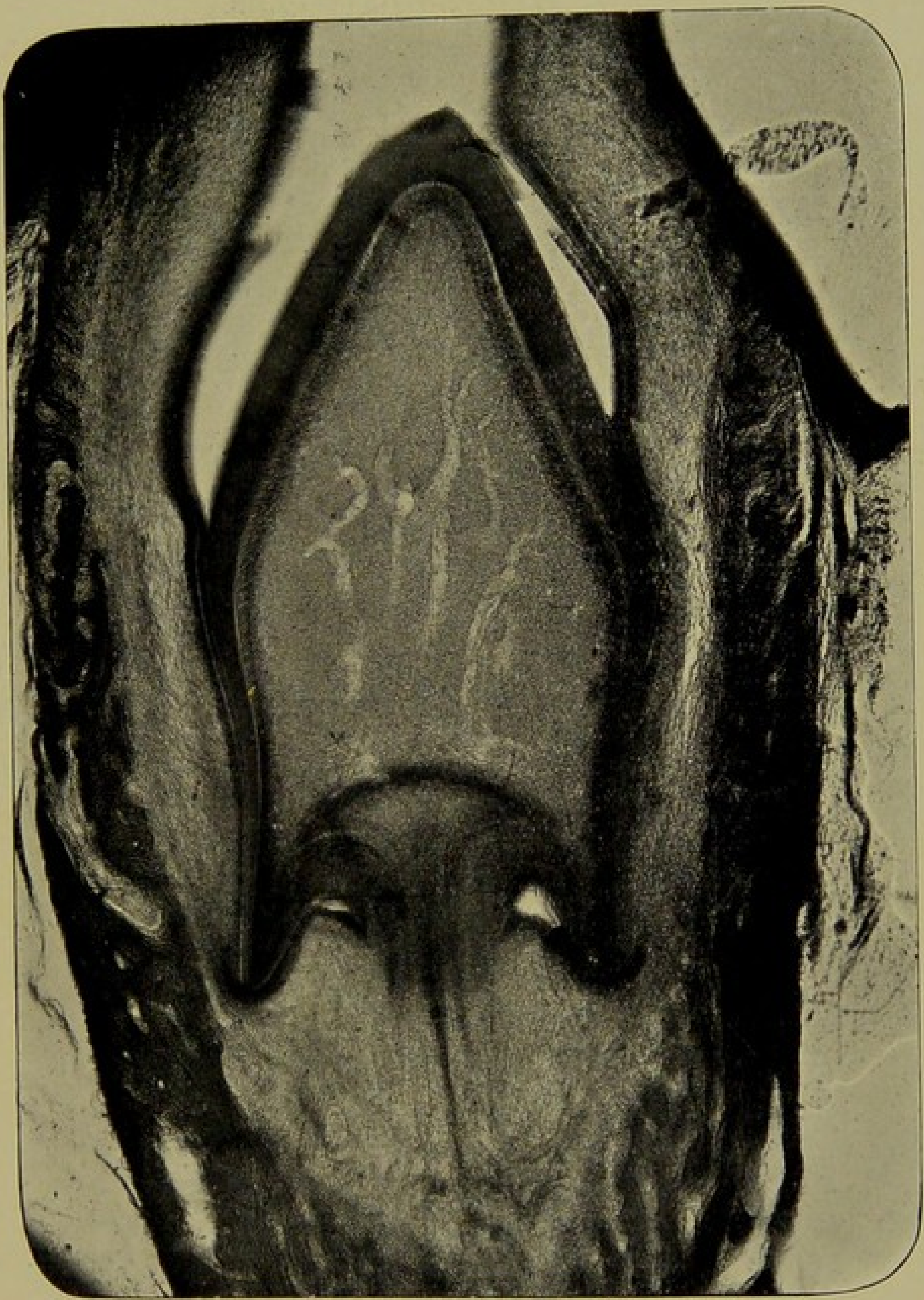


Fig. 209.—To shew the vascular supply of the dentine papilla. Magnified 55 times.

The remainder of the follicle becomes, almost synchronously, transformed into the periodontal membrane.

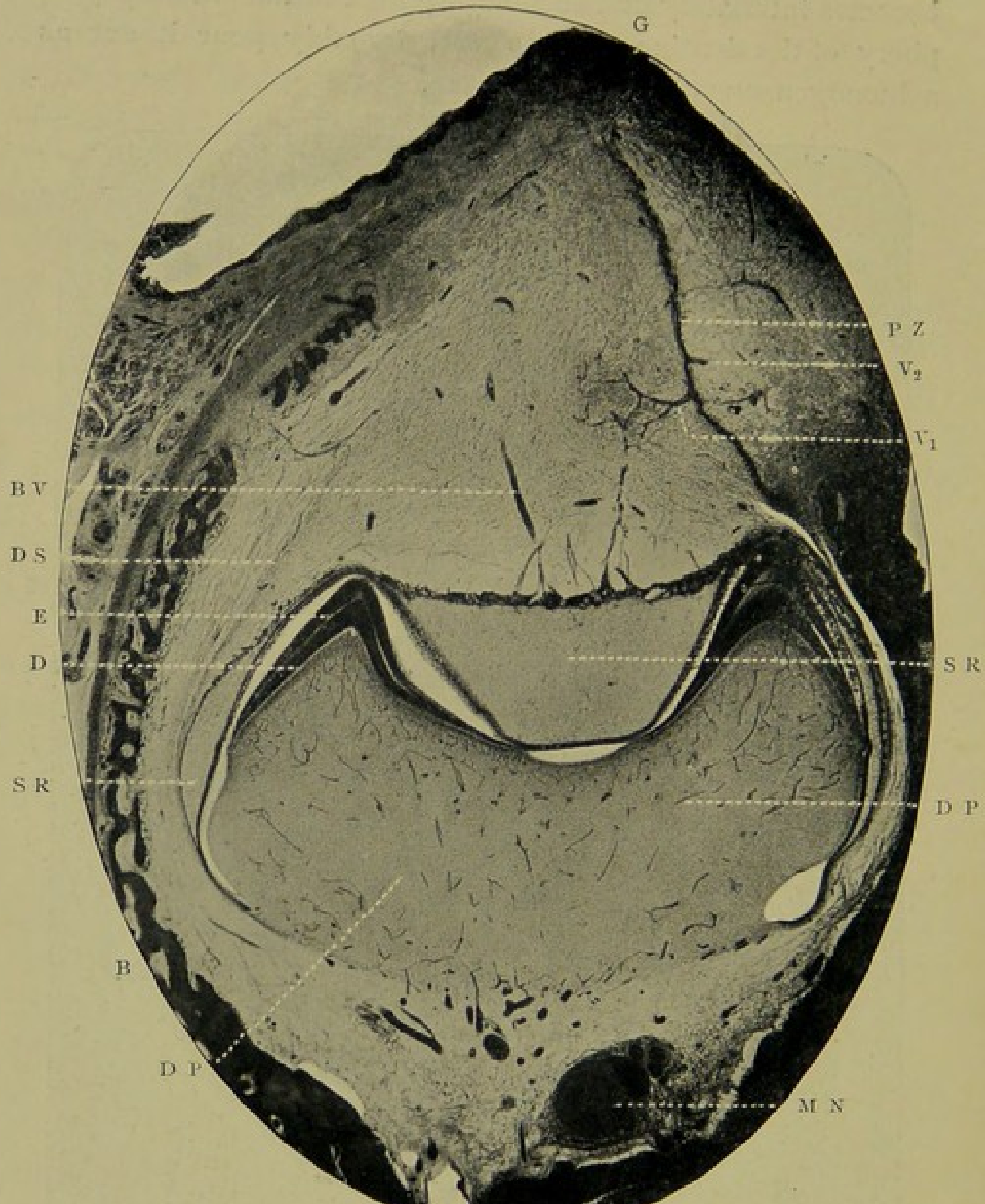


Fig. 210.—Coronal section through the mandible of a human fœtus, at about the 170th day of intra-uterine life. Prepared by decalcification, after fixing in formic aldehyde. Stained with hæmatoxylene, and counterstained with eosine. Magnified 15 times. E. Enamel of deciduous tooth; D. Dentine; S.R. Stellate reticulum; D.P. Dentine papilla; D.S. Dental sac; P.Z. Tooth band of permanent molar tooth on lingual side; B.V. Blood-vessels extending to external epithelium; G. Oral epithelium; B. Bone of jaw; M.N. Mandibular nerve; V_1. A supposed vestigial germ (pre-milk); V_2. A supposed vestigial germ (post permanent).

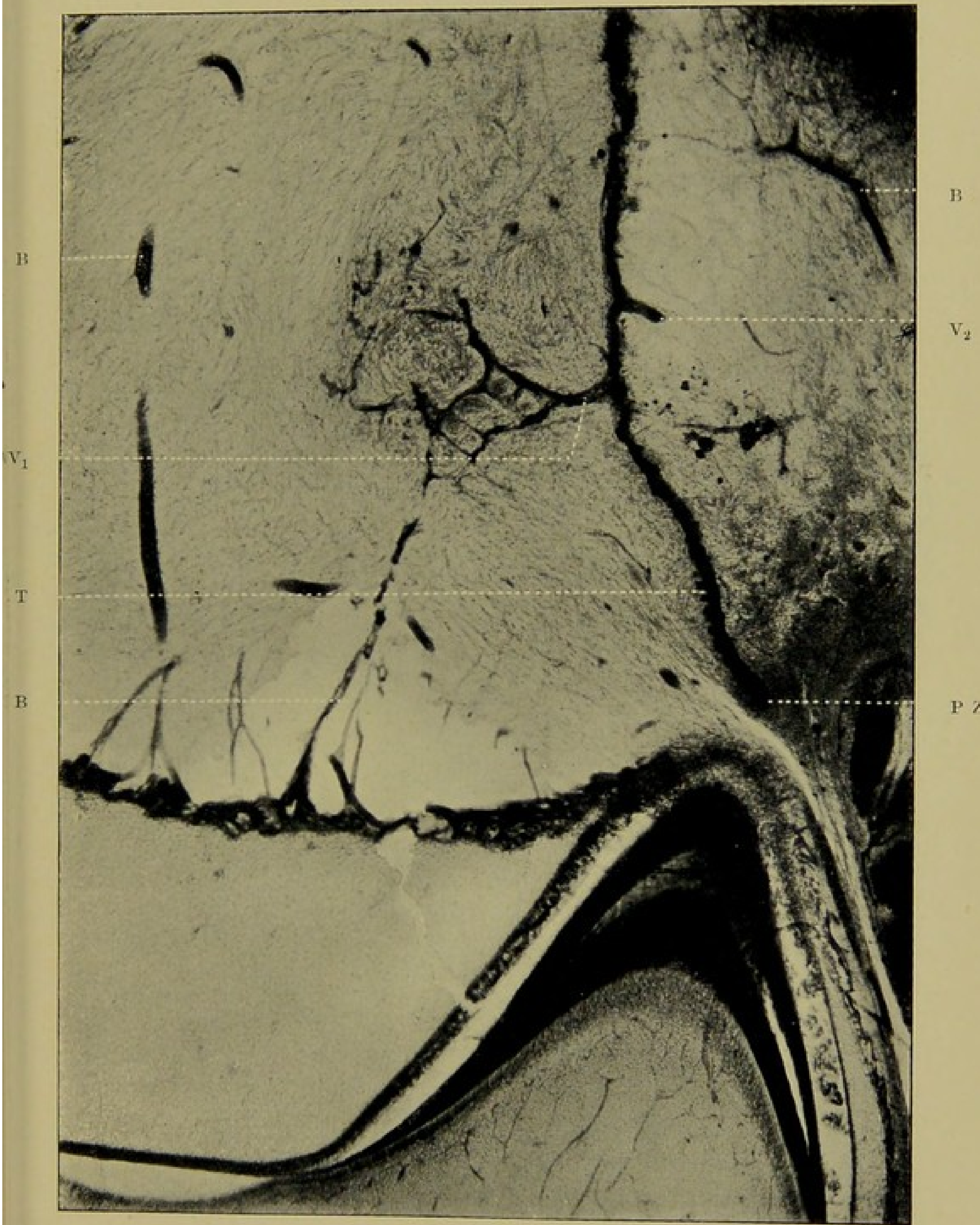


Fig. 211.—The same as the preceding. To shew the "tufts" on the tooth-band of the permanent germ. Magnified 75 times. P.Z. Zahnleiste of permanent tooth germ; T. "Tufts"; V$_1$. Part of the tooth-band which might be considered by some authorities to represent the tooth-band of a vestigial (pre-milk) tooth; V$_2$. That of post permanent tooth; B. Blood-vessels.

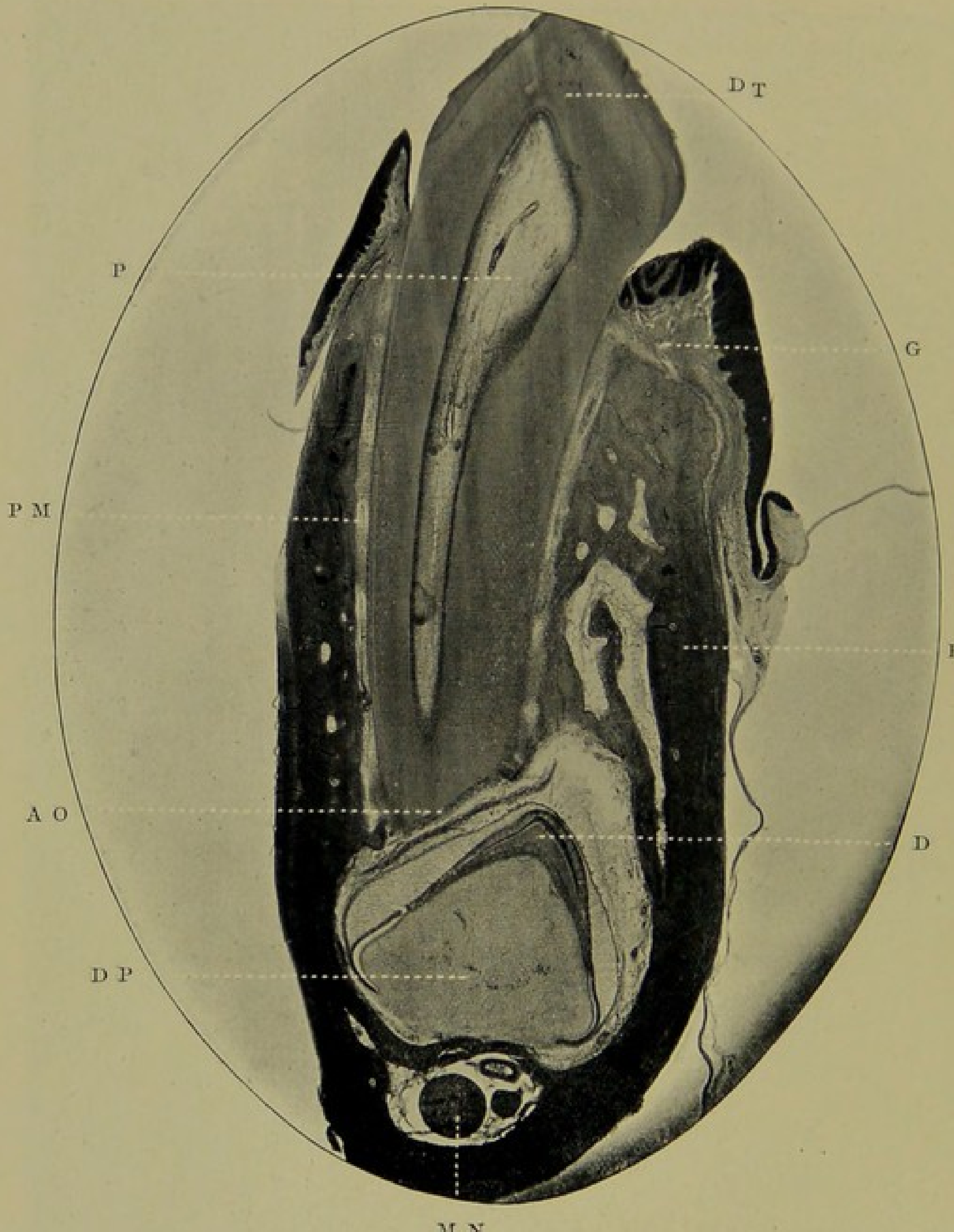


Fig. 212.—Sagittal section of mandible of kitten, with the deciduous and permanent teeth *in situ*. The former is fully erupted. Prepared by decalcification after fixing in formic aldehyde, and hardening in alcohol. Magnified 15 times. Represents the stage of development in man about the 18th month after birth. D.T. Dentine of deciduous tooth; P. Its pulp; P.M. Blood vessel in its root membrane; A.O. Its absorbent organ; D. Dentine of permanent tooth; D.P. Dentine papilla of same; B. Bone of jaw; G. Gum tissue; M.N. Mandibular nerve.

