Influence of Occlusal Wear and Age on Formation of Dentin and Size of Pulp Chamber

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The phenomenon of wear—attrition, abrasion—of teeth can be observed in ancient man as well as in contemporary individuals. The most common explanation offered in the literature regarding the influence of wear on dentin and pulp is that, in response to this stimulus, nature develops a calcific deposit—the so-called secondary dentin—thus causing a recession of the pulp as the wearing process progresses. It has also been asserted that this formation takes place opposite the abraded area, i.e., between the injury and the pulp.[1-6] In addition to abrasion, other factors, such as age, have been mentioned as causing secondary dentin formation[7-10] and it has also been suggested that this formation may even occur through a reflex action.[1,11]

In a previous study examining ancient skeletal material of which the teeth had suffered a considerable amount of wear of varying degrees, it was observed that the age factor would probably better explain the encroachment of the pulp tissue by progressive calcification from all directions than would the functional factor of wear but that excessive wear no doubt influences the degree of calcification to some extent.[12]

The purpose of the present study was to ascertain the influence of occlusal wear, and age on the formation of dentin. The sites of dentin formation in relation to the size of the pulp chamber were also investigated, no distinction being made between primary and so-called secondary dentin. The presence of "pulp stones" was not taken into consideration.

MATERIALS AND METHODS

One hundred and sixty-eight left permanent mandibular first molars of both sexes were used for this study. The sample included 93 molars of contemporary individuals in vivo ranging from six to seventy years of age, and 75 molars belonging to ancient skeletal material *in situ,* from five to forty-nine years of age at death, the latter material extending over the time-span 3000 B.C.—A.D. 1900, i.e., from Neolithic times to the beginning of the present century. The age at death of each of the ancient skeletal specimens was taken from previous anthropological studies.[13,14] With the criteria available at present, it is not possible to give this age to a close degree of accuracy,[15] especially where the age exceeds some twenty-five years.[16] The numbers of specimens of both groups examined are shown in Table 1 according to age.

The examination, visual and intraoral radiographic, was limited to normally aligned, sound, left, permanent, mandibular first molars, free of caries and/or any operative work. The calcification and development of this tooth in specimens belonging to our

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youngest cases were found at the stage at which the enamel cuticle was completed, formation of dentin had continued, and the floor of the pulp chamber (the cleft) at the bifurcation of the roots had begun to be formed. The gingival extremity at the bifurcation of the roots and the dentino-enamel junction at the center of the occlusal surface of this tooth were considered as two fixed points. For each case the age and estimated degree of occlusal wear were recorded in special charts, the degree of occlusal wear being assessed according to the method described in a previous paper.[12]

In the present study, only teeth with degrees of occlusal wear *0-V* inclusive (Fig. 1) were taken into consideration. Of the teeth showing wear at degree 7, those with no traces of enamel preserved at the dentino-enamel junction at the center of the occlusal surface were excluded, since this is one of the fixed points referred to above and constitutes one of the indispensable bases of our measurements, as will be seen below. The distribution of cases in both groups according to the assessed degree of occlusal wear is shown in Table 2.

TABLE 1

MATERIAL CLASSIFIED ACCORDING TO AGE GROUPS

Age Group	No. of Cases		Cumulative				Mean Degree of Occlusal Wear	
			No. of Cases		Per Cent of Cases			
	Contemporary	Ancient Skeletal Material	Contemporary	Ancient Skeletal	Contemporary	Ancient Skeletal	Contemporary Material	Ancient Skeletal Material
5-10	9	9	9	9	10	12	0.1	0.8
11-20	19	9	28	18	30	23	0.8	2.1
21-30	19	26	47	44	50	59	1.4	2.6
31-40	12	20	59	64	63	85	2.8	3.2
41-50	16	11	75	75	80	100	1.6	3.4
51-60	9		84		90		3.4	
61-70	9		93		100		3.0	
Total	93	75					1.7	2.6

TABLE 2

MATERIAL CLASSIFIED ACCORDING TO DEGREE OF OCCLUSAL WEAR

Degree of Occlusal Wear	No. of Cases		Cumulative Percentage of Cases		Age Range	
	Contemporary	Ancient Skeletal	Contemporary	Ancient Skeletal	Contemporary	Ancient Skeletal
0	15	4	16	5	6-24	5- 6
I	37	7	56	15	10-53	6-28
II	18	26	75	50	12-70	9-45
III	11	19	86	75	21-60	15-45
IV	8	15	94	95	36-67	25-40
V	4	4	100	100	36-70	40-49
Total	93	75			6-70	5-49

FIG. 1.—Cross-sectional anatomy from the buccal aspect of a left permanent mandibular first molar, showing successive stages of occlusal wear, from degree *0* to *V*.

