FORMATION OF ROOT-CANALS IN HUMAN TEETH[1]

By WALTER HESS, M.D., D.D.S., Zurich, Switzerland

THERE are already a number of treatises by various authors upon the anatomy of the root-canals of human teeth. Upon examination these works readily show that they are based upon material which in many ways does not suffice to determine conclusively the influences of age and development upon the form and number of root-canals. Excepting the work of Fischer, no other work has appeared which has more than briefly treated the anatomy of root canals of human teeth. Furthermore the statements of various authors are not universally accepted and have been corrected in many cases. The upper and lower incisors, cuspids, first and second bicuspids, with the third molars have been left unconsidered thus far. I shall present my observations made upon twenty-eight hundred specimens treated by a new method. I shall discuss the shape, size, number, and bifurcations of the canals in the apices tooth type. Also I am including many cuts of casts taken from teeth at different stages of life in order to make the work more comprehensive as well as to afford a working basis showing all the details upon which questions might arise.

During the last three years I was able to collect a great number of teeth—about three thousand—which I examined by the method suggested, with the help of my honored teacher, Dr. Stoppany, and a few dear associates. The greater part of the material used in the study was derived from military dental clinics during my own professional attendance.

Historical Note

In looking over the literature dealing with dental anatomy no statements will be found dealing with the apical anatomy of root-canals up to 1891. Most of the authors restrict their work to the external description of root forms. The most accurate description of root-canals with respect to their number and course was given by Carabelli in his textbook in 1844 in which he also included cuts of the pulp chambers. In the later publications we not only find no new additions concerning the character of the root-canals but even the statements of Carabelli, have been forgotten entirely, so that there is practically nothing concerning the anatomy of root-canals in the works of Wedls (1876), Charles Tomes (1880), and Baumes (1890). Muehlreiter (1891) was the first to undertake this study at all thoroly and he recorded various observations which have been shown to be correct by the casting method. In Boedeker's *Anatomy and Physiology of the Teeth* we search in vain for references concerning the anatomy of root-canals. Coulliaux (1896) only mentions Carabelli's work in his *Anatomy, Physiology and Pathology of the Dental Pulp,* while Miller (1903) in his *Conservative Dentistry* indicated the importance of an intimate knowledge of the anatomy of root-canals and included a few cuts of ground speci-

[1] "Zur Anatomie der Wurzelkanale des menschliches Gebisses," *Schweizerische Vierteljahrsschrift fur Zahnheilkunde,* 1917. Translated by Newton G. Thomas, A.B., M.A., D.D.S., and Herman Redlich, Chicago, Illinois.

mens which showed the variations of form and course of the canals. In general we have satisfied ourselves that the root-canals are complex and that a thoro knowledge if them is important, also, that the filling of marrow and crooked canals was impossible. Preiswerk (1901) is the first one who determined that the root-canals of human teeth are much more complex in structure than often thought. By means of metallic specimens of corrosion, he determined that there exists a great variability in form, number, and branching in the root-canals. Altho the results of his work are not accepted everywhere without contradiction, the method objected to, and the results looked upon as products of art, this valuable work has aroused further research in this field. A few years later Fischer (1908) made a number of observations by means of a new method, using a dilute celluloid fluid to bring out the delicate branchings of the root-canals, making observations on a wider basis upon human and animal teeth. He determined the physiological and pathological influences connected with the formation of root-canals and the branching at their apices as well as showing by means of macroscopic and microscopic preparations how greatly the anatomy of root-canals is differentiated by means of delicate branchings, communications, and spaces within the tissue. With respect to the different types of teeth, he determined according to his own observations by means of a percentage under what conditions the branchings occur, and finally concluded that on account of the complicated structure a complete removal of the pulp is impossible in upper first, second, and third molars and in the mesial roots of lower molars and upper bicuspids. In further observations in which by means of a simple lens Fischer determined the numerous apical branchings as fine canals at the apex of the tooth without further examining the anatomical details, he dealt with the arrangement of the branchings at the apices of different teeth.

In the course of time, the results of Fischer's were pronounced as artistic products, especially were the apical branchings pronounced incorrect, and also several statements regarding the form of root-canals, as for example that of the distal root of upper molars, and similar statements with regard to the form of upper and lower incisors, cuspids, and first and second bicuspids, which were not examined in sufficiently large numbers.

Additional observations with respect to the anatomy of the pulp chamber and root-canals were made by Loose, who used numerous ground specimens of single-rooted teeth to illustrate the variations in form and number of the root-canals and especially the topography of the pulp chamber, which were already emphasized by Fischer and here proved as exact statements. The finer apical branchings, however, were not dealt with in his work.

In 1905 the interest of Port became aroused in the examination of separate types of teeth by the observations of Chauvin and Brunsmann (1886). However, without using any exact method he proceeded to examine upper bicuspids and lower molars by means of an ordinary probe and to verify the results of Chauvin, but he came to the same conclusion as Fischer with respect to the number of root-canals, altho he did not determine the delicate structure of the root-canals.

In 1913 Adloff emphasized a new method which was first described by Spalteholz in connection with clarifying nontransparent specimens. Adloff was the first one to attempt to examine the relations of the pulp cavity of the entire tooth by filling the cavity with molten metal and then clarifying according to the method of Spalteholz. No one's results appeared with respect to the anatomy of the root-canals by this method.

Fasoli and Arlotta (1913) likewise

attempted to describe the anatomy of the root-canals by a modification of the technic used by Adloff, but they arrived at the same results as Fischer did, without backing their statements by a sufficiently large enough number of reproductions of the specimens.

Moral (1914) described a new method which consisted in filling the pulpal cavity with Chinese inks and then opening the tissues, according to the method of Krause. By using this method, Moral examined about one hundred teeth, namely upper molars, with respect to the division of the root-canals of the mesiobuccal root and the existence of a fourth canal which he actually found in 63 per cent of the specimens.

A General Description of the Macroscopic and Microscopic Conditions

In my examinations which were made of twenty-eight hundred teeth I have attempted to restrict my descriptions to purely anatomical conditions in the root-canals of human teeth since Fischer had already described the comparative anatomy and pathology of the root-canals in detail. I have used only those teeth for specimens which did not have a removed pulp so that the pathological influences which might have affected the delicate structures of the canals can be excluded. Since the previous observations brought no statements concerning the influence of age on the development of root-canals with reference to their size and form and the number of the reproductions of the conditions present in the root-canal I have arranged my observations to include a large number of specimens to afford a verification of the results of previous authors and numerous reproductions to form a basis for the results as well as an addition to statistics.

It was possible for me to collect teeth varying in ages from five to fifty-five years. In the case of lower first and second molars I was able to collect those from six to seventeen years, while in the remaining teeth I did not go below the age of twelve years and have fixed the first period as that from twelve to twenty years since I was governed by the sort of material at hand which was very difficult to secure. The remaining periods I fixed as twenty to thirty, thirty to forty, and forty to fifty-five.

With reference to the form and number of root-canals of human teeth the material showed in general that during youth the canals are voluminous and give no evidence of complications in structure as long as the apical foramen is not closed. It seems as tho the normal period of differentiation of the root-canals begins very early (to follow Fischer), that is, with the formation of the same, and to a greater or lesser degree according to the various influences of growth. "The roots of the young tooth germ enter the last stages of growth as soon as the tip of the crown penetrates the mucous membrane epithelium of the mouth. While the crown is assuming its place in the arch by gradual growth, the solidification of the root is furthered by additions of cementum and dentin. Next it appears that the apex of the young root still has a wide, spacious foramen which seems to decrease in size gradually as soon as the development of the main mass of the tooth has ended. The feverish activity of the young odontoblasts and pulpal fibrils becomes more moderate and the crown portions of the pulp proceed in development with a lessening amount of nutrition. The difficult point of growth is attributed to the basal portion of the root, where a gradual displacement of the pulp is taking place, due to the spreading out of the hard tissues, namely, dentin and cementum. The addition of these tissues may proceed with more or less irregularity and the pulp be divided forming channel-like extensions between newly formed dentin."

