

A Study of Mineral Density Surrounding Resorption Sites in Teeth

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ABSTRACT An investigation of mineral density surrounding lacunar resorption sites in cases of both internal and external root resorption, was carried out on 37 human primary and permanent teeth. In addition, equivalent areas of the roots of 14 normal appearing teeth were studied for comparison. Thirty-two of the teeth were analyzed using microradiographic and microhardness techniques and the remainder were studied microscopically after histologic preparation. The teeth used for microradiographic analysis were embedded in plastic, bisected and half of each tooth was sectioned at 70–100 μ . Microradiographs were taken at 9.5 kv and exposed to 30 milliamperes for 25 to 40 minutes. The other halves of the teeth were used for microhardness tests using a Tukon Microhardness Tester. One series of microhardness measurements was made 10 to 40 μ from sites of active resorption in root dentin and a second series was made 250 to 500 μ from these sites. The hardness measurements of the first series were found to be significantly lower than those of the second in cases of both external and internal resorption. Hardness values of the surface of normal appearing roots were also less than areas 250 to 500 μ deeper in the dentin. Microradiographs did not reveal any definite zone of subsurface demineralization although some resorption sites were bordered by irregular areas of decreased radio-density which may be due to superimposition of several resorption sites within the thickness of the tooth section. Histologic observations did not reveal a definite subsurface demineralization gradient. The lacunar resorption front was found to be a multilocular and completely interconnected system.

The cause of tooth resorption other than that related to the process of eruption and shedding of teeth, has interested numerous investigators for many years. The condition of irregular cavities within teeth resulting in "pink spots" was noted as early as 1890 by Miller, in 1894 by Gaskill and in 1920 by Mummery. There have been numerous studies of the characteristics of this pathologic process as well as a number of investigations concerned with its etiology.

To gain information concerning the prevalence of root resorption Massler and Malone ('54) examined the radiographs of permanent teeth of 708 persons and found 86.4% of the teeth examined or an average of 16 teeth in each person undergoing resorption to some extent. Thoma ('35) pointed out that tooth resorption may originate either on the internal or the external surfaces of the root. Considering the latter type, Henry and Weinmann ('51) found approximately 77% of external root resorption occurring in the apical third of the tooth, 20% in the middle third and

only 4% in the gingival third. It was located most often on the mesial and the buccal surfaces of the roots. They concluded resorption occurs more readily on those root surfaces facing physiologic movement, the areas where trauma was the greatest. They also found, as did Warner et al. ('47) that repair of roots with cementum or dentin-like substance occurred in a high percentage of the cases. Stafne and Slocumb ('44) found the central incisor the most frequently involved tooth. In consideration of causes, most investigators believed trauma was an important factor. This may be caused by occlusal interferences, (Orban, '28) orthodontic appliances, (Ketcham, '29; Hemley, '41; Oppenheim, '42) or chemical agents used in restoring teeth (Via, '55; Cabrini et al., '57; Rabinowitch, '57). Also the prolonged effects of inflammation is believed an important predisposing factor to this disease. Again Cahn ('32) and Scopp ('56) believe that idiopathic resorption may be due to an increase of pulpal blood supply which aids in the resorption

of calcium salts. Others believe systemic factors, perhaps hormonal, such as hyperthyroidism as suggested by Becks ('33) and by Henry and Weinmann ('51) or hyperparathyroidism which according to Young ('63) may predispose this process in experimental animals. There are many causes of resorption of both the internal and external surfaces of the root however, which cannot be explained by any of the above mentioned causes.

Recently modern scientific methods have been used in an attempt to gain further insight into the etiology of this process. Burstone ('53) found the ground substance of dentin adjacent to the area of internal resorption to contain more than normal amounts of glycoprotein material. He theorized this increase may be due in part to proteolytic activity of pulpal bacteria superimposed on the primary processes of resorption. Sognnaes ('59) utilizing microradiographic techniques found no evidence of a demineralization gradient in tooth resorption. In 1961, utilizing electron microscopy, he found a half micron alteration of the dentin surrounding a Howship's lacunae. There has been much work done on bone resorption and several investigations are pertinent to this discussion. Greulich ('61) utilizing high resolution, ultrasoft microradiography studied the distribution of organic mass at the sites of bone resorption. He observed a band or rind approximately 1-1.5 μ in width at the point of junction of the osteoclast. Goldhaber and Barnett ('60) demonstrated succinic dehydrogenase in osteoclasts and Burstone ('60) found dehydrogenase, acid phosphatase and leucine aminopeptidase in osteoclasts. Balough ('63) found osteoclasts to contain DPNH diaphorase, TPNH diaphorase, lactic and succinic dehydrogenase. Fullmer ('64) also noted osteoclasts contain high amounts of the latter. Ultrastructural studies by Hancox and Boothroyd ('63) revealed mineral crystals in the vacuoles of the osteoclasts and the resulting exposed collagen was noted to be enclosed in the folds of the cells' ruffled border. It was suggested that an initial mineral loss is followed by digestion of the fibrous matrix.

In an attempt to gain further information of the characteristics of the mineral density of the calcified tissue surrounding lacunar resorption sites in dentin, the present study was planned and has employed microradiographic, microhardness and histologic techniques.

