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Studies of the Pathology of Enamel of Human Teeth, with Special Reference to the Etiology of Caries.

BY FRANK ABBOTT, M.D., NEW YORK, N. Y.

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Studies of the Pathology of Enamel of Human Teeth, with Special Reference to the Etiology of Caries.

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By FRANK ABBOTT, M.D., New York, N. Y.

One of the most important questions in dentistry has always been the pathology and etiology of caries. Thoughtful dentists have long agreed that there is a marked difference, not only of individuals, but also of races, in the liability of teeth to decay. Quite recently a prominent dentist of New York directly accused civilization of being the most conspicuous factor in its production. It is an undeniable fact that, with advancing refinement of individuals and nations, decay of teeth is more prevalent. It seems to me, however, that even this recognized fact will not altogether explain the rapidly growing tendency toward this disease under all circumstances. It has many times occurred to me that there must be an anatomical substratum to fully explain the liability to caries in each single individual, aside from the acquired local causes to which caries has usually heretofore been attributed. Unquestionably, there are auxiliary agents in producing or fostering decay of teeth, such as certain kinds of food, more especially sweets, which are too often retained in the fissures always found in the grinding surfaces of certain teeth, upon irregular teeth, uneven surfaces of the enamel, etc. But all these cannot fully explain the fact that the simple change in modes of living should manifest itself in the sudden and rapid destruction of these organs. Strong, healthy individuals, upon being transferred from a country with comparatively simple habits of life into a country of high refinement, may soon become victims of caries of their teeth. Modern Germans and Irish, immigrating to America and enjoying luxuries (similar to those enjoyed by comparatively civilized old Egyptians, in whose mummies we observe, not without some surprise, a pronounced tendency toward decay of the teeth),

soon discover, to their great discomfort, at least that their teeth are becoming diseased.

With these questions in mind, I undertook to examine a large number of teeth which had been ground into thin slabs, with the precaution of preserving their soft parts, especially their living matter, a method first introduced into microscopic technique by Dr. C. F. W. Bödecker. The results of my observations, though not exhaustive, are highly satisfactory, inasmuch as they explain, quite positively, the tendency of certain teeth to decay, the cause of which is in direct relation to and dependent upon imperfections in their anatomical structure. I claim, based upon these observations, that certain deficiencies in the minute structure of the enamel must be directly considered as playing a most important part in the etiology of caries.

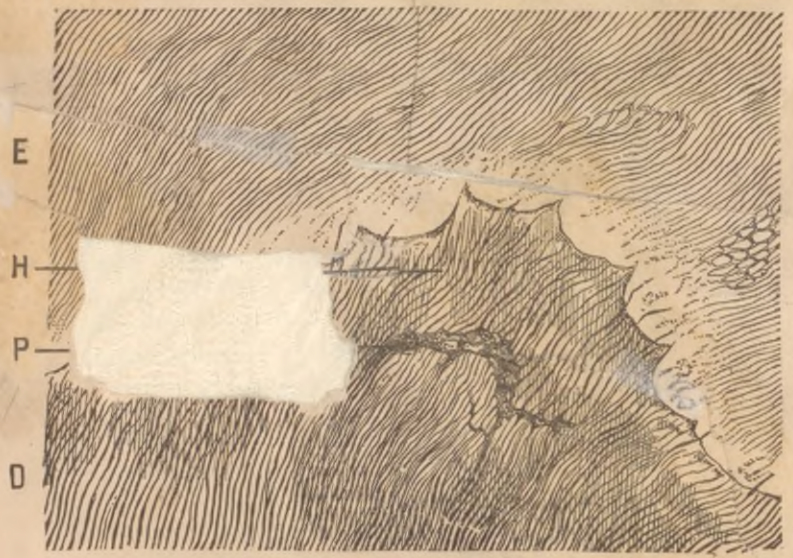
Before entering upon the description of the anomalies of enamel which I have discovered, I wish to briefly recapitulate the description of the structure of this tissue, and its relation to dentine, as first discovered and published by Bödecker, in his essay entitled "The Distribution of Living Matter in Human Dentine, Cement, and Enamel." (*Dental Cosmos*, 1878–1879.) According to this observer, the enamel is composed of rods and fibers of a slightly wavy course, interlacing between which delicate interstices are left. In these interstices run delicate fibers of living matter, which, during mineralization, shoots in a prevailingly vertical direction into the enamel-rods, producing the cross-lines long since known to exist in the enamel-rods, but shown by him to be far more delicate and numerous than ever described before. The square pieces of the enamel-rods are again subdivided into minute fields; they are separated from each other by delicate light interstices, and in all probability contain fibrillæ of living matter. Thus the enamel is raised to the dignity of a living tissue, in place of the former conception of its being a mere calcareous deposit. At the place of junction of the enamel with the dentine a direct connection is often seen between the enamel and dentine fibers. More commonly dentinal fibers run into the enamel varying distances, without a direct union between them and the enamel-fibers; as the latter do not generally reach the surface of the dentine, but terminate above its level, at different heights, while the zone close above their terminations is occupied by a delicate irregular net-work. In many places the dentinal canaliculi, upon entering the enamel, suddenly become enlarged and form spindle or pear-shaped cavities of varying diameters. They invariably contain protoplasm which is in direct connection with the terminations of the dentinal fibers, and on their periphery with the fibers of living matter of the enamel. In the teeth of young persons the spindle-

