

Epithelially Induced Denticles in the Pulp of Recently Erupted, Noncarious Human Premolars

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Eighty-five maxillary and 90 mandibular newly erupted, noncarious premolars from patients ages 11 to 15 were studied. All teeth were radiographed in mesiodistal and buccolingual projections to establish the presence of calcified bodies in the dental pulps. Of the premolars, 25.8% of the maxillary and 25.5% of the mandibular contained pulpal calcifications. Most were found in the radicular pulp near the apex. A slightly higher percentage of coronal calcified bodies and a significantly lower percentage of radicular calcified bodies was found in teeth whose roots were completed.

Selected specimens with radiographic evidence of calcification were sectioned serially for histological study. Two principal types of calcified bodies were found: epithelially induced denticles and pulp stones formed around amorphous cores of calcified pulp tissue.

Six denticles were selected for graphic, three-dimensional reconstruction, which demonstrated that denticles are initially thimble-shaped, with the open end facing apically. Later they become complete dentin shells around a central cavity. The improper classification of true and false denticles is discussed.

For over a century, reports have appeared in the dental literature on the subject of calcified bodies in the dental pulp. Although the earlier descriptions were rather anecdotal (1-3), several later studies have provided more extensive data on the incidence, location, and histological nature of pulpal calcifications in large samples of human teeth (4-9).

The findings of those studies suggest that several etiological factors may be involved in the development of calcified bodies in the pulp, specifically, changes in the pulp tissue as a result of aging, changes due to chronic irritations of pulp tissue, and inductive interactions between the cells of the epithelial root sheath and the cells of the dental papilla (10-15). However, the latter mechanism has not been universally accepted (14) and no adequate developmental descriptions are given in the literature.

The present study provides radiographic and histological data about the incidence, location, and morphology of calcified bodies in the pulps of newly erupted human premolars, which suggest that epithelially induced calcified bodies (here defined as *denticles*) indeed do exist. It also provides the first three-dimensional, graphic reconstructions of such denticles, illustrating their characteristic morphology at some stages of their development.

MATERIALS AND METHODS

A total of 175 (85 maxillary and 90 mandibular) newly erupted, noncarious human premolars were obtained for this study. The premolars had been extracted for orthodontic reasons. The ages of the patients ranged from 11 to 15 yr.

Radiographs were prepared of all of the teeth in both mesiodistal and buccolingual projections, using a dental X-ray machine with a 16-inch cone. The Kodak DF 57 (double packet) films were exposed at 50 kVp, 15 mA, and 75 imp and processed in an automatic processor at 68° for 3.5 min.

All radiographs were reviewed by both investigators independently on two separate occasions. A calcified body was considered to be present in the dental pulp if it had been observed four times or three of four times. Furthermore, the possibility that a calcified body might be present was noted if two findings were positive and two negative.

Based on the locations of the calcified bodies and the degree of completion of the roots, subgroups were established and eight representative teeth were selected for further histological study and graphic reconstructions. The specimens, which had been fixed previously in 10% formalin, were decalcified in 5% formic acid, embedded in paraffin, and routinely sectioned and stained with hematoxylin and eosin. The serial sections were cut in a plane perpendicular to the long axis of the tooth.

Tracings were prepared of all denticle-containing sections, at standard magnifications, with the aid of a projection microscope. The outlines of the traced denticles were retraced on the digitizing tablet of a Zeiss Videoplan microcomputer, using the internal and ex-

ternal dentin outlines of the tooth as registration landmarks.

Graphic three-dimensional reconstructions were prepared of a total of six selected denticles with the aid of a program designed to create three-dimensional impressions from serial sections. This program also permitted rotations of the graphically reconstructed denticles so that they could be studied from all sides.

RESULTS

The principal *radiographic* findings of this study are summarized in Tables 1 and 2. The incidence of radiographically distinct calcified bodies in the pulps was closely similar for maxillary and mandibular premolars: 25.8 and 25.5%, respectively (37.6 and 35.5% if pulps with possible calcifications were included). The majority of these calcified bodies was found in the radicular pulps and preferentially in the apical halves of these pulps (Fig. 1).