MATERIALS AND METHODS

A. Microradiography

Thirty-two primary and permanent teeth showing areas of external and internal resorption were fixed in 10% neutral formalin and then embedded in bioplastic. The teeth were then cut in half, one half being used for microhardness studies and the other half for microradiography. Sections were cut for microradiography on a water cooled, hard tissue sectioning machine¹ at 70-100 μ . The thickness of each section was measured with a micrometer to determine the proper time for radiographic exposure. These were stored in tap water until they were used. At that time they were allowed to air dry for 5-10 minutes, the excess bioplastic removed from the sections and then they were cemented with acetone onto Saran Wrap which had been cut into strips. These strips bearing the sections were adapted onto 1 \times 3 spectroscopic plates² in the dark room. These plates were placed in a camera bottom so that the source-object distance was 5.5 inches. A shutter was used with a film holder to make the bottom light tight so the film could be carried to and from the machine and the dark room.

The x-ray machine used was a Picker 50 K.V. industrial unit with a type AEG 50 machlett tube operated at 38 primary volts and 30 milliamperes which produced 9.5 K.V. This voltage gives x-rays of a wave length of approximately 2.2 A which is the proper wave length for maximal absorption by calcium ions. Exposures varied from 25-40 minutes depending upon the thickness of the sections. After exposures were made the plates were developed in Kodak D-19 at 68°F for five minutes, washed, fixed and dried. They were studied and photographed on a microscope.

¹ Gillings Hamco Thin Sectioning Machine, Hamco Machines Inc., Rochester, New York.

² Kodak type 649-0.

B. Microhardness

The undecalcified halves of the teeth used for microhardness were sliced into slabs averaging one-half millimeter thick and smoothed by hand on a glass slab using no. 60 wet sand paper. Final polishing was accomplished with a felt wheel at high speed for ten seconds. The sections were then affixed to glass slides and tested for microhardness³ using a 25 gm weight. The instrument was standardized each day to assure consistent results. Only uniform indentations showing diamond-shaped impressions with the long axis seven times greater than the width were used. The areas considered to be undergoing resorption, were those showing obvious scalloping either on the internal or external surfaces of the tooth root. The diamond indenter was positioned to gain measurements in two areas. The first area was as close as possible to the zones of resorption. These were all within 10–40 μ from these sites. A second area studied for comparison was 250 to 500 μ from these areas. To facilitate interpretation of the areas of the crown measured, the tooth sections were magnified and tracings of each section were made. Another series of five normal appearing teeth were studied in the same manner. The hardness of the root surface area underlying cementum was compared to an area again 250 to 500 μ away in the dentin.

C. Histologic

Another series of normal appearing human teeth and some undergoing resorption were fixed in formalin, decalcified with formic citrate and then sectioned, mounted, stained with hematoxylin and eosin and Mallory's connective tissue stain and examined microscopically. Attempts were made to examine similar areas as evaluated by the microradiographic and hardness techniques. Photomicrographs were then made of sections believed pertinent to this study.

RESULTS

Microhardness study

The average mean Knoop hardness (KHN) of dentin 10 to 40 μ from sites of active root resorption was found to be

37.6 in primary teeth and 43.1 in permanent teeth or an average of 40.4 KHN for both series of teeth. The KHN of dentin 250 to 500 μ from these zones was found to be 52.8 in primary teeth and 56.1 in permanent teeth. It is observed that this is a difference of 15.2 KHN in primary teeth and 13.0 in permanent teeth between the areas of resorption and the areas deeper in dentin. An explanation of these findings is shown in figures 1, 2 and 3 and in tables 1 and 2.

A test of the significance of the hardness of the dentin at the resorption fronts as compared to areas of non-resorbing dentin was done by calculating the "T" values of the mean hardness of the two areas in each individual tooth. Most of them were found to be significantly different at the 95% level of confidence. Also the teeth were found to show some variation in hardness within the two locations studied. It was noted that the mean hardness of the resorbed area in permanent teeth was greater than that of the primary teeth by only 5.5 KHN and in the non-resorbed area 3.3 KHN. There was an indication of a slightly increased hardness of the permanent dentition over the primary.

In an attempt to gain more information about the characteristics of the surface as opposed to deeper areas in dentin, it was decided to analyze a series of normal appearing teeth. Five teeth with normal appearing roots were prepared in the manner previously indicated and indentations were made 10–40 μ from the surface of the root dentin immediately underlying the cementum. A second series of indentations were obtained 250 to 500 μ deeper in the dentin. The surface dentin underlying cementum was found to be less hard than that situated deeper in the root (table 3 and fig. 4). An average mean hardness of 42.0 KHN was found for the surface and 62.2 KHN for the deeper dentin or a difference of 20.2 Knoop Hardness Numbers. Using a one way analysis of variants the F ratio revealed this difference between the means to be significant at the 99% confidence level. There appears thus to be a band of softer peripheral dentin of the root underlying the cementum. The

³ Tukon Microhardness Tester with Knoop Diamond Indenter.