In various human teeth the development of the apical foramen shows, as proved by my specimens, that no branch-

ings take place at the apex during youth, but after closure of the foramen the branching of the pulp appears at the apex. The closure of the apical foramen occurs at quite different times in teeth of the same type. In almost all types of teeth I have been able to determine that the closure of the foramen takes place between the ages of three and five; therefore the addition of dentin is quite irregular.

In most types of teeth (upper third molars excluded) between the ages of twelve and twenty years few apical branches were found; the greatest percentage of branching was found in teeth between the ages of twenty and forty years. In teeth between the ages of forty and fifty-five years having only one root-canal a decrease took place, while those with more than one root-canal showed an increase in apical branches. The marrow canals also showed similar conditions. In young teeth few or no marrow canals were shown, while teeth of from twenty to forty years showed the greatest percentage of marrow canals, namely, those having one root-canal as the upper and lower incisors and cuspids; and in teeth of from forty to fifty-five years decrease was shown. The percentage of marrow canals increased with age in those having more than one root. It seems as though the physiological addition of dentin takes place more rapidly in the single-rooted teeth than in those of more than one root (see statistical table and Plates I-IV). The numbers of the statistical table with regard to the apical branchings and marrow canals in the various periods are only relative since great variabilities occur in the different age periods of human teeth. But considering the large number of examined teeth we can view these figures as approaching very near to the actual conditions.

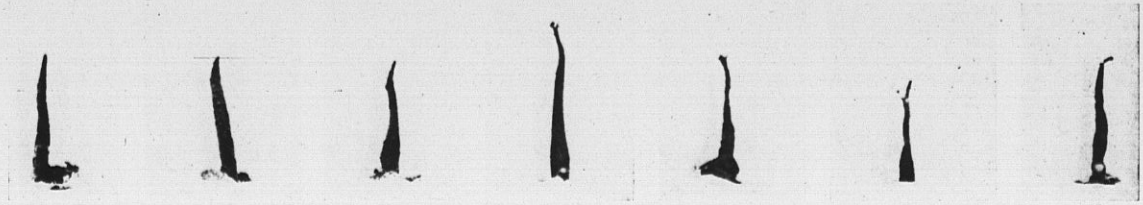
The observations of Trueb show, with reference to the pulp chambers of teeth, that by the increase in formation of dentin in a physiological sense the wide chambers of the young organism are gradually narrowed by age, for the older a tooth becomes the thicker become the walls. Fischer already called attention to the physiological processes of growth of dentin and dentikel and their importance to the differentiation of the pulpal chamber within the root. Those roots which during the youthful period had wide, flattened walls, as in the lower incisors, and large molars, upper bicuspids and the disto-buccal root of upper molars, according to Fischer, seem to form a branched system of calcium salts by the irregular accumulation of dentin at the opposite lying walls within the pulp of the root, and may appear more complex according to the irregularity in function of the accompanying factors during the process of growth. The physiological activity may reach its highest point by almost completely obliterating the root-canals in senile teeth. Muehlreiter is of the same opinion with regard to the formation of two mesial root-canals in lower molars, which only occurs in old teeth, while, in young individuals there is one large spacious canal.

The fact that in rare cases a finer differentiation may take place in very young teeth has been shown by Fischer, but according to my own observations I have come to regard this statement as exceptional, since in general the young teeth exhibit simply constructed voluminous canals. The upper bicuspids especially, and some roots of the upper and lower molars exhibit differentiation due to the physiological addition of dentin, which may result in the formation of a new separate root-canal, as shown by Moral in the case of mesio-buccal roots of upper molars. My specimens will verify these results.

The formations of the pulpal canal undergo a physiological change during the entire life, according to Fischer. These differentiations according to

[2]Compensatory canals.

Plate A 1



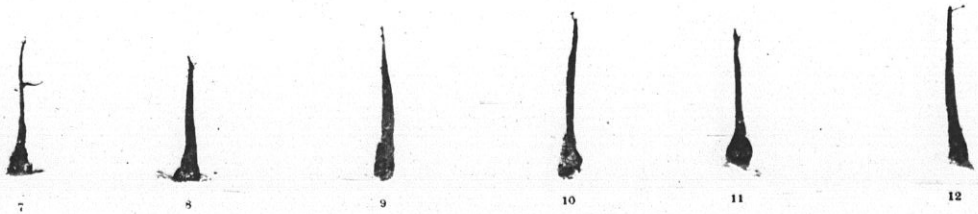
1 2 3 4 5 6 7

8 9 10 11 12 13

Upper Central Incisors

Plate A 2

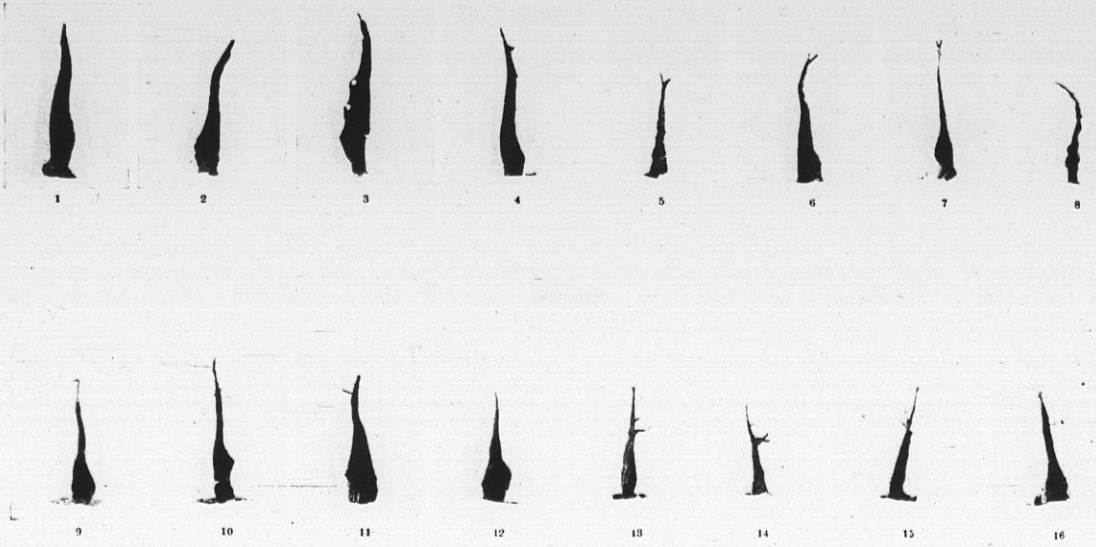
1 2 3 4 5 6



7 8 9 10 11 12

Upper Lateral Incisors

Plate A 3



Upper Cuspids

Fischer appear (1) as simple branches and twigs, lateral extensions and marrow canals within the root dentin, (2) as cross-bridge systems, (3) as island-like parts within the tissue. These differentiations are exhibited in lower incisors and bicuspids as strands of bifurcation and branches at the apical foramen; in the upper incisors as delicate lateral extensions; and those in upper bicuspids and all molars may cause a complicated structure, the result of their more frequent and delicate arrangement.

According to the results of my own observations, I am able to accept the views of Fischer with a few exceptions, which I will touch upon in the description of the results.

By means of numerous reproductions and specimens of various ages, the anatomical relation of all the different teeth will be described with reference to the number of root-canals, apical branchings, and marrow channels.