shaped enlargements are comparatively larger and more regular than in the teeth of old people. The boundary line between the dentine and enamel is usually slightly wavy and with more or less deep, bay-like excavations, the concavities of which are directed toward the dentine.

In examining a large number of specimens of ground teeth, I met with formations in two instances which are to be considered as rather anomalous, though not strictly pathological. In one instance, that of a temporary molar, there was on the buccal surface a protrusion of dentine into the enamel with a fluted surface, which was

I.—Anomalous Relation between Dentine and Enamel.

Fig. I



PROTRUSION OF DENTINE INTO ENAMEL.

E, enamel; D, dentine; H, hill of dentine with fluted summit; P, protoplasmic bodies in the dentine. X 400.

produced by a series of bay-like excavations, present also at the junction of the dentine with the enamel in this tooth in general, but not so marked as in this protruding spot. The center of this protrusion was occupied by an eccentric protoplasmic formation, differing in shape from the ordinary interglobular spaces. The dentinal fibers at the periphery were bifurcated in the usual manner, but very few of them penetrated the enamel. The portion of the enamel nearest to the protrusion was destitute of prisms, while in the immediate vicinity such prisms were traceable almost in contact with the den-

tine. The zone immediately above the protrusion was but slightly brownish, whereas the prisms of the enamel exhibited a very distinct brown pigmentation.

In a second case, that of a permanent cuspid, also on the buccal surface near the edge, a protrusion of dentine was observed, occupying nearly one-half of the breadth of the enamel. This protrusion was of a conical shape, and without a distinct boundary but blended with an oblong field of enamel of quite remarkable struct-

PROTRUSION OF DENTINE INTO PATHOLOGICAL ENAMEL.

E, enamel; D, dentine; G, granular enamel; A, summit of the dentine; S, sloping borders of the granular enamel. X 200.

ure. The dentinal canaliculi exhibited at their peripheral portions numerous bifurcations, and terminated in small pear-shaped enlargements, many of which could be traced in connection with dentinal fibers, whereas the most peripheral ones, owing to their devious course, looked isolated. The adjacent enamel showed but very indistinct rods, the main mass of the enamel being occupied by brownish globular fields, separated from each other by irregular in-

terstices closely resembling the interglobular spaces of dentine, though of considerably smaller size. The deepest pigmentation and the largest number of such *interprismatic* spaces occurred along the periphery of this anomalous formation, especially toward the outer surface of the enamel. The vicinity of the enamel proper was marked by the presence of slightly pigmented rods, more wavy in their course than normal. Toward the dentine the anomalous formation was sloping, and the line of demarkation between the normal and anomalous enamel exhibited either brown and very wavy prisms or small *interprismatic* spaces, decreasing in diameter the nearer they approached to the dentine. I wish to emphasize and call particular attention to the fact that the dentine of this tooth was nowhere traversed by interglobular spaces; the anomalous construction being confined to the enamel.

II.—Stratification of Enamel.