TABLE 1
Primary teeth

Tooth no.	Resorbed areas			Non-resorbed areas			Calculations	
	No. of indents	KHN	S.D.	No. of indents	KHN	S.D.	"T" value	Signif.
D-1	26	30.6	5.9	8	40.9	3.0	3.6	yes
D-2	30	29.9	2.1	8	43.3	1.3	7.8	yes
D-3	19	31.7	7.9	5	58.8	2.3	3.9	yes
D-4	32	31.0	7.9	8	41.8	3.5	3.6	yes
D-5	37	35.1	3.2	13	45.8	1.0	8.2	yes
D-6	34	31.9	3.6	12	45.7	4.2	3.3	yes
D-7	13	31.8	2.0	11	54.0	4.8	6.1	yes
D-8	20	29.1	2.8	10	56.6	4.1	20.7	yes
D-9	21	38.6	4.5	12	61.9	6.3	7.8	yes
M-1	25	52.2	10.2	29	58.5	13.1	1.9	no
M-2	15	45.1	6.3	24	58.2	11.3	3.9	yes
M-3	16	44.5	17.3	27	50.0	12.4	1.3	no
M-4	11	45.5	14.5	17	53.2	14.3	1.3	no
M-5	25	41.8	10.7	16	51.4	15.1	2.1	yes
C-1	27	55.2	13.4	17	55.5	14.2	0.08	no
Total	351			217				
Average		37.6			52.8			

TABLE 2
Permanent teeth

Tooth no.	Resorbed areas			Non-resorbed areas			Calculations	
	No. of indents	KHN	S.D.	No. of indents	KHN	S.D.	"T" value	Signif.
IR-12 area 1	28	49.9	7.7	9	55.6	6.7	1.5	no
IR-12 area 2	33	44.9	3.6	10	56.9	4.0	6.5	yes
IR-13	16	39.8	4.2	11	54.6	3.7	7.2	yes
IR-14	28	53.1	8.1	13	59.7	2.3	2.7	yes
IR-15	10	33.6	2.2	10	60.3	4.0	73.1	yes
IR-16 area 1	24	36.5	2.7	10	58.3	1.1	7.5	yes
IR-16 area 2	20	31.8	2.9	14	48.9	2.9	16.3	yes
Total	159			77				
Average		43.1			56.1			

TABLE 3
Permanent teeth. Normal appearing root dentin

Tooth no.	Surface			Below surface		
	No. of indents	KHN	S.D.	No. of indents	KHN	S.D.
N-1	28	36.1	4.6	28	64.0	6.4
N-2	17	43.5	4.0	17	59.0	6.1
N-3	26	43.8	3.6	26	62.9	5.3
N-4	26	43.8	5.5	26	65.4	7.1
N-5	14	43.1	8.3	14	59.8	5.3
Total	111			111		
Average		42.1			62.2	

surface measurements of both series of permanent teeth at 10 to 40 μ from the surface of dentin were found to have very similar hardness values. The normal appearing surface was 42.0 KHN and the abnormal 43.1 KHN.

It is of interest that because of the extent of resorption, the location of some of the microhardness measurements were located near central root dentin or the area where the hardness was originally the greatest.

Microradiographic study

Microradiographs of the 70–100 μ thick dentin specimens revealed the oval shape of the resorption cavities and the interrelationship of large groups of these spaces (figs. 5, 6). It is of interest to observe that as many as 50 to 75 may be present in the thickness of a 70–100 μ slab. Many of the lacunae appear to range from 30 to 200 μ or more in size and in some cases a number of smaller ones appear in contact with a larger cavity (fig. 6). The larger cavity may be termed "primary" sites and the smaller lacunae associated with the larger areas "secondary" sites. The multilocular areas in figures 5 and 6 reveal how a number of lacunae may be grouped, many of them appear superimposed in the radiograph. No evidence appears of a gradient of mineral resorption around the sites. The resorption cavities shown in figures 5 and 6 were from a case where little tissue destruction had occurred. This could be considered a young active site. The lacunae appear smaller and more numerous than those of figures 7 and 8. The site shown in figure 7 is from an advanced case of internal resorption and much dentin was missing. This probably is an older site which has lost some of the spicules of dentin which helped define the smaller sites. As these sites expanded the spicules are eliminated resulting in the formation of larger sites. The edges of the resorption cavities appear equally as dense as the adjacent areas with the exception of the small area appearing in the center and upper left of figure 7. This area again may consist of a number of smaller sites, however, which are associated with the adjacent larger one. The microradiograph shown as figure 8 is of a

deep, tunnel-type defect. This kind of defect was found in several of the teeth and is thought to be related to an accessory root canal. This theory is substantiated by the fact that this microradiograph was taken of an area near the apical canal. The boundaries of this space appear to be altered by numerous small lacunar sites. Many of the resorption fronts revealed areas of repair. Microradiographic appearance of areas of secondary deposition of bony or cementum-like substance on the root surface are shown in figures 9 and 10. Figure 9 is from an area of internal resorption and figure 10 from an external site. In a few areas, what appeared as a sub-surface demineralization front was observed (fig. 11). As this is from an area of internal resorption, it is possible that the less radiopaque area represents pre-dentin. A possible similar area can be seen in figure 13 where the resorption is in an early stage and some of the pre-dentin is still present. Pre-dentin is quite radiolucent and may appear as shown in figure 13. The diagram shown in figure 12 is an interpretation of the multilocular nature of the resorption sites and their various means of communication. All of the sites are connected with the surface of the advancing front and each site is usually connected with the smaller ones above, below and/or the one to the right and left of it. By this means a vast surface area is maintained and small islands of dentin are produced and efficiently eliminated.