FIG. *2*.—Cross-sectional anatomy from the buccal aspect of a left permanent mandibular first molar and technique for obtaining measurements.

Radiographs were taken as follows. In each case the film was placed close to the tooth and its overlying tissues and parallel to its long axis, without bending the film. The distance from target to film was 8 inches, with the central ray perpendicular to the long axis of the tooth from the buccal aspect, passing through the middle of the cemento-enamel junction at the cervix, and parallel with the interproximal spaces of the neighboring teeth. Under these conditions, all radiographs were taken using 65 Kvp at 10 Ma. Each radiograph was then magnified X10 by means of a projector specially set up in a standard horizontal position, the projection being at right angles to the screen to minimize inaccuracies. Diagrams were drawn on these enlargements for each case. Millimetric measurements were then taken as follows.

Two axes (Fig. 2) were considered: (1) Axis *a-d,* passing through the dentino-enamel junction at the occlusal surface of the tooth and, specifically, through the center *a,* to the center *d* of the gingival extremity at the bifurcation of the roots; and (2) axis *a'-d',* running perpendicular to *a-d,* in each case bisecting *b-c* (minimum height of the pulp chamber). The *a'-d'* axis approximately coincided with the mesio-distal diameter of the tooth (crown) at the cervix.

The following measurements were taken on these two axes: (1) *a-b,* the thickness of dentin at the roof of the pulp chamber; (2) *b-c,* the height of the pulp chamber; (3) *c-d,,* the thickness of dentin at the floor of the pulp chamber; (4) *a-d,* the total distance from the dentino-enamel junction to the bifurcation of the roots; (5) *a'-b',* the thickness of the mesial (axial) wall of dentin; (6) *b'-c',* the width of the pulp chamber; (7) *c'-d',* the thickness of the distal (axial) wall of dentin; and (8) *a'-d',* the total mesiodistal (width) diameter of the tooth at the cervix. The material was subjected to statistical analysis.

RESULTS

Tables 1 and 2 reveal the differences between the two groups of observations with respect to age and occlusal wear and show why it was necessary to use both of them in our study. Thus the contemporary molars were of known age, whereas for the ancient skeletal molars the ages were not known to a close degree of accuracy,[15,18] particularly as 77 per cent of the cases fell into the higher-age groups. Moreover, the mean degree of occlusal wear in both groups seemed to increase with age, but not at the same rate (Table 1). Thus the observed contemporary molars displayed a significantly lower degree of occlusal wear than did the ancient skeletal ones, besides which occlusal wear seemed to appear at a later age in the former case than in the latter. More specifically, only 15 per cent of the ancient skeletal molars exhibited occlusal wear less than degree II (Table 2), while the corresponding percentage among the contemporary molars was 56—a difference which becomes still more impressive if we consider that the total age range of the contemporary molars examined was from six to seventy years, whereas for those of the skeletal material it was from five to forty-nine years. Similar conclusions emerged from an examination of the age range corresponding to each degree of occlusal wear (Table 2). This is wider for the contemporary material than for the ancient skeletal observations, chiefly because the upper end of the range probably corresponded to a rather greater age in the former case than in the latter, although again one must bear in mind the limitations of age determination for ancient skeletal material.

In order to illustrate the association between each of the variables of classification and the various tooth measurements under study, Tables 3 and 4 were drawn up.