It is likely that a special cement organ, which according to Magitot partakes of the nature of fibro-cartilage, exists over

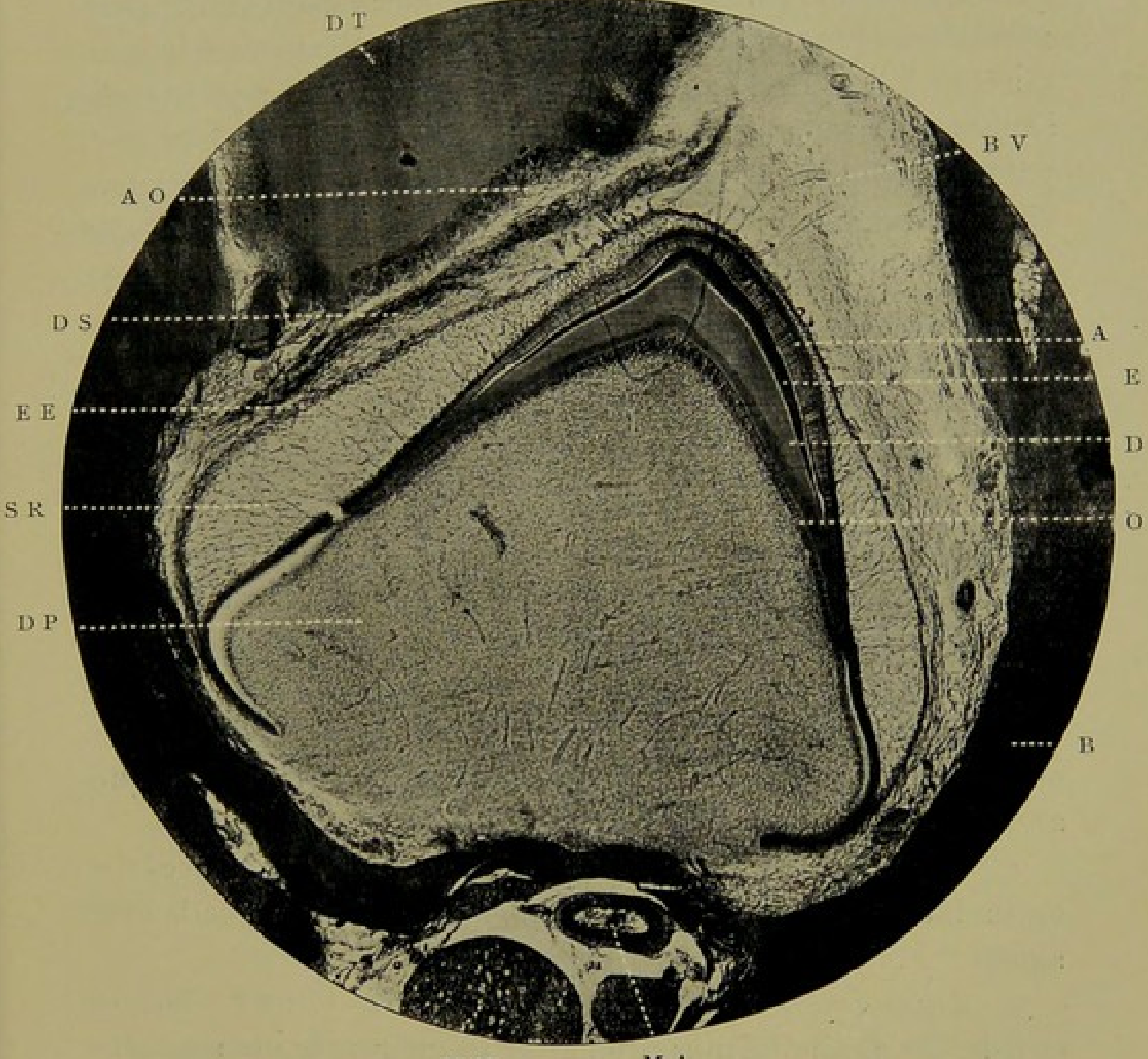


Fig. 213.—The permanent tooth germ of preceding figure. Magnified 65 times. D.P. Dentine papilla; O. Odontoblasts; D. Dentine; E. Enamel; A. Ameloblasts; S.R. Stellate reticulum; E.E. External epithelium; D.S. Dental sac; B.V. Blood vessels going down to external epithelium; D.T. Dentine of deciduous tooth; A.O. Absorbent organ of deciduous tooth; B. Bone of the jaw; M.A. Mandibular artery; M.N. Mandibular nerve.

the crowns of the developing teeth of the ruminating groups in *Artiodactyla*. A cement organ, as such, has no existence, however, in the teeth of man.

An examination of the zahnleiste of the permanent tooth, in Figs. 210 and 211, would lead one to suppose that here was a truly remarkable example of four successive tooth germs in man, viz.: pre-milk, deciduous, permanent and post-permanent (V_1., E., and D.P., P.Z. and V_2). Some authors, including Röse, Leche, Kukenthal, &c., would accept the off-shoots, as these aberrant tooth bands. As Tomes, however, points out (*op. cit.* p. 363), scepticism can only be removed when these structures have become differentiated into external and internal epithelia, and calcification is seen to be commencing.

(xiii) *Recapitulation*

It seems advisable, for the simplification of a somewhat abstruse subject, such as the Development of teeth in *Mammalia*, to here append a brief outline of the histories of the various structures met with during such a study.

1. *Epithelial Inflection.*—Due to individual proliferation of deepest layers of cells of the oral epithelium, and collective penetration into the sub-lying tissues: undergoes cleavage longitudinally; thus forms (*i*) Labio-dental strand and (*ii*) tooth band. Fig. 182.

2. *Dental Furrow.*—A slight superficial indentation over the epithelial inflection: and *Zahn-wall*—Heaping up of cells over same.

3. *Labio-dental Strand*, or *Lippenfurche.*—Outer division of primary epithelial inflection after its cleavage: elongates in vertical direction; widens; central cells atrophy; thus producing open sulcus between lips or cheeks and teeth and alveolar processes of jaws. Fig. 184.

4. *Tooth band*, or *common dental germ*, or *Zahnleiste.*—Inner division of primary epithelial inflection, after its cleavage: elongates: has (*i*) *as one portion*, on *labial* side, depression which goes to form enamel-organs of ten temporary teeth; and *as another portion* (*ii*) free end or border on *lingual* side, which, continuing to grow, produces enamel organs of ten permanent teeth on lingual side of temporary germs; and

still growing, extends backwards to form enamel organs of first, second and third permanent molars; is continuous around whole length of jaw: degenerates and becomes cribriform; finally disappears, leaving sometimes small epithelial remnants *in situ*, known as "glands" of Serres, or also glands in dental follicle.

5. *Enamel organ.*—Formed by expansion of base of tooth band: epiblastic in origin; assumes various shapes; consists of external epithelium, stellate reticulum, stratum intermedium and internal epithelium; disappears after jaw bones are completed.

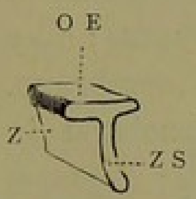


FIG. 214.

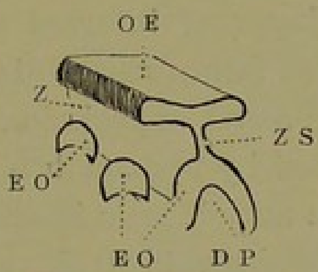


FIG. 215.

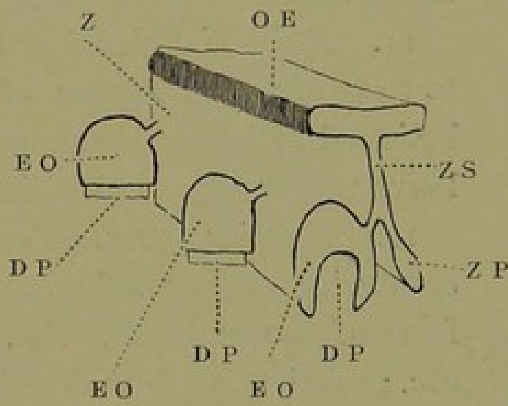


FIG. 216.

Figs. 214, 215, 216.—Diagrams to shew the tooth band, method of evolution of the tooth germs of the deciduous teeth, and continuation of the tooth band to form enamel organs of their permanent successors. O.E. Oral epithelium; Z.S. Tooth band in section; Z. Tooth band seen sideways as a continuous sheet; E.O. Enamel organs; D.P. Dentine germs of deciduous teeth; Z.P. Continuation of tooth band going shortly to form enamel organ of permanent tooth germ on lingual side of the others. (After Stöhr).

6. *Neck of Enamel Organ.*—Attenuated form of original tooth band: atrophies.

7. *External epithelium* of enamel organ.—Peripheral layer of round cells continuous with rete Malpighii on one hand and internal epithelium on other: undergoes modification and probably forms cellular layer of Nasmyth's membrane.

8. *Stellate Reticulum.*—Epiblastic in origin: derived from central cells of tooth band; acts probably as "packing material"; consists of large stellar cells with prominent nuclei, and long branching processes; nuclei atrophy and network entirely vanishes.

9. *Stratum Intermedium.*—Layer of round or polygonal cells intervening between last-named tissue and internal epithelium, from which it is separated, according to Leon Williams, by outer ameloblastic membrane: disappears.

10. *Internal Epithelium.*—Continuous at edges with external epithelium; forms enamel-depositing cells or ameloblasts; thickest over cusps of teeth through individual cells being longest in these situations: as such disappears after enamel calcification is completed, but most probably persists in modified form as translucent pellicle of Nasmyth's membrane.

11. *Epithelial sheath of Hertwig.*—Continuation downwards to base of dentine germ of layer of internal epithelium: is believed to determine shapes of future roots; disappears; may leave remnants as epithelial "rests" in periodontal membrane.

12. *Dentine germ.*—Formed by upgrowth of mesoblast in concavity of enamel organ: mesoblastic in origin; assumes form of future tooth, viz., conical, bicuspidate, molariform, etc.; persists as dental pulp.

13. *Dentogenetic zone.*—Band of formed but uncalcified dentine, bounded externally by fully completed tissue, internally by layer of odontoblasts: disappears when work of calcification is done.

14. *Membrana eboris* or *odontoblasts.*—Cylindrical bipolar cells situated at periphery of dentine organ and dental pulp; bounded externally by dentine, internally by basal layer of Weil: perpetually persists.

15. *Dental Sac* or *follicle.*—Connective tissue capsule investing each tooth germ: mesoblastic in origin, whence are derived periodontal membrane and cementum; persists till near time of eruption, then atrophies.

FORMATION OF THE HARD TISSUES

The study of the phenomena of the calcification of bone and other allied tissues involves the discussion of several subjects, such as chemistry, physics, physiology, as well as histology. It is obvious that the history of the embryology of the teeth would be incomplete if a record as to the modes by which osseous matter is deposited in the soft formative organs were omitted.

The histological aspects of such a study can alone be included in a work of this character: for the principles of calcification generally readers are referred to the well-known writings of Tomes, Sims Woodhead, &c.

DEVELOPMENT OF THE ENAMEL

Sir John Tomes and his son, Andrews, Leon Williams, and others have paid much attention to investigating this

FIG. 217.

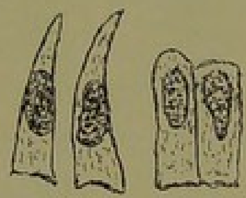


FIG. 218.

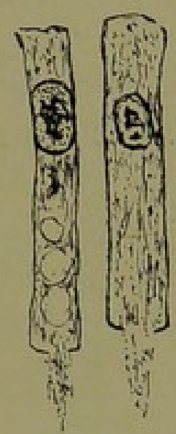


FIG. 219.

Fig. 217.—Ameloblasts, with Tomes' processes. (After John Tomes).

Fig. 218.—Ameloblasts, two of which have been immersed in glycerine, and present trumpet-shaped ends towards the enamel. (After Tomes).

Fig. 219.—Ameloblasts, shewing globular bodies, Tomes' processes, and the spongioplasm of the cells. (After Tomes).

difficult question: and it may be repeated here that the absolute truth of the matter is unknown: but the balance of favour rests with those who hold the conversion theory.

The following are brief outlines of various theories:—

Sir John Tomes considered that the enamel is formed by conversion of the ameloblasts. The pronounced extremities of these cells undergo, first of all, certain chemical changes; later on calcification ensues. The central portions of the cells calcify later than the peripheral; contiguous cells become united as calcification proceeds.

Charles Tomes, in his recent researches on the development of enamel in marsupials, is led to the following conclusions:—

(i) The ameloblast itself does not become calcified.

(ii) The chemical and calcareous changes take place in or around a fibrillar process (Tomes' process), which, being continuous with the protoplasm of the ameloblast, serves for the entire length of an enamel rod, and solidifying equally throughout in the enamel of man and all animals but marsupials and certain others. See p. 109.

(iii) A tubular condition of the enamel rods is probably merely a stage through which all rods pass during their histogenesis.

Graf Spee[1] was the first to notice and describe globular masses of some kind of calcareous material enclosed in the reticulum of the ameloblasts.

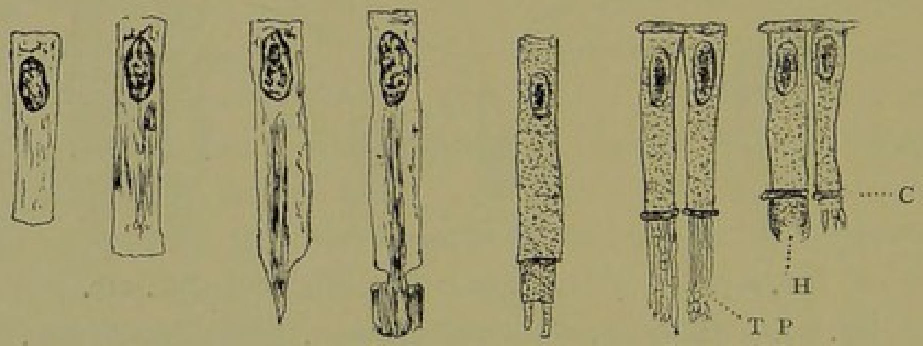


FIG. 220. FIG. 221. FIG. 222. FIG. 223.

Fig. 220.—Ameloblasts prior to the start of formation of the enamel. (After Walkhoff).

Fig. 221.—The same, with commencement of formation of the enamel. (After Walkhoff).

Fig. 222.—An ameloblast. (After Waldeyer).

Fig. 223.—Isolated ameloblasts. H. Homogeneous mass of calcified material, extended from the cell through (C) the enamel membrane (cuticular-saum) by dialysis. T.P. Tomes' processes. (After von Ebner).

Kölliker (*op. cit.* p. 306) conjectured that enamel rods are produced by a secretion by the cells of the enamel membrane which penetrates the *membrana preformativa* in a fluid condition, but hardens and ossifies beneath it.