Histologic study

The microscopic studies were of teeth some with internal and others with external resorption sites and the observations clarified some of the previous findings. Figure 13, as previously noted, was a primary site probably caused by chemical trauma on the pulp, $\text{Ca}(\text{OH})_2$. The initial stage of resorption is indicated by the degenerating odontoblasts and little loss of tissue at this time except the uncalcified pre-dentin. It also appears that pre-dentin deposition has ceased. Figure 14 illustrates a dense staining zone bordering a resorption site and may be indicative of such chemical changes as mineral loss to the depth of several microns. Functional dentin appears on the right with the proto-

plasmic processes of the odontoblasts still in the dentinal tubules. Figures 15 and 16 both are from early and acutely active resorption fronts. In both figures observe the area of pre-dentin (P) still present along the pulp border. It is apparent how this zone is bypassed along with an attached spicule of dentin as the front moves deep into the tissue. Close association of cells in the lacunae and the fibrous appearing substance in the background is evident. Finally, no definite subsurface alteration was revealed in the histologic study.

DISCUSSION

Analysis of the mineral density at 10 to 40 μ from lacunar resorption sites by microhardness measurements revealed a significant decrease in amount. If this is a stage in this pathologic process then it should be considered relative to the series of events that characterize resorption. Before doing this it is best to consider several technical factors that might lead to misinterpretation of the data. First, it is possible to produce a curved surface on the edge of a bone or tooth sample bordered by a softer substance such as plastic by over polishing. It has been noted by other investigators, Craig and Peyton ('58) and Rautiola and Craig ('61) that curved surfaces may produce distorted indentations. In the present study several precautions were taken to prevent this possible error. (1) Polishing was limited to ten seconds and (2) only diamond shaped indentations in which the long axis was seven times the width were used. Any distortion in this pattern caused immediate rejection of the measurement. Again possible false readings might be obtained from measurements taken in an area undermined with resorption sites. However only a few of the teeth were noted to be affected in this manner as discussed in the microradiographic findings. Measurements in such areas could produce distorted impressions yet few were obtained and these were excluded from the study.

The finding of less hard peripheral dentin underlying cementum in normal appearing roots is in agreement with the findings of Rautiola and Craig ('61). They found a narrow band of peripheral dentin

located between the central root and cementum to have a KHN of 38. Central root dentin on the other hand, had a mean KHN of 69. These figures for permanent teeth agree closely with the findings in the present study of normal permanent teeth which was 42 KHN for peripheral dentin and 62 KHN for areas of one-fourth to one-half millimeter nearer the central root. These are also similar to the findings of 56 KHN for non-resorbed areas of the pathologic permanent teeth. Again the extent of resorption in each tooth was different so the location of the hardness measurements would vary. In one case the resorption front would be located in central root dentin and in the next it would be nearer the periphery. That is why no overall statistical correlations were attempted, only the statistical difference between each resorption site and the area deeper in the same tooth. It is of interest that 17 to 22 resorbing teeth showed significant differences in the hardness of the two areas. Therefore if all technical errors have been excluded it is possible that a subsurface demineralization gradient exists. Such a gradient of 10 to 40 μ was not apparent microradiographically although it has been shown previously by Avery et al. ('61) that Tukon microhardness measurements reflect changes in mineral density that are not discernable by microradiography. This is true at least under the limitations of the equipment and techniques used.

Other investigators have noted the surface of root dentin to be less hard. It has been termed the "granular layer" as it appears microscopically to contain interglobular spaces. It is described as a developmental feature by Orban ('62).

Resorption of mineral to the depth of 1 to 2 μ have been described by a number of authors. Sognnaes et al. ('61) with the electron microscope described the characteristics of resorption surfaces of dentin and noted distinct ultrastructural changes to the depth of 0.6 μ . This change involved a reduced electron density and evidence of denuded fibrillar material. He stated he found no evidence of demineralization beyond the half micron. He also stated this in an earlier study in 1959 in which he used microradiography. The ultra-

structural studies of Hancox and Bothroyd ('63) on avian bone revealed a mineral loss lining a lacunae. Further, they found crystals in the vacuoles of the osteoclasts and exposed collagen fibrils were found enclosed in the folds of the cell membrane. They believe this is suggestive of a process of continuous digestion. Other investigators who have not found demineralized collagen fibers believe the primary change to be solution of the collagen fibers: Scott and Pease ('56); Gonzales and Karnovsky ('61)); and Dudley and Spiro ('61).

Whether the mechanism involves first the alteration of the collagen fibril resulting in a subsequent release of mineral and final digestion of the fibril or vice versa is yet to be answered. It is hoped the present observations of a possible subsurface demineralization front may aid in the clarification of this complex process.

CONCLUSIONS

1. The microhardness 10 to 40 μ from lacunar resorption sites was consistently less than that of dentin 250 to 500 μ from these sites.

2. The various amounts of root dentin lost during resorption resulted in measurements of some lacunar sites which were located in areas previously highest in mineral density.

3. Microhardness of normal appearing dentin 10 to 40 μ near the root surface was consistently less than that of dentin 250 to 500 μ from these sites.