KerZ/caZ *measurements.*—An examination of Tables 3 and 4 reveals that, regardless of variables of classification, measurement *a-b* does not display a systematic change in either group of observations, except possibly for a trivial upward trend with respect to age observed in the ancient skeletal material. One might contend, however, that even this may be spurious, arising from inaccuracies in the determination of age at death for the ancient anthropological material. Consequently, our measurements permit the formulation of a preliminary hypothesis, according to which (and as far as

TABLE 3

VERTICAL AND HORIZONTAL MEAN MEASUREMENTS (IN MM.) ON FIRST LEFT MANDIBULAR PERMANENT MOLARS OF CONTEMPORARY AND ANCIENT SKELETAL MATERIAL CLASSIFIED BY AGE

			VERTICAL MEASUREMENTS				HORIZONTAL aMEASUREMENTS			
TYPE OF MATERIAL	No. CASES	Age Groups	Thickness of Dentin at Roof of Pulp Chamber *a-b*	Height of Pulp Chamber *b-c*	Thickness of Dentin at Floor of Pulp Chamber	Over-all Length from Den tin o-enamel Junction to Bifurcation of Roots *a-d*	Thickness of Mesial Wall of Dentin	Width of Pulp Chamber *b'-c'*	Thickness of Distal Wall of Dentin c'-d'	Over-all Mesiodistal Diameter of Tooth at Cervix *a'-d'*
		(1)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Contemporary..	9	6-10	3.13	1.46	1.60	6.19	2.25	4.28	2.43	8.96
	19	11-20	3.12	1.34	2.14	6.60	2.48	3.89	2.50	8.87
	19	21-30	3.19	0.86	2.41	6.46	2.67	3.64	2.66	8.97
	12	31-40	3.19	0.72	2.56	6.47	2.68	3.45	2.72	8.85
	16	41-50	3.11	0.47	2.71	6.29	2.90	3.40	2.76	9.06
	9	51-60	3.40	0.35	2.66	6.41	2.84	3.70	2.68	9.22
	9	61-70	3.37	0.25	3.26	6.88	2.85	3.33	2.70	8.88
Ancient...	9	5-10	3.03	2.18	1.47	6.68	2.18	4.73	2.20	9.11
	8	11-20	3.19	1.15	2.37	6.71	2.60	3.59	2.48	8.67
	27	21-30	3.35	0.67	2.77	6.79	2.71	3.71	2.63	9.05
	20	31-40	3.37	0.40	2.95	6.72	2.79	3.49	2.64	8.95
	[11	41-50	3.56	0.48	2.83	6.82	2.85	3.73	2.64	9.22

our material is concerned) neither age nor occlusal wear seemed to affect the thickness of dentin at the roof of the pulp chamber *{a-b)* significantly over the age ranges and degrees of occlusal wear considered.

Contrariwise, the examination of the group mean measurement *b-c* with respect to age, as also with respect to occlusal wear, indicates a change inversely proportional to both variables of classification and of equal intensity for both groups of observations. The same holds true, but conversely, for measurement *c-d;* i.e., the thickness of dentin at the floor of the pulp chamber increased with age and/or occlusal wear. All these changes took place without the over-all measurement *a-d* being affected in any systematic fashion.

Horizontal measurements.—With regard to horizontal measurements, although the evidence afforded by Tables 3 and 4 is less clear, especially with respect to measurements *a'-b'* and *c'-d',* they suggest that the dentin of the mesial and distal walls increased in thickness with age and occlusal wear, while the width of the pulp chamber decreased mesiodistally.

Further, it emerges both from the examination of the group means and from the comparison of the grand means of both groups of observations that the over-all mesiodistal diameter of the tooth at the cervix (a'—(Tables 3 and 4) not only displayed a remarkable stability with respect to both variables of classification, as was expected, but also appeared to coincide with the average as determined by other investigators,[10]

TABLE 4

VERTICAL AND HORIZONTAL MEAN MEASUREMENTS (IN MM.) ON FIRST LEFT MANDIBULAR PERMANENT MOLARS OF CONTEMPORARY AND ANCIENT SKELETAL MATERIAL CLASSIFIED BY DEGREE OF OCCLUSAL WEAR

