Microscopic investigation of root apexes

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The necessity for an exact and complete knowledge of the topographic and microscopic anatomy of the dental apex has been recognized. That these studies have not been made has been acknowledged by Orban,[1-4] Blayney,[5-8] Skillen,[9,10] Grove,[11-16] Ono[17] and others.

Anatomy, of course, is the foundation of the art and science of healing. The terminal part of the root canal and the tissues which surround it are the center of the most activity and the greatest concern in the treatment and filling of the root canal. The works of Preiswerk,[18] Fischer,[19,20] Hess,[21] Barrett[22] and Davis[23,24] and others which date from the end of the last century and from the beginning of the present one, had as their almost exclusive center of interest the number of root canals and their divisions.

Up to the present time the endodontist has worked with extremely poor data. The roentgenogram of the apex seldom offers a clear view of the terminal part of the canal; therefore, one is obliged to use information not scientifically proved. Much of the information available was obtained from a limited number of studies, mostly macroscopic, of apexes principally in transverse sections of the root.

The prevailing idea of the topographic and microscopic anatomy of the apex, that is, the direction, form, diameter and so forth of the terminal part of the canal, the location of the foramen, its size and the thickness of the cementum, is completely erroneous. Blayney, Grove and many other authors share this same opinion. The extreme assertions about the

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apex made by Grove's opponents have produced only greater confusion.

MATERIAL AND METHOD

Two hundred and sixty-eight teeth were obtained, 95 per cent of which were extracted from cadavers. Some of the teeth had superficial caries. All the teeth were without periapical disease and had been in normal occlusion.

Only teeth from cadavers whose age at death was known were used. One series of teeth were from those between 18 and 25 years and the other series were from those 55 years and older.

After the teeth were cleaned, the roots were cut, and the pulp was extracted with a barbed broach that reached only the apical third. A drop of ink was immediately placed on the opening of the canal and driven into it with a thin and smooth broach until the ink appeared in the foramen or foramens. With a magnifying glass it was determined whether the foramen (when there was only one) was to be found at the end or in the center of the apex. In this instance the roots were equally usable for sectioning, either mesiodistally (MD) or vestibulolingually (VL). If the foramen was located somewhat toward the mesial or distal side of the apex, the cut was made mesiodistally; if it was toward the vestibular or lingual side, the section was made accordingly. If there were two or more foramens, the section was on the same plane in order to enclose both or all of them.

The sections were obtained by the initial grinding with a motor stone of the two parallel surfaces of the root (only in the last 4 or 5 mm. of the apex) until the canal colored with ink appeared. With the guide of the magnifying glass, diamond wheels and disks thinned the root. The final polishing then was accomplished with sandpaper disks. Many roots were wasted or broken in the process of thinning. In others it was impossible to obtain data on all 21 factors to be investigated.

The roots were submerged in a small well with eosin and studied under the microscope with a magnification of 21 diameters, or of 56 diameters when necessary. The measurements of the roots were made with a 37.5 diameter ocular micrometer. The data obtained from these measurements were noted in special columns, and arithmetical averages were computed (Tables 1 and 2). All the preparations were sketched and classified (Fig. 1).

The age group 18 to 25 was chosen because the apex is completely formed at this stage, even in the third molars. It has been estimated that when a tooth occludes with its opponent (Table 3)[25] three years are necessary for the completion of the apex. Few teeth were discarded when observed with a magnifying glass and incomplete apexes or foramens were noted, especially third molars. The second group included teeth from people 55 years and older.

Approximately one half of the sections were vestibulolingual. The other half were mesiodistal, the only aspect seen in the roentgenogram.

In most instances eight teeth of each kind were obtained, that is, eight upper central incisors, eight upper lateral incisors and so forth.