4. Microradiographs of resorption sites revealed some to be bordered by irregular areas of decreased radiodensity which was believed to be caused by superimposition of several resorption sites in the thickness of the slab or to zones of pre-dentin.

5. Microradiographs of resorption sites in dentin revealed the lacunae to be oval shaped, multilocular and a completely inter connected system, with themselves and with the surface of the front.

Author's Note

The authors would like to dedicate this paper to Professor Wilfrid T. Dempster, a friend, an associate and a constant inspiration in teaching and research.

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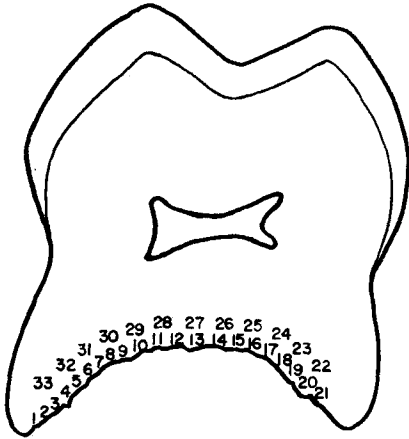
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PLATE 1

EXPLANATION OF FIGURES

Figures 1 thru 4 are projection diagrams of sections of human teeth to show the location of the microhardness measurements. The area indicated by the lower series of numbers was taken within 10-40 μ from resorption sites as seen in figures 1, 2 and 3 and 10-40 μ from the surface of the normal appearing root in figure 4. The higher series of numbers were taken one-fourth to one-half millimeter from these areas. The figures are expressed as Knoop Hardness Numbers.

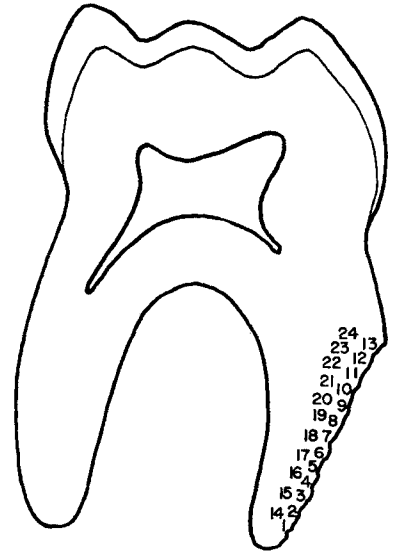
- 1 A primary molar undergoing external resorption probably related to the process of eruption of its permanent successor. Orig. Mag. \times 4.
- 2 A primary molar tooth undergoing external resorption of the lateral surface of only one root. Orig. Mag. \times 4.
- 3 A projection diagram of a human permanent tooth undergoing internal resorption. The superficial zone adjacent to the pulp has smaller Knoop Hardness Number indicating it is not as hard as the deeper dentin seen. Orig. Mag. \times 4.
- 4 A projection diagram of a normal appearing human tooth. In this case the peripheral zone of the root dentin immediately underlying the cementum was found to be softer than adjacent deeper root dentin. orig. Mag. \times 4.



Knop Hardness Numbers

1. 32.8	12. 33.3	23. 56.6
2. 47.6	13. 37.8	24. 56.6
3. 40.7	14. 37.3	25. 55.6
4. 40.1	15. 38.9	26. 56.6
5. 46.9	16. 37.8	27. 56.6
6. 37.3	17. 40.7	28. 61.9
7. 26.0	18. 45.4	29. 69.6
8. 39.5	19. 37.3	30. 68.2
9. 38.9	20. 36.2	31. 69.6
10. 39.5	21. 39.5	32. 69.2
11. 38.3	22. 53.7	33. 69.2

1



Knop Hardness Numbers

1. 23.4	9. 24.2	17. 41.9
2. 23.4	10. 24.0	18. 36.2
3. 17.7	11. 24.2	19. 34.7
4. 23.1	12. 17.7	20. 34.2
5. 23.4	13. 22.1	21. 34.7
6. 21.9	14. 50.0	22. 34.2
7. 21.9	15. 36.8	23. 34.2
8. 20.9	16. 41.9	24. 34.7

2

KHN

1. 28.4	11. 27.7	21. 33.3
2. 28.8	12. 27.7	22. 49.2
3. 32.4	13. 28.0	23. 50.0
4. 32.9	14. 34.7	24. 49.2
5. 28.4	15. 32.8	25. 49.2
6. 32.8	16. 33.7	26. 48.4
7. 36.1	17. 34.7	27. 46.1
8. 35.8	18. 33.7	28. 49.2
9. 37.3	19. 29.5	29. 48.4
10. 33.3	20. 29.5	30. 48.4
	21. 58.6	31. 45.4
	22. 49.2	32. 46.1
	23. 50.0	33. 47.2
	24. 49.2	34. 48.4
	25. 49.2	
	26. 48.4	
	27. 46.1	
	28. 49.2	
	29. 48.4	
	30. 48.4	
	31. 45.4	
	32. 46.1	
	33. 47.2	
	34. 48.4	

