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DETERMINATION OF AGE IN HUMANS FROM ROOT DENTIN TRANSPARENCY

by

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INTRODUCTION

In forensic medical and forensic odontological work one is often confronted with the problem of determining the age of unknown bodies. In adults this may prove difficult especially if the person in question has been subjected to combustion, putrefaction or severe external force. Even in such cases, however, the teeth may be well preserved and present the only means for age determination.

Several investigations have been carried out regarding changes in the teeth with age. This work has been reviewed by *Pedersen* and *Keiser-Nielsen* (1961), *Bang* (1962), *Miles* (1963), *Saunders* (1965) and *Gustafson* (1966).

Gustafson (1947, 1950) was the first to employ the transparency of the root dentin as one of six criteria of age, stating that it increases in extent as the individual grows older.

Subsequently, *Miles* (1963) found a certain relationship between age and the extent of root transparency whereas *Johnson* (1968) was unable to arrive at a good correlation between the area of transparent dentin and age.

The root dentin usually appears to become transparent during the third decade starting at the tip of the root and advacing coronally with age. The alteration is believed to be caused by a reduction of the diameter of the dentinal tubules caused by increasing intratubular calcification. Thereby

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the difference in refractive indices between intratubular organic and extratubular inorganic material will be equalized resulting in increasing translucency of the dentin so affected.

Except for the studies of *Gustafson* (1947, 1950), *Miles* (1963) and *Johnson* (1968) few attempts at finding practical methods for age evaluation from teeth in adults have been published.

The present investigation was carried out in an effort to arrive at a simple and relatively objective method of age determination by means of evaluating the degree of root transparency only.

MATERIAL AND METHODS

Except for root-filled teeth, intact, restored and decayed teeth were included in the study provided the roots were macroscopically unaffected. Originally, 1013 teeth representing 1132 roots were collected but definite measurements could not be obtained from some of these specimens. These teeth were excluded from the study. On a few other teeth the transparency of the roots could not be measured either on the intact roots or on the longitudinal sections and for computational reasons these teeth were also omitted. Thus the material consisted of 926 teeth comprising 978 roots including 450 extracted teeth from 201 patients, 112 men and 89 women, in a mental institution and 476 teeth collected from 64 persons, 46 men and 18 women, at autopsy. The number and origin of the different types of teeth examined are shown in Tables I and II, and the age distribution of the subjects and the teeth is shown in Tables III, IV and V.

Soft tissue was removed from the root surface and the teeth were kept in 10 % neutral formaldehyde solution (formalin). Multirooted teeth were split, each root being measured separately and counting as one root in the calculations.

The teeth were orientated, fixed, with crown wax and labiolingual sections were cut in a Thin Sectioning Machine (Gillings-Hamco). Thus, intact roots, IT, as well as 400 μ thick longitudinal sections, SS, from the midline of the roots were studied.

In both cases the total length of the root, RL, was measured bucally in the midline from the cemento-enamel junction to the apex. The transparent root dentin was measured from the apex of the root in coronal direction to the borderline between transparent and opaque dentin. If this junction was not depicted as a relatively even horizontal line both the minimal (TL 1) and maximal (TL 2) extension of the transparency was recorded, Fig. 1. If the junction was outlined as a fairly even horizontal line only one measurement was taken

Table I
Distribution of teeth by subjects
Upper Jaw

	Central incisors		Lateral incisors		Cuspids		First premolars		Second premolars		First molars		Second molars		Third molars	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
Teeth extracted from living subjects	15	13	15	16	22	11	7	8	11	25	14	14	26	17	24	5
Teeth collected at autopsy	28	5	22	4	24	8	9	1	10	5	6	0	12	2	5	2
Total	43	18	37	20	46	19	16	9	21	30	20	14	39	19	29	17
♂ + ♀	61		57		65		25		51		34		57		36	

Table II
Distribution of teeth by subjects
Lower Jaw

	Central incisors		Lateral incisors		Cuspids		First premolars		Second premolars		First molars		Second molars		Third molars	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
Teeth extracted from living subjects	11	22	14	21	9	17	11	10	13	25	6	3	6	11	17	11
Teeth collected at autopsy	56	21	57	22	57	24	44	9	24	6	3	2	1	3	2	2
Total	67	43	71	43	66	41	55	19	37	31	9	5	7	14	19	13
♂ + ♀	110		114		107		74		68		14		21		32	

Table III

Distribution of subjects by age

Age groups (years)	Number of subjects: Patients ♂	Patients ♀	Autopsy material ♂	Autopsy material ♀	Total number of subjects
10—19	2	5	4	1	12
20—29	22	15	3	0	40
30—39	34	23	1	1	59
40—49	16	20	4	3	43
50—59	26	15	8	2	51
60—69	9	10	9	3	31
70—79	3	1	15	6	25
80—	0	0	2	2	4
Total	112	89	46	18	265
Total ♂+♀	201		64		265