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Table 1 • Summary of data concerning dental apex

	18 to 25 year group				55 year and older group			
	VL No.	MD No.	Total No.	%	VL No.	MD No.	Total No.	%
Center of foramen in apical vertex or center (1)	29	34	63	32	24	15	39	20
Center of foramen outside apical vertex or center (2)	62	69	131	68	58	88	146	80
Union CDC clear with magnification of 21 diameters (14)	103	130	233	57	145	148	293	74
Union CDC clear only with magnification of 56 diameters (15)	73	54	127	31	41	48	89	21
Union CDC not clear (16)	15	9	24	6	1	3	4	1
Union CDC nonexistent (17)	10	14	24	6	5	8	13	4
Teeth obtained			142				126	
Roots separated from crowns			197				186	
Apexes prepared			208				194	
Principal canals studied			225				211	

This research was carried out to help improve the treatment of root canals; therefore, the main canal, the most central and vertical one, or the one of the greatest caliber, that is, the one that the endodontic instrument would follow, seemed most interesting. The lateral, secondary and accessory small canals, although sketched and noted, were not studied because in most instances they do not present a clinical problem. In the bifurcations and deltas the canals which most approached the principal axis were studied, that is, the ones which offered the greatest possibilities for the endodontic instrument to enter so that the principal foramen could be reached.

The foramen in this study is understood to be the circumferential line of the canal that forms an angle above the surface of the root, or, in other words, the lineal circumference of the end of the canal (Fig. 2, below, #4).

RESULTS

In 32 per cent of the roots of the teeth in the first series (the 18 to 25 year group), the center of the principal foramen was localized in the apical vertex or center (Fig. 3, above) and generally followed the axis of the canal (Fig. 2, below left, #1 and Table 1, #1). In the teeth of the second series (the 55 years and older group) the coincidence of the center of the foramen and the vertex or center of the apex was found in 20 per cent (Fig. 2, below right, #1 and Table 1). The remaining 68 per cent of the roots in the first series had the center of the foramen somewhat outside or toward some side of the center or vertex of the apex (Fig. 2, below left, #2), whereas in the second series (Fig. 2, below right, #2), 80 per cent were located outside the center or vertex of the apex (Table 1, #2).

The average distance between the vertex or apical center and the center of the foramen was 495 microns in the first series (Fig. 2, below left, #3) and 607 microns in the second series (Fig. 2, below right, #3 and Table 2).

The average diameter of the foramen in the first series (Fig. 2, below left, #4) was 502 microns and that of the second

series (Fig. 2, below right, #4) was 681 microns (Table 2, #4).

The diameter of the foramen is seldom found to be perpendicular to the axis of the apical canal; nevertheless, instances of this situation of the diameter were noted. A diameter was measured whose line departed from the end of the foramen closest to the axis of the canal, crossed the axis of the canal perpendicularly and ended at the other end inside the canal; therefore, the perpendicular diameter was smaller than the diameter of the foramen. The average diameter of the foramens perpendicular to the axis of the apical canal in the first series (Fig. 2, below left, #5) was 375 microns and in the second series (Fig. 2, below right, #5) was 425 microns (Table 2, #5). As a result of the separation of the two diameters, a base of a triangle is formed (Fig. 2, below, #6). This base measured 255 microns in the first series and 287 microns in the second series (Table 2, #6).

Much fruitless polemic between Grove and his opponents could have been avoided had they come to an agreement on terminology. Nobody can doubt the existence of a uniting line between the cementum and the dentin (Fig. 3, CD). This union (with very few exceptions, such as that shown in Fig 3, above) arrives at the canal, a point that shall be