			Vertical Measurements				Horizontal Measurements			
Type of Material	No. of Cases	Degree of Occulsal Wear	Thickness of Dentin at Roof of Pulp Chamber *a-b*	Height of Pulp Chamber *b—c*	Thickness of Dentin at Floor of Pulp Chamber c-d	Over-all Length from Dentino-enamel Junction to Bifurcation of Roots *a-d*	Thickness of Mesial Wall of Dentin *a'-b'*	Width of Pulp Chamber *b'-c'*	Thickness of Distal Wall of Dentin *c'-d'*	Over-ail Mesio-distal Diameter at Cervix of Tooth *a'-d'*
		(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Contemporary..	T5	0	3.14	1.33	1.88	6.35	2.36	4.11	2.49	8.96
	37	I	3.24	0.86	2.52	6.62	2.71	3.59	2.66	8.96
	18	II	3.07	0.79	2.49	6.35	2.79	3.53	2.71	9.03
	11	III	3.12	0.61	2.73	6.46	2.64	3.78	2.68	9.10
	8	IV	3.37	0.33	2.71	6.41	2.64	3.24	2.60	8.48
	4	V	3.27	0.30	2.73	6.30	2.89	3.76	2.60	9.25
Ancient...	4	0	3.05	2.67	1.03	6.75	2.05	5.39	1.95	9.39
	7	I	3.26	1.67	2.04	6.97	2.51	4.04	2.39	8.94
	26	II	3.28	0.67	2.75	6.71	2.70	3.72	2.65	9.07
	19	III	3.50	0.67	2.75	6.92	2.73	3.59	2.67	8.99
	15	IV	3.28	0.45	2.82	6.55	2.77	3.54	2.61	8.92
	4	V	3.40	0.40	2.99	6.79	2.78	3.41	2.50	8.69

i.e., at 9 mm. This suggests that the technique used for obtaining measurements from projected radiographs is in fact presenting us with the desired cross-sectional anatomy of the tooth at the cervix, from the buccal aspect.

However, the aforesaid hypotheses regarding changes in the various measurements on the teeth studied were formulated on the basis of observations of the group means, with consequent loss of information; moreover, the observed changes were the result of the combined influences of both variables of classification, which were highly correlated, as a study of Tables 1 and 2 indicates.

We did not, however, test for the significance of the correlation coefficient between the two variables of classification and the measurements made. First, the conditions for the application of "Analysis of Variants" methods are that the observations must be random and the parent population normal, neither of which condition was obtained in the present case. Second, even if we had employed the large-sample test for the significance of the correlation coefficient, [S.E.r (standard error of *r)* =2= *l/\/n,* where *n* ~ size of sample] dispensing with the normality assumption above, our test would still have been invalidated by the absence of the first condition, that of randomness of observations.

It was thus felt desirable to verify and estimate with greater accuracy the trends that had been suggested by the examination of the group means of tooth measurements classified with respect to age and occlusal wear and to isolate and estimate for each case the uncontaminated influence of each of the two variables of classification. We therefore proceeded to the computation of the total correlations between every one of the tooth measurements and each of the variables and then the partial correlations, which measure the net uncontaminated influence of each of the variables.

TABLE 5

TOTAL CORRELATIONS BETWEEN AGE, OCCLUSAL WEAR, AND TOOTH MEASUREMENTS

MEASUREMENTS	CONTEMPORARY F$_{12}$ =+0.6290		ANCIENT SKELETAL r$_{12}$— +0.6074	
	Age/Tooth Measurements	Wear/Tooth Measurements	Age/Tooth Measurements	Wear/Tooth Measurements
Vertical..........	fr$_{13}$*=+0.2080	r$_{23}$f=+0.0513	ri3*= +0.3809	r$_2$+=+0.1290
	r$_{14}$ =-0.7479	^24 = —0.5100	r$_{14}$ =-0.7152	r$_{24}$ = —0.6031
	r$_{15}$ =+0.6781	f25 =+0.3641	r$_{15}$ =+0.4727	r$_{25}$ =+0.3750
	r$_{16}$ =+0.1181	r26 =—0.0547	He =+0.0866	r$_{26}$ =-0.0935
Horizontal. . .	fr$_n$ =+0.5143	r$_{27}$ =+0.2200	fn =+0.5389	r$_{27}$ =+0.3639
	r$_{18}$ =-0.4095	r28 =-0.2290	r$_w$ =-0.4305	r$_{28}$ =-0.4789
	r$_{19}$ =+0.3703	r$_{29}$ =+0.1121	r$_{I9}$ =+0.3974	^29 =+0.2862
	/no — +0.0530	r$_2$io = —0.0303	/'no = +0.0324	^2io — —0.1355

*ru·^=0.04 (contemporary) and 0.15 (ancient).
tn$_3$ — 0 (contemporary) and 0.02 (ancient).