Andrews has shewn (*Trans. World's Columbian Dental Congress*, vol. I., 1893) that there is a deposition of droplets or spherules of calcoglobulin formed in the ameloblast, and that

[1] "Ueber die ersten Vorgänge der Ablagerung des Zahnschmelzes."—*Anat. Anzeig.*, 1887.

these are excreted by these cells at their dentinal ends to build up the enamel rods. The "fibres of Andrews" act as a sort of reticulum or scaffolding to determine the arrangement of the deposition; the existence of these fibres being ultimately blotted out by the dense calcification of the tissue.

G. Arnell in "*Zur Kenntniss der Zahnbildenden Gewebe*" in Retzius' "Biologische Untersuchungen herausg.," II., demonstrated, as long ago as 1882, that the inner ends of the ameloblasts are directly concerned with the formation of the enamel rods, a finely granular deposit occurring round these ends.

Heitzmann and Bödecker consider that the ameloblasts "break up" into "embryonal corpuscles," which afterwards become calcified.

Xavier Sudduth thinks that the ameloblasts excrete the enamel. He is more concerned with the problem whence they get their nutritive supply, and suggests that the calcium salts are stored up in the meshes of the stellate reticulum of the enamel organ, which thus furnish material for the first formed layer of enamel.

After this is laid down, the enamel organ having disappeared from over this calcified layer, a further supply of calcium salts is provided by a rich plexus of capillaries which is found in direct communication with the ameloblasts.

Leon Williams holds views on somewhat similar lines. According to him, the *stratum intermedium* absorbs from the capillaries an albumen-like substance. This is ingested by the ameloblasts, which transform it into enamel globules, and so form the rods. Globules are successively produced within the ameloblasts.

"The cytoplasm," he writes, "of the ameloblasts has a fairly uniform structure, which consists of a number of globular masses of spongioplasm of the same diameter as the cell, and united longitudinally by somewhat coarser plasm-strings—'the fibres of Andrews.'" "There are many indications that these enamel globules are formed by the nucleus of the ameloblast; and they appear to pass down the cell by the natural process of growth, as new ones are formed above, to be finally shed off the inner ends of the cells on to the surface of the forming enamel, where they

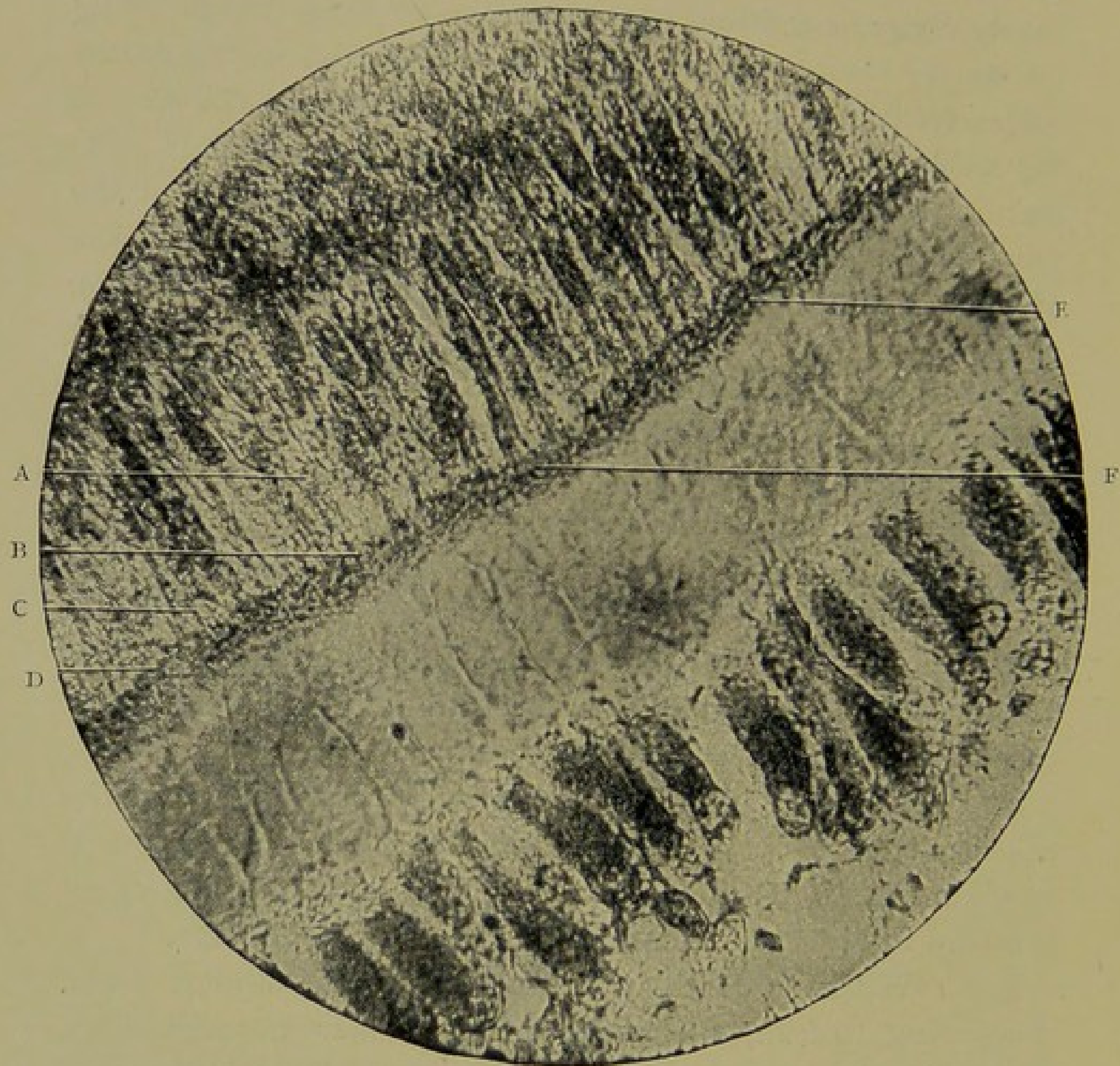


Fig. 224.—Section of developing tooth of a calf, at the commencement of enamel formation. Magnified 1,000 times. It is clearly seen that the organic substructure of enamel and dentine is formed from the cytoplasm of the cells. A. Cytoplasmic network in ameloblast; B.C.D.E. Globular or spherical patterns of cytoplasm. Radiating lines are seen to pass from a central mass to a rim which bounds the circumference, thus resembling nuclear structure. A like appearance is shewn in the completely-formed enamel rods. F. Shews the cytoplasm of ameloblast passing without break of continuity into the forming enamel. Photomicrograph by Leon Williams.

become completely infiltrated with the albumenoid lime-conveying substance, and calcified. Enamel globules are of uniform size, and quite distinct from the more transparent and irregularly-sized masses of calcoglobulin." "Enamel rods are manufactured by successive, rhythmical, orderly deposits of these enamel globules, the calcoglobular masses fusing and forming the interprismatic substance."

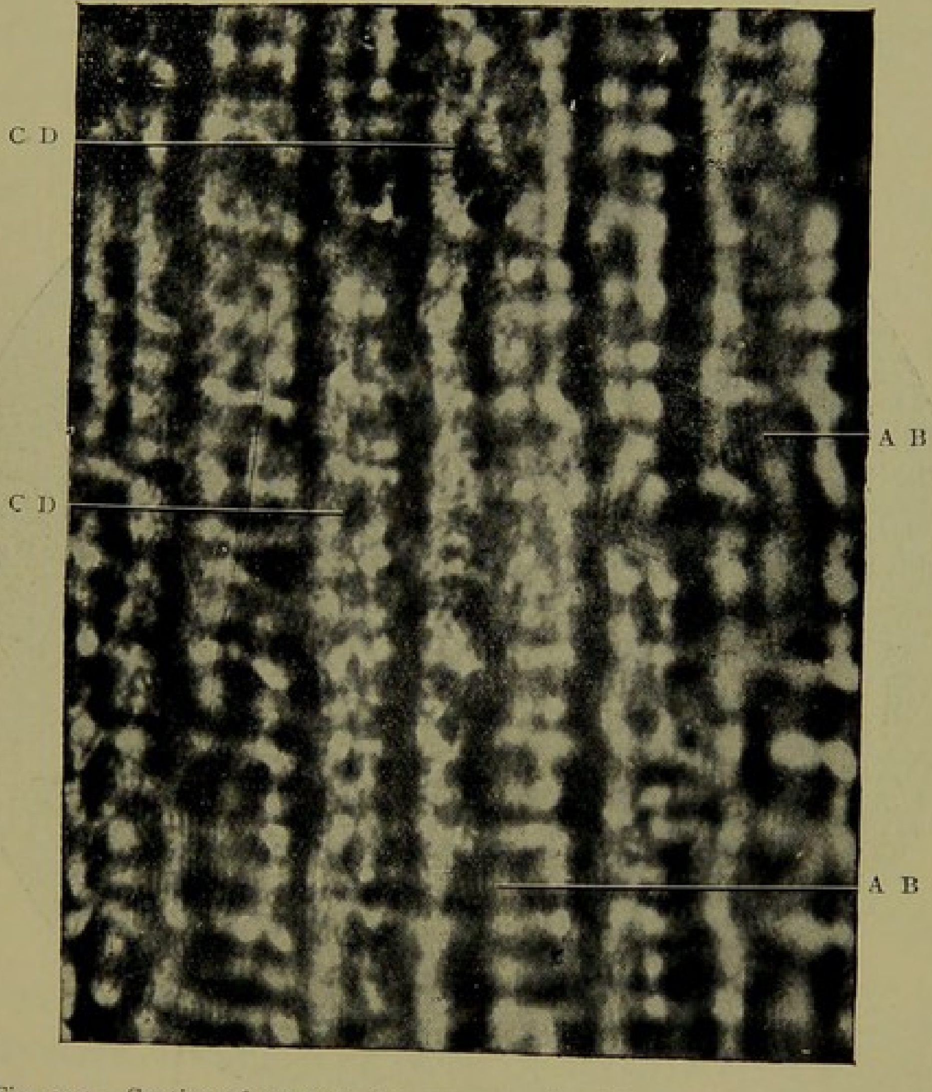


Fig. 225.—Section of mature human enamel of fine quality. Magnified 3,000 times. A.B. Calcified cytoplasmic network composed of very fine granular threads of fibres; C.D. Enamel-rods built up of sectional or globular arrangement of calcified cytoplasm. Radiating granular threads pass from a central mass to the border of the sectional part of the rod. Photomicrograph by Leon Williams.

He finally further adds (*The Dental Cosmos, p.* 477, *June*, 1896):—"There are two distinct products of the enamel-forming organ. One of these products, from which the enamel rods are built up, is formed by the ameloblasts, and is probably a direct nuclear formation. In the enamel cells it takes the shape of globular bodies containing granules, sometimes arranged with more or less order, so as to resemble the nucleus of the cell. In the formed enamel rod these globular bodies are, more or less, compressed into disc-like shapes, and are sometimes nearly, or quite, melted into one another. Simultaneously or alternately with the deposit of the globular bodies, a trans-

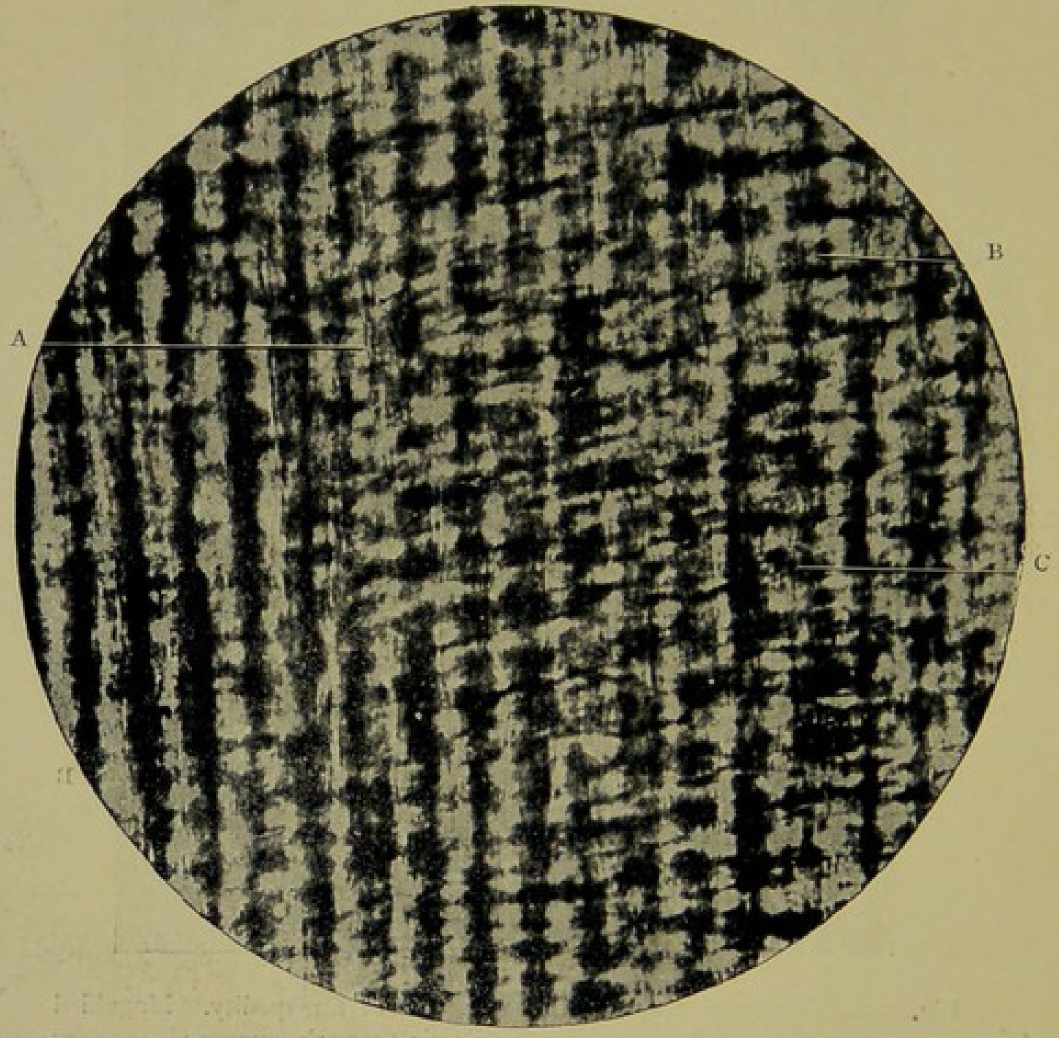


Fig. 226.—Section of mature enamel, shewing calcified cytoplasmic network at A B. and C. Magnified 1,500 times. Photomicrograph by Leon Williams. Compare Fig. 224.

lucent albumen-like appearing substance is seen passing out of the ameloblasts. This substance is probably taken from the blood by the secreting cells of the *stratum intermedium*, and evidently contains the mineral matter of which the completed enamel consists. As the globular bodies pass from the ameloblasts they are seen to be connected by plasmic strings, which strings can often be plainly seen in the body of the ameloblasts. The globular bodies are often connected laterally by strings or projecting processes. Around the skeleton thus formed, which constitutes the real structure of enamel, the albumen-like substance flows, supplying the cement substance, and probably the mineral matter for the calcification of the whole. All of this structure can be plainly seen in mature enamel; but in normal enamel it is everywhere completely calcified, and contains no trace of organic matter."

To sum up:—The theories may be classified under four distinct headings:—

(1) Enamel rods are produced by conversion or transformation *in situ* of the ameloblasts.—(John Tomes, Waldeyer, Kölliker, &c.)

(2) Enamel rods are produced by excretion or secretion, from the ameloblasts (Charles Tomes, Leon Williams, Sudduth, Andrews, Schäfer, &c.)

(3) Enamel rods are produced by growth of the ameloblasts at the end next to the formed enamel, and the new growth in the younger part is calcified as soon as it is formed (Schwann).

(4) Enamel rods are produced by the dentine, from an exudation furnished by the dentinal canals. (Mentioned by Kölliker, *op. cit.* p. 306).

In the light of recent research and modern microscopical methods, the last-named is obviously unscientific and incorrect.