KHN

1. 38.9	11. 37.3	21. 35.6
2. 39.5	12. 36.8	22. 35.1
3. 38.9	13. 37.8	23. 35.6
4. 38.9	14. 38.3	24. 38.9
5. 38.3	15. 37.3	25. 58.6
6. 39.5	16. 27.7	26. 57.6
7. 37.8	17. 33.7	27. 57.6
8. 37.3	18. 32.8	28. 57.6
9. 37.8	19. 33.3	29. 58.6
10. 37.3	20. 33.3	30. 58.6
11. 37.3	21. 35.6	31. 60.8
12. 36.8	22. 35.1	32. 59.7
13. 37.8	23. 35.6	33. 58.6
14. 38.3	24. 38.9	34. 57.6
15. 37.3	25. 58.6	
16. 27.7	26. 57.6	
17. 33.7	27. 57.6	
18. 32.8	28. 57.6	
19. 33.3	29. 58.6	
20. 33.3	30. 58.6	
21. 35.6	31. 60.8	
22. 35.1	32. 59.7	
23. 35.6	33. 58.6	
24. 38.9	34. 57.6	
25. 58.6		
26. 57.6		
27. 57.6		
28. 57.6		
29. 58.6		
30. 58.6		
31. 60.8		
32. 59.7		
33. 58.6		
34. 57.6		

3

KHN

1. 42.6	11. 34.2	21. 35.6
2. 41.9	12. 29.1	22. 35.1
3. 35.8	13. 31.9	23. 35.6
4. 33.3	14. 28.8	24. 38.9
5. 30.3	15. 36.2	25. 58.6
6. 33.3	16. 38.9	26. 57.6
7. 31.9	17. 34.2	27. 57.6
8. 32.8	18. 29.1	28. 40.1
9. 33.7	19. 31.9	29. 39.5
10. 29.9	20. 29.9	30. 40.7
11. 34.2	21. 34.2	31. 40.1
12. 29.1	22. 29.1	32. 39.5
13. 31.9	23. 31.9	33. 59.7
14. 28.8	24. 28.8	34. 58.6
15. 36.2	25. 36.2	35. 57.6
16. 38.9	26. 38.9	36. 54.6
17. 34.2	27. 34.2	37. 65.7
18. 38.9	28. 38.9	38. 56.6
19. 34.2	29. 34.2	39. 55.6
20. 29.9	30. 29.9	40. 58.6
21. 35.6	31. 35.6	41. 56.6
22. 35.1	32. 35.1	42. 63.1
23. 35.6	33. 35.6	43. 46.9
24. 38.9	34. 38.9	44. 58.6
25. 58.6	35. 58.6	45. 59.7
26. 57.6	36. 57.6	46. 65.7
27. 57.6	37. 65.7	47. 68.2
28. 57.6	38. 56.6	48. 68.9
29. 58.6	39. 55.6	49. 61.9
30. 58.6	40. 58.6	50. 71.0
31. 60.8	41. 56.6	51. 68.2
32. 59.7	42. 63.1	52. 69.6
33. 58.6	43. 46.9	53. 68.2
34. 57.6	44. 58.6	54. 65.7
	45. 59.7	55. 66.9
	46. 65.7	56. 71.0
	47. 68.2	
	48. 68.9	
	49. 61.9	
	50. 71.0	
	51. 68.2	
	52. 69.6	
	53. 68.2	
	54. 65.7	
	55. 66.9	
	56. 71.0	

4

PLATE 2

EXPLANATION OF FIGURES

- 5-6 Microradiographs of areas of internal resorption of root dentin. These lesions were from areas of very little tissue destruction. It is noted that all of the resorption cavities are of similar size and not very large. The numerous radiolucent resorption cavities appear superimposed in those sections 70-100 μ in thickness. No distinct demineralization gradient appears around the sites. (D), Dentin. Orig. Mag. \times 450.
- 7 Microradiograph of an advanced area of internal resorption. In this case much of the root dentin was missing. Larger resorption cavities appear in the remaining dentin than in the cases shown in figures 5 and 6. The radiopacity is generally uniform except in the center of the picture where secondary sites are noted. Orig. Mag. \times 100.
- 8 Microradiograph of an area of internal resorption located near the apical foramina. Numerous resorption cavities appear along the walls of this deep defect which may be an accessory root canal. Orig. Mag. \times 100.