The symbols adopted range from 1 to 10. Thus (1) signifies age, (2) occlusal wear, (3) thickness of dentin at the roof of the pulp chamber, (4) height of the pulp chamber, (5) thickness of dentin at the floor of the pulp chamber, (6) over-all distance from the dentino-enamel junction to the bifurcation of the roots, (7) thickness of the mesial wall of dentin, (8) width of the pulp chamber, (9) thickness of the distal wall of dentin, and (10) over-all mesiodistal diameter of the tooth at the cervix.

Thus in our text and tables, correlations are denoted (for example) as follows: r_{13} stands for total correlation (Table 6) between age and thickness of dentin at the roof of the pulp chamber. Similarly, $r_{14 \cdot 2}$ stands for partial correlation (Table 7) between age and height of pulp chamber, with occlusal wear held constant.

The total correlations (Table 5) offer statistical corroboration of the finding that the thickness of dentin at the roof of the pulp chamber (that is, from the fixed center *a* to the fixed center *b)* was independent of the degree of occlusal wear, the corresponding r|$_3$* being practically nil and 0.02 for the contemporary and the skeletal material,

* r^2 being taken as the measure of the proportion of the variability of either of the two variables attributable to the presence of the other.

respectively. On the other hand, the influence of age, although far stronger, was still too small to be of any statistical significance, $r|_3$ being equal to 0.04 and 0.15, respectively.

Again, computations based on individual observations confirmed what the examination of group means had already suggested, revealing a high correlation between the two variables of classification and the height of the pulp chamber. Moreover, the correlations with age were greater than those with wear, r_{14} being —0.75 and —0.72, as against —0.51 and —0.60 for r_{24}, for the contemporary and skeletal material, respectively. The situation with r_{15} and r_{25} was similar, the only difference being that these correlations were positive and weaker. As expected, the r_{26} correlations were very nearly zero.

Regarding the horizontal measurements, the correlations were less pronounced, ri_7 being the strongest, followed by r_{i8} and r_{19}. Although the correlations with age were remarkably stable as between contemporary and ancient skeletal material, those with

TABLE 6

PARTIAL CORRELATIONS BETWEEN AGE, OCCLUSAL WEAR, AND TOOTH MEASUREMENTS

MEASUREMENTS	CONTEMPORARY MATERIAL: Age/Tooth Measurements (Wear Constant)	CONTEMPORARY MATERIAL: Wear/Tooth Measurements (Age Constant)	ANCIENT SKELETAL MATERIAL: Age/Tooth Measurements (Wear Constant)	ANCIENT SKELETAL MATERIAL: Wear/Tooth Measurements (Age Constant)
Vertical.................	^13.2 = +0.2263	7*23.1 = —0.1046	7*13.2 =+0.3840	7*23.1 =-0.1394
	ru.2 = —0.6386	t24.i = —0.0767	7*14.2 = —0.5507	7*24.1 = —0.3039
	fis.2 = +0.6202	7*25.1 =-0.1092	7*15.2 =+0.3326	7*25.1 =+0.1256
	Zi6.2 =+0.1964	7*26.1 — —0.1671	fis.2 =+0.1813	^26.1 = —0.1846
Horizontal.............	rn.2 =+0.4956	7*27.1 = —0.1552	7*17.2 =+0.4297	7*27.1 =+0.0547
	^i8.2 ——0.3500	7*28.1 =+0.0413	7*18.2 = —0.2002	Z28.1 =-0.3032
	7*19.2 =+0.3881	7*294 = —0.1673	7*19.2 =+0.2938	7*29.1 =+0.0615
	/no.2 = +0.0928	7*210.1 — —0.0819	7*110.2 = +0.1458	7*210.1 = — 0.1955

wear showed discrepancies. Here too, however, the correlations with the over-all measurements were practically zero for both age and wear.