The influence of age in the gradual obliteration of the root-canals may be seen in various teeth, also the effect upon the pulp chamber, since the various teeth of older life exhibit a narrowing of the volume of the canal, altho not regularly. Great variations may occur in this process of obliteration of the root-canals, but these are teeth of older life which exhibit large voluminous canals, contrary to an expected narrowing, while in some young teeth, of course not very frequently, the beginning of the process of obliteration is noticeably in progress. In this case the pathological conditions described by Fischer are brought to the foreground. In general, then, a lessening of volume of the pulpal canal was found with increasing age, which here and there may lead to a complete obliteration of the canal.

Microscopic Results

In order to determine the delicate microscopic branchings described by Fischer and for the purpose of following out more definitely the marrow canals running from the root-canals to the peridental membrane and the apical branchings already described macroscopically, I have made a series of approximately fifty sections of teeth of all types. Of the fifty teeth examined, forty-eight exhibited apical branchings of various forms. In addition to the macroscopically determined branches, a whole row of canaliculi of the most delicate type were found in the apical regions, often uniting into a system resembling a sieve-like gate of the apex (see Plates a-k).

The marrow canals extend to the peridental membrane from the root-canal thru the root dentin, either singly or as a union of several canals, forming a connecting channel at various levels of the root which is not seldom filled with blood vessels. Besides, numerous lateral extensions occur between the canals.

The mesio-buccal roots of upper molars and the mesial canal of lowers probably exhibit the most branchings. However, the upper third molars as well as the upper and lower bicuspids do not rank far behind the above in their complexity. The incisors and cuspids, both uppers and lowers, in most cases show delicate apical branchings and marrow canals, indicating that these single-rooted teeth are not to be regarded as having simple apical regions.

The narrowing or displacement of root-canals of older individuals by a formation of dentikel likewise determines a complicated condition of the apical part of the root.

The microscopical results verify the conditions of the branching systems of the root-canals of the various teeth already indicated by the macroscopical specimens (see Plates a-k).

A Special Description of the Results of Each Tooth Separately

Upper Central Incisors

The root-canals of the upper central incisors are characterized in general by primitively formed spaces. The root-canals are in conformity with the form

of the root. The crown portion is compressed labio-lingually, exhibiting a wider mesio-distal than labio-lingual diameter, but near the apex it gradually becomes narrower and assumes a more cylindrical form.

In young individuals the canal is quite wide and without complications in structure (Plates I a and I b) or a complete obliteration of the canal would result (Plate c, 6). The decrease in volume of the canal may be clearly seen in Plates I a and I b.

Besides the root-canals, so-called marrow canals also occur. The first one to call attention to this sprout was Preiswerk. He was followed by Fischer, who mentioned the delicate ramifications and tufts which appeared to him especially in lateral incisors; however, he did not discuss them with the aid of specimens. In a later work by the same author he described the conditions at the apical foramen by enlarging the external canals with their ramifications at the apex by means of a probe; however, no specimens or proof by the "corrosion method" were furnished.

According to my own observations which are based upon 280 upper central incisors, I obtained the following results: The upper central incisors possess a main canal. In approximately 25 per cent of the teeth examined one to three apical ramifications of the root-canal were found besides the main canal. In addition to these ramifications or together with them, 20 per cent of the teeth examined exhibited so-called marrow canals which run from the main canal to the peridental membrane thru the root dentin, partly singly in the apical region and partly as a union of several in the upper half of the root (Plate A 1, 6-12, Plates I a and I b, 32-51, Plate i, 17.)

The young teeth, often to twenty years, showed neither apical ramifications nor marrow canals; those of twenty to forty years showed the greatest percentage of such differentiations, while teeth of forty to fifty-five years showed a decrease in ramifications, probably due to the increased narrowing of the canals. The results are expressed in Table 1.

TABLE 1. UPPER CENTRAL INCISORS

Age	Number	Number of Root-Canals		Number of Apical Branchings					Percentage	Number of Marrow Canals					Percentage
		1	2	1	2	3	4	5		1	2	3	4		
10-20	20	20	.....	2	.....	.....	.....	.....	10	.....	.....	.....	.....	.....	....
20-30	190	190	.....	40	.....	10	.....	.....	20	40	5	.....	.....		23
30-40	40	40	.....	10	.....	2	.....	.....	30	8	2	.....	.....		25
40-55	**30**	**30**	.....	5	.....	.....	.....	.....	**16.6**	4	1	.....	.....		10
	280	280	.....	57	.....	12	.....	.....	25	52	8	.....	.....		21.4

UPPER LATERAL INCISORS

The root-canals of the upper lateral incisors in general show the same conditions as the upper central incisors, except that they are somewhat less spacious and generally correspond to the form of the root.

With reference to the development of age we notice the same conditions in the upper lateral incisors as in the upper centrals, namely, a decrease in the volume of the root-canals with age, and the presence of apical ramifications and marrow canals. In addition to the main canal there are ramifications in the apical portion of the root and marrow canals which form a connection between the main canals and the peridental membrane (Plate e, 10).

Out of 248 examined upper lateral incisors, 77 showed apical ramifications, that is 33 per cent. With respect to the upper centrals there is an increase in apical ramifications. The marrow canals also show a small increase over

those of the upper centrals, the percentage being 22 per cent and mainly distributed in the twenty-to-forty-year-old group (Plates II a, II b, A 2). The results are summarized in Table 2.

TABLE 2. UPPER LATERAL INCISORS

Age	Number	Number of Root-Canals					Number of Apical Branchings					Percentage	Number of Marrow Canals					Percentage
		1	2	3	4	5	1	2	3	4	5		1	2	3	4	5	
12-20	22	22					2					9						
20-30	140	140					42	8				36	28	6				25.5
30-40	60	60					16	3				30	15	3				30
40-55	26	26					5	1				23	4					15.5
	248	248					65	12				31	47	9				22

UPPER CUSPIDS

In general the root-canals of the upper cuspids are in conformity with the form of the root. These canals are more spacious than those of the upper incisors and the labio-lingual diameter is greater than the mesio-distal diameter. The young upper cuspids in particular have a large spacious root-canal which, however, with the influence of age is narrowed down by the physiological addition of dentin into a finer canal (Plates III a and III b).

In the apical region of the root-canals of the upper cuspids delicate ramifications are found which are much simpler in form than those of the upper central incisors. Usually the main canal divides into two side canals in the form of a fork, of which one side usually opens externally slightly coronal to the apex and palatinal as already determined by Fischer by means of a probe (Plate A 3, No. 4-7). Outside of the apical ramifications there are likewise marrow canals found traversing the root dentin in the upper half of the root mostly and running from the main canal to the peridental membrane often as one or two united (Plate A 3, 7-12, Plates III a, III b 10-20, 30-40).

In examining 154 upper cuspids, 39, that is 25 per cent, showed apical ramifications the greater percentage between the ages of twenty and forty, and 28 of the 154 showed marrow canals, that is 18 per cent. There is a general decrease in the percentage of both the apical ramifications and marrow canals in upper cuspids with respect to the upper incisors. The exact relation of figures is shown in Table 3.