Table 2 • Measurements in dental apex

	18 to 25 year group							55 year and older group						
	VL		MD		Total		%	VL		MD		Total		%
	Av.*	No.	Av.*	No.	Av.*	No.		Av.*	No.	Av.*	No.	Av.*	No.	
Distance from center of foramen to apical center (3)	510		487		495			510		661		607		
Diameter of foramen (4)	563	91	449	103	502	194		694	82	661	103	681	185	
Diameter of foramen perpendicular to axis of canal (5)	491		318		375			451		403		425		
Unevenness of foramen (6)	302		202		255			257		313		287		
Diameter of canal at height of two even CDC (7)	346	43	270	39	306	82	53	282	55	274	54	274	109	60
Diameter of canal at apical union CDC (8)	310	28	280	39	298	67		280	29	287	39	268	68	
Diameter of canal at cervical union CDC (9)	349	35	302	43	327	78	47	315	33	247	42	285	75	40
Minor diameter of canal in cementum (10)	253	14	246	23	255	37	26	246	27	219	23	240	50	29.5
Minor diameter of canal in dentin (11)	331	30	239	30	299	60	42	299	21	218	29	254	50	29.5
Minor canal diameter at union CDC (12)	250	22	216	25	244	47	32	207	32	217	38	210	70	41
Distance from foramen to minor canal diameter (13)	566		454		524			600		696		659		
Thickness of cementum on right side canal (18)	467		522		508			875		734		802		
Thickness of cementum on left side canal (19)	514		496		505			882		672		767		
Thickness of cementum outside canal (r. side) (20)	315		344		343			618		580		619		
Thickness of cementum outside canal (l. side) (21)	289		340		326			637		464		551		

*In microns.

called "cemento-dentino-canal (CDC) uniting point" (Fig. 3, below, and Fig. 2, below, #14). What is in doubt is the place in which such a point is found, inasmuch as it is not a fixed point. From the measurements of the sections for this study, however, an average can be obtained that will give an approximate location. The lengthwise cutting of an apex in any direction which crosses the canal will give two points CDC, one on each side of the section of the canal.

In 53 per cent of the first series these two points CDC were found in each canal and at the same level or height (Fig. 2, below left, #7). The average diameter of the canal between these two points was 306 microns. In the second series the two points CDC were found at the same level in each canal in 60 per cent, and the average diameter was 274 microns (Table 2, #7). The average diameter of the vestibulolingual preparations was slightly greater than the mesiodistal ones in both series.

In the remaining 47 per cent in the first series and in 40 per cent in the second series, the two points CDC were not found on the same level (Fig. 2, below right, #14a and #14b) but the apical one was closest to the foramen (Fig. 2, below right, #14a). The average canal diameter at this level was 298 microns in the first series and 268 microns in the second series (Table 2, #8). The other point CDC, the cervical, was farthest from the foramen and therefore closer to the dental cervix (Fig. 2, below right, #14b) with an average diameter at this level of 327 microns in the first series and 285 microns in the second series (Fig. 2, below right, #9 and Table 2, #9).

In order to determine where the minor diameter of the apical portion of the canal was located, the following data were obtained: In 26 per cent in the first series and in 29.5 per cent in the second series, the minor diameter of the canal was localized in the cementum portion of the canal with an average of 225 microns in the first series and 240 microns in the second series (Table 2, #10).

In 42 per cent of the first series and in 29.5 per cent of the second series the minor diameter of the canal was found in the dentinal portion of the canal with an average of 299 microns in the first series (Fig. 2, below left, #11) and of 254 microns in the second series (Table 2, #11).

In the remaining 32 per cent of the first series and in 41 per cent of the second series, the minor diameter of the canal was found exactly at the height of the two even points CDC, that is, at the