The established facts that require no controversion about this intricate matter are quite clear, and seem to be that the layer of formed but uncalcified developing enamel is outside the main body of the ameloblasts; that it has Tomes' processes penetrating it at regular intervals; that it is produced *pari passu* with the first layer of uncalcified dentine against which it is applied; that it is at first *formed* and afterwards calcified; that it stains deeply with osmic acid; and that it chemically resembles keratin, inasmuch as it offers great resistance to destruction by any of the mineral acids.

DEVELOPMENT OF THE DENTINE

Researches as to the methods of formation, calcification, and the growth of dentine are not so beset with the innumerable difficulties attending like investigations with regard to the enamel. Though the first genesis of this tissue occurs at a period of time slightly antecedent to that of enamel, the fact of its continuance after the disappearance of the enamel organ is completed, and the part it plays in the

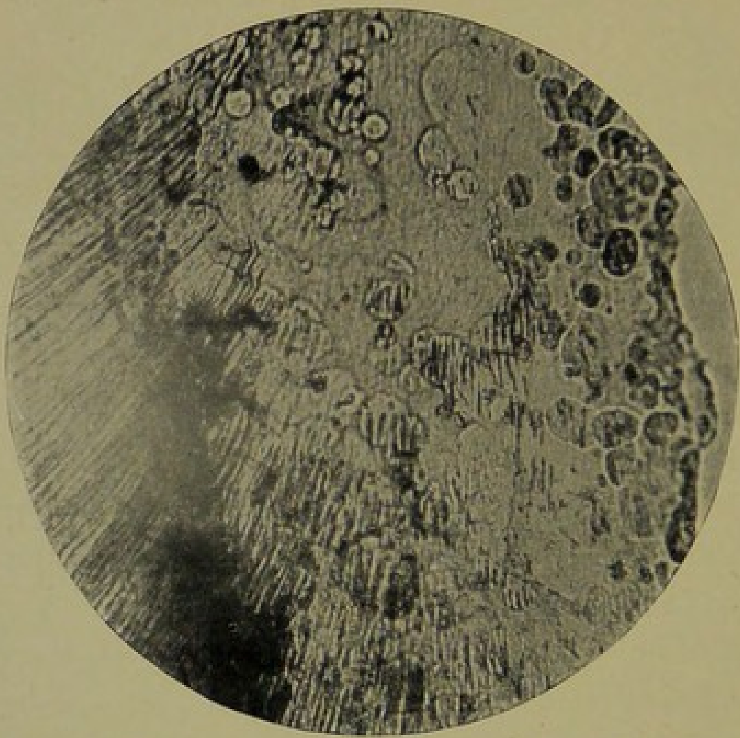


Fig. 227.—To shew the process of calcification of human dentine. Regularly-arranged tubules traverse the matrix, the sheaths of Neumann being indistinct, till they cross one of the calcospherites in which calcium salts are being deposited. Here they appear as black lines. From a section in the possession of A. W. W. Baker, of a tooth erupted at birth.

production of the roots of teeth, with or without persistently-growing pulps, as a physiological process, make investigation easier. It must likewise be remembered that certain pathological conditions of the pulp (*q.v.*) in which calcareous (dentinal) masses are developed—pulp nodules, adventitious dentine, &c.—are of fairly common occurrence. Added to this, also, must be the fact that opportunities sometimes arise of observing the manner of growth of dentine in odontomes where the fibrous tissue capsule is still in normal anatomical relationship with the hard parts. (See Chapter XXIII).

Hence it follows that recent discoveries have a tendency to prove the fallaciousness of the tenets maintained by Waldeyer in 1870, and also held by Boll, Beale and others, and that, in a word, dentine formation proceeds on somewhat similar lines to those which obtain in intra-membranous ossification of bone. These lines are not quite identical, inasmuch as the so-called odontoblast cells possess persistent processes, and do not become encapsuled as is the fashion with osteoblasts.

Since 1889 the author has never held the view, which had been originally formulated by Waldeyer,[1] that odontoblasts form matrix, sheath of Neumann, and dentinal fibril ; and Howard Mummery following up and amplifying the work of von Ebner in tracing throughout the pulp a fine connective tissue stroma which is continuous with that in the dentine matrix, has unconsciously, perhaps, but none the less certainly, corroborated this hypothesis.

Thus there is now established, with a probably great degree of accuracy, the opinion that dentine is a product of certain round cells of the pulp of an osteoblastic nature, whose function it is to abstract lime salts or carbon dioxide, from the vessels of the pulp and lay down matrix as a continuous sheet of formed material on the periphery of that organ. This is found in the teeth of man, as well as fish, (vaso-dentines).

Howard Mummery's paper, *Philosop. Trans. Royal Soc. of London*, Vol. 182, pp. 527-545, entitled "Some Points in the Structure and Development of Dentine," should be perused by all interested in the matter. Here it need only be said that his summaries point to the opinions that :—

(i) The mode of development of hard dentine presents a strong analogy to the development of bone in membrane.

[1] "Human and Comparative Histology," Stricker's "Handbook ;" Sydenham, Soc., Vol. I., p. 463, 1870.

(ii) In human dentine trabeculæ are seen shooting inwards into the pulp from the surface of the forming dentine; these trabeculæ sometimes exhibiting "an appearance as if stiffened by the deposit of lime salts in advance of the general line of calcification," and being continuous with the connective tissue fibres of the pulp.

(iii) The fibres and trabeculæ are covered with cells which in many parts thickly clothe them, and have similar functions to osteoblasts. "Smaller cells are intimately associated with the odontoblasts proper, the latter cells being also involved in the connective tissue stroma in continuity with the dentine, and, according to the view which, under the circumstances, seems most reasonable, these cells together secrete a material which calcifies along the lines of the odontogenic fibres." (See Figs. 35, 36, 37, 38, 39, and 40).

Most histologists accept this explanation of the calcification of dentine; a few, however, still retain the older opinion. Thus Carl Huber, in "A Text-book of Histology," by A. A. Böhm, M. von Davidoff, and C. Huber, 1900, writes on page 218:—"The dentine is developed by the odontoblasts by a process analogous to that observed in the formation of bone by the osteoblasts. These epitheloid cells secrete, at their outer surfaces, a homogeneous substance which fuses to form a continuous layer—the *membrana preformativa*. The further development of the dentine is as follows:—Its ground substance is deposited at the cost of the lateral portions of the odontoblasts (under the *membrana preformativa*), the axial portions of the cells remaining intact, as the dentinal fibres; the basal portions of the cells containing the nuclei persist, later constituting the odontoblasts of the adult pulp. By the fusion of the segments of the ground substance formed by each cell it becomes a homogeneous mass, but soon displays connective tissue fibrils which gradually undergo a process of calcification. The *membrana preformativa* has no fibres, and calcifies much later. It lies immediately beneath the enamel or cementum, and in the normal tooth always contains small inter-globular spaces. In the adult tooth, this membrane in its entirety is known as Tomes' granular layer." In the light of recent research these views are quite untenable.

THE GROWTH OF THE DENTINE

The following is a *précis* of Aitchison Robertson's experiments and observations on the growth of dentine in the permanently-growing incisors and also in the canine teeth of rabbits and cats. They were undertaken to determine whether this tissue increased in size by interstitial growth or not; and the subjoined Tables of measurements and their summaries are exceedingly instructive. (See *Trans. Roy. Soc. Edinburgh*, Vol. xxxvi).

METHOD OF INVESTIGATION

"For the purposes of this inquiry the lower incisor teeth of the rabbit were chosen, for these teeth grow from persistent pulps and are therefore never shed. To observe their condition at different stages of growth they were examined in (1) a rabbit newly born; (2) in a rabbit one month old; and (3) in an adult animal. These teeth, while still *in situ* in the lower jaw, were decalcified and sections made in an antero-posterior direction parallel to their long axis. The sections from the very centre of each tooth were alone used for measurement, as they contained the largest pulp cavity and went directly through the centre of the crown. These teeth, as they are worn down in front, are always being added to from behind and thus pushed forwards. The enamel is only found on the anterior and lateral surfaces, and is always thickest in the former position, where also the dentine is harder. Consequently, as the crown of the tooth is worn down, the anterior part, being harder, is not worn so fast, and thus the tooth becomes chisel-shaped.

Measurements of Lower Incisor Teeth in Rabbits

	Newly-born.	One Month Old.	Adult.
Total length of tooth ..	$\frac{1}{5}$ inch 0·2	$\frac{1}{2}$ inch 0·5	$1\frac{1}{8}$ inch 1·12
Greatest length of pulp cavity	$\frac{1}{6}$,, 0·17	$\frac{52}{120}$,, 0·43	1 ,, 1·0
Greatest breadth of pulp cavity	$\frac{1}{30}$,, 0·033	$\frac{1}{25}$,, 0·04	$\frac{1}{14}$,, 0·073
Thickness of dentine at middle of tooth ..	$\frac{1}{158}$,, 0·0063	$\frac{1}{42}$,, 0·024	$\frac{11}{250}$,, 0·044
Greatest thickness of dentine at crown ..	$\frac{1}{48}$,, 0·02	$\frac{1}{12}$,, 0·08	$\frac{6}{50}$,, 0·12
Diameter of dentinal tubules at origin ..	$\frac{1}{24000}$,, 0·0000416	$\frac{1}{24000}$,, 0·0000416	$\frac{1}{24000}$,, 0·0000416
Width of intertubular dentine..	$\frac{1}{8000}$,, 0·000125	$\frac{1}{6000}$,, 0·000165	$\frac{1}{6000}$,, 0·000165
Character of dentinal tubules	Run obliquely in straight lines; no branches; slightly wider near origin.	Wavy course; not branched.	Wavy course; many branches.

The results of this table may be summarized as follow :—

1. The fact of the great increase in length of the tooth is evident, it being six times longer in the adult than in the newly-born rabbit.

2. The pulp cavity increases in length in the same proportion.

3. The width of the pulp cavity increases in a progressive manner.

4. The thickness of dentine at the middle of the tooth and also at the crown increases nearly six times.

5. The diameter of the dentinal tubules at the proximal end remains the same at each stage of growth. They are all slightly larger at their origin and diminish in calibre very gradually as they are traced outwards.

6. The dentinal tubules become gradually more wavy in their course, and their lateral branches become evident in the adult tooth.

"The odontoblasts form a complete lining to the inner surface of the dentine, and thus form, as it were, a bag enclosing the pulp and having its mouth at the inlet of the pulp cavity. Dr. Haycraft suggested that the ring of odontoblasts which forms the mouth of this bag might fitly be called the 'formative ring,'' because it is apparently here that new dentine is constantly being formed. The new dentine pushes upwards that previously formed, which carries with it the odontoblasts attached to its inner surface by the dentinal fibrils. The odontoblasts which once composed the 'formative ring' are therefore carried up by the rising dentine, for as soon as each has deposited a little dentine at the extreme base of the tooth, it becomes fixed as a permanent odontoblast and is afterwards lifted up. Fresh cells are continually growing below those engaged in the production of dentine, and thus the existence of the 'formative ring' is continued. From whence do these new cells arise? Are they derived from odontoblasts, or are they derived from the connective tissue cells of the pulp? Dr. Robertson inclines to the belief that they arise from the pulp cells. 'If we trace the layer of odontoblasts, we find that as the dentine becomes thinner so the size of the dentine-forming cells decreases, till at the lower limit of the dentine they are small spindle-shaped cells attached to the dentine by their distal processes. Even below the extreme limit of the dentine we can still follow the line of odontoblasts downwards as a layer of fusiform connective tissue cells, gradually become smaller till they fade imperceptibly into the pulp tissue. There is no line of demarcation between them and the ordinary small round cells of the pulp.'

"The question now is, How are we to explain how the tooth has increased so much in size? There appear to be four processes all at work at the same time in the growing tooth. These processes are:—

(i) Increase in length of the tooth by an addition of new dentine at the lower end of the fang. This addition more than compensates for the loss caused by the grinding down of its crown. In adult age, the growth of new dentine and the wearing down balance one another, and the tooth therefore remains of constant length.

(ii) Increase in width of the tooth by the gradual widening of the " formative ring."

(iii) A slight interstitial increase in the dentine, causing the formation of an increased amount of matrix between the tubules. This interstitial increase appears only to occur in the very young tooth.

(iv) As the tooth grows, new layers of dentine are deposited on the inner surface of the already existing dentine. This deposit is probably due to the influence of odontoblasts, since they are concerned in the production of dentine from the beginning.

" As the entire tooth is pushed onwards by the growth of new dentine at its lower end, the crown is continually being worn down in grinding. The upper end of the pulp cavity is very narrow and contracted, owing to the large amount of dentine which has accumulated on its surface, for in this situation the dentine is of oldest date and so is thickest. Unless provision were made to prevent it, the pulp cavity would soon become exposed by reason of the grinding down of the crown. It is here, however, at the upper part of the pulp cavity, that the dentine reaches its maximum thickness, and so reduces the diameter of the pulp cavity, that it persists only as a fine channel of considerable length leading from the pulp cavity to the free surface of the tooth. Osseous tissue is developed in this channel, which, together with many small round cells and capillaries, prevents any direct communication between the surface of the tooth and the pulp. No odontoblasts remain in this connecting channel; therefore, since the dentinal fibres in the crown of dentine have lost their connection with nerves the grinding surface of the rabbit's incisor has lost sensitivity. These laminæ of bone which help to block up the remains of the pulp-cavity at the apex of the tooth may be part of the layer of cement which, in the persistently-growing teeth of many animals, covers over the crown of the tooth, and which may when worn away sink into the almost occluded apex of the pulp-cavity and grow there. It may, however, be developed directly from the tissue of the pulp.

"In the adult rabbit's tooth, then, the growth of dentine at the 'formative ring,' the continual deposition of new dentine on the inner surface of the old, and the extent to which the tooth is worn down externally, exactly balance one another, and thus the tooth remains of the same size throughout life. In the young growing animal, however, the first two of these processes exceeds the third, and so the tooth grows greatly in length, diameter, and thickness of dentine.

"Having seen how a simple conical tooth increases in size, the next question which naturally arose was, How do flask-shaped teeth, such as the canine tooth of a cat, increase in size? To answer that question, the canine tooth of the lower jaw was examined in (i) a newly-born kitten; (ii) in a kitten of one month old; and (iii) in the adult cat. These teeth in the cat, as in all *carnivora*, are shed at an early period of existence. This introduces a slight fallacy, for it compels one to compare deciduous with permanent teeth.

Measurements of Lower Canine Teeth in Cats

	Newly-born.	One Month Old.	Adult.
Total length of tooth ..	$\frac{1}{5}$ inch 0·196	$\frac{183}{500}$ inch 0·366	$\frac{59}{100}$ inch 0·59
Greatest length of pulp cavity	$\frac{9}{50}$,, 0·18	$\frac{8}{25}$,, 0·32	$\frac{1}{2}$,, 0·5
Greatest breadth of pulp cavity	$\frac{7}{125}$,, 0·056	$\frac{37}{500}$,, 0·074	$\frac{1}{25}$,, 0·04
Thickness of dentine at middle of tooth ..	$\frac{7}{1200}$,, 0·006	$\frac{9}{250}$,, 0·036	$\frac{3}{50}$,, 0·06
Greatest thickness of dentine at crown ..	$\frac{1}{60}$,, 0·0166	$\frac{23}{500}$,, 0·046	$\frac{9}{100}$,, 0·09
Diameter of dentinal tubules at origin ..	$\frac{1}{17000}$,, 0·0000589	$\frac{1}{17000}$,, 0·0000589	at base $\frac{1}{12000}$ inch 0.0000833 at crown $\frac{1}{27000}$ inch 0·000037
Width of Intertubular dentine..	$\frac{1}{4250}$,, 0·000235	$\frac{1}{4250}$,, 0·000235	at base $\frac{1}{4250}$ inch 0·000235 at crown $\frac{1}{6000}$ inch 0·000166

This table shews that (i) The lower canine tooth of the adult cat is fully three times as long as it is in the newly-born kitten.

(ii) The pulp cavity grows longer in the same proportion.