Table IV

Distribution of teeth by age

Upper Jaw

Age groups	Central incisors	Lateral incisors	Cuspids	First premolars	Second premolars	First molars	Second molars	Third molars
10—19	3	3	0	1	2	1	2	1
20—29	5	7	6	4	8	2	9	9
30—39	9	10	9	6	12	14	11	12
40—49	13	12	18	5	10	5	14	10
50—59	14	10	10	3	8	6	9	1
60—69	10	8	10	4	9	4	5	1
70—79	5	6	10	1	1	2	5	2
80—	2	1	2	1	1	0	2	1
Total	61	57	65	25	51	34	57	36

and called TL 1, that is to say TL 1 = TL 2 in these cases, Fig. 2. The mean value $\frac{\text{TL }1+\text{TL }2}{2}$ was designated TM. If a distinct zone of cementum was discernible at the tip of the root on the longitudinal sections it was not included in the transparent root length.

Table V

Distribution of teeth by age
Lower Jaw

Age groups (years)	Central incisors	Lateral incisors	Cuspids	First premolars	Second premolars	First molars	Second molars	Third molars
10—19	2	2	0	0	4	1	0	1
20—29	6	8	6	7	7	3	2	13
30—39	6	4	5	5	10	3	8	11
40—49	18	15	13	10	11	3	5	2
50—59	30	32	26	19	12	1	3	1
60—69	23	28	26	19	13	0	1	1
70—79	21	21	24	12	8	3	2	3
80—	4	4	7	2	3	0	0	0
Total	110	114	107	74	68	14	21	32

1

2

Fig. 1. Longitudinal section of lower, left central incisor, —1,*) from a 65.2 year old male illustrating minimal, TL1 = 6.0 mm, and maximal, TL2 = 9.0 mm, extent of root transparency. The mean transparent length, TM $= \frac{6.0+9.0}{2} = 7.5$ mm. Estimated age = 63.7 years (Table IX). (x1).

Fig. 2. Longitudinal section of lower, right central incisor, 1—, from a 44.6 year old female illustrating well defined horizontal junction between transparent and opaque dentin. The extent of root transparency, TL1 $\equiv$ TL2 $\equiv$ TM = 3.5 mm. Estimated age = 47.7 years (Table IX). (x1).

*) According to the Haderup dental stenography + indicates the upper jaw, — the lower jaw. If the sign is placed on the right of the digit, the right tooth is indicated and vice versa. The teeth are numbered from the central incisors, 1, to the third molars, 8.

The values of TL 1, TL 2 and TM in relation to total root length, RL, expressed in per cent, were also calculated, leaving a total of 12 variables:

1 = Intact root, minimal length of root transparency: IT, TL 1
2 = Intact root, maximal length of root transparency: IT, TL 2
3 = Intact root, mean length of root transparency: IT, TM
4 = Longitudinal root section, minimal length of root transparency: SS, TL 1
5 = Longitudinal root section, maximal length of root transparency: SS,TL 2
6 = Longitudinal root section, mean length of root transparency: SS, TM
7 = Intact root, percentage minimal length of root transparency or total root length: IT, $\frac{TL1}{RL} \cdot 100$
8 = Intact root, percentage maximal length of root transparency of total root length: IT, $\frac{TL\ 2}{RL} \cdot 100$
9 = Intact root, percentage mean length of root transparency of total root length: IT, $\frac{TM}{RL} \cdot 100$
10 = Longitudinal root section, percentage minimal length of root transparency of total root length: SS, $\frac{TL\ 1}{RL} \cdot 100$
11 = Longitudinal root section, percentage maximal length of root transparency of total root length: SS, $\frac{TL\ 2}{RL} \cdot 100$
12 = Longitudinal root section, percentage mean length of root transparency of total root length: SS, $\frac{TM}{RL} \cdot 100$

The measurements were recorded to the nearest 0.5 mm by means of a sliding caliper in front of a constant light source.

Twenty-five longitudinal root sections were measured again following storage in 10 % neutral formaldehyde for 5 years.

A small number, 55, of root-filled teeth as well as 14 impacted teeth were studied separately. The root-filled teeth originated from 39 subjects, age 30 to 83 years, while the impacted teeth, 11 upper cuspids and 3 upper third molars, were surgically removed from 10 persons ranging from 31 to 62 years of age.