It is known that dentine, without exhibiting pathological features, is sometimes composed of strata, more or less distinctly marked, slightly deviating from its normal structure, and altogether independent of the formations known as secondary dentine. We often meet with similar formations in the enamel. We observe layers varying in width and more or less sharply marked by a straight line, which in longitudinal sections of teeth exhibit concentric layers, the broadest portion always corresponding to the cusps, the narrowest always to the neck, of the tooth.

At the outer periphery of the enamel there may occur strata, which, contrary to the general construction as above described, are broadest toward the neck and narrowest toward the cusp, though never reaching its summit. In transverse sections the enamel shows simply concentric lines, separating from one another layers of greatly varying diameters. With higher powers of the microscope we ascertain the fact that the lines of stratification, as a rule, do not alter the general course of the enamel-prisms,—in other words, a single enamel-prism will show an oblique line of demarkation, corresponding to the general line of stratification, without being altered in its construction or its course. An exception to this rule will occur only at the peripheral portions of enamel, occupied by the tapering ends of the above-described secondary strata, which I would like to term *neck-layers*, in contradistinction to the central *cusp-layers*. The tapering ends of the neck-layers may exhibit enamel-rods, almost parallel with the surface of the enamel, a feature which is never seen at the outer periphery of the cusp-layers, where the enamel-rods are invariably directed more or less vertically to the surface.

The stratification of the enamel is of the utmost importance for

Fig. 3

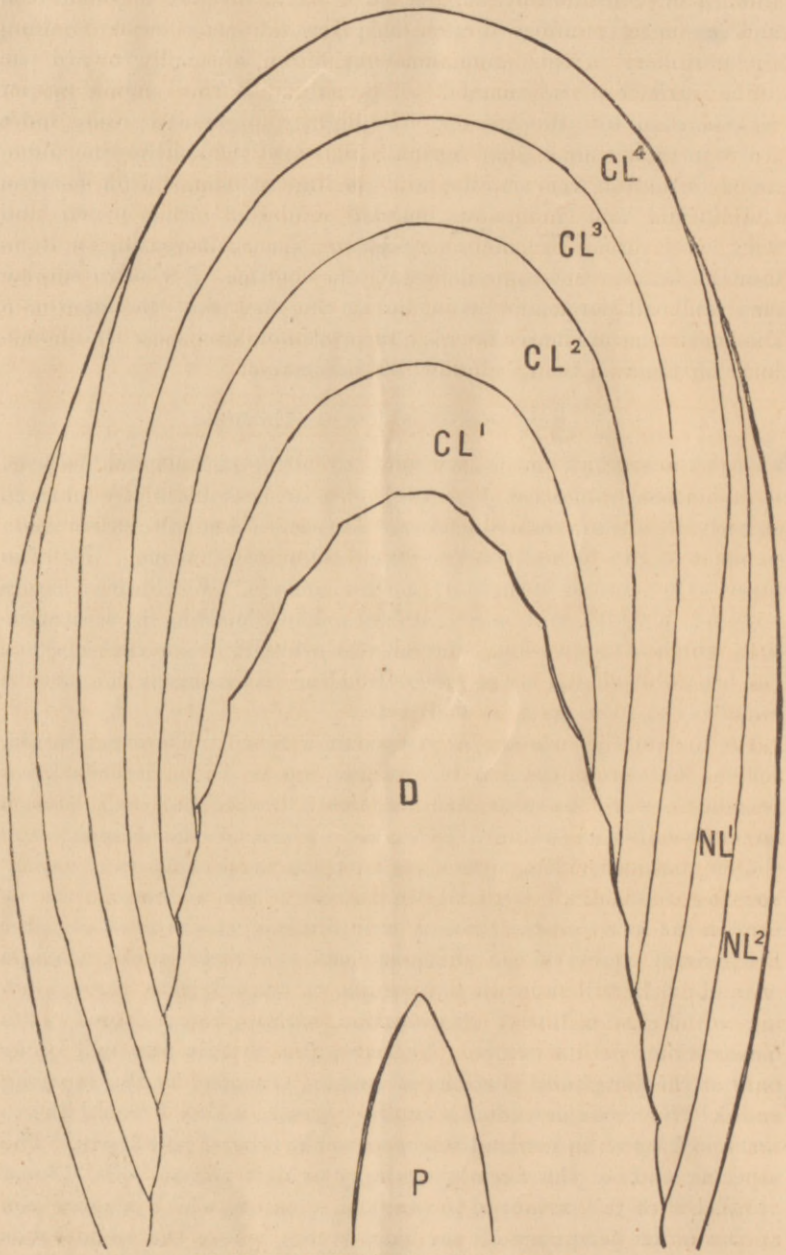


DIAGRAM OF STRATIFICATION OF ENAMEL.