(iii) As regards the width of the pulp cavity, it seems first to increase in breadth, but in the adult tooth the breadth is less than in the newly-born kitten.

(iv) At the middle of the tooth the dentine increases to a thickness ten times greater than in the newly-born kitten ; while at the crown it increases to about six times.

(v) The diameter of the dentinal tubules was the same in the young kittens. In the adult cat, however, the tubules at the base of the tooth are one-half larger than those of the younger cats ; but near the crown their diameter decreases greatly, being a half less than in the younger cats, and even two-and-a-half times smaller than at the base of the same adult tooth.

(vi) The width of the intertubular substance remains the same in the canines of kittens and also at the base of the adult tooth. At the crown of the adult tooth, however, it is only three-fourths of the breadth of what it is at the root, or in the younger teeth.

"Before describing how this tooth grows, particular attention must first be directed to a fact on which the importance of this inquiry rests, viz., this, that the canine tooth of young kittens is not flask-shaped, but merely conical, resembling the extinguisher of a candle, the sides sloping downwards and outwards from the crown. This originally conical tooth increases in size as follows:

(1) By the gradual dilatation of the 'formative ring' of cells at the base of the dentine it is increased in diameter.

(2) It is increased in length by the addition of new dentine at the base of the tooth and the consequent elevation of the whole tooth. This also is due to the action of the *formative ring*.

"These two processes go on simultaneously, and so the base of the tooth is always growing larger while the tooth is growing in length. This outward extension of the basal *formative ring* of odontoblasts goes on till a maximum is reached. This broadest part of the pulp in the growing tooth of the kitten is at the base, while in the adult cat it remains about the middle of the tooth. Thus in the newly-born kitten the broadest diameter of the pulp cavity was at the base of the conical tooth, and measured 0·056 inch. In the kitten one month old, the basal diameter of the pulp was still the greatest, the tooth still being conical, and measured 0·074 inch. It had not yet become flask-shaped, but about this time the pulp cavity attains its greatest breadth and afterwards diminishes. The elongation of the tooth still continues, but the *formative ring* now gradually contracts, and thus forms an inverted basal cone and so leads to the production of the flask. The narrowing of this basal ring continues until in the adult it becomes a small ring surrounding the vessels and nerves going to the pulp. The elongation of the tooth has also caused its broadest part to be situated about midway between crown and base. Thus the tooth is made up of two cones joined at their bases, the 'crown-cone' being formed by a dilatation of the 'formative ring' and the fang-cone' by the gradual narrowing of the ring.

"(3) During the whole time that the tooth is growing in length, a constant deposition of new dentine is taking place on the inner surface of the old. Thus the maximum diameter of the pulp cavity in the young tooth becomes lessened, till, in the adult, the original pulp cavity is much reduced in size compared with its width in the newly-born kitten. Having reached this stage the processes of growth cease, and thus a typical flask-shaped tooth is produced. We see now how the apparent anomaly regarding the width of the pulp cavity arises. From the table we find that the width of this cavity is less in the adult tooth than it is in the new-born kitten. This is due to the large deposit of new dentine on the inner surface of the old causing such a narrowing of the pulp cavity that the above condition is produced.

"(4) It is also shewn that there has been an interstitial change. The dentinal tubules are smaller and closer together near the crown of the adult tooth than near the base. At the base the amount of intertubular dentine remains the same as it is in the younger cat's tooth, though the tubules themselves are a good deal larger in diameter than in the earlier conditions.

"Regarding fang-formation, we have seen how a single rooted tooth, as the canine, is developed by the gradual narrowing of the basal dentine-forming ring. If, however, this *formative ring*, having reached its maximum dilatation, becomes constricted at two opposite points till these meet like a figure-of-eight, then two smaller *formative rings* are produced. If these both go on forming dentine and diverging from one another, we have two 'fang-cones' produced, springing from one body and giving us a double rooted tooth. In a similar manner, if the formative ring becomes sub-divided into three or four rings, we have a three or four rooted tooth resulting. The tooth follicles themselves, even of the molar teeth, are quite simple and show no indication of roots. It is only after the body of the tooth has been completed that the roots are produced.

"This inquiry shews that the growth of a tooth is only to a very slight extent interstitial. Interstitial growth is seen in the incisor tooth of the rabbit, where the dentinal tubules become further separated by an increase of dentinal matrix, but this appears to take place only in the young tooth. Probably it causes a slight increase in the size of the rabbit's tooth. In the cat, however, it does not cause any increase in the size of the tooth, the width of the intertubular substance remains the same. It is only in the upper part of the adult tooth that the tubules are smaller and more closely packed. All we can affirm in this case is that the interstitial increase of the matrix simply encroaches on the size of the tubules and so does not cause any increase in the size of the tooth.

Examination of the Teeth of Young Rabbits fed on Madder

While working at this subject Professor Haycraft gave Dr. Robertson the teeth of three young rabbits which had been fed on madder for a fortnight. He carefully examined these, as he thought they might throw some light on the mode of growth in teeth.

I. The first rabbit was killed after being fed on madder for two weeks. All the stained part of the tooth is that produced while the madder was added to the food. In the section this staining reached the very crown of the tooth, but only at the centre. This clearly demonstrates that there is a constant deposit of new dentine on the inner surface of the old. At the apex of the pulp cavity the colour is deepest, for most of the new dentine was deposited in that situation. It is also seen that there is a narrow band of stained dentine which immediately surrounds the pulp. These teeth also shew that the incisor teeth increase in length much more rapidly than the molars; for, while the incisor is stained in three-fourths of its length, the premolar is stained in only half its length.

II. The second rabbit was fed for two weeks on madder and then on ordinary food for a similar period. The lower part of the incisor tooth, and also a narrow strip of dentine surrounding the pulp cavity and extending up to the grinding surface, is now unstained. This is all new dentine, formed during the last two weeks of the animal's life. In the premolar the axial staining is hardly yet worn away. The deeper staining of the dentine on the concavity of the incisor may be due to the more rapid growth which there is in this situation, and the greater consequent absorption of the circulating stain.

III. The third rabbit was also fed on madder for two weeks, then on ordinary food for three weeks. The teeth shew merely a further development of what No. II. did. These madder-stained teeth corroborate entirely the explanation of the growth of the dentine which has been already given.

The results of this investigation into the growth of teeth may be thus summarised. There is—

(1) Increase in the length of the tooth by addition of new dentine at its base.

(2) Increase of diameter by dilatation of the basal *formative ring*. In the case of teeth with fangs, these are produced by the gradual contraction of this ring with or without subdivision.

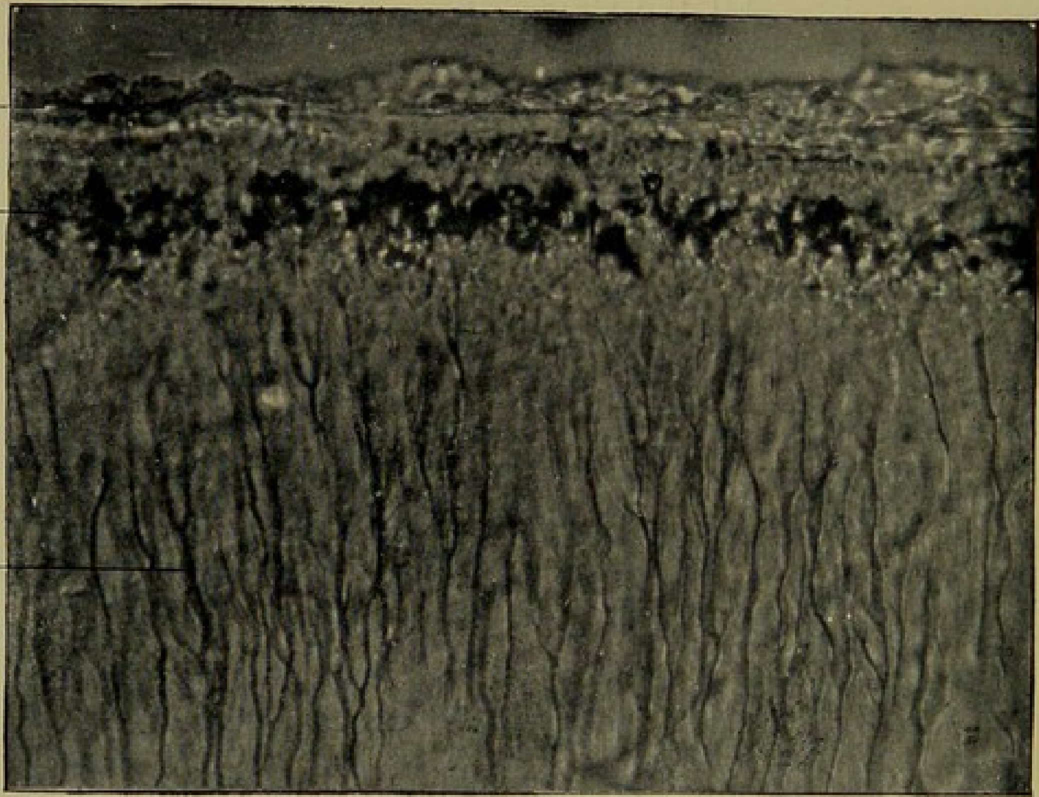


Fig. 228.—To shew an early stage in calcification of cementum. Magnified 500 times. A. Granular layer of Tomes partly calcified; B. Young cementum. Photomicrograph by Norman Broomell.

(3) Deposit of new dentine on the inner surface of the old.

(4) A slight increase in the matrix of the dentine by interstitial growth.

DEVELOPMENT OF THE CEMENTUM

Of this there need be but little said; mere repetition of descriptions of phenomena which are probably now understood with the greatest certainty, is needless. Suffice it to say, that there is every reason to believe that cementum is developed ordinarily after the manner of intramembranous ossification of bone. Where thick layers of the tissue exist over the crowns of teeth, Magitot's opinion that development and ossification in a cement organ of fibro-cartilaginous character is most probably accurate.

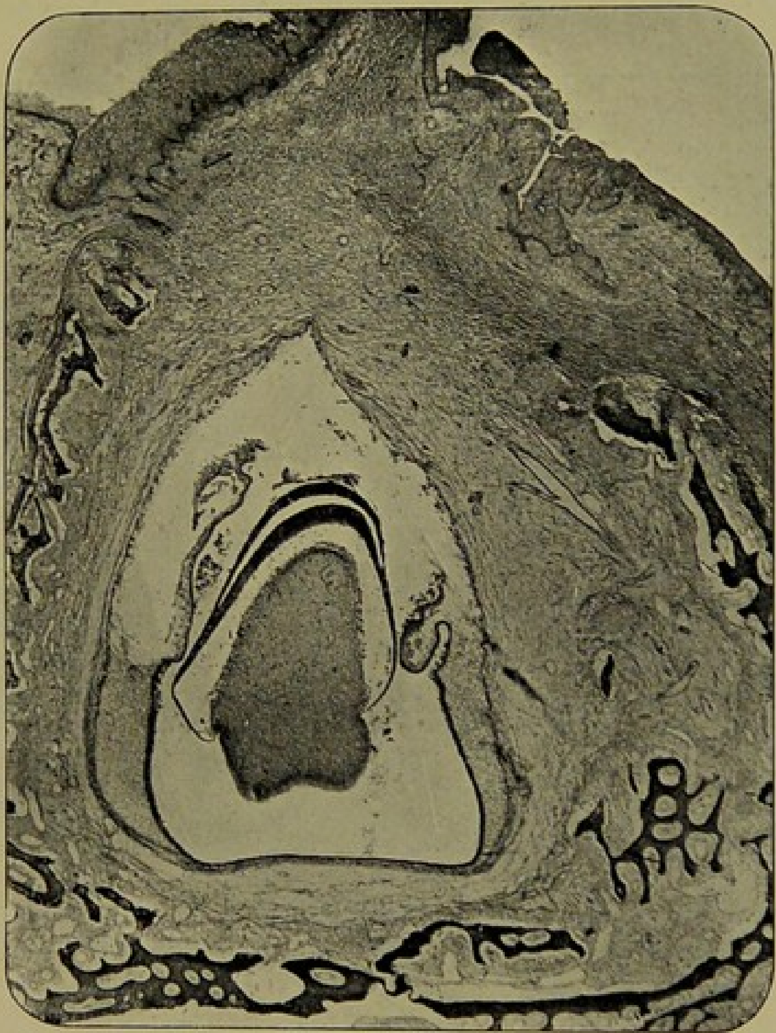


Fig. 229.—From region of first maxillary deciduous incisor. Magnified 30 times. For description of this and following figures, see Tables A. and B. on pp. 289 and 290.

THE STAGES OF DEVELOPMENT OF THE JAWS AND TEETH IN A HUMAN EMBRYO OF HALF-TERM

For the purposes of investigation, and in order to put on record a careful account of the degrees of development arrived at, at a certain period of growth, the right half of the upper jaw of a human fœtus of about 20 to 25 weeks was employed. This was apparently absolutely normal, and, as far as could be ascertained, believed to be unaffected by rachitis, syphilis, &c.

The jaw was subdivided into seven sections, beginning at the front, in a sagittal, and behind, in a coronal direction, and included the following regions, enclosing deciduous teeth:—1, first incisor; 2, second incisor; 3, canine; 4,

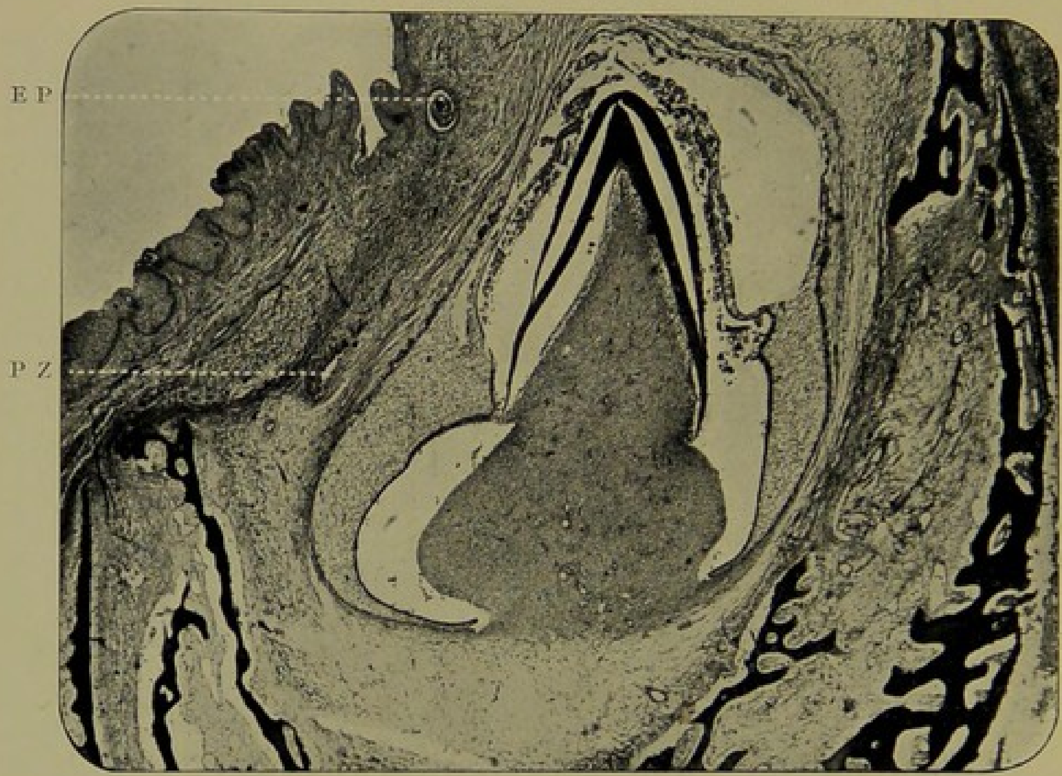


Fig. 230.—From region of second incisor as in preceding figure. Magnified 30 times. P.Z. Permanent tooth-germ; E.P. Epithelial "Pearl" or "Gland of Serres."

anterior molar; 5 and 6, posterior molar, and 7, behind the posterior molar, near the maxillary tuberosity. The latter shewed no dental structures whatsoever. (The figures at the heads of the following columns indicate these various regions. See pp. 289 and 290).