If the stage of root development was taken into account, the percentages of teeth with calcified bodies in the coronal pulp were slightly higher after root completion than before. In contrast, significantly fewer calcified bodies were found in the radicular pulps after root completion than before.

Histologically, two distinctly different types of calcified bodies were observed, here identified as pulp stones and denticles.

In *this* material, the first type, the pulp stone, consisted of a mixture of tubular dentin (usually more centrally located) and atubular, calcified tissue (usually more peripherally located). These tissues surrounded one or several dense, irregularly calcified, basophilic cores. Pulp stones were found in coronal as well as in radicular pulp tissue. They were frequently found in association with diffuse calcification of the surrounding pulp tissue (Fig. 2). They will not be described in more detail here.

The second type, the denticle, consisted of a shell of tubular dentin which surrounded a central cavity filled with cell remnants. In the somewhat older denticles, these cell remnants could not be readily identified. However, during the earlier developmental stages, the enclosed cell remnants resembled the isolated epithelial remnants that were found occasionally in the pulp tissue near the denticles (Fig. 3). This finding and the fact that odontoblasts were located at the periphery of each denticle suggested that these

calcified bodies had been epithelially induced (Figs. 3 to 5). In teeth whose root development was not completed, the denticles nearest the apical end had a rather characteristic thimble shape with the open end facing apically (Fig. 6, A to C).

The diameter of the central cavity varied between 20 and 50 μ m. The thickness of the dentin shell was 25 to 90 μ m, while the heights of the denticles varied between 180 and 260 μ m. In this material, denticles were found exclusively in the radicular pulp, not in the coronal pulp. Free denticles were abundant in teeth whose root development was not complete.

In teeth with more advanced or completed root development, most denticles were attached or embedded in the dentin wall, but remained recognizable by their central cavities and their general outlines (Fig. 7). A few denticles remained free in the central pulps of these more mature teeth (Fig. 8). Such denticles, however, no longer were thimble shaped. A complete dentin shell surrounded the central cavity (Fig. 6D), and the enclosed epithelial cells had undergone degeneration. In some free denticles, the initial tubular dentin shell was partially or completely surrounded by layers of atubular, calcified tissue. The lumina of the dentinal tubules were narrower than in the thimble-shaped denticles.

In this relatively small sample of histologically studied pulps of teeth with radiographic evidence of pulpal calcification, a total of 35 pulp stones and 24 denticles were observed in serial section. In the coronal pulps only pulp stones were seen, surrounded by multiple

TABLE 2. Radiographic incidence of pulpal calcifications in newly erupted human premolars, related to stage of root development

Total Teeth	Teeth with Coronal Calcifications	% of Total	Teeth with Radicular Calcifications	% of Total
A 9				
a: 29	1	3.4	11 (14) ¹	37.9 (48.3)
b: 56	5 (7)	8.9	5 (12)	8.9 (21.4)
		(12-5)		
B				
a: 40	3	7.5	15(23)	37.5 (57.5)
b: 50	4(5)	8(10)	2(4)	4(8)

* A, maxillary premolars; B, mandibular premolars; a, prior to root completion; b, after root completion.

¹ The numbers without parentheses represent positive findings. The numbers enclosed in the parentheses represent both positive and possible findings. In some cases calcifications were seen in both coronal and radicular pulps of the same teeth. Such teeth are therefore listed in both categories.

TABLE 1. Radiographic incidence of pulpal calcifications in newly erupted human premolars

Total Teeth	Teeth with Calcifications	% of Total Teeth	Teeth with Coronal Calcifications	% of Total Teeth with Calcifications	Teeth with Radicular Calcifications	% of Total Teeth with Calcifications
A*: 85	22 (32) ¹	25.8 (37.6)	6 (8)	27.3 (25)	16 (26)	72.7 (81.3)
B: 90	23 (32)	25.5 (35.5)	7 (8)	30.4 (25)	17 (27)	73.9 (84.4)

* A, maxillary premolars; B, mandibular premolars.