TABLE 3. UPPER CUSPIDS

Age	Number	Number of Root-Canals	Number of Apical Ramifications		Percentage	Number of Marrow Canals		Percentage
		1	2	3		1	2	
12-20	40	40	3		7.5			
20-30	69	69	20	3	33	13	3	33
30-40	30	30	8	2	33	6	3	30
40-55	15	15	2	1	20	2	1	20
	154	154	30	6	25	21	7	18

LOWER CENTRAL AND LATERAL INCISORS

While there are few statements in literature concerning the detailed anatomy of the upper incisors and cuspids, and there is an absence of any exact description concerning their apical ramifications and marrow canals accompanied by specimens, there are statements concern-

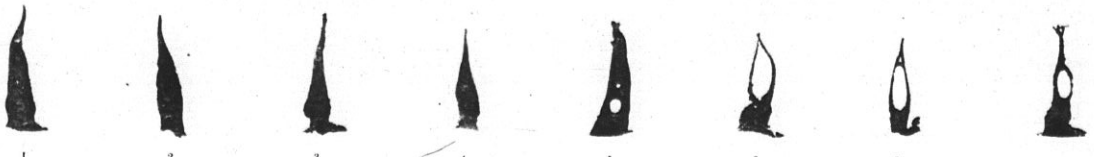
Plate B 1

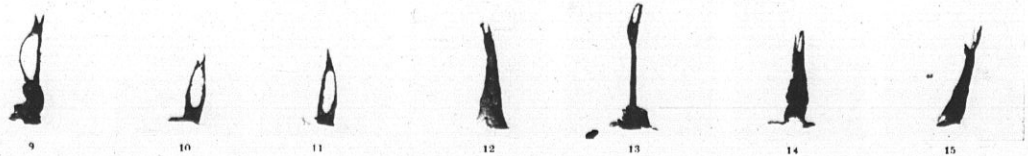
1 2 3 4 5 6 7

8 9 10 11 12 13

Lower Central and Lateral Incisors

Plate B 2





Lower Cuspids

ing the lower incisors by Carabelli, who states that their root-canals may exist either as one main canal or it may be split into a double canal in the lower part of the root, making either one or two exits. These statements were also verified by Baume, Caulliaux, Mettnitz, Muehlreiter, Hattyasy, Scheff, and Fischer.

There is a frequent division of the root-canals of the lower central and lateral incisors, contrary to the upper incisors in which the canals are single. Loose determined by means of numerous ground specimens of lower incisors that it is not infrequent that branches of these canals are formed by means of a mesio-distal septum of dentin whereby the simple canal divides into a labial and lingual canal which may again unite at the end of the septum and open at the apex in a single mouth or as two separate exits. The root-canals of the lower incisors in general appear constricted mesio-distally corresponding to the form of the root. During the youth period these lower incisors present simple, voluminous canals without either bifurcations or apical ramifications (Plate IV a, 1-21, Plate B 1, 1-4). The differentiations of the root-canals first occur after the closure of the apical foramen, when an addition of dentin takes place within the canal on the mesial and distal sides corresponding to the external mesial and lateral grooves in location, which makes the canal so narrow as to cause the mesial and distal inner walls to meet, forming a septum of dentin which divides the main canal into a labial and a lingual canal. This septum may stretch along the whole length of the canal or only partly, in which cases a penetration of this septum will be found in a greater or lesser degree forming a bridge system between the two canals. Usually the two separated canals will again unite shortly before reaching the apex and end as a simple canal (Plate B 1, 5-9, Plates IV a and IV b, 35-53).

In addition to this method of division there is another manner of division in which the main canal first divides in the apical third and represents a forklike arrangement in which case the canals end separately and no second union takes place. In older teeth these canals may be narrowed or obliterated by additions of dentin, so that in place of two former canals only one persists. In general, these canals show a considerable decrease in volume (Plates IV a and IV b).

Besides the bifurcation the lower incisors also show apical ramifications but in a much less degree than in the upper incisors and the marrow canals are also less frequent. Fischer examined 36 lower incisors and in 53 per cent he found bifurcations. I am unable to state from my observations whether or not the apical branches always occur plurally.

Out of 136 lower incisors I examined I found 50, that is 37.6 per cent showing bifurcated root-canals; the rest showed only one canal. Apical ramifications were found in 30 per cent and marrow canals only in 10 per cent. There is a decided decrease in the percentage of apical ramifications and marrow canals in the lower incisors as compared with the upper (Table 4).

TABLE 4. LOWER CENTRAL AND LATERAL INCISORS

Age	Number	Number of Root-Canals					Percentage	Number of Apical Branches					Percentage	Marrow Canals					Percentage
		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5	
12-20	30	26	5	....	....	....	16	.....	....	....	....	....	....	....	....	....	....	....	....
20-30	60	30	30	....	....	....	50	152	....	....	....	....	28	6	1	....	....	....	11
30-40	32	20	12	....	....	....	37	102	....	....	....	....	37	4	2	....	....	....	20
40-55	14	10	3	....	....	....	22	30	....	....	....	....	22	1	....	....	....	....	7
	136	86	50	....	....	....	37.6	284	....	....	....	....	21	11	3	....	....	....	10

Lower Cuspids

The lower cuspids, contrary to the upper cuspids which have a simple undivided canal greatly resemble the lower incisors in differentiations of the root-canals. In the case of a simply constructed canal the canal in general corresponds in form to the form of the roots, and the labio-lingual diameter is greater than the mesio-distal.

During the first period the root-canals are quite voluminous and simple in structure without apical ramifications or marrow canals, while here and there indications of a bifurcation are noticed (Plates V a and B 2). Later in life bifurcations appear in the root-canal by a formation of dentinal bridges mesio-distally which lead to the formation of a septum and causes a division of the main canal into a labial and lingual canal. Altho Fischer still speaks of a simple canal, Loos had demonstrated the bifurcation in many specimens which results my own findings support (Plate V b. 31-52). This bifurcation of the root-canal into two, in which case there is also an external splitting of the root, results in two apices besides which bifurcations there are also those which show a bifurcation in the apical third resulting in a forked canal but having a simple canal in the incisal two-thirds (Plate B 2, 12-15). Besides these differentiations there are also the delicate apical ramifications and marrow canals (Plate c 5, Plate h, 15). Apical ramifications are found in the simply constructed canals as well as in those having the divided canals, and in the latter case after their union just short of the apex they split up into short twigs, in which case it is not uncommon that the main canal opens somewhat coronal to the apex of the root (Plate B 2, 8-15).

The reduction of volume of the root-canals of young teeth up to the oldest is shown in Plates V a and V b.

Out of 125 examined lower cuspids, 54 or 43 per cent showed bifurcation, 39 per cent showed apical ramifications, and only 12 per cent showed marrow canals. The result of examinations according to the different periods is given in Table 5.

Table 5. Lower Cuspids

Age	Number	Number of Root-Canals					Percentage	Number of Apical Branchings					Percentage	Number of Marrow Canals					Percentage
		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5	
12-20	15	14	1				7	1					7	2					13.3
20-30	63	30	33				55	25	4				40	4	2				25
30-40	30	16	14				46	12	3				50	2	2				14.5
40-55	18	18	6				33	4					31	1	1				11
	126	78	54				43	42	7				39	9	5				12

Lower First Bicuspid

The root-canals of the lower first bicuspid are mostly simple in structure, corresponding to the root in form. According to Muehlreiter a bifurcation may take place due to a lateral grooving of the root, with the result that two separate prongs may persist. In this case there is also a splitting in the root-canal into two delicate canaliculi. Fischer states that two root-canals may exist during lateral grooving of the root and that these canals may either end separately or join again shortly before the apex and then break up into delicate ramifications.

During youth the canal is simple in structure and voluminous, and gradually diminishes in size toward the conical apex (Plate VI a). In older teeth the root-canal volume is reduced and exhibits apical ramifications, as well as marrow canals which consist of one or

two side channels leading from the main canal to the peridental membrane thru the root dentin at various levels. I was unable to determine a bifurcation of the root in my observations; I found only a slight indication thereof (Plates VI a and D 1).

Out of 75 examined lower first bicuspids, 2 or 2.3 per cent showed indications of a bifurcation, 44 per cent showed apical indications, and 17.3 per cent showed marrow canals. The results of my observations are summarized in Table 6.

three canals will be present (Plates VI b and D 2, 6-12). Usually the bifurcation takes place in the apical region of the root in which case the canal breaks up into a number of fine branches.