Carefully decalcified and embedded in paraffin, the tissue was cut serially, and typical mesial vertical sections selected for pictorially and verbally illustrating the phases of development. It will be observed that in consequence of the

Table A.—General Appearances

	1.	2.	3.	4.	5.	6.
Enamel.	Thick cap: extends more than half-way down side of dentine.	Thick investment: reaches nearly to base of dentine.	Spear-like point.	As in 3.	None.	None.
Dentine.	Thick investment: meets dentine papilla at junction of lower and middle third.	Thick cap over apex.	Slender cap.		First traces.	None.
Enamel Organ.	Continuous around tooth germ.	Narrow: tooth band of permanent tooth germ just discernible.	Broad: discontinuous at base of tooth germ. Tooth band of permanent tooth germ bulbous.	Narrow: tooth band of permanent tooth germ visible.	Wide: broad trace of tooth band of permanent tooth germ.	Semilunar in shape.
Dentine Papilla.	Conical in shape; very embryonic; capillaries ill-defined.	Triangular in shape: vessels assuming usual characteristics.	Triangular, with smaller triangle over apex: very embryonic constituents.	Flat, with two triangular eminences: more structurally developed than 3.	As in 4.	Surface raised in several eminences.
Ameloblasts.	Pronounced.	Pronounced.	Pronounced.	Pronounced.	Pronounced.	Immature.
Odontoblasts.					Immature.	None.
Stellate reticulum.	Continuous with base of papilla.	Discontinuous around tooth germ.	Broad: large amount.	Broad: flat.	Marked.	Well-formed: nuclei of cells plump and oval.
External Epithe ium.	Continuous around tooth germ.	Discontinuous.	Cubical cells, continuous with dental follicle at base of tooth germ: small epithelial "tufts" appear.	Wavy in outline: "tufts" appear.	As in 3.	Ill-defined.
Dentogenetic Zone.	Marked.	Broad near base of dentine.	As in 2.	Marked.	None.	None.
Dental Sac.	Differentiated.	Differentiated.	Differentiated into outer & inner parts.	As in 3.	No differentiation into two parts.	As in 5.
Maxillary Bone.	Well developed: gutter nearly closed.	Thick: several layers; gutter widely open.	Greatly developed away from oral surface: very wide gutter.	Thick.	Thick at base: gutter narrow.	Largely developed.

Table B.—Dimensions of Parts, in Millimetres

		1.	2.	3.	4.	5.	6.
Enamel	(a) Thickness	0·6	0·12	0·05	0·05	None.	None.
	(b) Extent	1·2	1·75	0·5	0·75		
Dentine	(a) Thickness	0·12	0·35	0·12	0·15	None.	None.
	(b) Extent	1·4	2·0 (slightly less)	0·8	1·2		
Dentine Papilla	(a) Width	1·1	1·5	1·75	3·75	3·0	1·75
	(b) Length	1·3	2·5	2·0	2·5	1·75	0·75
Enamel Organ	(a) Length	2·8	2·8	3·0	1·75	3·0	1·6
	(b) Breadth	1·75	2·25	2·0	5·0	4·25	1·5
Depth of Enamel from Free Oral Surface		3·0	2·6	1·8	2·2	Depth of Apex of Dentine Papilla from free oral surface 3·75	Depth of Apex of Dentine Papilla from free oral surface 5·0
Width of Orifice of Bony Crypts, including Tissues surrounding the Temporary and Permanent Tooth Germs		3·2	4·0	3·5	3·75	3·75	2·5

action of reagents some shrinkage of the embryonic dentine germ has taken place. To prevent tautology, brief tables only need here be introduced.

THE HISTOGENESIS OF OVARIAN TEETH

Not much is known as to the development of those anom-

Fig. 231.—From region of canine, as in preceding figure. Magnified 30 times.

alous misshapen dental structures found in the oöphoronic cysts of the human ovary. Bland-Sutton has, however, examined many specimens. These are fully described in his "Tumours, Innocent and Malignant," 1901. The accom-

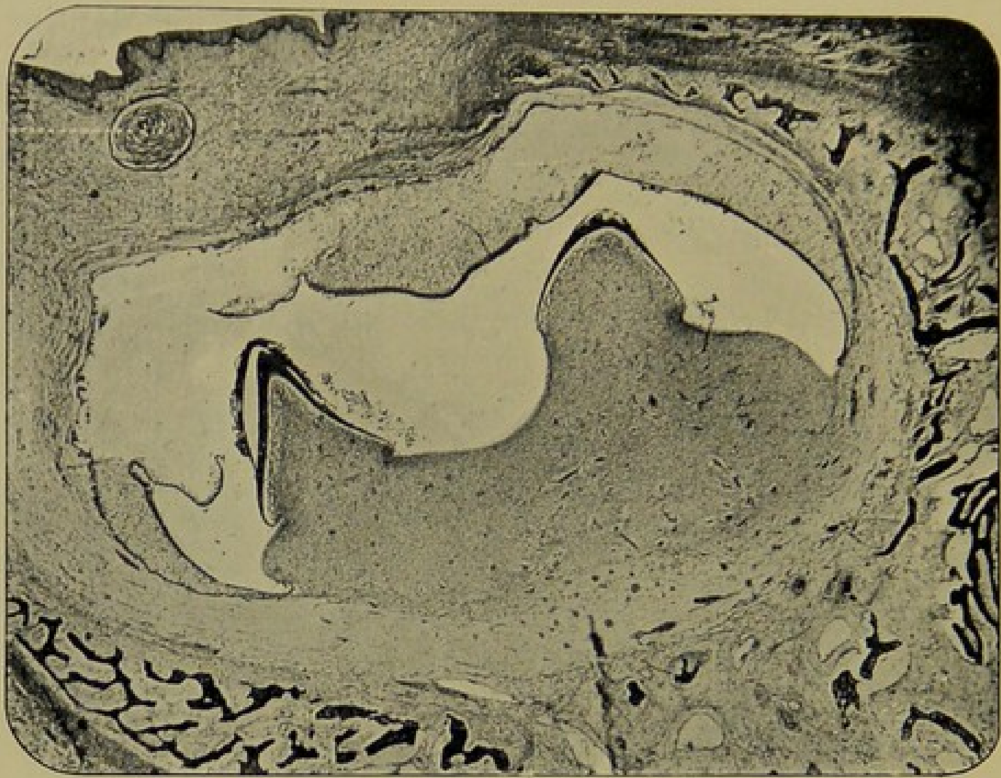


Fig. 232.—From region of deciduous first molar, as in preceding figure. Magnified 15 times. E.P. Epithelial "Pearl" or "Gland of Serres."

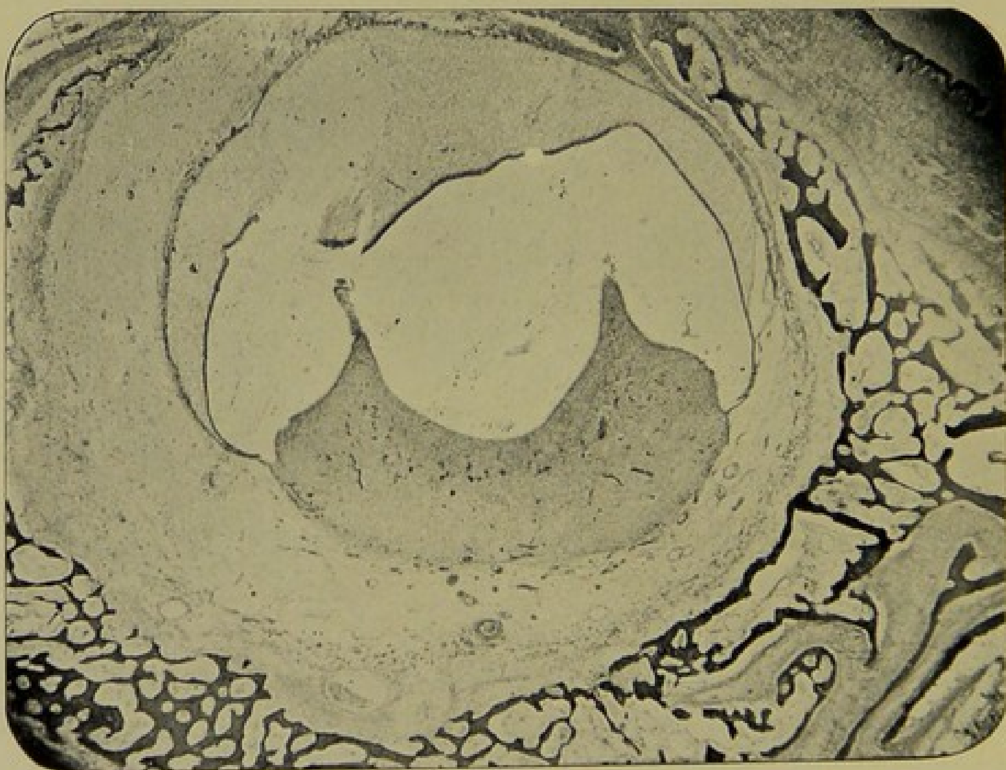


Fig. 233.—From region of deciduous second molar, as in preceding figure. Magnified 15 times.

Fig. 234.—From posterior portion of region of deciduous second molar as in preceding figure. Magnified 10 times.

panying Fig. 235, taken by permission from his work, shews the component parts in the formation of a tooth. *Cf.* the "Epithelial Pearl" (E.P.), with the same bodies in Figs. 230 and 232. These are regarded by Bland-Sutton as enamel organs.

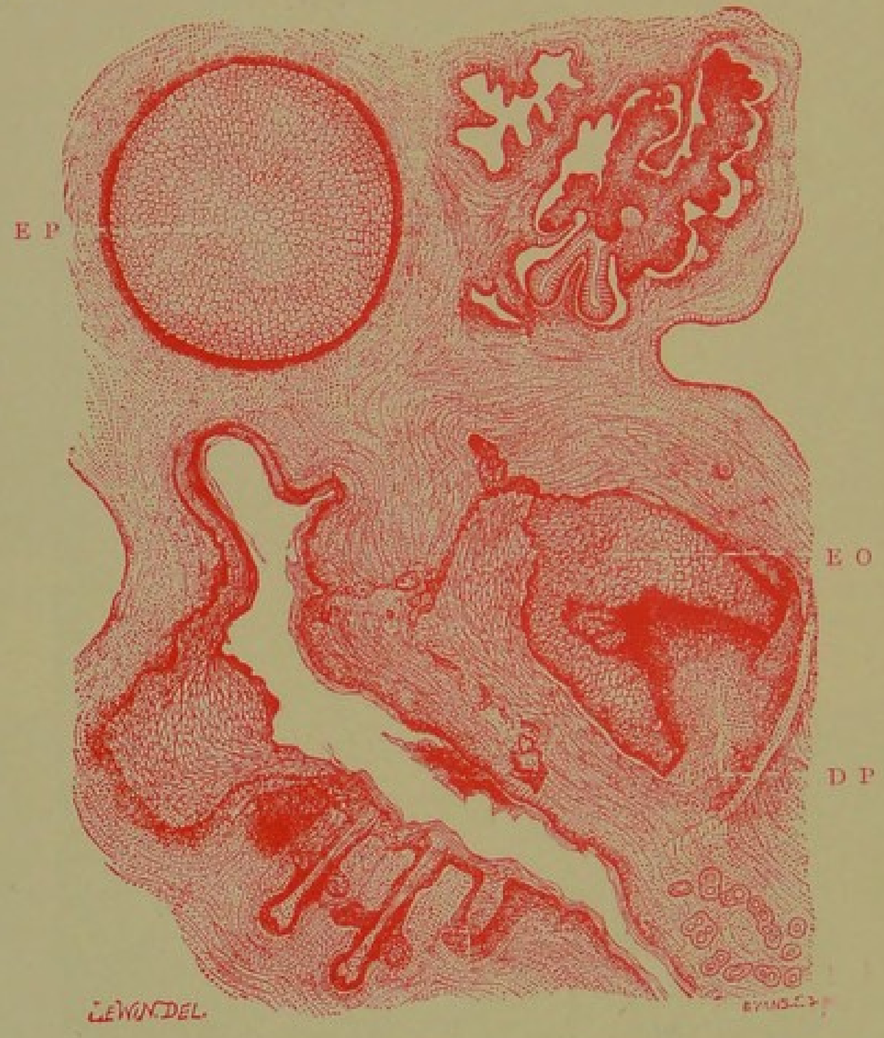


Fig. 235.—Composite drawing of the microscopical appearances in a dermoid cyst of the ovary. E.O. Enamel organ; D.P. Dentine papilla; E.P. Epithelial pearl.

CHAPTER XIII

DEVELOPMENT OF THE TEETH IN PISCES, REPTILIA AND BATRACHIA

MICROSCOPICAL ELEMENTS IN: Developing Teeth of (i) Cod; (ii) Dog-fish; (iii) Crocodile; (iv) Lizard; (v) Snake; and (vi) Newt.

I

In *Pisces*

Fishes are vertebrate animals which live in water, and breathe the air dissolved in the water by means of gills or branchiæ. The two-chambered heart consists of a ventricle and auricle or atrium. The limbs, excepting in the *Cyclostomata* and *Leptocardii* (which are apodal), are modified into fins, supplemented by unpaired median fins. The skin is either naked, scaly, or covered with osseous plates. Fishes, as a rule, are oviparous.

The class of Fishes is divided into 3 sub-classes and 9 orders.

Sub-class I. Teleostei. Skeleton ossified, with completely separated vertebræ. Heart with a non-contractile Bulbus arteriosus; intestine without spiral valve; optic nerves decussating. Orders: (i) *Acanthopterygii*, (ii) *Pharyngognathi*, (iii) *Anacanthini*, (iv) *Physostomi*, (v) *Lophobranchii*, (vi) *Plectognathi*.

Sub-class II. Palæichthyes. Skeleton either cartilaginous or ossified. Heart with a contractile Conus arteriosus; intestine with a spiral valve; optic nerves non- or only partially decussating. Order: (vii) *Ganoidei*, (viii) *Chondropterygii*.

Sub-class III. Cyclostomata. Skeleton cartilaginous or notochordal. Heart without Bulbous arteriosus; intestine simple. One nasal aperture only. No jaws; no limbs; no ribs; suctorial mouth surrounded by a circular lip. Order: (ix) *Cyclostomata*.

It is unnecessary, in a work of this character, to give more than a brief outline of the manner in which the teeth of Fishes are evolved. The simplicity of the process is remarkable and of interest, especially when the development and succession of teeth in *Mammalia* have been studied.

Two examples need only be here detailed.

One occurs in the *Teleostei*, the other in the *Palæichthyes*.

In *Teleostei*

Example.—Order : (iii) *Anacanthini*. Group *Gadidæ*, in division Gadoidei (Cod-fishes).

The simplest arrangements of parts are well exhibited in the jaws of young Cod-fishes of about 10 cm. body length. *Gadus luscus* may be taken as a type.

Under low powers the oral epithelium is seen to be noted for its depth and strength ; its thickness may exceed that of the sub-mucous tissue. The free surface is somewhat thrown into wrinkles or folds. The deeper layer of cells is of the usual columnar shape. The submucous tissue extends into the former in the form of many narrow numerous papillae.

The tooth germs, originating *de novo*, are developed in the tissue which fills a papilla, which, with the growth of the germ, becomes widened and flattened.

Minute structure of tooth germ.—There is no zahnleiste and no zahnwall. An ill-constituted enamel organ exists, the *stellate reticulum* of which is of a rudimentary character, consisting merely of strands of fibres ; no cells and no nuclei fill the inter-spaces. The ameloblasts are short cylinders with large oval nuclei separated from a well-defined *stratum intermedium* by a clear narrow zone.