The results obtained for the partial correlations (Table 6) seemed to bolster the preliminary conclusions borne out by a scrutiny of Tables 3, 4, and 5. The four partial correlations with respect to the height of the pulp chamber (ri4.2, f24.i), for instance, were always smaller than the corresponding total ones (Table 5). Despite this, the decrease was smaller in the case of age, where the partial correlations still remained high, than in the case of occlusal wear, where they became considerably lower or very nearly vanished (compare r_{14} with $r_{14\cdot 2}$ and $r_{24\cdot 2}$ with r_{24tl} in Tables 5 and 6). The same held true, but conversely, for measurement *c-d.*

It should be noted that the correlations with age seemed to verify the hypotheses about the independence of measurement *a-b* of the factor of age and the close relationship between age and measurements *b-c* and *c~d* better in the case of contemporary material than in that of the ancient skeletal material. This discrepancy may simply have been due to inaccuracies in estimation of age at death for the latter.

Finally, it was decided to attempt to determine the relative rates of formation of dentin on the walls considered, over the age range covered by our observations. For this to be possible, however, it was necessary to know the exact ages of the teeth under study, and we were thus compelled to limit ourselves to the contemporary material. We therefore split the contemporary material into two groups, an early group (up to twenty-five years) and a late group (from twenty-five years onward), and observed (Table 7) the behavior of the group correlations as compared with the correlations for the total number of observations, which were used as a standard.

Regarding the vertical measurements, the correlation of age with tooth measurement 3 *(a-b)* almost disappeared for the early age group but seemed somewhat stronger for the late group. For tooth measurement 4 *(b-c),* this correlation became similarly attenuated for both age groups, while for tooth measurement 5 *(c-d)* the correlation showed a dramatic increase for the early age group, becoming much smaller for the late age group.

TABLE 7

TOTAL AND PARTIAL CORRELATIONS BETWEEN AGE AND TOOTH MEASUREMENTS
(Contemporary Material Only)

	Total Correlations			Partial Correlations	
	Early Age Group (Up to 25 Years)	Late Age Group (Over 25 Years)		Early Age Group (Up to 25 Years)	Late Age Group (Over 25 Years)
	+0.0534	+0.2200		+0.1032	+0.2330
r_{14}...............	-0.0547	—0.5000		+0.4930	—0.4780
ris................	+0.8374	+0.0940		+0.8053	+0.1097
rn...............	+0.6010	+0.1731	*rn 2-* •	+0.5503	+0.2562
r_{18}...............	—0.3673	—0.0751		—0.2753	+0.1193
rw..............	+0.2918	-0.0418'	fl9.2..................	+0.3246	-0.0048

On the other hand, for the horizontal measurements, the correlation with age for tooth measurement 7 *(a'-b')* was intensified for the early age group, at the expense of the late age group, which was considerably lower. For tooth measurement 8 *(b'-c/),* the correlation with age almost disappeared for the late age group, while for the early age group it did not in fact become stronger than the total correlation for the same measurement (see Table 5). Finally, the correlation with age for tooth measurement 9 *(c'-d')* almost disappeared for the late age group but seemed somewhat stronger for the early group. The corresponding partial correlations exhibited similar behavior.

DISCUSSION

On the basis of this study, it became evident that the formation of dentin was a continuous process throughout the age range studied. This continuous formation was observable in the examined molars of both groups, i.e., those of contemporary individuals, which had been but little exposed to occlusal wear, as well as those from ancient skeletal material, where the teeth had been subjected to the highest degree of occlusal wear considered in this study. The formation of dentin seemed to go on uninterruptedly and on all dentin walls throughout the life of the tooth, taking place faster during the early years of its growth but more slowly later on, the exact rate at any one time depending on the particular dentin wall concerned. Thus (Fig. 3), a five-year-old specimen (3, *A)* showed dentin formation up to this age as having taken place at considerable speed, especially on the roof, less on the mesial and distal walls of dentin, with an island of dentin present on the floor of the pulp chamber at the bifurcation of the roots. Specimens in the six to ten-year age range (3, *B)* showed dentin formation occurring at considerable speed on the floor, as well as on the mesial and distal walls of dentin, while that on the roof of the pulp chamber was proceeding at a slower rate. Specimens in the eleven to twenty-year age range, again (3, C), showed an over-all decrease in dentin formation rate, the relatively greatest decrease being again at the roof and the least on the floor of the pulp chamber. The progress of these dentin formations continued at the same relative gradients of decrease for the remaining age groups studied. All the walls of the pulp chamber studied showed a continuously declining rate of dentin formation with increasing age. For any one age group, however, the amount of dentin formation was always greatest on the floor and less on the mesial and distal walls. Surprisingly, it was always least on the roof of the pulp chamber itself.