In young teeth neither bifurcations nor apical ramifications appear and the canal is of simple structure and voluminous. In older teeth there is the usual reduction in the volume of the canal and the appearance of apical ramifications and marrow canals. According to Fischer this branching takes place in 35 per cent of them (Plate b, 3, Plate f, 12).

TABLE 6. FIRST LOWER BISCUSPID

Age	Number	Number of Root-Canals					Percentage	Number of Apical Branchings					Percentage	Number of Marrow Canals					Percentage
		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5	
12-25	10	10						1					10						
25-35	40	39	1				2.5	16	5				52	7	1				20
35-45	25	24	1				4	9	2				44	4	1				20
	75	73	2				2.3	26	7				44	11	2				17.3

LOWER SECOND BICUSPID

The lower second bicuspids show conditions similar to those of the lower first bicuspids. The root-canals are simple in structure but somewhat more spacious than those of the lower first bicuspids. In addition to a simple cylindrical canal, which gradually diminishes toward the apex, there may also be a bifurcation of the root-canal, as already stated by Fischer. According to my specimens, this bifurcation takes place in the apical half of the root in the form of a fork, and of these two canals, one may again bifurcate, so that

Out of 65 lower bicuspids which were examined, 5 or 7½ per cent showed bifurcation of the root-canal, 49 per cent showed apical ramifications and 20 per cent showed marrow canals. The result of investigation according to the various ages is given in Table 7.

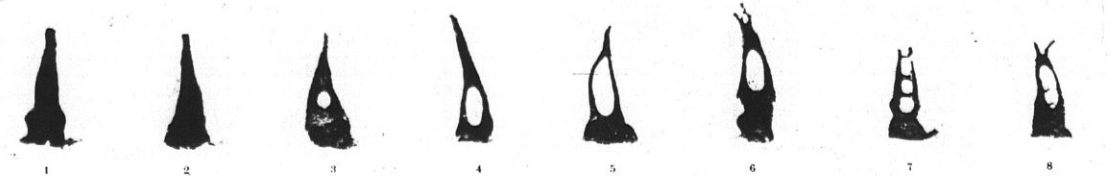
UPPER FIRST BICUSPIDS

The upper first bicuspid usually has two roots, which, however, may be fused and result in a single root. Occasionally a three-rooted form may be found, and in this case the buccal root usually divides into two, while the like is not noticed in the lingual root (Baume).

TABLE 7. SECOND LOWER BICUSPIDS

Age	Number	Number of Root-Canals					Percentage	Number of Apical Branchings					Percentage	Number of Marrow Canals					Percentage
		1	2	3	4	5		1	2	3	4	5		1	2	3	4	5	
12-25	5	5						1					20						
25-35	34	32	2				6	16	2				53	6					18
35-45	26	23	3				11	13	1				45	7					27
	65	60	5				7.5	30	3				49	13					20

Plate C 1



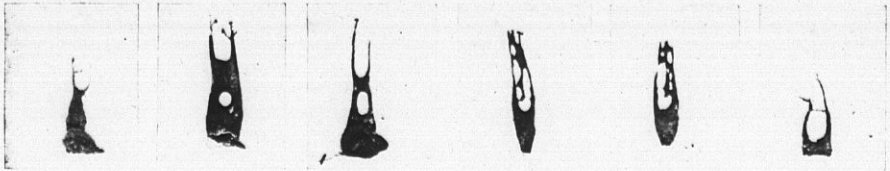
1 2 3 4 5 6 7 8

9 10 11 12 13 14 15 16

Upper First Bicuspids

Plate C 2

1 2 3 4 5 6 7



8 9 10 11 12 13

Upper Second Bicuspids

In general there are two roots of which one lies to the buccal and the other to the lingual. In the case of a three-rooted upper first bicuspid, there is a corresponding division of the root-canals, in which the buccal canal divides into two resembling a fork (Plate XI b, 50-53, Plate C 1, 15-16).

The two-rooted bicuspids always have two root-canals and the single only one, which is usually somewhat compressed laterally. Often, however, the single-rooted upper first bicuspids show two canals which separate to the apex.

In the upper first bicuspids we find similar extensions of the root-canals as in the lower incisors and cuspids. In young individuals, the root-canals of two-rooted bicuspids are simply constructed, spacious canals. These canals are separated into a buccal and lingual canal in bicuspids of fused roots by the formation of a dentinal wall mesio-distally during the lapse of years. According to Loos, this separation occurs as the result of the formation of a dentinal wall which forms symetrically against the pulp with a convex surface. This division may take place at various levels of the root-canal.

These two separated canals may unite again beyond the dentinal wall separating them and end in single canal opening at the apex, or a second division may take place after reuniting, resulting in a forklike ending with apical ramifications.

This separation and reuniting of the root-canals, together with the several dentinal walls separating these canals which overlie one another, resembling bridges, complicate the root-canal system of the upper first bicuspids to a great extent (Plate XI a, 11-20, Plate XI b, 31-40, Plate C 1, 2-8).

In addition to this complicated differentiation of the root-canals there are the fine apical ramifications and marrow canals. In single-rooted upper first bicuspids, numerous apical ramifications are shown, and in addition there are marrow canals forming connections between the peridental membrane and the root-canal (Plate f, 11). Similar conditions are noticeable in the two-rooted first bicuspids in which there is also a great tendency toward the apical ramifications. In case of the three-rooted first bicuspids, the buccal canals exhibit delicate apical ramifications (Plate XI b, 52).

Out of 33 examined upper first bicuspids, Fischer noticed 19 or 58 per cent with delicate ramifications.

In counting only the apical ramifications, the result is a lower percentage according to my observations. Out of 260 upper first bicuspids that I examined, 19.5 per cent had only one root-canal, 79.2 per cent had two root-canals, and 1.2 per cent had three root-canals. Forty-one per cent had apical ramifications and only 18 per cent had marrow canals. Table 8 gives a summary of the results.

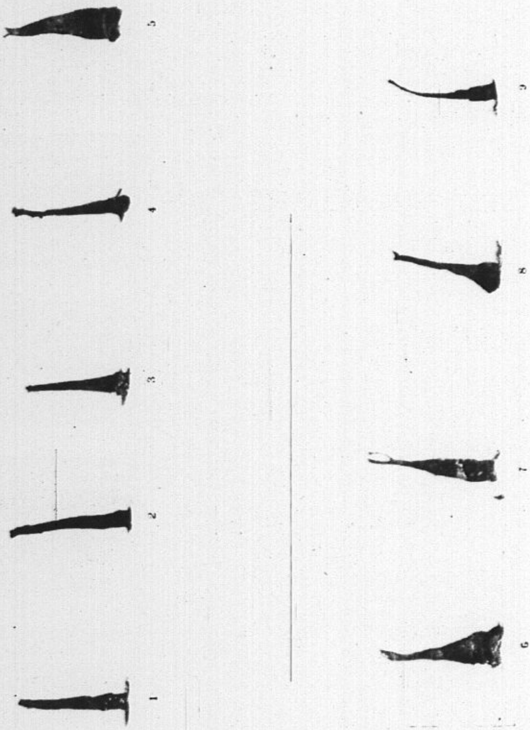
TABLE 8. UPPER FIRST BICUSPIDS

Age	Number	Number of Root-Canals				Number of Apical Branchings					Percentage	Number of Marrow Canals					Percentage
		1	2	3	4	5	1	2	3	4	5		1	2	3	4	5	
10-20	20	4	16	....	....	....	....	3	....	....	....	13	....	....	....	....	....	....
20-30	160	30	127	2	....	....	....	55	6	2	1	40	20	6	....	....	....	16
30-40	60	11	47	1	....	....	....	21	3	1	2	45	10	5	....	....	....	25
40-50	20	5	17	....	....	....	....	7	1	1	2	55	4	2	....	....	....	30
	260	50 19.5%	207 79.3%	3 1.2%	....	....	....	86	10	4	5	41	34	13	....	....	....	18