The odontoblasts are prominent. At the base of the dentine germ, the mesoblast cells going to form the pulp are sharply differentiated from the underlying structures, and no dental follicle, as such, occurs. The odontoblasts of mature teeth are rounded or flattened, adhering closely to the dentine, and in a striking way resembling osteoblasts. They are not distinguishable from the pulp cells in any other particular than their position. These same cells in younger teeth shew transitional changes from these round forms to long cylindrical cells, whose nuclei are not particularly marked.

In the *Gadidæ* (*e.g.*, *Gadus Morrhua*) Röse[1] describes the odontoblasts as extraordinarily long and thin cells in the young tooth rudiments. But Fig. 3, which accompanies his paper, shews the cells to be longest and thinnest over the deepest base of the dentine, and gradually diminishing in length and width as they approach the cutting edge.

In every section of *Gadus luscus* prepared by the writer this is not the case. The cells half-way down the

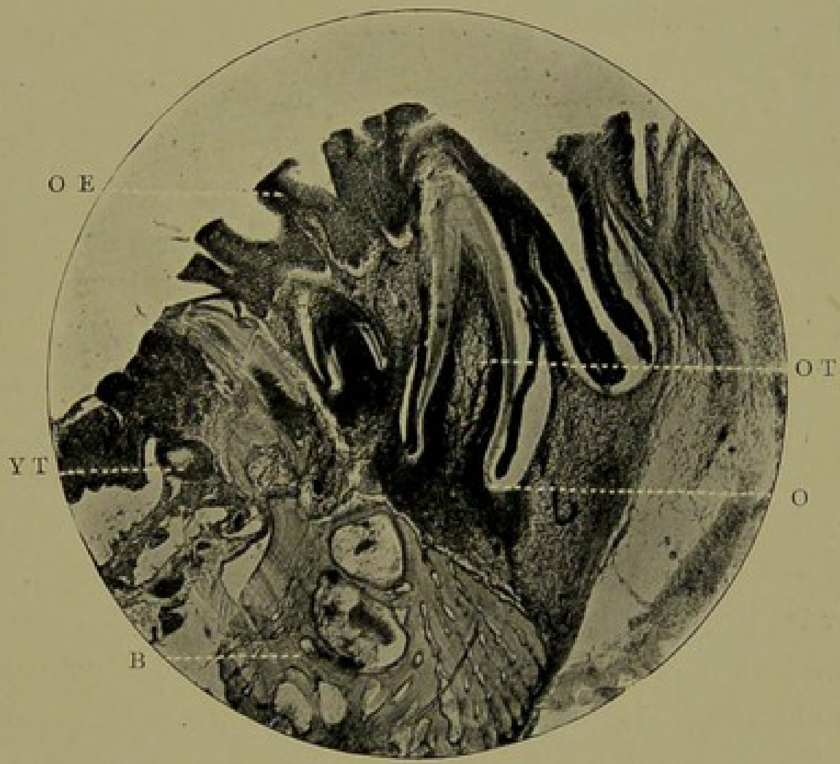


Fig. 236.—Vertical section through jaw of a young cod fish. Prepared by hardening and decalcification. Stained with Ehrlich's acid hæmatoxylene. Magnified 50 times. O.T. Oldest tooth germ ; O. Odontoblasts, in several layers, at base of tooth ; Y.T. Youngest tooth germ ; O.E. Oral epithelium B. Bone of the jaw.

young tooth germs are the largest, those at the oral edge and at the base smaller and rounder, till at the extreme limit of the developing pulp, they are flat and scale-like and adherent to the dentine. Inspection of the photomicrograph, however, at first sight would seem to indicate that Röse's

[1] "On the various Alterations of the Hard Tissues in the Lower Vertebrate Animals." Translated from the *Anatomischer Anzeiger*, in the *Journal Brit. Dent. Assoc.*, Jan., 1899. Pp. 31 and 32.

description is correct. But the appearances here produced are due to *several layers of small cells*, which become curiously congregated in this way. The chief point is that the *nuclei* are in no sense of the word increased or elongated. The section is rather thick.

In structure the dentine is *vitro-dentine*, according to Röse. (For the meaning of this term see p. 122). In the cases just noted it (the dentine) possesses no canals, scanty tubes, but faint laminations. The tooth germs move in an outward direction, and when fully completed are found perched on the pedestal of bone known as the "bone of attachment."

In *Palæichthyes*

Example.—Order, *Chondropterygii*; sub-order, *Plagiostomata*; family, *Selachoidei*: division, *Scylliidæ* (Dogfish).

Specimens of *Scyllium caniculum* afford excellent types of the genesis, evolution and eruption of the teeth.

The epithelium of the mouth is not flat, as in *Mammalia*, but is beset with myriads of elevations of microscopic size.

The outermost layers are not particularly cornified.

At varying distances there occur on the outer surface of the lip, the dermal spines, each of which is imbedded by means of a widened broad base in the submucous tissue. In some places their close association causes these spines to become imbricated.

An inspection of the accompanying photomicrograph shews the remarkable analogy between the teeth and these placoid scales or dermoid spines. In fact, the latter may all be considered modified teeth, differing chiefly in function and position.

In addition to the variation in their positions, these spines are modified in regard to shape, size, and structure.

In form, the greater number which cover the surface of the skin of the animal are flattened plates, with a slightly convex free margin, and wedge-shaped bases securely dovetailed into the firm dermal connective tissue.

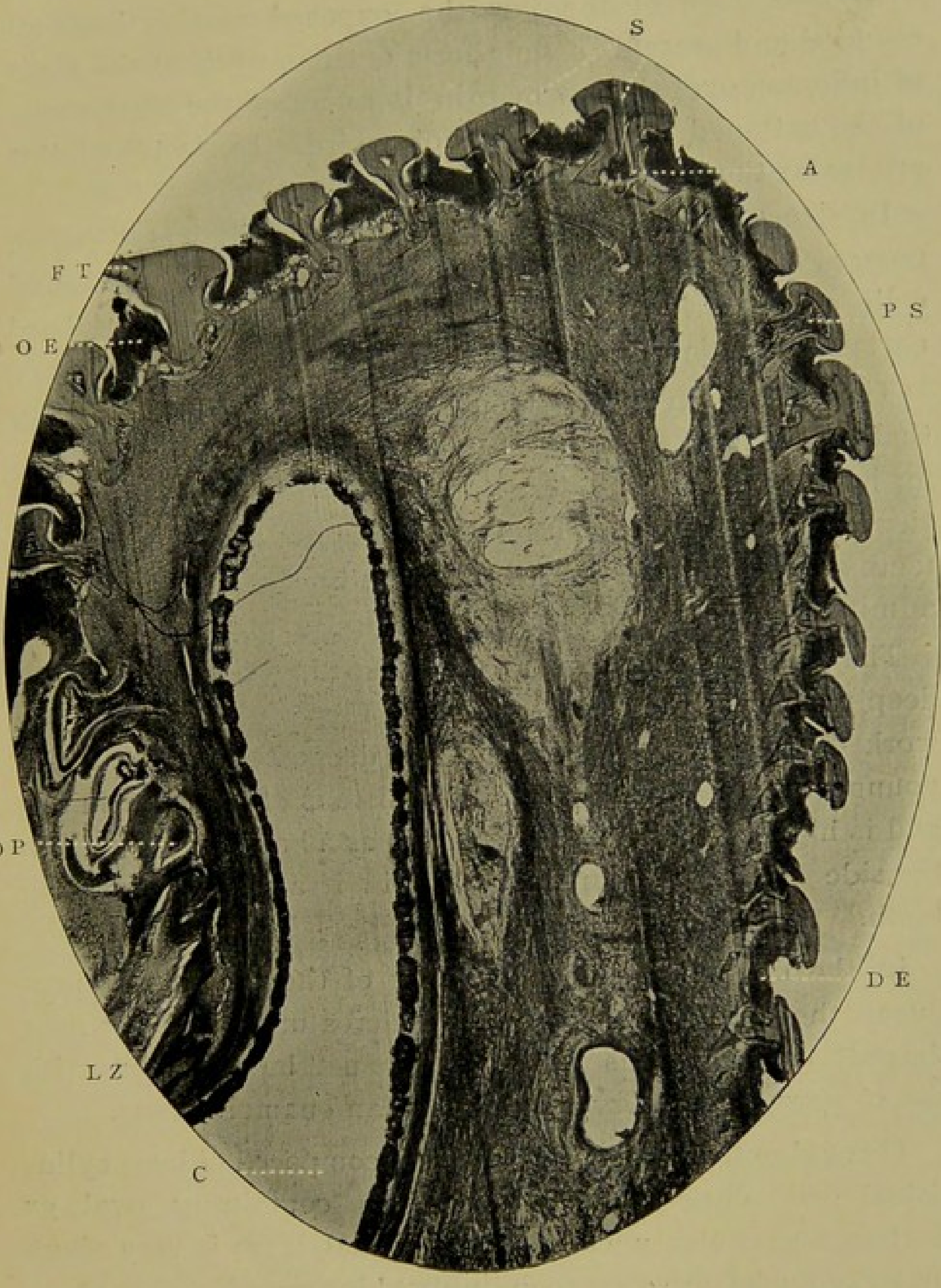


Fig. 237.—Vertical section through the jaw of a young dogfish. Prepared by hardening and decalcification. Stained with borax-carmine and Ehrlich's acid hæmatoxylene. The vertical lines are markings made by a dull razor during cutting on an ether-freezing microtome. Magnified 25 times. C. Cartilage of the jaw, with semi-ossified external crust; D.E. Epithelium of the skin; O.E. Epithelium of the mouth; L.Z. Lowest extent of the tooth band; D.P. Dentine papilla of young tooth germ; F.T. Functional tooth; S. Two teeth about to be shed; P.S. Pulp tissue in centre of a dermal spine; A. Aperture at base of dermal spine for passage of blood-vessels to the pulp.

On the edge of the jaw the exposed portion becomes rounded and presents a fungiform outline, while at the place of inflexion over the jaw margin it assumes the appearance of the flattened head and beak of a bird. In size, the latter are by far the larger.

In structure, each spine, similarly to each dental organ, possesses a central pulp chamber, filled with abundant round cells and a fairly well organised blood system. The hard parts contain dentinal tubes, which radiate in the usual way.

The epithelium of the mouth is considerably deeper than that of the skin, and extends almost to the base of the tooth, for here, at the oral border, the spines become teeth in function, being merely transitional in structure. It embraces the teeth very intimately. An aperture at the *side* of the base admits the passage of blood vessels to the pulp.

The zahnleiste is continuously growing, and dips down deeply as far as the curved recess of the cartilaginous framework of the jaw. Here, as in the deepest locality, are the youngest teeth germs. This zahnleiste is of great thickness, and is highly specialised. It extends as a broad column down the side of the jaw cartilage, and in it are the developing teeth.

In the dogfish the deepest layer of the tooth band produces the ameloblasts as in other creatures; and the next deepest layer of cells forms what must be analogous with the *stratum intermedium* of mammalian enamel organs.

Throughout, the deepest layer is composed of long cylindrical cells closely packed together, containing oval or flattened granular nuclei. The external layer is very short and the nuclei are correspondingly abbreviated.

By counter-staining, the young teeth may reveal what is probably a thin superficial band of enamel.

The dentine and the pulps of the teeth are developed from the connective tissue. The cells in the situation of the future dentine papilla become approximated, and in the pulps, while still retaining their rounded forms, can be easily seen to deposit ossific material on the sides of the connective tissue scaffolding of the dentine.

In the interspaces of the developing teeth, the deepest layer is arranged like a loop.

Thus, enamel organs as highly specialised as in *Mammalia*, are non-existent and no dental follicles surround the papillæ.

II

In *Reptilia*

The class of Reptiles is divided into the following orders :—i. *Crocodilia ;* ii., *Rhynchocephalia ;* iii., *Lacertilia ;* iv., *Ophidia ;* and v., *Chelonia.* In i. (Crocodile, Gavial, Alligator) the teeth are implanted in sockets ; in ii. (New Zealand Lizard or *Sphenodon punctatus*) they are ankylosed to the summits of the jaws, the bone at their bases undergoing a secondary upgrowth (hyperacrodont)[1], but are soon lost by attrition, their functions being carried on by the dense free margins of the maxilla and mandible ; in iii. (Lizards) they are ankylosed and non-socketed ; and in iv. (Snakes) the same ; while in v. (Turtles and Tortoises) they are absent.

In *Crocodilia*

The genesis of the teeth in Crocodiles resembles in a marked degree that of mammalian animals. An exhaustive description would be, in the main, little better than a mere recapitulation of the story. Suffice it so say that the teeth succeed vertically, being thecodont—*i.e.*, contained in the same socket. Absorption of the functional tooth by its successor takes place, owing, no doubt, to some form of absorbent organ, as in man. It is interesting to compare photomicrographs of these two conditions. (See Figs. 212 and 238).

In *Lacertilia*

The common English Green Lizard (*L. viridis*) may be employed as a type.

The chief characteristics are the great length of the zahnleiste, and the consequent depth of the enamel organ and dentine germ. As far as the maxilla is concerned, the

[1] See paper by Howe and Swinnerton on "The Development of the Skeleton of the Tuatera." *Trans. Zoological Soc.*, Feb., 1901.

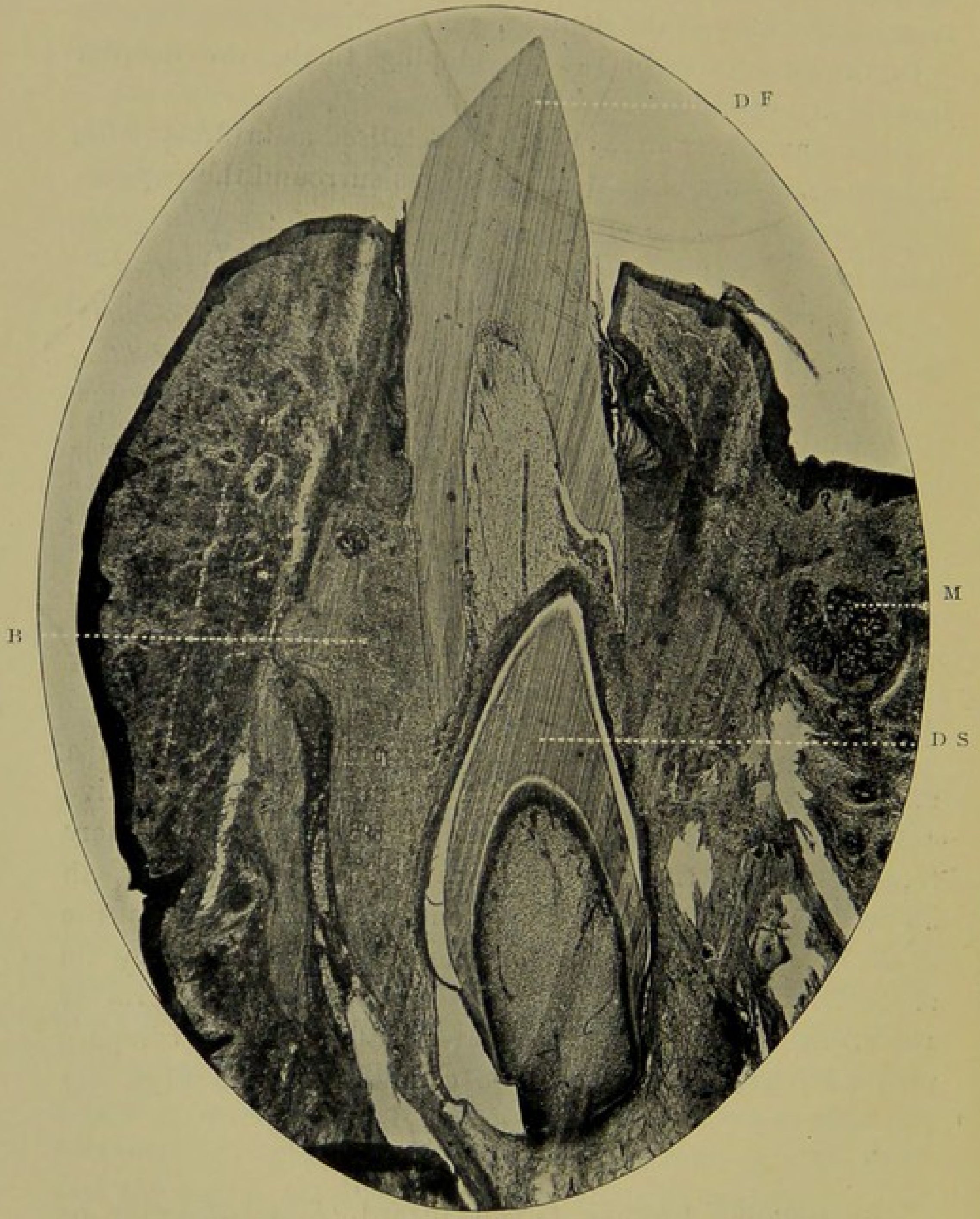


Fig. 238.—Vertical section of mandible of young crocodile. Prepared by hardening and decalcification. Stained with borax-carmine and Ehrlich's acid hæmatoxylene. Magnified 20 times. D.F. Dentine of functional tooth; D.S. Dentine of successional tooth; B. Bone of jaw; M. Mucous gland.

whole tooth germ is placed as closely as possible to a concavity in the upper and inner surface of the jaw at the base of the functional tooth.