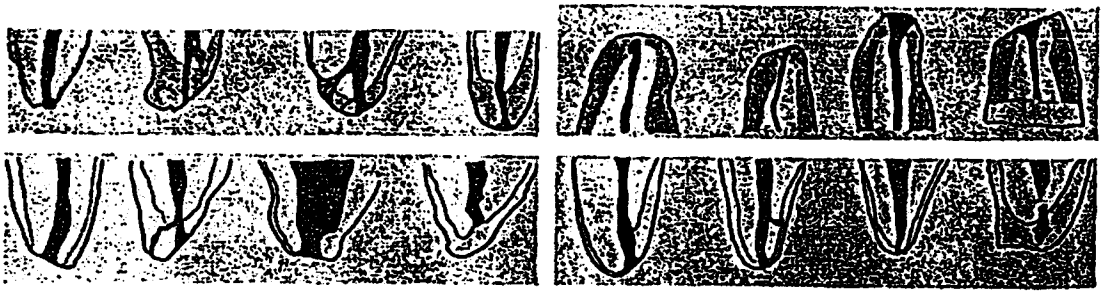


Fig. 1 • Dental apexes. Above left: Lower lateral incisors, older age group. Vestibulolingual sections except mesiodistal section at far right. Above right: Upper third molars, older group. From left to right—lingual root, distal root, mesial root, mesiodistal sections; far right, distal root, vestibulolingual section. Below left: Lower second molars, younger group. Two at left, mesial roots, mesiodistal sections; at right, distal roots, vestibulolingual and mesiodistal sections respectively. Below right: Lower second bicuspids, younger group. Two at left, mesiodistal sections; at right, vestibulolingual sections

Table 3 • Average ages at which permanent teeth arrive at occlusion

	Dental classification						
	1	2	3	4	5	6	7
Upper arch	8-10-9*	9-8-27	12-4-26	10-10-13	11-7-19	7-3-4	13-2-28
Lower arch	7-10-11	8-10-21	11-5-26	11-3-24	11-7-19	7-3-17	12-7-14

*Denotes 8 years, 10 months and 9 days.

same level. The average diameter was 244 microns in the first series and 210 microns in the second series (Table 2, #12).

The distance between the center of the foramen and the narrowest part of the apical canal was an average of 524 microns in the first series and 659 microns in the second series (Fig. 2, below, #13 and Table 2, #13).

The union or point CDC is not always found; therefore, it was studied from histological sections. In 57 per cent of the sections of the first series and in 74 per cent of the second series, this union was precise and was distinctly visible with a magnification of 21 diameters (Fig. 2, below left, #14 and below right #14a and b and Fig. 3, below, CDC). In 31 per cent of the first series and 21 per cent of the second series, a greater magnification was necessary and 56 diameters was used. In 6 per cent of the first series and 1 per cent of the second series, the point CDC was so confusing that its location could not be determined with any magnification (Table 1, #16). In 6 per cent of the first series and 4 per cent of the second series, the point CDC did not exist, either because the line of union between the cementum and dentin did not reach the canal or because the cementum was nonexistent (Fig. 3, above and Table 1, #17).

It is widely known that the thickness of the cementum diminishes from the apex to the dental cervix and that the cementum thickens with age. The thickness of the cementum on each side of the canal was measured, and the following results were obtained: On the right side of the canal the thickness of the cementum in the first series was an average of 508 microns and 802 microns in the second series (Fig. 2, below, #18 and Table 2, #18). The thickness of the cementum on the left side of the canal was an average of 505 microns in the first series and 767 microns for the second series (Fig. 2, below, #19 and Table 2, #19).

It was attempted to determine whether there exists any relationship between the teeth that have been in occlusion the longest and the thickness of the cementum. The order of eruption is known to be that expressed in Table 4.[25] The order of the teeth in the first series with the thickest cementum on the right side of the cementum canal is given in Table 5. A comparison of the tables indicated that there was no relationship. The thickness of the cementum probably depends on the strength of mastication rather than on the length of time the teeth have been in occlusion.

The thickness of the cementum was measured somewhat outside the canal where it often thins quickly. The average thickness of the cementum on the right side of the canal in the first series was 343 microns and for the second series 619 microns (Fig. 2, below, #20 and Table 2, #20). The measurement on the left side of the canal was 326 microns for the first series and 551 microns for the second series (Fig. 2, below, #21 and Table 2, #21).