UPPER SECOND BICUSPIDS

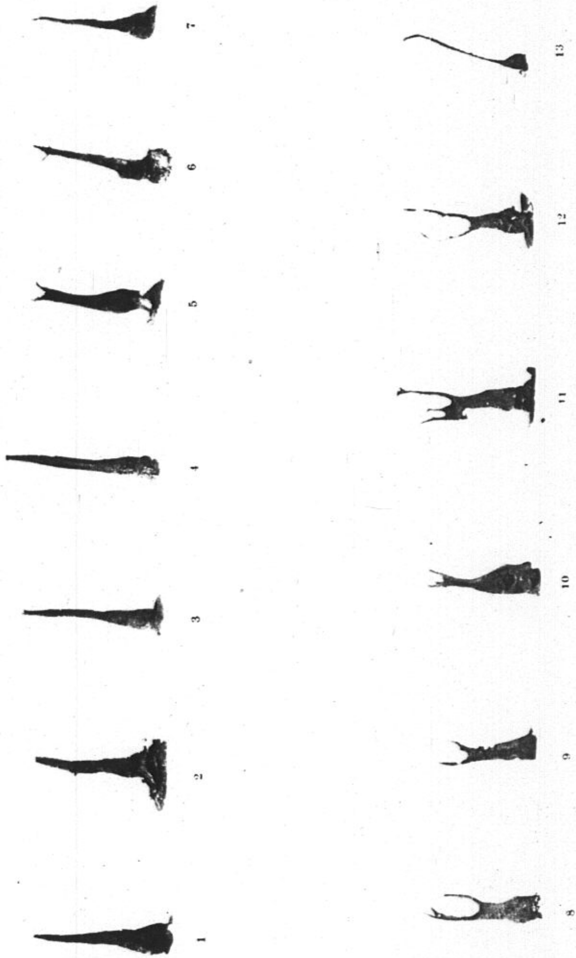
In the majority of cases, specimens of the upper second bicuspid show only a simple root, altho some will be found

Plate D 1



Lower First Bicuspids

Plate D 2



Lower Second Bicuspids

with the indication of a bifurcation of the root at the apex, but an extended bifurcation as in the case of the upper first bicuspid is rare.

The root-canals show a great variety in form and number. In the case of a bifurcation of the root, there are always two root-canals. A great number of single-rooted upper second bicuspids also show two root-canals and these may again bifurcate in a forked manner at the apex (Port).

The young type are usually built simply and without ramifications. However, as age progresses the root-canals assume differentiations as were found in the upper first bicuspids. By means of dentinal walls mesio-distally, the canal may be divided into a buccal and lingual canal, which may still be connected by small canals resembling bridges (Loos). The division may occur at any level of the root and may range from a simple connecting canal to a full separation of both canals (Plate XII b, 30-50, Plate C 2, 8-13). These canals open at the apex either simply or in a forked manner with ramifications. Besides these divided canals, there are a great number of simply constructed canals which first bifurcate at the apical third and then give off apical ramifications (Plate XII a and b, 11-30, Plate C 2, 3-8). Port was able to find similar results by examining 53 upper second bicuspids and in 50 per cent he found a bifurcation of the root-canals. Fischer comes to the same conclusion, and out of 33 upper second bicuspids examined, 13 or 40 per cent had two root-canals. In addition to these variations, it is necessary to mention the apical ramifications and marrow canals, the former of which Fischer found to occur in 40 per cent of his specimens (Plate a, 1).

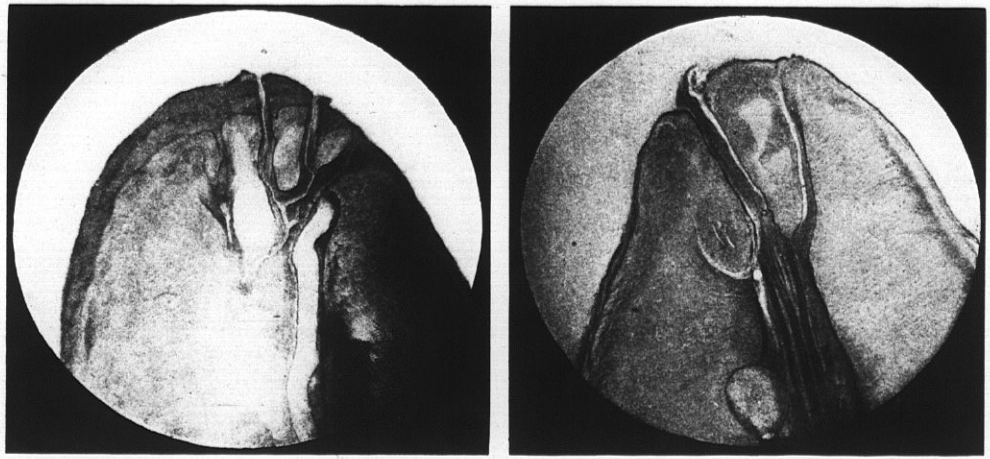
My observations are based on 246 upper second bicuspids, of which 56 per cent had one root-canal, 42 per cent two root-canals, and 2 per cent had three root-canals. Apical ramifications were found in 50 per cent and marrow canals in 19 per cent. (Table 9).

TABLE 9. UPPER SECOND BICUSPID

Age	Number	Number of Root-Canals					Number of Apical Branchings					Percentage	Number of Marrow Canals					Percentage
	-	1	2	3	4	5	1	2	3	4	5		1	2	3	4	5	
15-20	16	16	....	....	....	....	6	....	....	....	....	37	....	....	....	....	....	....
20-30	156	80	73	3	....	....	64	4	3	1	....	48	22	3	....	....	....	16
30-40	50	29	21	....	....	....	24	2	2	....	....	53	8	2	....	....	....	20
40-50	24	12	10	2	....	....	10	2	2	....	....	61	10	2	....	....	....	50
	246	137	104	5	....	....	104	8	8	1	....	50	40	7	....	....	....	19
		56%	42%	2%	....	....												

[*To be concluded*]

Plate a

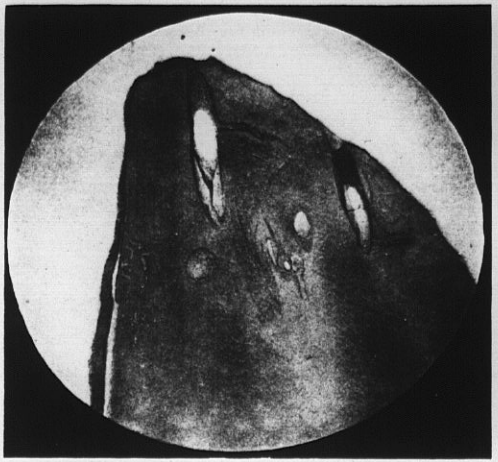


1 2

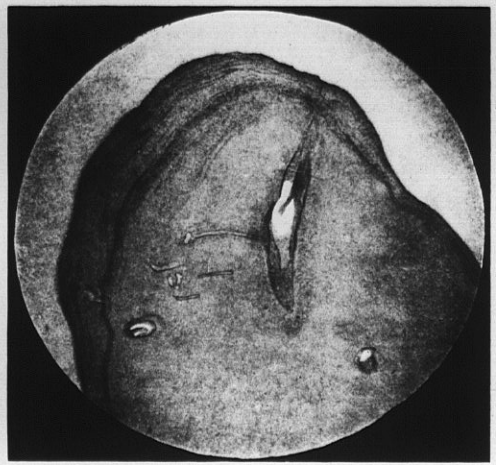
1, Longitudinal section thru the apical foramina of an upper second bicuspid. Arborescent network of pulp canals in apex. Patient thirty-five years old.