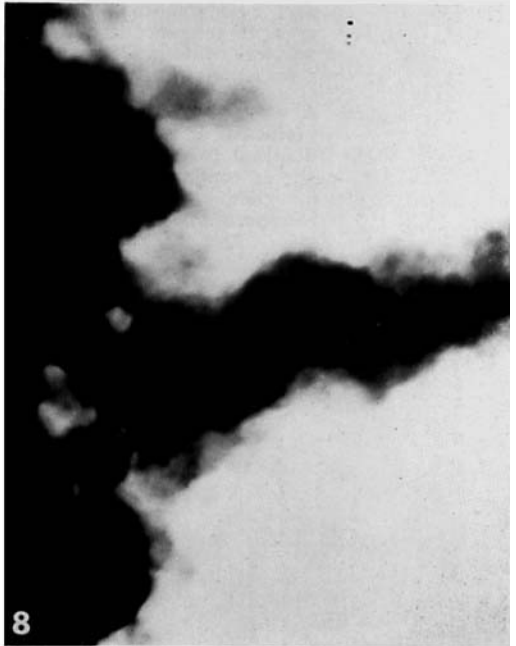
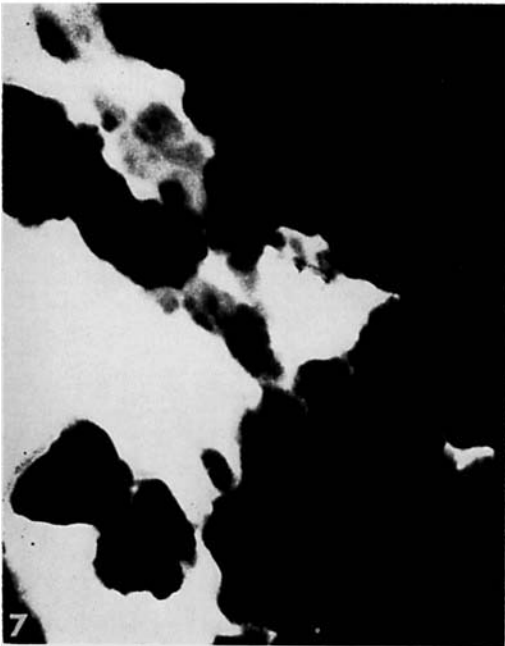
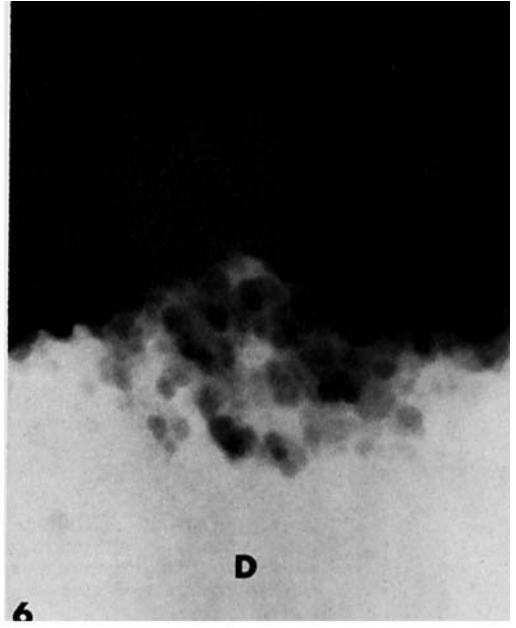
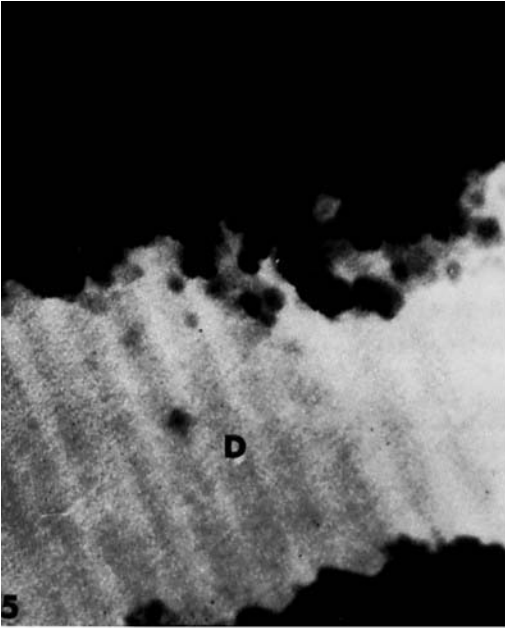


PLATE 3

EXPLANATION OF FIGURES

- 9 A resorption site which originated along the pulpal aspect of a human tooth. The dentinal tubules are visible as is the ragged edge of the resorption front. No mineralization gradient is seen. An area of bony repair can be seen partially filling a defect, (R), Repair. Orig. Mag. $\times 100$.
- 10 A resorption site located on the external aspect of a tooth. The areas of repair appear extensive. It is probable that this bone or cementum has also undergone some resorption with a cavity resulting in the central area of the secondary deposition. Orig. Mag. $\times 100$.
- 11 A microradiograph of a resorption site originating from the internal aspect of a tooth. The dentin tubules are faintly visible as is an area of radiolucent matrix. This appears as an area of decreased mineral content. Because of its location it is possible that this area represents pre-dentin. Orig. Mag. $\times 540$.
- 12 A diagram of a resorption front in dentin representing an interpretation of the microradiographic data. The relationship of the dentinal tubules and the numerous lacunar sites are shown. Each site is connected with another as well as to the surface of the primary site. As the oval shaped sites are expanded they isolate small islands of dentin which in turn are then finally resorbed.