Excluding molars, a random sample consisting of 510 of the longitudinal sections from the material listed above were placed in a photographic enlarger. The total area of the root and the area of transparent root dentin were outlined enlarged five times on white paper. These areas were then each measured twice with an Ott-compensating Polar Planimeter. The mean

Table VI

Distribution of 480 teeth subjected to measurements of the area of transparent root dentin

	Upper jaw				
Teeth	Central incisors	Lateral incisors	Cuspids	First premolars	Second premolars
Number	46	42	48	9	29

	Lower jaw				
Teeth	Central incisors	Lateral incisors	Cuspids	First premolars	Second premolars
Number	70	78	72	43	43

value of the two recordings were used in the calculations. It proved impossible to arrive at definite measurements on 30 of these specimens, leaving a total of 480 teeth, Table VI, in this study.

Finally, the suggested method for age determination was tested on a new material consisting of 168 teeth from 24 persons between 26—85 years of age.

All measurements were carried out as a blind study by the same investigator.

Error of the methods.

Two months after the first observations duplicate recordings of all linear measurements were carried out on a random sample consisting of almost half of the material. The double set of data formed the basis for an analysis of the error of the method. Student's t-test was used to test if the mean of the differences between the first and second measurements for each observation deviated significantly from zero. The precision was evaluated by calculating the standard error, S_e, on a single reading for all variables from the formula $S_e = \sqrt{\Sigma d^2/2n}$ where d is the difference between the first and the second measurement and n the number of double determinations. No significant difference at the 5 % level ($P>0.05$) between the first and second set of measurements of the length of root transparency was found. The estimated standard error, S_e, on a single observation is presented in Table VII. The results indicate that the method of registring the length of root transparency is acceptable for the present investigation.

Duplicate area measurements were done on 25 random samples. Measuring the same area twice with the planimeter gave no significant difference in the

Table VII

Evaluation of the error of the method. Standard error (S.E.) on a single determination calculated from double determinations.

Variable	Number of roots	S.E.
Intact root. root length	410	0.67 mm
Intact root, TL 1	402	0.83 mm
Intact root, TL 2	17	0.87 mm
Longitudinal section, root length	303	0.84 mm
Longitudinal section, TL 1	300	0.76 mm
Longitudinal section, TL 2	48	0.64 mm

planimeter readings between the two recordings. Testing the method used for registration of the area of root transparency showed, however, a significant difference between the first and second set of measurements, ($P<0.001$). Consequently, further studies along these lines were discontinued.

Statistical Methods

In a statistical sense the material is very heterogenous. Hence we cannot answer statistically whether there are population differences, sex differences or differences between the different types of teeth, in the degree of root transparency.

It seems reasonable to assume that the variable to be estimated in our study, the age, has a conditional normal distribution at given values for transparent length. The discussion of the results are based on this assumption.

Age has been computed as the dependent variable from both a first and a second degree polynome of the 12 expressed variables separatly after dividing the material in different groups. All the corresponding empiric (total) correlation coefficients, r, correlation indexes, r_2, standard deviation on estimated age, S_A, and Student's significance-test of the regression coefficients (B_1 and B_2) have been calculated.

Usually the second degree polynome gave a better estimate of age ($P<0.10$) than the first degree polynome, although the differences were never marked. The correlation index, (*Kendall* & *Buckland*, 1960), r_2, is a measure of »goodness of fit» for a polynomial regression line and defined by

$$S_A^2 = S^2(1\text{-}r_2^2)$$

where S^2 is the total variance of the age in the material. When the best estimation of age is linear, r and r_2 are identical. The advantage of computing a regression-equation from each of the 32 teeth separately is that we avoid the bias that would arise from using different numbers of roots from each person in our calculations. We do not know if this has been considered in previous publications.

By studying the second degree polynomes it appears that theoretically the length of root transparency will start decreasing around the age of seventy. Biologically, however, such a reduction obviously would be hard to explain. Possibly this is due to the small and probably biased sample of teeth from very old persons in our material. Realizing that statistical theory is not strictly adhered to, we suggest use of the first degree polynomial regression for the highest values of root transparency while at the same time it appears most reasonable to employ the second degree polynomes for lower values. Studying all the first and second degree regression lines it seems reasonable to use the first degree polynomes for root transparencies exceeding 9 mm.

Wherever possible the correlation coefficients between the lengths of transparent root dentin in contra-lateral teeth from one person, as well as between corresponding teeth from the upper and lower jaws, were calculated. Owing to the composition of the material this could not be done for molars. All the empirical correlation coefficients were found in the area $r = 0.80$—0.90 exhibiting a strong covariation between the lengths of root transparency in teeth from one person. The number of persons these correlations are based on varies between 20—48.