It was believed that the canal is more or less conical, following in its apical third the same direction as the middle and cervical third and ending in the ex-

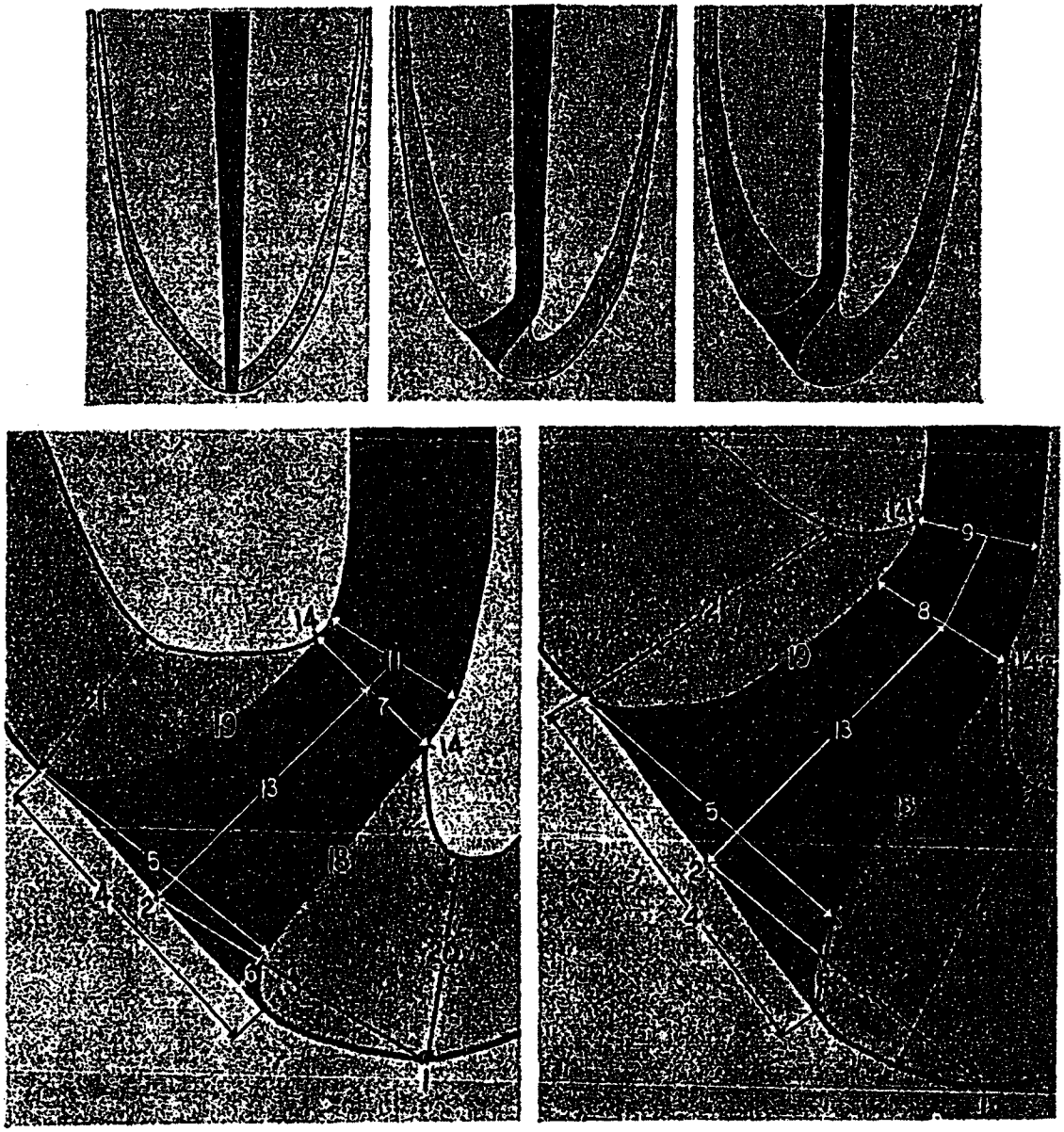
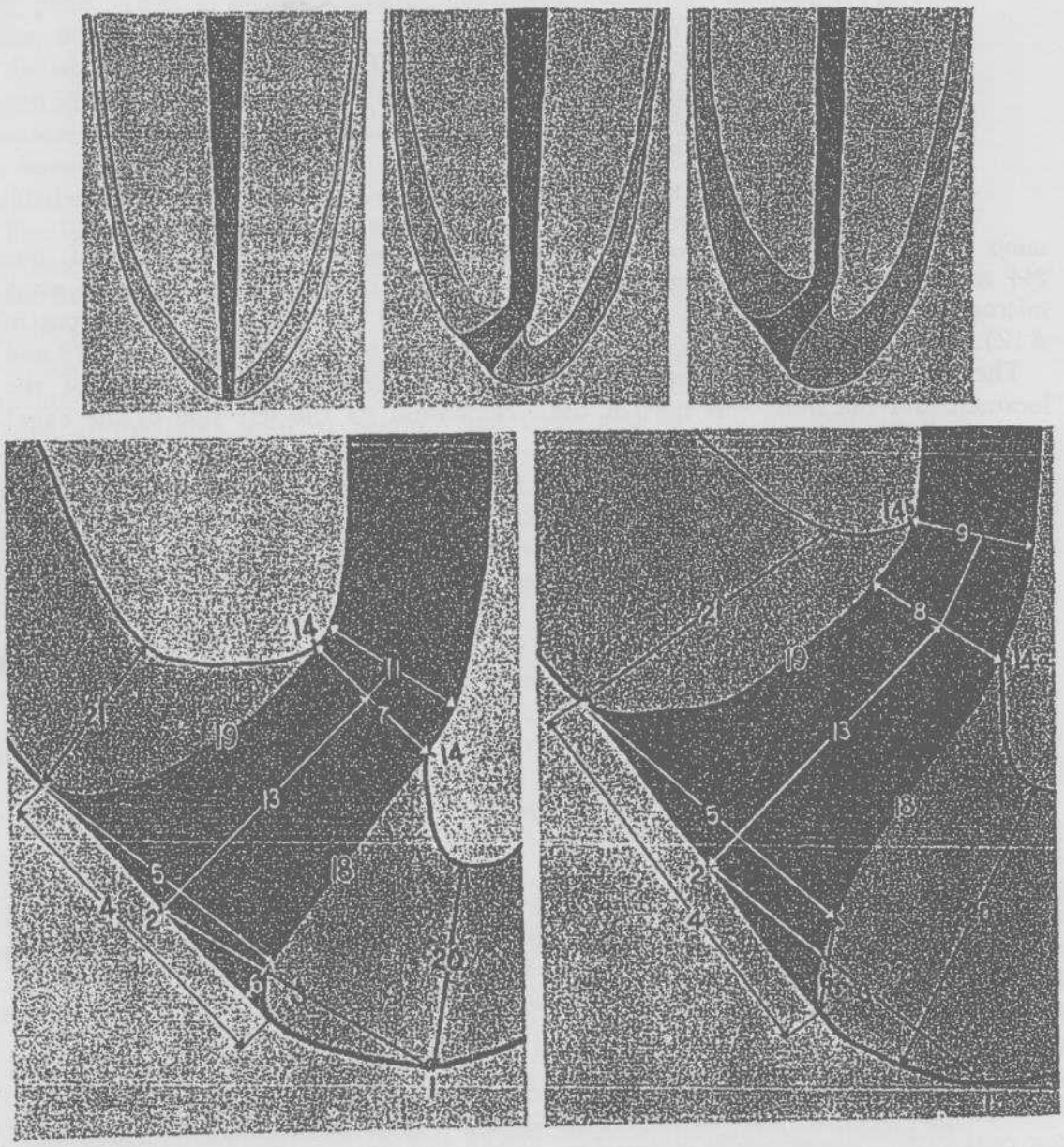