P, pulp-chamber; D, dentine; CL1, CL2, CL3, CL4, cusp-layers of enamel; NL1, NL2, neck-layers of enamel.

the understanding of its pigmentation and granulation. As I will show later on, both the pigmentation and granulation correspond to the general strata of the enamel, thus showing in longitudinal section of teeth a fan-like appearance.

It can scarcely be doubted that the stratification of this tissue is in close relation to the history of its development. We know that the first appearing enamel-cap of temporary teeth, in the seventh month of intra-uterine life, has the configuration of the innermost cusp-layer,—i. e., it is broadest in the direction of the future cusp, and tapers toward the future neck of the tooth. It seems reasonable to assume that the subsequent layers of enamel form on the plan of the first, but there may be a temporary stoppage of its construction, due perhaps to slight ailments of the mother before delivery of the child, or slight ailments of the infant after delivery, which causes interruptions in its organization. Slight ailments of a general nature will not interfere with the final result of an otherwise sound enamel; whereas severe ailments, particularly local, may lead not only to stratification, but to a decidedly pathological condition, which I have before called pigmentation and granulation. These conditions invariably involve a deficient deposition of lime-salts.

III.—Anomalous Arrangements of the Enamel-Rods.

In normal enamel longitudinal sections will, in the majority of cases, exhibit slightly wavy rods, interlaced by comparatively small bundles, cut in a transverse direction. Toward the periphery the curvatures of the rods gradually become less, until when close to the surface they present a nearly straight course. I have never seen transverse sections of enamel-rods directly in contact with the interzonal layer.

Deviations from this rule seem to be rare, and then the enamel-rods seem to lack all regularity in their arrangement. It may occur that close to the interzonal layer the enamel-rods show extensive fields occupied by these transverse sections, which gradually blend with oblique and longitudinal, producing a wavy appearance, to such an extent that beautiful figures arise, reminding one of the grain of *lignum-vitæ*. Still more complicated figures arise if the transverse bars of the longitudinal rods are unusually conspicuous. In such enamel it may occur that the curvatures of the rods remain very marked up to the surface; and consequently groups of transverse sections may be seen directly at the outer surface.

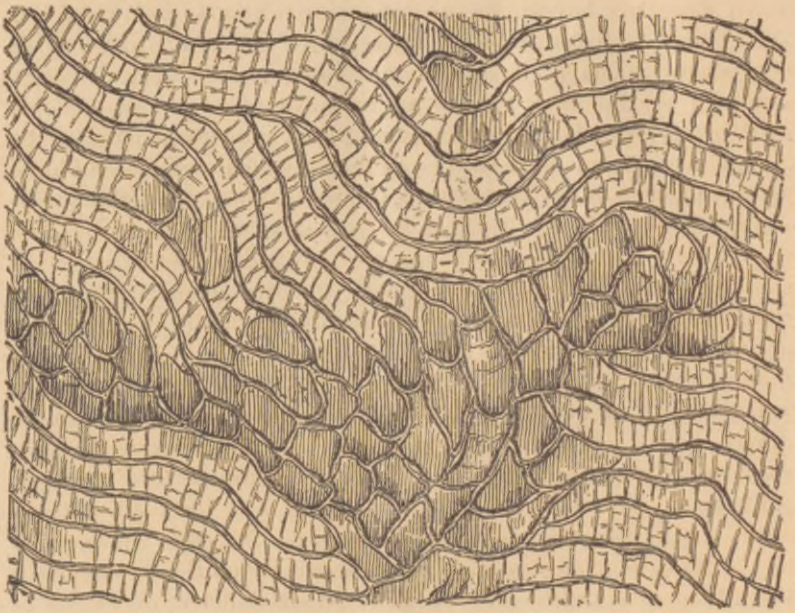
Enamel of this description may be seen only on one portion of the tooth, while the rest is normal. With this curly appearance of the enamel-rods, in all my specimens, pigmentation is combined as a marked feature, and the interstices between the rods are a trifle

wider than normal. Both of the latter features must involve a deficient calcification, and consequently extreme brittleness. It is very difficult to obtain perfect specimens of such enamel. The dentine subjacent to such anomalous formations is freely supplied with interglobular spaces (which is likewise a sign of deficient calcification).