¹ The numbers without parentheses represent positive findings. The numbers enclosed in the parentheses represent the totals of both positive and "possible" findings. In some cases calcifications were seen in both coronal and radicular pulps of the same teeth. Such teeth are therefore listed in both categories.

small foci of diffuse calcification. In the radicular pulps it was possible to find either pulp stones and denticles within the same pulp, or pulp stones alone, or denticles alone. A comparison between the number of calcified structures found radiographically and the number found histologically in the same tooth suggested that, with the particular film and exposure factors that were

eruptive human premolars, extracted for orthodontic reasons, and it most closely resembled the sample of James (5), who reported a 52% incidence of calcifications.

Our values are lower, as might be expected, since they are based on radiographic evidence. In order to perceive a difference in radiographic density, there must be a 25 to 50% change in calcified tissue volume and a reasonably sized structure (16). A comparison of radiologic and histological findings in this study

DISCUSSION

Various studies have reported on the incidence of calcifications in human dental pulps. The values vary from a low of 8% (7, 8) to a high of 90% (4, 8). Generally, it appears that the incidence is higher in older teeth (4, 8) and in carious and/or operated teeth (5, 7-9).

The published values on the incidence of pulpal calcifications in young, noncarious teeth, all based on histological studies, are 8 (7, 8), 19.5 (6), 52 (5), and 66% (4). These different values are most likely due to the differences in the composition of the samples that were studied. The present sample consisted of pos-

showed that calcified bodies with a diameter smaller than 200 μm could not be seen in the radiographs. With this constraint, our incidence figures agree more closely with the higher (4, 5) than with the lower (6-8) values reported in the literature. This may reflect the fact that these "orthodontic" premolars constitute a somewhat unique sample, for reasons discussed below.

The small increase in coronal pulp calcifications in the slightly older teeth of this sample may be explained as a simple result of aging, whereby possible earlier

existing calcifications attained a large enough diameter to be detected radiographically. The decrease in the incidence of radicular pulp calcifications in the slightly older teeth appeared to be due largely to the incorporation of many of the existing pulp stones and denticles in the root dentin, transforming them from free into embedded structures. In addition, it is also possible that the increased thickness of the root dentin in older teeth caused an attenuation of the X-ray beam sufficient to mask smaller calcified structures in the pulp.

The particularly low kV, which is beyond clinical tolerance, was utilized by us to obtain optimal contrast for the detection of pulpal calcifications (17). This, and the fact that most calcifications occur near the apex, explains why many of these calcified bodies are not seen clinically.

Most recent studies on the development of calcified bodies in the pulp have dealt with the structures referred to by us as pulp stones (18-20). Pulp stones form around foci of calcifying pulp tissue components (collagen fibrils, necrotic cell remnants, ground substance). The mineral phase of the pulp stones appears to be more like that of bone than of dentin (20). Frequently, pulps that contain one or more pulp stones exhibit diffuse calcification as well.

The structures referred to by us as denticles have been described in the older literature as "canalized" denticles (10). The present study clarifies the shapes of these structures. Central to the identification of the denticles is their noncalcified cavity. The fact that epithelial remnants are present in these cavities and that tubular dentin with a peripheral layer of odontoblasts directly surrounds these remnants suggests that denticles form as the result of inductive interactions between cell remnants of the epithelial root sheath and cells of the immature dental pulp.

In the thimble-shaped denticles, the open end always faced apically. It is therefore reasonable to assume that odontoblast differentiation proceeds in an occlusoapical direction during the formation of these structures. If the development of the denticle continues undisturbed, the dentin shell is completed subsequently by dentin deposition at the apical end.