A possible explanation is that, so far as the roof of the pulp chamber is concerned,

FIG. 3.—Successive stages in growth of a left permanent mandibular first molar, showing dentin formation and reduction in size of pulp chamber with age *(A-H)*.

the process of dentin formation had already been virtually completed at an age corresponding to the youngest age groups (see Tables 3 and 4), which was long before the teeth were subject to wear with consequent exposure of dentin. The dentin at this point continued to exhibit no significant quantitative change right up to the latest age groups. This was true regardless of occlusal wear up to degree *V,* where traces of enamel were preserved at the dentino-enamel junction at the center of the occlusal surface of the tooth.

This observation clashes with previously expressed views, according to which, to counteract the influence of occlusal wear, nature causes the formation of a layer of dentin (the so-called "secondary dentin") opposite the abraded area, that is between the injury and the pulp, as if to protect the vitality of the tooth. It has been propounded, moreover, that the pulp of the tooth receded along with advancing occlusal wear, in other words, that the reduction in size of the pulp chamber proceeded chiefly from above, with the formation of a substantial layer of dentin on the roof of the pulp chamber between the injury and the pulp.

Owing to the fact that occlusal wear increased, whereas the pulp chamber became smaller with advancing age, the reduction in size of the pulp chamber has been simply attributed to the coexistent occlusal wear. This fallacy can perhaps be accounted for by the failure of previous workers to examine simultaneously both the varying rates of dentin formation on the respective walls and the relative significance of age and occlusal wear in the changing size of the pulp chamber.

If occlusal wear were the basic cause of the reduction in size of the pulp chamber, there should be a greater formation of dentin at the roof of the pulp chamber, which is not the case. In fact, the thickness of dentin at the roof of the pulp chamber remained almost unaffected by age and occlusal wear, whereas it was the thickness of dentin at the floor which increased considerably with age, over the age range considered, and caused the observed reduction in the size of the pulp chamber occlusogingivally. Meanwhile, the distance between the cemento-enamel junction at the center of the occlusal surface and the gingival extremity at the center of the bifurcation of the roots remained practically the same.

Black observed[11] that "the formation of secondary dentin took place in the same way and to the same extent on the teeth of the same person which were abraded as on those which were not, due to the extraction of their opposing teeth many years before." Our findings are in agreement with this observation, as well as with that of other investigators,[7*, 8] although Black attributes this phenomenon to "reflex action." The present data offer a simpler explanation—that of the influence of age, an interpretation that also explains why "the pulp chambers of both the unworn and the abraded teeth were obliterated in the same way."[11]

Through these dentin formations, in the first place, we got a decrease in the size of the pulp chamber of the tooth with increasing age, a decrease which was greater vertically than it was mesiodistally. During this process, it seems that the pulp horns were gradually squeezed between the thin layer of dentin formed on the roof of the pulp chamber and that formed on the upper halves of the mesial and distal walls of dentin. The root canals were further squeezed with advancing age, as a result of the dentin formed on the lower halves of the mesial and distal walls of dentin, together with the greater mass of dentin at the floor of the pulp chamber. This resulted in their narrowing down and even, on occasion, in their obliteration.