2, Longitudinal section thru the apex of an upper first bicuspid. Patient forty-one years old. Ramification of root-canals in apical region. Complicated dentin structure.

Plate b



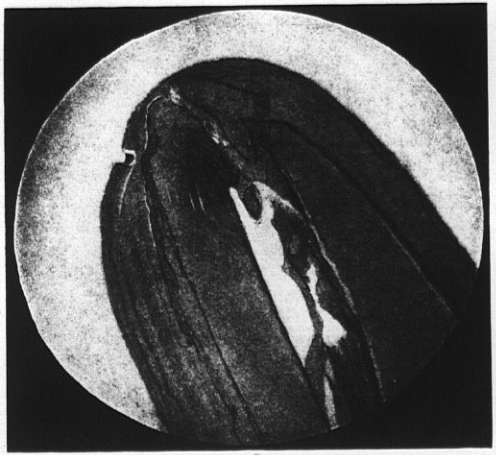
3



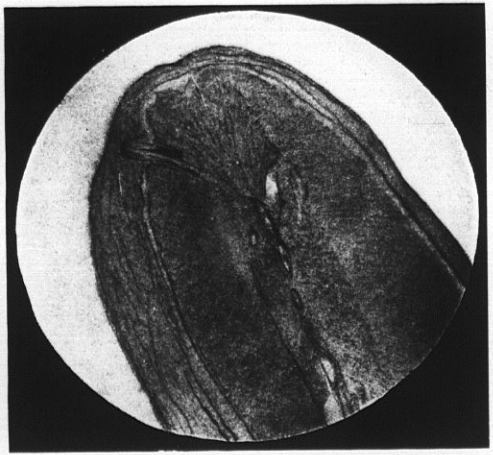
4

3. Longitudinal section thru the apex of a lower second bicuspid. Patient thirty years old. Some of the fine apical ramifications are cut longitudinally and some transversely. From the pulp canal some fine tubules extend into the dentin.

4. Longitudinal section thru the mesial root of a lower first molar. Patient twenty-eight years old. Some of the fine apical canals are cut longitudinally and some cut transversely. Slender anastomosing branches connect the individual canals.



5

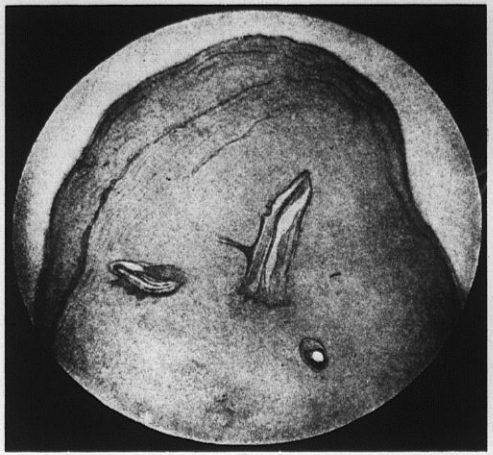


6

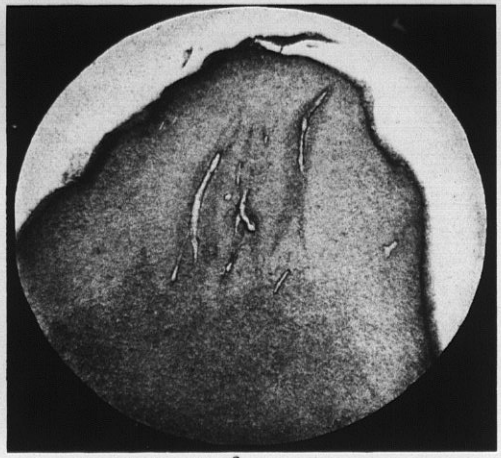
5, Longitudinal section thru apex of a lower cuspid. Patient thirty-two years old. The root-canal branches out into fine apical ramifications.

6, Longitudinal section thru apex of an upper central incisor. Patient fifty-one years old. The root-canal is partly obliterated but still shows some slender branchings in the apical region.

Plate d



7

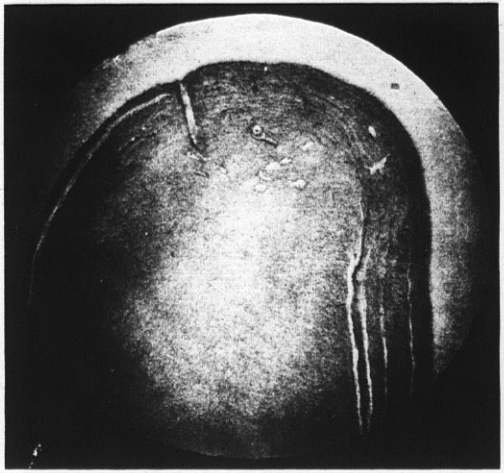


8

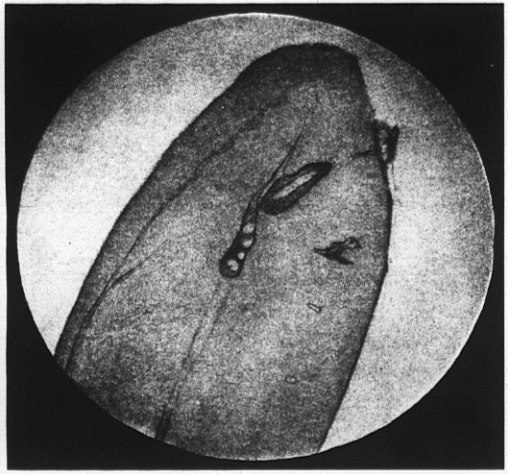
7, Longitudinal section thru the distal root of a lower second molar. Patient twenty-one years old. The ramifications of the root-canal are cut transversely. Slender marrow canals extend from the root-canal into the root dentin.

8, Longitudinal section thru the apex of an upper third molar. Patient forty years old. The whole apex is penetrated by a fine network of canaliculi.

Plate e



9

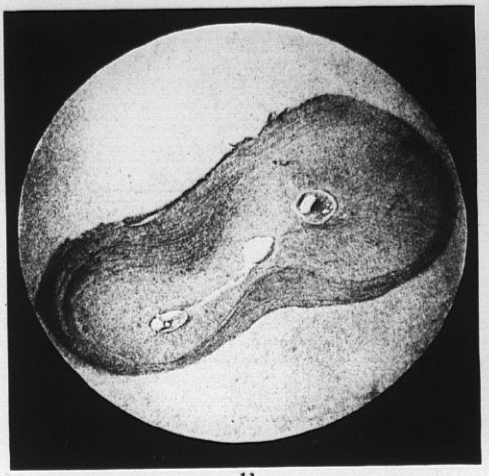


10

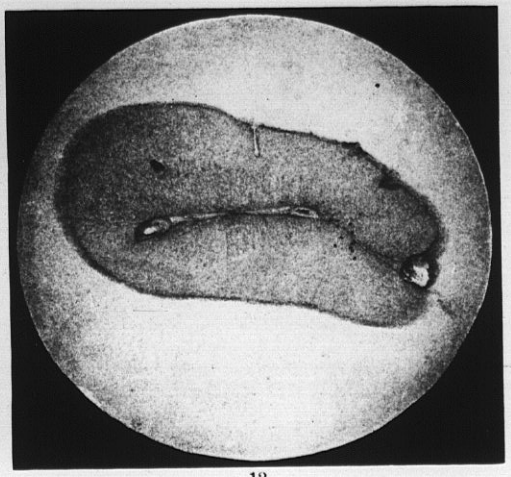
9, Longitudinal section thru mesial buccal apex of an upper second molar. Patient thirty-five years old. The apical region shows a finely extended net-work of canals which look like perforations in the apex.

10, Longitudinal section thru apex of an upper lateral incisor. Patient thirty-one years old. The apex shows fine ramifications. Some lateral indications show tubules running to the periosteum (peridental membrane).