Fig. 2 • Above left: Erroneous concept of apex. Above center: Apex of younger group from averages obtained. Above right: Apex of older group according to averages obtained. Below: Apexes of younger group (left) and older group (right)—1, vertex or apical center; 2, center of foramen; 3, distance between vertex or apical center and center of foramen; 4, diameter of foramen; 5, diameter of foramen-canal perpendicular to axis of canal; 6, unevenness of two diameters; 7, diameter of canal at height of two even CDC union points; 8, diameter of canal at height of apical CDC union points; 9, diameter of canal at height of cervical CDC union point; 11, place of minor diameter of canal (42 per cent); 13, distance between center of foramen and minor diameter of canal; 14, union points of cementum, dentin and canal, 14a (apical), 14b (cervical); 18, cementum of right side of canal (note thickness); 19, cementum of left side of canal (note thickness); 20, cementum of right side at point at which it thins rapidly; 21, cementum of left side at point at which it thins rapidly



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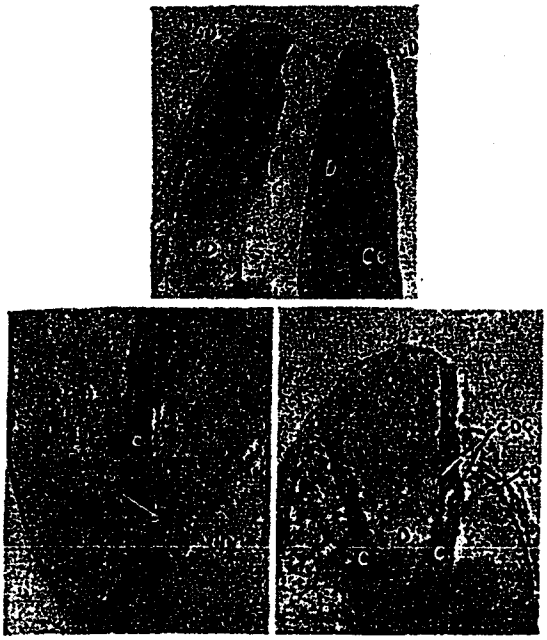

Fig. 3 • Apexes. Above: Upper cuspid of 21 year old, mesiodistal section, magnification 40 diameters. Below left: Distal root of lower third molar of 24 year old, mesiodistal section, magnification, 40 diameters. Below right: Mesial root of upper second molar of 58 year old, vestibulolingual section, magnification, 22 diameters. C, canal; D, dentin; Ce, cementum; CD, cemento-dentin union line; CDC, cemento-dentino-canal union point

treme apex with a very narrow foramen. Figure 2, above left, shows such an erroneous picture of the apex, above center shows a schematic representation of the apex in the majority of roots of those 18 to 25 and above right shows the apex as it is in the majority of roots of those 55 and older.

In many roots of the group over 55 years it was impossible, even with a magnifying glass, to find the canal after separating the roots from the crowns. It was found only after cutting away sections of the root in the middle or even apical third, as in the apex farthest to the right in Figure 1, above right, in which the canal was found only in the last 3 mm. of the apex.

The diameters of the foramens of the second series were found to be larger than those of the younger group.

It is proved, therefore, that textbooks are in error which refer to the reduction of the root canal as being caused by the strangulation of the pulp tissues because of the narrowing of the foramen with increase in age. This biological process is different from what had been thought, and should be investigated.

SUMMARY

The purpose of this research was the study of the microscopic basis of the anatomy of the dental apex in order to improve endodontic technics. Four hundred and two healthy dental apexes, from teeth extracted mostly from cadavers 18 to 25 or 55 years and older at death, were studied and measured by the ocular micrometer.

CONCLUSIONS

1. The center of the foramen deviates more and more from the vertex or apical center with an increase in age and resulting thickening of the apical cementum.