A study of all parameters, equations and tests resulted in the following method for estimating age from the degree of root transparency. The formula given for computing standard deviation of age based on an arbitrary number of teeth from one person is slightly simplified as compared to the theory. The correct formula for computing S_A on the estimated mean age from n teeth from the same person is:

$$S_A^2 = \frac{1}{n^2}(S_{a_1}^2 + \cdots\cdots + S_{a_n}^2 + 2\sum_{i\,j}^{n} r_{ij} S_{a_i} S_{a_j})$$

Since we are not able to compute all correlation coefficients, r_{ij}, in our material and since, excluding molars, S_a values do not differ much for the different teeth, mean approximately 10, we think the best approximation would be to susbtitute all r_{ij} by 0.85 and all S_a by 10 in the covariances. Hence:

$$S_A^2 = \frac{1}{n^2}(S_{a_1}^2 + \cdots\cdots\cdots + S_{a_n}^2 + 2\frac{n(n\text{-}1)}{2} \cdot 0.85 \cdot 10 \cdot 10)$$

$$S_A^2 = \frac{1}{n^2}(S_{a_1}^2 + \cdots\cdots\cdots + S_{a_n}^2 + 85 \cdot n\,(n\text{-}1))$$

Because of the reservations pointed out above the method was tested on a new material of known age.

It should be mentioned that other samples consisting of almost the whole set of teeth from each person could probably be used to compute one general equation to estimate the age from an arbitrary number of teeth.

RESULTS

In a fairly high proportion, 14 %, of the intact molar roots the degree of transparency could not be determined while at the most only 2 % of the other roots, both intact roots and longitudinal root sections, proved impossible to measure (Figs. 3 and 4). It was also considerably more difficult to arrive at definite measurements of the root transparency on premolars and molars, both intact roots and longitudinal sections of roots, than on incisors and cuspids (Figs. 3 and 4).

While on intact roots it was necessary to record a minimal, TL 1, and a maximal, TL 2, length of transparency in 7.8 % of the cases this increased to 21.7 % when measuring longitudinal root sections. Examples of variations in the pattern of extension of the root transparency are illustrated in Figs. 5 and 6.

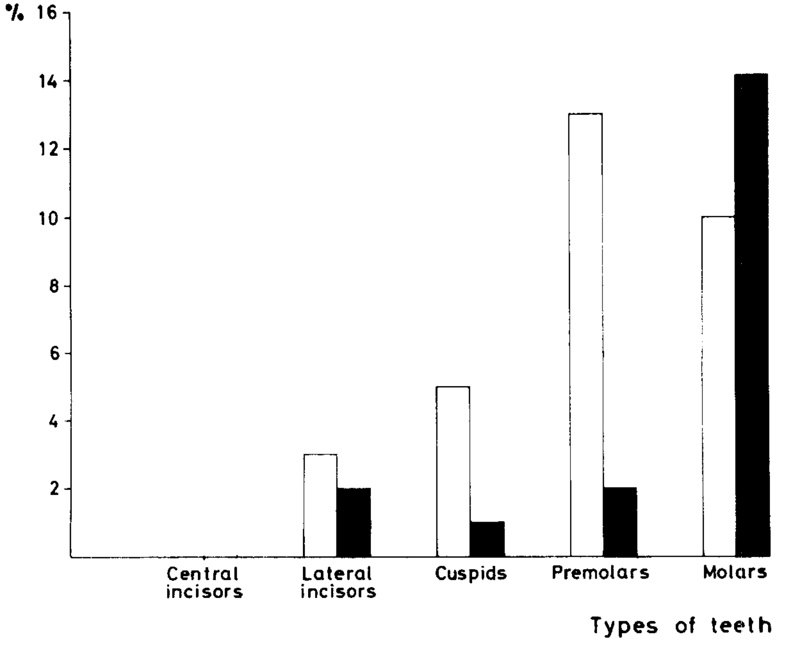


Fig. 3. Histiogram illustrating the percentage of the different types of intact roots where it proved difficult, □, or impossible, ■, to arrive at definite measurements of the length of root transparency.