IV.—Deficient Calcification of the Enamel without Pigmentation.

The friability alluded to under the previous heading is in some instances very marked,—so much so, in fact, that it is impossible to ob-

Fig. 4



Extremely irregular course of rods in slightly pigmented enamel. The longitudinal rods deviating to a great extent from the field of the specimen, show oblique and transverse sections. The interstices are widened and contain very conspicuous enamel-fibers. X 800.

tain an unbroken slab of a tooth even with the finest grinding-stones. With low powers of the microscope we observe that the broken ends of the enamel-rods look as if corroded, or as if some of them had been displaced or torn off by the process of grinding. Neither pigmentation nor an anomalous course of the enamel-rods is necessarily connected with such a condition of the tooth. The most striking feature, however, visible even with low powers, is that the enamel-rods are unusually narrow, the interstices between them unusually wide, and their tenants, the enamel-fibers, very prominent.

The cross-lines of the enamel-rods are likewise considerably widened and irregular, so that the fields of basis-substance look unusually small and irregular. The reticulum in the immediate vicinity of the interzonal layer is also unusually prominent.

Such a condition of the enamel may occur both in temporary and permanent teeth, and may be combined with pigmentation. It is a feature of such deficient enamel that it readily stains with an ammoniacal solution of carmine, something that normal enamel will never do. The subjacent dentine, under such conditions, may either be perfectly developed, as before stated, or be deficient in its formation, as shown by the presence of more or less numerous interglobular spaces.

All clinicians have observed congenital white or yellow spots in the enamel of teeth, which if broken into are found to be of the consistence of chalk. Such spots have been termed "white decay," although they do not correspond to the process of caries as we usually understand it. They mean nothing but deficient calcification. Again, all clinicians have seen teeth across which a row of pit-holes exists, where in many instances in the bottom of the depressions no enamel is to be found. This condition is also always congenital, and closely related in its origin to pigmentation and the white or yellow spots. In other instances an originally smooth enamel is mutilated mechanically by the process of mastication, with the result of loss of substance, with abruptly broken, jagged edges. Again, we see teeth with a great portion of their crowns covered by a brownish-yellow substance in place of enamel, which is so soft as to be easily removed, leaving the dentine bare of its covering and extremely sensitive to the touch of an instrument, the pressure of food in mastication, etc. These conditions, again, are, in most instances at least, connected with pigmentation and the white or yellow spots. We might call them exaggerated cases of the same condition. Obviously these congenital defects are dependent upon deficient deposition of lime-salts in the basis-substance, rendering the enamel less resistant and more friable.

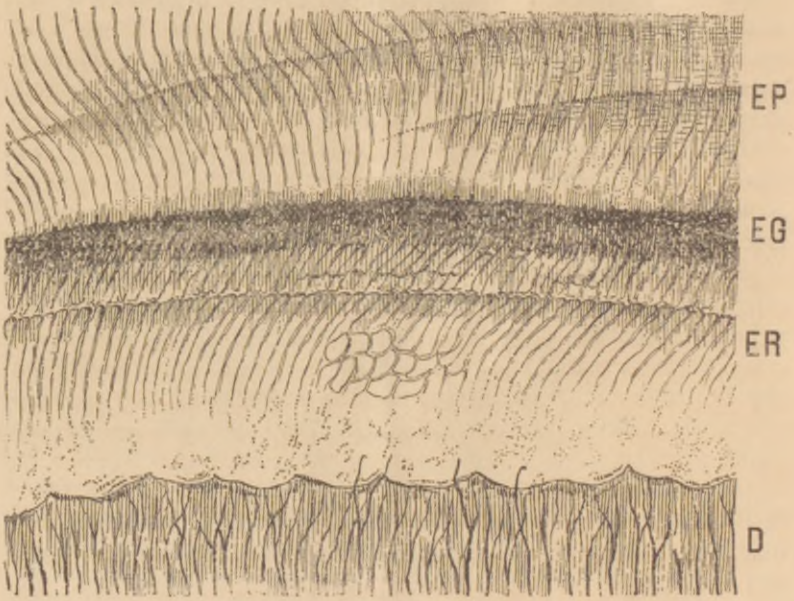
V.—Pigmentation of Enamel.