The ameloblasts are considerably elongated, and extend deeply down the sides of the dentine germ. The layer is continuous, as in man, with the external epithelium. There

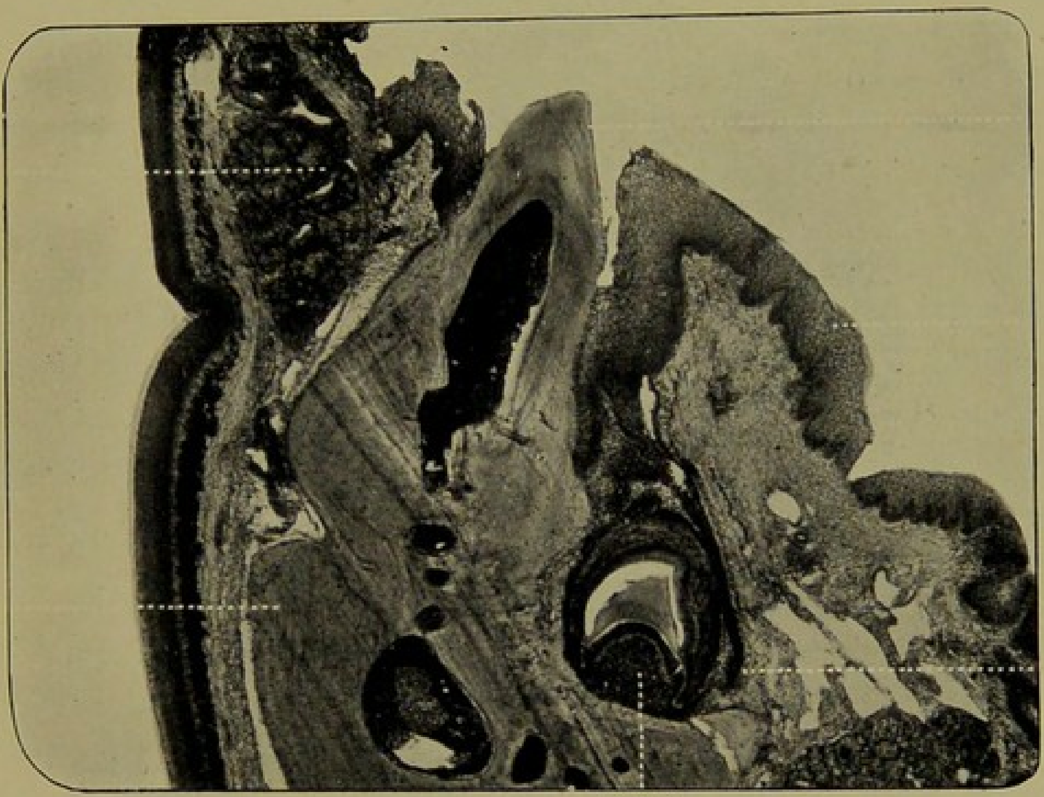


Fig. 239.—Vertical section of jaw of an acrodont lizard. Prepared as in preceding figure. Magnified 25 times. D.F. Dentine of functional tooth; D.P.S. Dentine papilla of successional tooth germ; O.E. Oral epithelium; C.Z. Continuously-growing tooth band; B. Bone of jaw to which the functional tooth is ankylosed; M. Mucous gland.

is no *stellate reticulum* in the otherwise well-differentiated enamel organ, but the intermediate space is occupied by a few cells with elongated nuclei. Apparently no cells analogous to the *stratum intermedium* exist.

The continuation of the zahnleiste is in a line with the deep part of the external epithelium of the enamel organ of the neighbouring young tooth germs, and in direct continuity with the deepest layer of cells of the original tooth band.

The dentine germ is made up of a dense mass of oval cells, which at the periphery are somewhat elongated.

The submucous tissue by condensation of its cells and fibrous tissue produces an "adventitious capsule."

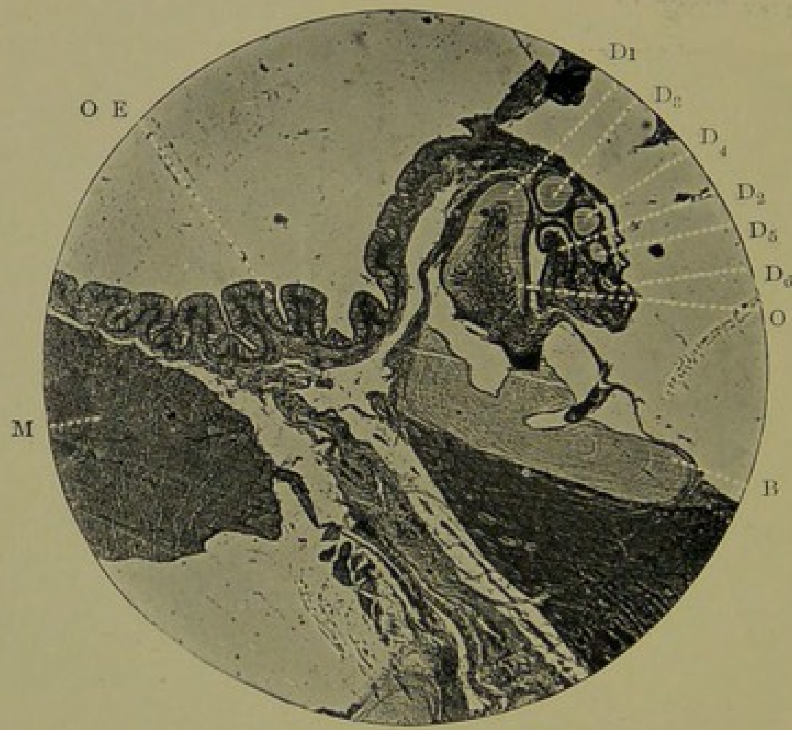


Fig. 240.—Vertical section of jaw of snake. Prepared as in preceding figure. Stained with Ehrlich's acid hæmatoxylene. D_1. Dentine of oldest tooth germ; O. Odontoblasts of the dentine papilla of the same; D_2. Dentine of next oldest tooth germ; D_3, D_4, D_5, Dentine of younger tooth germs; D_6. Dentine of youngest tooth germ; B. Bone of jaw; O.E. Oral epithelium; M. Muscle fibres.

In *Ophidia*

The bone of the jaw of the Common or Ringed Snake (*Tropidonotus natrix*) is somewhat pyriform, with a broad flattened base. The functional tooth surmounts this. Occupying a site internal to the bone, the young tooth germs are found very closely placed, not only to one another, but to the body of the bone itself.

Typical sections shew the oldest tooth germs to be triangular in outline, while the developing teeth in vertical sections have, as a rule, a circular shape. The oldest of the developing teeth in some sections presents a V-shaped outline. This apparent morphological difference is due to the fact that the circular teeth are cut transversely, and the others obliquely, lying as they do in a recumbent or semi-recumbent position before they assume the erect attitude.

The great part of the tooth is composed of ortho-dentine. The layer of odontoblasts is of interest, inasmuch as the cells near the base are the most elongated of all, those at the incisive margin being small and round. The tooth band is very short, surrounding each germ. It is of continuous growth.

The oral epithelium differs in a curious fashion from that of other reptiles. Here it consists of long, narrow cells, which have almost the appearance of ciliated columnar cells. There is only one layer, and it is arranged on a sort of basement membrane, which is puckered up into folds after the fashion of the fungiform papillæ of the tongue.

III

In *Batrachia* (Frogs and Newts)

These animals are cold-blooded vertebrates, which for some, or the whole, period of their existence breathe by gills, and in adult life from lungs. The heart is tri-lobed, having two ventricles and one auricle. Some are ecaudate and apodal. The larva is fish-like and breathes by means of gills, which later on are replaced by lungs. Some, however, retain their gills, while certain frogs leave the egg in a perfect form. They may be oviparous and ovoviviparous.

They are divided into the following orders:—

(i) *Ecaudata*—Frogs and Toads, the former of which is edentulous as far as the lower jaw is concerned, the latter, as to both jaws.
(ii) *Caudata*—Newts, Salamanders, &c.
(iii) *Apoda*, or Cœcilians.

The palate and mandibular bones of the newt (*Molge vulgaris*) are extremely thin and delicate. In the median line, at its innermost margin, the palate bones are thickest, the intervening portions being of remarkable tenuity.

Development of the teeth begins in the oral epithelium which is near the free margins of the bone, by a downgrowth of epithelium. The zahnleiste is shallow, but very flat, and grows continuously towards the middle line.

The oral epithelium possesses several characteristics.

The cells are exceedingly brilliant, being almost transparent in nature, that is, the protoplasm is scarcely granular. This makes the large oval nuclei particularly prominent, and

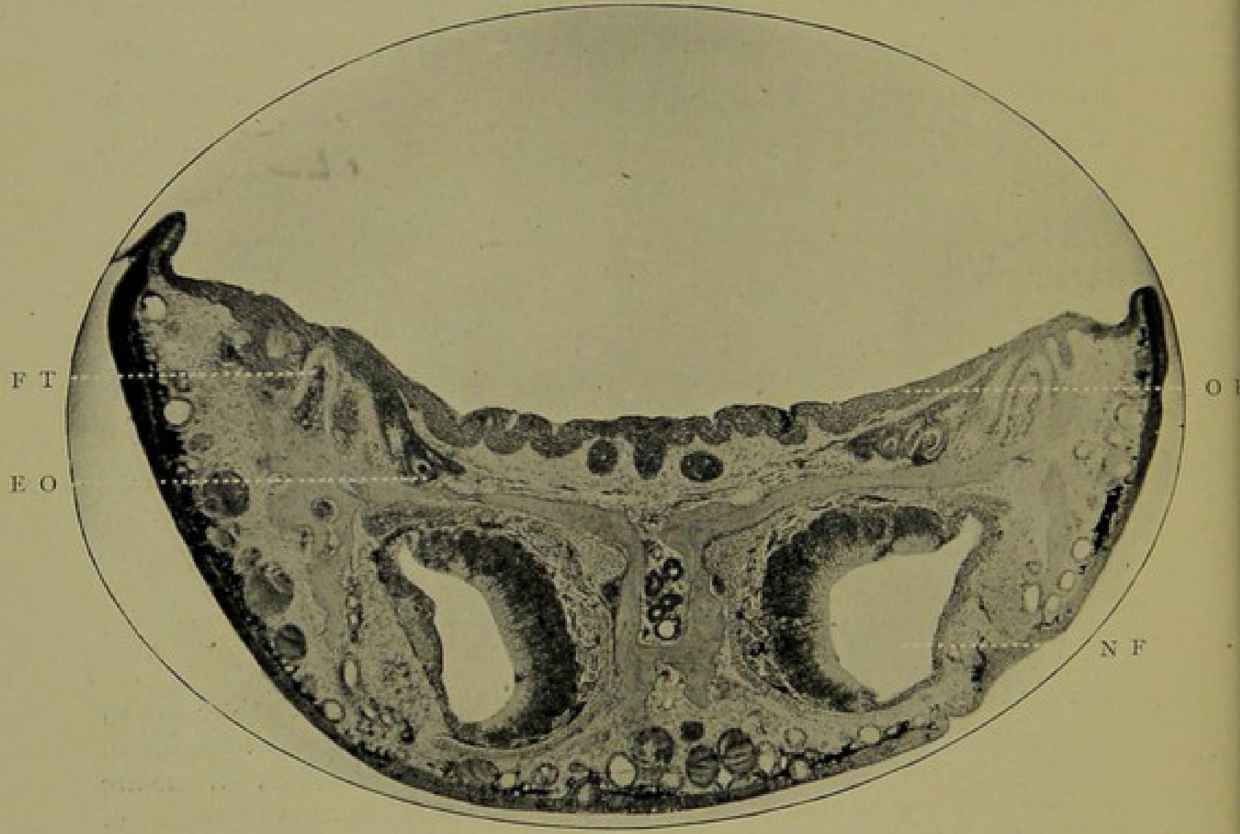


Fig. 241.—Coronal section of the head of a newt, with the mandible detached and removed. Prepared similarly to the preceding figure. Magnified 15 times. O.E. Oral epithelium; F.T. Functional tooth; E.O. Enamel organ of young tooth band, the zahnleiste being continued beyond it towards the centre of the palate. N.F. Nasal fossa.

helps, too, to reveal the spongioplasm they contain. The phenomena of karyokinesis may be well studied here. The epithelial layer is almost twelve cells deep. There is no cellular differentiation into a *rete Malpighii*

The constituents of the zahnleiste are flattened bodies with flat nuclei, and they lie more or less in a direction which is parallel to the palate.

In a typical tooth germ which is beginning to assume a definite shape, the dentine organ is occupied with an assemblage of large elongated cells with reticular nuclei. The dentine is formed at a very early period of growth.

Outside this hard tissue is a layer of smaller rounder cells, and outside this is a second layer, separated from the former by a clear translucent line or space.

There is hardly any attempt at the formation of an enamel organ ; if it exists at all, it is an exceedingly rudimentary structure.

In the anterior part of the mouth, the two inwardly-extending tooth bands of the palate meet and become fused, and form a continuous uninterrupted sheet of epithelium, cut off on the outer side from the oral epithelium, by a thin band of submucous tissue, whose characteristics are small narrow cells imbedded in a clear matrix scantily supplied with fibres, and forming a succession of young teeth placed side by side on the thin jaw bone. The youngest tooth germs are in the centre of this band, the oldest at its margin.

DEVELOPMENT OF VASO- AND PLICI-DENTINE

The process of development is essentially the same as that described in connection with hard or orthodentine (*q. v.* p. 274). It is, however, somewhat modified by the fact that the odontoblasts are of rounded shape like osteoblasts (Tomes), which deposit calcific material along the bundles of connective tissue fibres, which in the case of fishes are most pronounced on the surface of the pulp. The capillaries remain *in situ*, and the dentine is deposited around them, leaving channels in the dentine.

With regard to plici-dentine, the mode of formation is identical, but the capillaries are not conserved in the dentine.

In *Carcharias*, as Tomes has pointed out, the organic matrix of the outer layer (probably enamel) is furnished by a specialized layer of the dentine papilla, and over this are ameloblasts of enormous length. They may measure 70μ or 80μ.

DEVELOPMENT OF OSTEO-DENTINE

The surface of the pulp is first ossified in the usual way by deposition of lime salts around its odontogenic fibres. Thus the outer sheath of hard dentine is manufactured.

The bulk of the tissue is, however, developed after the manner of intra-membranous ossification of bone; that is, rods of osseous material run through the long axis of the pulp, being continuous externally with the rest of the great fasciculi of connective tissue fibres which freely traverse the central soft organ. As Tomes says (*op. cit.* p. 189): "Osteoblasts clothe, like an epithelium, the trabeculæ and the fibres attached to them, and by the calcification of these the osteodentine is formed."