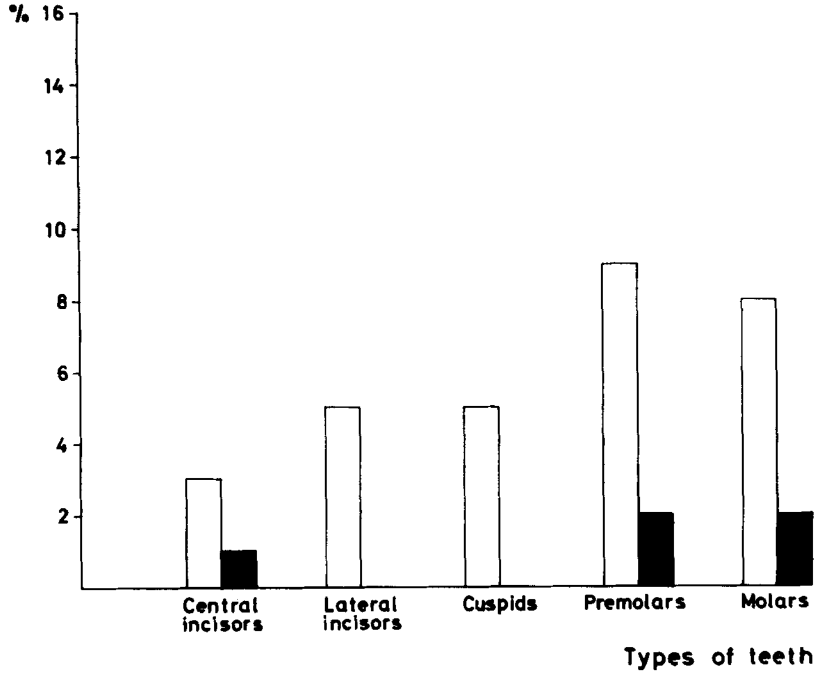


Fig. 4. Histiogram illustrating the percentage of the different types of longitudinal root sections where it proved difficult, □, or impossible, ■, to arrive at definite measurements of the length of root transparency.

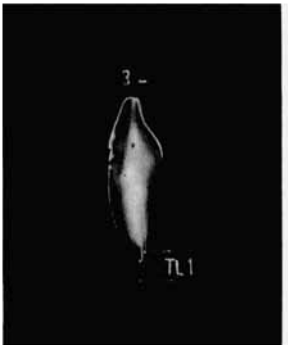
5 

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Fig. 5. Longitudinal section of lower, right cuspid, 3-, from a 44.4 year old female illustrating difficulties encountered in deciding the extent of root transparency because of a marked zone of transparent dentin at the perihpery of the root, TL1≡TM=3.5 mm. Estimated age = 49.3 years. (Table IX). (x1).

Fig. 6. Longitudinal section of upper, left cuspid, + 3, from a 68.8 year old male illustrating difficulties encountered in deciding the extent of root transparency because of an uneven distribution of the transparent zone. TL1=4.0 mm, TL2=16.0 mm, $TM=\frac{4.0+16.0}{2}=$ 10.0 mm. Estimated age = 62.5 years. (Table IX). (x1).

There was no significant difference ($P > 0.10$) between the measurements of the length of transparent root dentin on longitudinal sections before and after storage in 10 % neutral formaldehyde for 5 years.

Testing the correlation between the age of a subject and the length of root transparency in the whole material, 978 roots, as expressed in variables 1 to 12, a significant increase ($P < 0.01$) of the root transparency with age was found (Figs. 7 to 13). Empirical correlation coefficients being about 0.70.

The teeth erupt and the roots are completed at different ages in one individual. But taking into account the age of the tooth from the time the roots are completed rather than the chronological age of the individual gave no better estimate of age when considering the material as a whole.

The material was divided in 4 groups: men-women, teeth collected at autopsy, and teeth extracted from living subjects. Because of the heterogenity of the material it was considered irrelevant to test possible sex differences or differences between teeth from living and dead persons. None of the correlation coefficients in these groups, however, were higher than those obtained when testing the material as a whole. Nor did there appear to be any marked group differences. Excluding molars the remaining 20 different teeth, when

Fig. 7. Longitudinal sections of 1+, +1, +2, 2−, 1− from a 17.0 year old male illustrating no appreciable transparency of the root dentin. TL = 0.0 mm. Estimated age = 21.6 years. (Table IX). (x1).

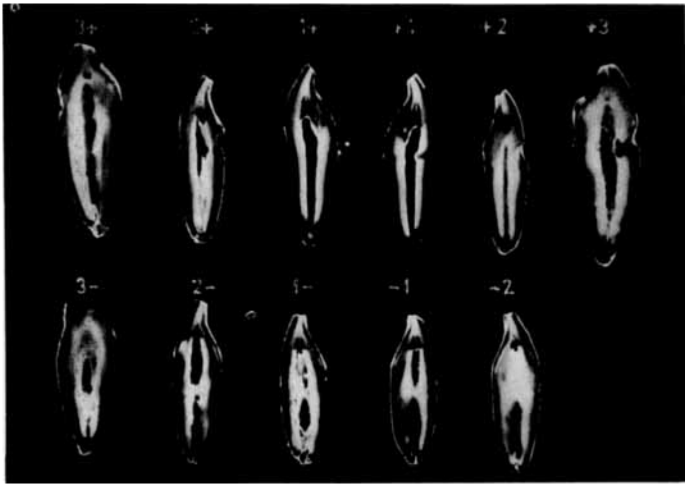


Fig. 8. Longitudinal sections of 3+, 2+, 1+, +1, +2, +3, 3—, 2—, 1—, —1, —2 illustrating transparency of root dentin in a 28.6 year old male. Good contralateral and over all correlation in the extent of root transparency.