SUMMARY

Dentin formation and size of the pulp chamber were studied in 168 sound, left, permanent mandibular first molars of both sexes, belonging to contemporary individuals, and ancient skeletal material of different age groups suffering varying degrees of occlusal wear. These teeth were examined clinically and radiographed so as to show their cross-sectional anatomy from the buccal aspect under identical standard conditions. The resultant radiographs were enlarged ten times, and diagrams were drawn. Measurements were then taken by means of eight defined indexes and analyzed. The data were tabulated separately for the contemporary and ancient skeletal observations, according to age groups and assessed degrees of occlusal wear. Dentin formation and the size of the pulp chamber under the influence of the two factors—age and occlusal wear—were investigated. The material was subjected to statistical analysis.

The main findings were as follows: (1) There appeared to be no significant change in the dentin at the roof of the pulp chamber with increasing age over the entire spans of age and occlusal wear studied. (2) The dentin at the floor of the pulp chamber showed a definite increase in thickness with increasing age, this being chiefly responsible for the reduction in size of the pulp chamber occlusogingivally. (3) The mesial and distal walls of dentin increased in thickness with increasing age, causing the reduction in size of the pulp chamber mesiodistally. (4) Both the height and the width of the pulp chamber showed a definite decrease with advancing age, regardless of the degree of occlusal wear studied.

It thus appears that, regardless of occlusal wear up to degree *V,* dentin formation goes on uninterruptedly throughout the life of the sound tooth, faster in the early years but more slowly later on. It is this continuous formation of dentin with age that is responsible for the decrease in size of the pulp chamber.

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REFERENCES

1. BLACK, G. V. *Operative Dentistry,* 4:303-5. 7th ed. Chicago: Medico-Dental Publishing Co., 1936.
2. MELLANBY, MAY. *Diet and Teeth: An Experimental Study.* III. *The Effect of Diet on Dental Structure and Disease in Man,* p. 114. (Special Report Services; Medical Research Council, No. 191.) London: His Majesty's Stationery Office, 1934.
3. GOLDMAN, M. H. *Periodontia,* p. 205, *also see* Fig. 148, p. 203. St. Louis: C. V. Mosby Co., 1942. From NOYES, SCHOUR, and NOYES, *Dental Histology and Embryology.*
4. SCHWEITZER, J. M. *Oral Rehabilitation,* p. 723. St. Louis: C. V. Mosby Co., 1951. Schweitzer refers to M. RUSSELL STEIN, The Seven Ages of a Molar, *D. Surgery,* 14:1315,1938.
5. KLATSKY, M., and FISHER, R. L. *The Human Masticatory Apparatus,* p. 46. Brooklyn, N.Y.: Dental Items of Interest Publishing Co., 1953.
6. MOSES, H. C. Human Tooth Form and Arrangement from the Anthropologic Approach, J. *Pros.* De»., 9:198, 1959.

7. BENZER, S. The Development and Morphology of Physiological Secondary Dentin, *J. D. Res.,* 27:640,1948.
8. MIDDLETON SHAW, J. C. *The Teeth, the Bony Palate and the Mandible in Bantu Races of South Africa,* p. 88. London: John Bale, Sons & Danielson, Ltd., 1931.
9. WHEELER, R. C. *A Textbook of Dental Anatomy and Physiology,* pp. 256-57. 3d ed. Philadelphia and London: W. B. Saunders Co., 1958.
10. *Ibid.,* p. 20.
11. BLACK, C. V. *Operative Dentistry,* 1:319-20. 7th ed. Chicago: Medico-Dental Publishing Co., 1936.
12. PHILIPPAS, G. G. Effects of Function on Healthy Teeth: The Evidence of Ancient Athenian Remains, *J.A.D.A.,* 45:443, 1952.
13. ANGEL, J. L. Skeletal material from Attica, *Hesperia,* 5:289, 1945; also personal communication.
14. ---------. *Human Skeletons from Grave Circles at Mycenae: Preliminary Report.* Philadelphia: Daniel Baugh Institute of Anatomy of the Jefferson Medical College and the University Museum.
15. *Basic Readings on the Identification of Human Skeletons: Estimation of Age.* New York: Wenner-Gren Foundation for Anthropological Research, Inc., 1954.
16. SMITH, S. *Forensic Medicine: A Textbook for Students and Practitioners.* 8th ed. London: J. & A. Churchill, Ltd., 1945.