One of the most common pathological conditions of the enamel is its pigmentation. Sometimes it is so slightly marked that the naked eye discovers only a slight yellow-brown discoloration; in other instances it is quite prominent and readily discernible. Specimens of such teeth under the microscope will correspondingly exhibit either a dim yellow tint in the enamel or a very marked brown discoloration. The pigmentation may occur either in non-stratified or in stratified enamel. In the first instance there is no demarkation

of the brown spot toward the colorless enamel; only faintly-marked offshoots of the main spot, tapering toward the dentine, and running in an oblique direction, will indicate the fact that pigmentation has occurred during its formation. In the second instance, on the contrary, if pigmentation invades stratified enamel, there is a close relationship between the two, inasmuch as the deepest stain invariably corresponds to the boundary line of the strata, tapering toward the neck, and gradually fading toward the proximal end of each stratum. Thus, in longitudinal sections, a beautiful fan-like configuration is produced.

The pigmentation may invade all layers of the enamel, often being more marked in the deeper than in the superficial portions. Higher

Fig. 5



PIGMENTED AND GRANULAR ENAMEL.

D, dentine; ER, layer of slightly pigmented rods broken off; EG, layer of highly pigmented and granular enamel; EP, stratified pigmented enamel. X 400.

powers of the microscope reveal the following facts: First, that the brown discoloration concerns the basis-substance of the enamel-rods only. Secondly, that the interstices between the pigmented enamel-rods are widened,—not due to the contrast in color, but to a deficiency in the formation of the basis-substance. Thirdly, that the transverse lines of the enamel-prisms are likewise (at least in many instances) enlarged. Fourthly, that the enamel-fibers and their lateral offshoots

are more conspicuous than in normal enamel, and more so even than in the enamel of temporary teeth, and in many places distinctly beaded. Pigmented portions of the enamel are very prone to take up a red stain on being treated with an ammoniacal carmine solution.

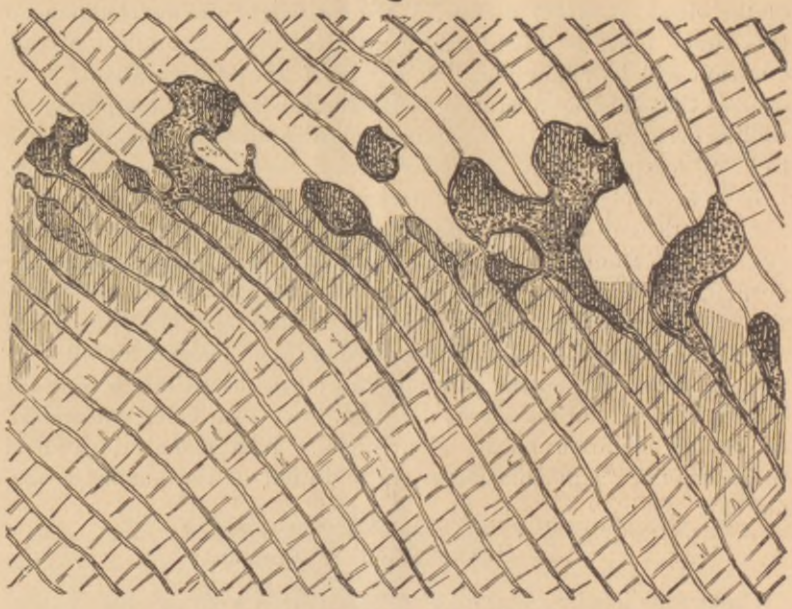
As to the origin of the brown discoloration, I have to say, as a suggestion simply, that at the time of the formation of this tissue there must have been a disturbance in the enamel organ which interfered with the proper construction of the basis-substance and the deposition of lime-salts. What this disturbance really was, I am unable to say. All pigments of the body depend upon and are closely related to the coloring-matter of the blood. I am loath, however, at this time, to attribute pigmentation of enamel to the extravasation of blood-corpuscles or diffusion of the coloring-matter of the blood. Careful studies in the history of the development of this tissue must be made before an attempt at a solution of this question will be admissible. One point I am positive about, however, is that this pigmentation is congenital, invading temporary as well as permanent teeth. Acquired pigmentation of enamel seems to be of comparatively rare occurrence, except as a result of caries. I have seen pigmentations of its surface, of a deep orange color, not penetrating the enamel-tissue in the least. Caries on the surface often causes an orange discoloration, diffused and fading toward the normal portions. Several of my specimens plainly show an invasion of the enamel by caries, on spots pigmented congenitally; secondarily, an orange diffused discoloration has taken place, which is likewise prone to take up the carmine stain; thus beautiful shadings of brown, orange, and red are to be seen, the brown being congenital, the orange acquired, and the red artificial. What chemical may lead to an acquired pigmentation or discoloration of the enamel I cannot say.