	3+	2+	1+	+1	+2	+3	3—	2—	1—	—1	—2
TM (mm)	1.0	1.0	3.0	1.5	1.5	2.0	1.5	1.5	1.5	1.0	1.0
Estimated age (years)	27.8	29.9	38.6	35.5	32.2	34.5	36.1	35.7	30.3	34.7	30.9

Mean estimated age: 33.3 years (Table IX). (x1).

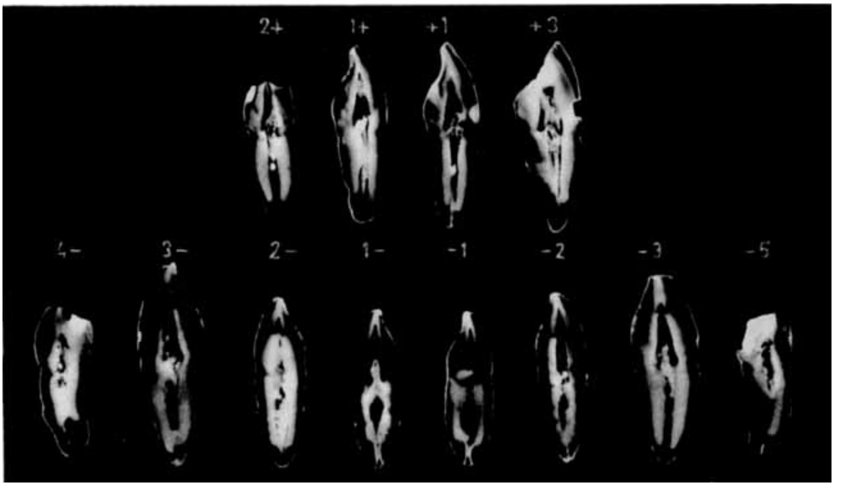


Fig. 9. Longitudinal sections of 2+, 1+, +1, +3, 4—, 3—, 2—, 1—, —1, —2, —3, —5 illustrating transparency of root dentin in a 35.6 year old male. Good contralateral and over all correlation in the extent of root transparency.

	2+	1+	+1	+3	4—	3—	2—	1—	—1	—2	—3	—5
TM (mm)	2.0	3.0	2.5	4.5	3.0	1.5	2.5	3.0	2.5	2.0	2.0	3.0
Estimated age (years)	36.4	38.6	40.8	45.2	43.9	36.1	43.6	43.8	45.3	38.6	39.9	39.5

Mean estimated age: 41.0 years (Table IX). (x1).

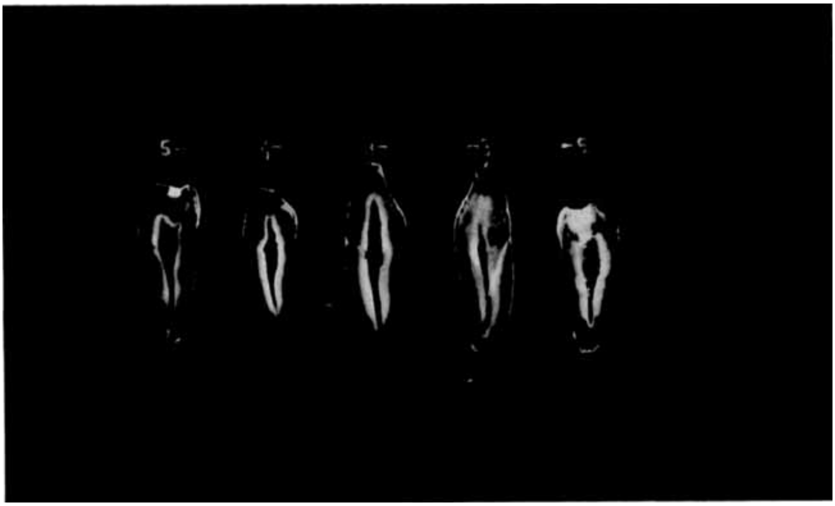


Fig. 10 Longitudinal sections of 5—, 4—, 3—, —3, —5 illustrating transparency of root dentin in a 43.5 year old male. Good contralateral correlation in the extent of root transparency.

	5—	4—	3—	—3	—5
TM (mm)	5.0	5.0	2.5	2.0	4.0
Estimated age (years)	48.9	53.2	39.7	39.9	44.3

Mean estimated age: 45.2 years (Table IX). (x1).