Plate f



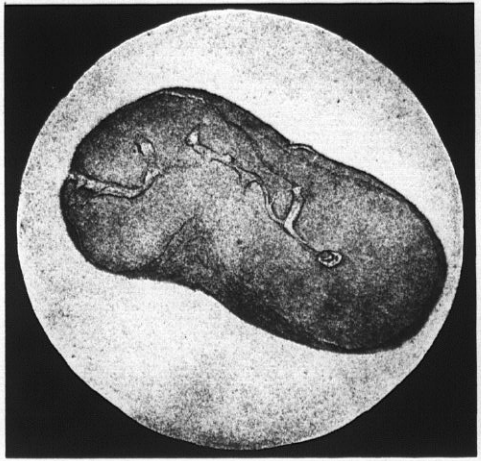
11



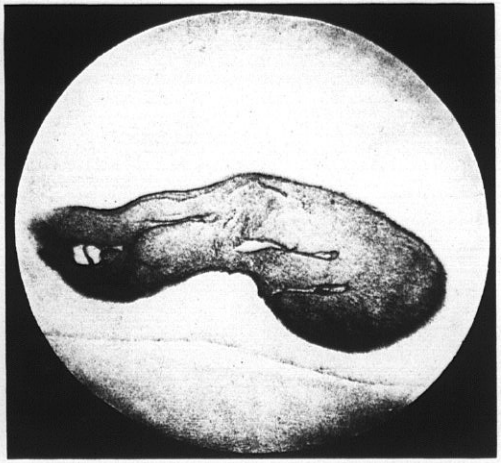
12

11. Cross-section thru apex of an upper first bicuspid. Patient twenty-five years old. Besides the two root-canals, there appears a third one in the center, which is connected with the buccal canal. Some slender tubules in cross-section are also seen.

12. Cross-section thru the apex of a lower second bicuspid. Patient sixteen years old. The lingual and buccal root-canals are connected thru cross-branches with a median canal.



13

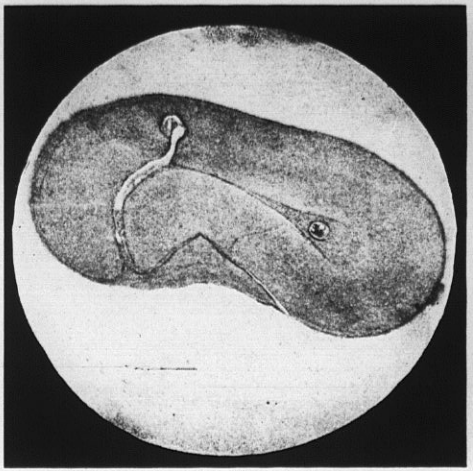


14

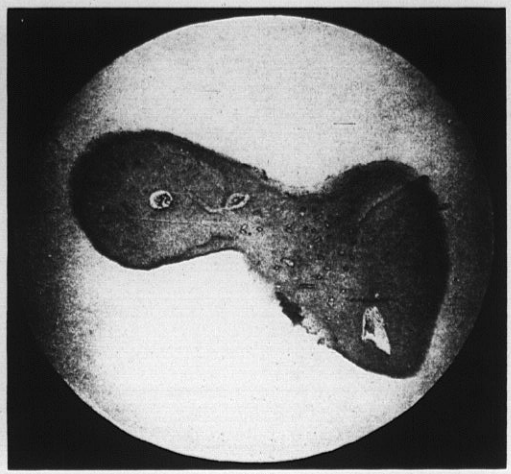
13. Cross-section thru apex of the mesial root of a lower second molar. Patient forty years old. Slender network with tubules.

14. Cross-section thru the apex of the mesio-buccal root of an upper first molar. Patient thirty-one years old. Numerous slender canals traverse the apical region.

Plate h



15

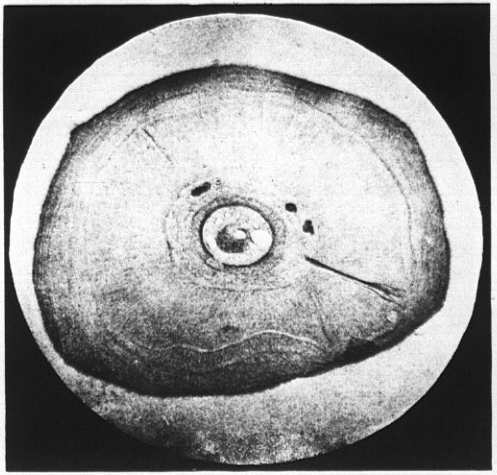


16

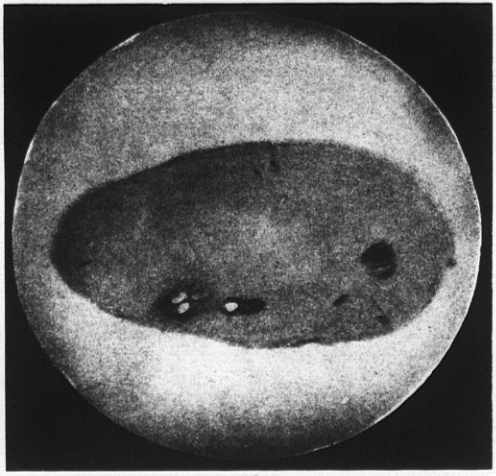
15, Cross-section thru apex of a lower cuspid. Patient thirty-five years old. Besides the two root-canals there is a side-branch which is connected with periosteum (peridental membrane).

16, Cross-section thru the apex of an upper third molar. Patient forty-five years old. Besides the apical branchings there are to be seen numerous slender cribiform canaliculi.

Plate i



17

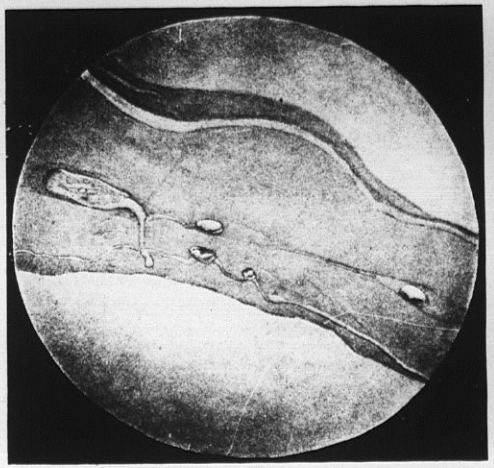


18

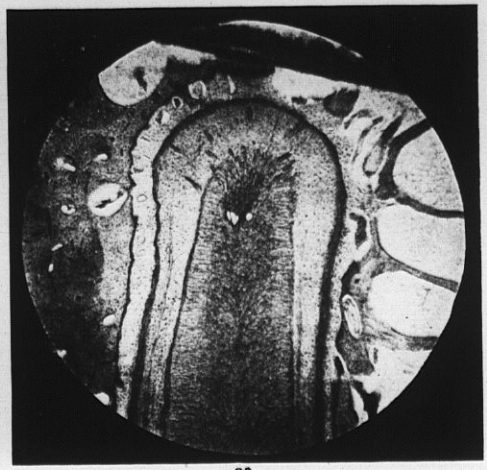
17. Cross-section thru the root of an upper central incisor in the upper third of the root. Patient twenty-four years old. A tubule is seen to extend from central (root) canal to the periosteum (peridental membrane).

18. Cross-section thru the apex of the distal root of a lower first molar. Patient thirty-eight years old. Several apical branches are seen in transverse section.

Plate k



19



20

19, Cross-section thru the fusion point of two roots of an upper second molar. Patient thirty years old. Numerous tubules traverse the root dentin.

20, Longitudinal section thru the tooth of a rabbit showing the bushy appearance of the apical branchings of the root-canal.