VI.—Granulation of Enamel.

Under this heading I propose to describe a very peculiar pathological condition of this tissue, which, so far as my specimens indicate, is by no means rare. It consists of pear, spindle, and club-shaped spaces in the middle of the substance of the enamel. Such spaces were known to exist heretofore at the junction of the dentine and enamel only. They may appear in pigmented and invariably do in stratified enamel; the stratification in the latter instances being due to their presence. Club-shaped spaces may appear at the distal boundary of one of the cusp-layers, or there may be several rows of such spaces, varying in extent and degree, but it sometimes occurs that only the outermost cusp or neck layers are freely supplied with them, whereas the rest of the enamel is normal or more or less pigmented.

Higher powers of the microscope demonstrate that the spaces are enlargements of the interstices between the prisms and the tenants of the interstices. The enamel-fibers are in direct connection with the contents of the spaces,—i. e., with living matter. The spaces, at their stem-like beginnings, run accordingly parallel with the interstices; but in their broader portions may cross the enamel-prisms in different directions. If they are few in number they may protrude from the boundary line of a cusp-layer, and penetrate the adjacent cusp-layer obliquely to the main direction of the enamel-rods. In this instance I could trace the connections of the enamel-fibers even with the club-shaped ends projecting into the neighbor-

Fig. 6



INTER-GRANULAR AND SLIGHTLY PIGMENTED ENAMEL.

Club, spindle, pear-shaped, and irregular spaces at the boundary of a cusp-layer in the middle of enamel. X 800.

ing cusp-layer. If these spaces are present in large numbers, the enamel, with lower powers of the microscope, will look dark and granular; hence the name "granulation of enamel" which I have given it.

Fig. 2 represents this condition of granulated enamel with a low power.

Fig. 6 shows the condition under a high power.

In stratified and granular enamel, single strata may be produced

by an interruption of the pigmented enamel-rods, by convex ends directed toward the adjacent peripheral cusp-layer. (See Fig. 5.)

The *interprismatic* spaces of the enamel bear some resemblance to the interglobular spaces of the dentine. I have seen both conditions in a highly-marked degree present in one of my specimens. Whenever these *interprismatic* spaces are present along the border of a cusp-layer they considerably lessen the degree of consistence of the enamel, which upon being ground easily breaks off along the dark granular line.

The nature of the *interprismatic* spaces is plain enough. They mean an incomplete formation of the enamel, owing to some deficiency of function in the enamel-organ during its formation. Obviously not only the basis-substance is deficient, but also the amount of lime-salts is considerably less than normal; hence its brittleness and proneness to decay.

Under the foregoing headings I have described a number of pathological conditions of the enamel, which, at least so far as stratification, pigmentation, and granulation are concerned, mean a deficient formation of the basis-substance, together with decreased deposition of lime-salts. These conditions are, in my judgment, of the utmost importance in the etiology of caries. Ailments either of the mother during gestation or of the infant in the earliest periods of life obviously cause such anomalies in this tissue. These ailments are known to occur far more frequently in refined people, debilitated, as it were, by civilization, than in strong, hard-working, plain-living people, continually engaged in a struggle for life. Thus, I have directly demonstrated and anatomically shown, in a measure, at least, the reasons why refined people are far more subject to caries of the teeth than people lacking such refinement.

As to the literature upon the subject of pathology of the enamel, I have nothing to say, since, to my knowledge at least, none exists.

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