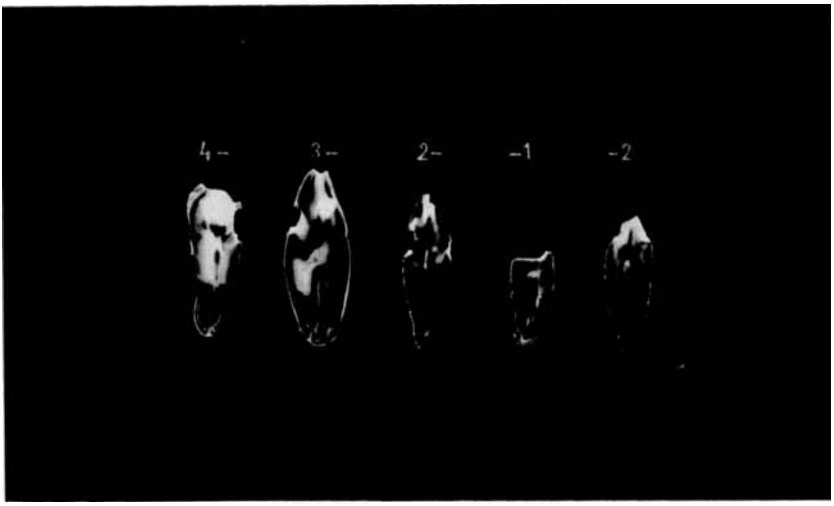


Fig. 11. Longitudinal sections of 4—, 3—, 2—, —1, —2 illustrating transparency of root dentin in a 59.2 year old male. Good over all correlation in the extent of root transparency.

	4—	3—	2—	—1	—2
TM (mm)	5.0	7.0	7.5	6.0	6.0
Estimated age (years)	54.8	65.4	65.6	58.8	60.7

Mean estimated age: 61.1 years (Table IX). (x1).

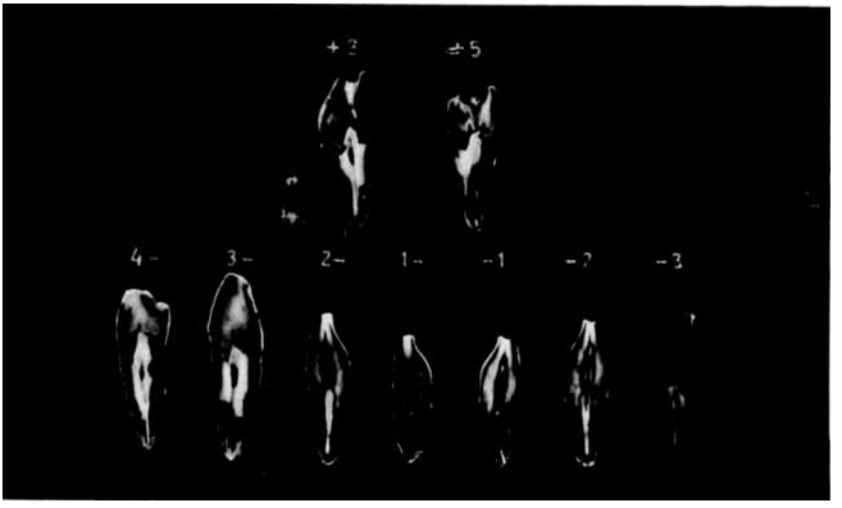


Fig. 12. Longitudinal sections of +3, +5, 4—, 3—, 2—, 1—, —1, —2, —3 illustrating transparency of root dentin in a 64.8 year old male. Good contralateral and over all correlation in the extent of root transparency.

	+3	+5	4—	3—	2—	1—	—1	—2	—3
TM (mm)	8.5	9.0	8.0	8. 0	7.0	6.0	7.0	7.0	8.0
Estimated age (years)	58.7	63.2	65.3	68.4	64.7	61.7	63.0	64.0	69.2

Mean estimated age: 64.2 years (Table IX). (x1).

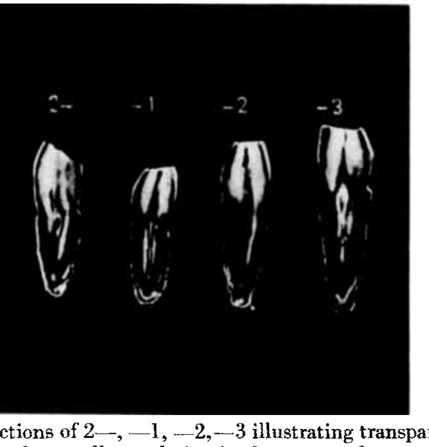


Fig. 13. Longitudinal sections of 2—, —1, —2, —3 illustrating transparency of root dentin in a 75.0 year old male. Good over all correlation in the extent of root transparency.