Stenvik and MjSr (21) described the occurrence of denticles following experimental intrusion of human premolars that were slated for orthodontic extraction. They noted the presence of both denticles and pulp stones in the apical areas of the pulps of control and experimental teeth, with evidence of a substantial increase in the numbers of denticles after experimental intrusion of the teeth. The histological appearance of the denticles described by these authors was similar to the appearance of the structures observed by us and complements the description of the developmental sequence suggested by us. However, no further three-dimensional information was provided.

It should be emphasized that in both the present study and in the study of Stenvik and MjØr (21), a population of orthodontic premolars has been used. It is possible that delays occur in the normal development and eruption of these teeth, which might cause an increased incidence in the formation of denticles, pulp stones, or both. This suggestion is strengthened by an incidental observation of what appears to be a denticle in the pulp of a rat incisor with arrested eruption (22). Since pulpal calcifications are not normally found in rat incisors, this finding may have significance in the interpretation of the present data. Additional research on premolars, with accurate individual case histories, and on samples of different teeth is needed to provide further insight. Such studies are currently under way.

In reviewing the available data, it appears that denticle formation may be limited in *time* to the period of root formation and in *location* to the radicular pulp and the furcation areas of molariform teeth (unpublished data). The location and appearance of the epithelial remnants found in the radicular pulps of human premolars in this study and in the study of Stenvik and MjØr (21) suggest that these cell clusters are irregular, pulpally oriented off-shoots of the root sheath, which have lost contact with the parent epithelium (as verified in serial sections). In contrast to the "postinteractive" epithelial remnants of Malassez, these cells are probably "preinteractive" at the time they lose continuity with the root sheath. The epithelial cells may be able to engage in inductive interactions with responsive mesenchymal cells for a limited period only, since early developmental stages of denticle formation were found consistently just occlusal to the location of the epithelial diaphragm.

It has been customary to classify calcified bodies in the pulp as either "true" or "false," based on their histological composition. Calcified bodies which contain tubular dentin have been described as "true denticles," while the structures composed of atubular calcified tissue have been described as "false denticles." For many investigators this distinction implied that the genesis of the two types of calcified bodies differed: true denticles might have formed as the result of inductive interactions whereas false denticles might have formed around foci of calcified pulp tissue. Numerous objections against this classification have been made, but it continues to be used in most standard textbooks of dental histology.

In our material most of the calcified bodies were composed of a combination of tubular dentin and atubular calcified material. Tubular dentin was always present in epithelially induced denticles, but it was also regularly present in the pulp stones, which formed initially around calcified foci. The presence of tubular dentin in a calcified body did not *necessarily* indicate that the calcified body was formed as the result of an

inductive interaction. However, denticles invariably possessed a characteristic central cavity, which was present in all developmental stages studied here, while the pulp stones were compact masses of calcified tissue.

Therefore, it seems more appropriate to make a distinction between calcified bodies in the pulp according to their mode of genesis, as was done in this study: denticles, which form after an inductive interaction between epithelium and pulp tissue, versus pulp stones, which form around foci of calcified pulp components. The former may reflect a slight disturbance in the normal developmental sequence of root formation, which, although it remains as yet imperfectly understood, does not appear to have a major physiological impact on the pulp tissue. The latter may reflect degenerative changes of the pulp tissue, even at an early age, which tend to increase in number and severity as the individual grows older.

The response of the surrounding pulp tissue to an inductive stimulus appears to be age dependent. It is a common finding that pulp stones, which develop in older teeth, consist entirely of atubular dentin. Calcified bodies (denticles and pulp stones), which are initially composed of tubular dentin, tend to become surrounded by atubular dentin with age.

The formation of tubular dentin in either type of calcified body in younger pulps appears to reflect the ability of the cells in the immature pulp tissue to undergo differentiation into odontoblasts for a limited period of time, provided the proper inductive stimulus is received, whether this stimulus originates from epithelial cells or not. Therefore, the use of the terminology true and false denticles no longer appears to have any validity.

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