2. The diameter of the foramen increases with age because of the apposition of new layers of cementum. The average diameter of the foramen in the 18 to 25 year age group and in the group 55 years and older is somewhat larger vestibulolingually than mesiodistally.

Table 4 • Order of eruption of permanent teeth

	Dental classification							
	1	2	3	4	5	6	7	8
Upper arch	4	6	10	7	12	1	14	15
lower arch	3	5	9	8	11	2	13	16

Table 5 • Order of teeth with thickest cementum

	Dental classification							
	1	2	3	4	5	6	7	8
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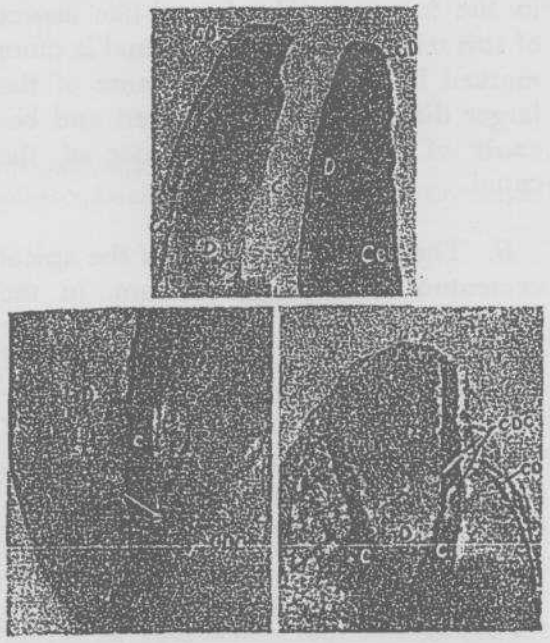

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3. Because of the existence of an unevenness in the extremities of the diameter of the foramen and because of the funnel shape of the cementum canal, this portion of the canal cannot be filled hermetically, unless it is overfilled with cement.

4. In the majority of sections the two points of union cemento-dentino-canal are found at the same level. In others, one point CDC was closer to the foramen than the other.

5. The minor diameter of the root canal is found usually in the dentin, just before the canal penetrates the cementum portion, and from that point it gradually widens to the foramen, taking on a funnel shape. A constricted portion exists in the canal, but this constriction is not located in the foramen. The funnel-like aspect of this terminal part of the canal is more marked in older people, because of the larger diameter of the foramen and because of the smaller diameter of the canal.

6. The average thickness of the apical cementum was above 0.5 mm. in the younger age group and thicker in the older age group. The thin layers of cementum often found introduced over the dentin covering the internal ends of the dentin tubules in the last portion of the dentinal canal and the oblique inclination and occasional verticality of the tubules in the same portion directed toward the dental cervix give justification for filling the root canal only as far as 0.5 mm. before reaching the foramen.

Lerma 335-2

Dangers of Active Ignorance • The appearance of science as a major social force has created many problems. We are justly proud of our American civilization. But how much scientific culture does Mr. Average American have? Our educational system has failed miserably in raising the culture of our people to an appreciation of the need of basic science. There is even less of what James B. Conant has called an "Understanding of Science."

Mr. Average American has not been taught to think critically or to weigh evidence. In the current controversy over the incorporation of fluorides in drinking water the public uses personal testimonials on the same basis as scientific evidence. Should our amusement not be tempered with sadness when we read "I found that drinking one bottle of Hadacol cured my rheumatism?" With even more sadness, we find some scientifically trained people thinking in the same fashion. . . .

In very few areas of our educational system have the basic facts and methods of science been properly incorporated and taught. The result is that the majority of our people are scientifically "illiterate." This creates an extremely dangerous situation, anticipated by Goethe when he said, "There is nothing more frightful than an active ignorance." *Ward Pigman, "Wanted: More Ivory Towers," The Scientific Monthly 80:252 April 1955.*