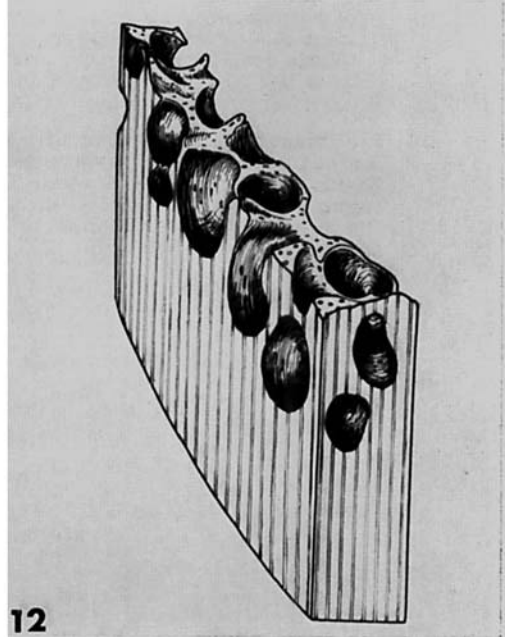
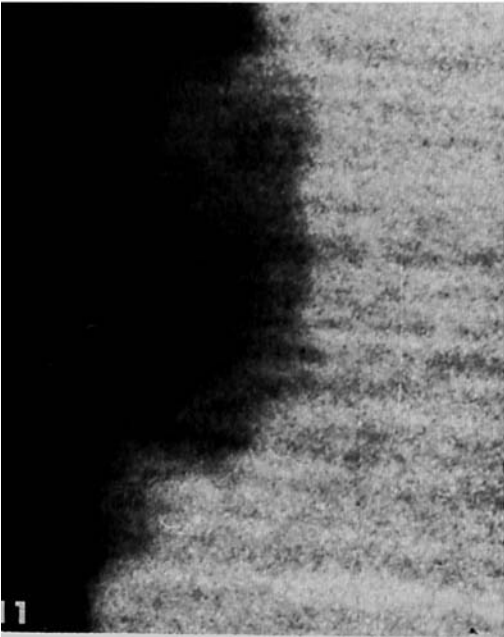
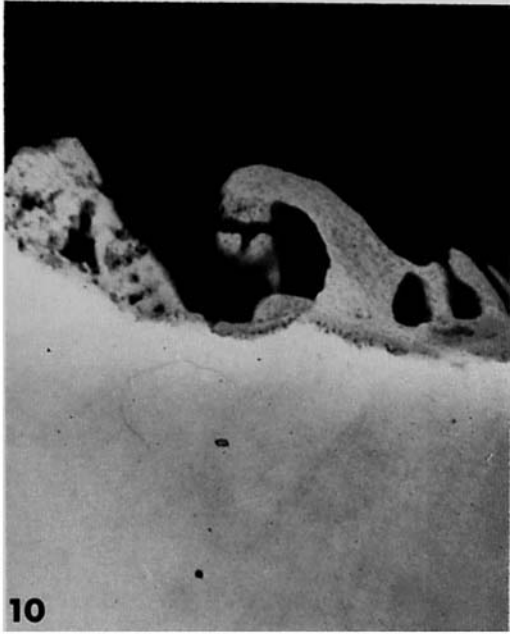
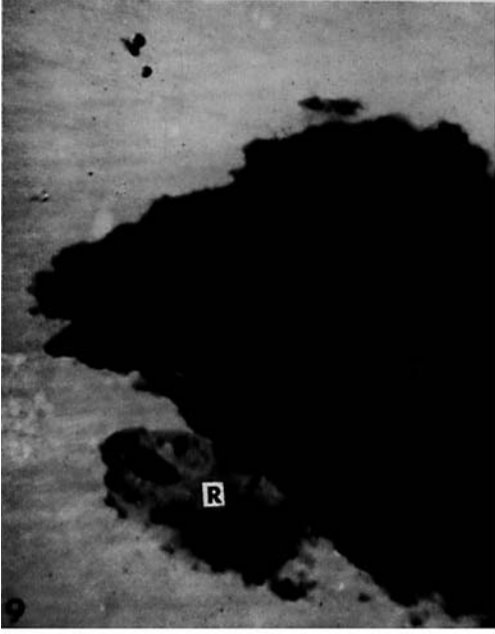


PLATE 4

EXPLANATION OF FIGURES

- 13 Photomicrograph of an initial or early site of internal resorption revealing a loss of some predentin. The odontoblasts have degenerated and the degenerative changes in the pulpal connective tissue can be seen. Some predentin, but not dentin, has already been destroyed. Vascular granulation tissue has invaded this area adjacent to a site of amputation of the pulp with calcium hydroxide. This amputation was done necessarily to remove a necrotic area of the pulp. (P), Predentin, (D), Dentin. Hematoxylin and eosin stain. Orig. Mag. $\times 450$.
- 14 Photomicrograph of an area of internal resorption revealing a dense staining of the matrix immediately adjacent to the resorption front to a depth of several microns. This may be indicative of chemical changes related to the resorption process such as demineralization of the matrix. Mallory's connective tissue stain. Orig. Mag. $\times 450$.
- 15 Photomicrograph of an area of internal resorption showing the dentinal tubules in cross section and a remaining spicule of dentin and attached predentin, (P), predentin and (arrows) indicating predentin. The normal architecture of the pulp is lost and some large multinucleated cells appear along the resorption front. Hematoxylin and eosin stain. Orig. Mag. $\times 450$.
- 16 Photomicrograph of an area of active internal resorption. The cross sectioned dentin tubules and the lacunar resorption sites can be seen. Note the cells and fibrous appearing material within the lacunae. Below can be seen a spicule of dentin and adjacent attached predentin, (P), Predentin, and (arrows) indicating predentin. It would appear as if the resorption front is skirting this area. Hematoxylin and eosin stain. Orig. Mag. $\times 450$.