	2—	—1	—2	—3
TM (mm)	10.0	10.5	11.0	16.0
Estimated age (years) (Table IX)	65.6	60.4	67.9	64.7
Estimated age (years) (Table XI)	68.8	70.2	73.6	85.8

Mean estimated age 64.7 years (Table IX)
Mean estimated age 74.6 years (Table XI). (x1).

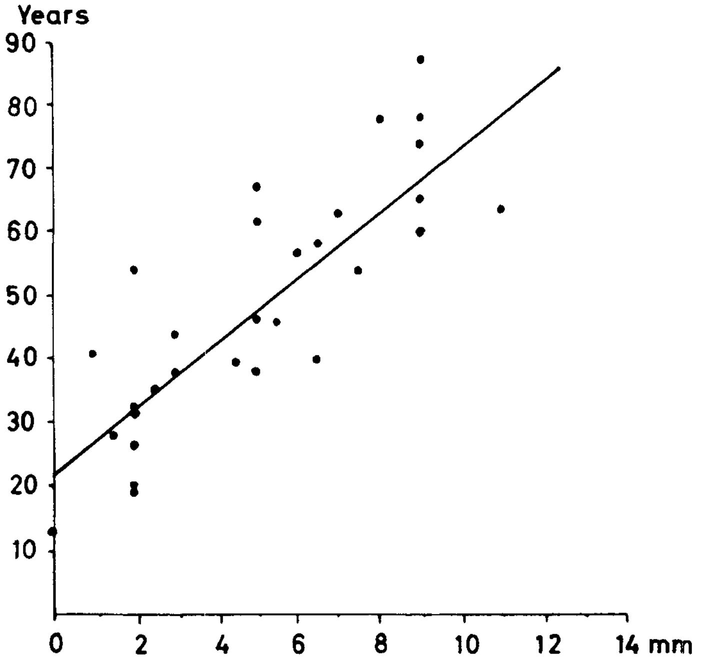


Fig. 14. The extent of transparent root dentin at various ages in intact roots of 31 upper, right lateral incisors. Correlation coefficient = 0.83. Y = 22.06+5.36 · X (Table X).

subdivided in groups consisting of only corresponding roots from each subject, exhibited higher correlation coefficients between age and the variable than those found for the material as a whole.

While there was no noticable difference between the correlation coefficients from contralateral teeth there was a tendency for higher regression coefficients for roots from the right side, although this difference was not significant at the 5 % level (Figs. 14 and 15).

When divided in groups consisting of one corresponding tooth from each individual the material proved too small for testing sex differences or differences between roots collected at autopsy and extracted from living subjects.

Results for contralateral teeth from individual persons showed a very high correlation in the extent of root transparency, r=0.80—0.90, Figs. 8, 9 and 12. In these cases also the regression coefficients for roots from the right side of the jaws usually were somewhat higher than for roots from the left side.

Studying many teeth from one individual there seemed to be a good over all conformity in the extent of root transparency, Figs. 7 to 13, even though there was a tendency for higher regression coefficients for teeth in the upper

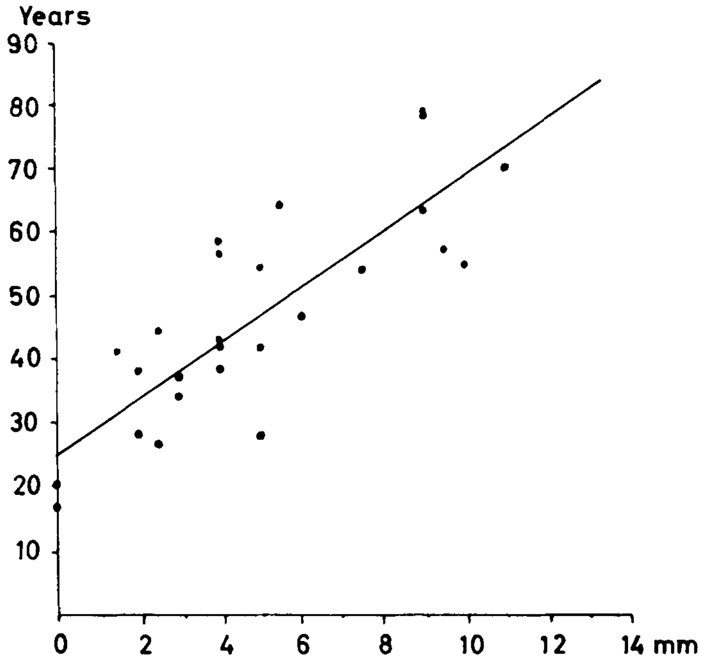


Fig. 15. The extent of transparent root dentin at various ages in intact roots of 26 upper, left lateral incisors. Correlation coefficient = 0.82. Y = 25.57 + 4.38 · X (Table X).

jaw as compared to their corresponding teeth in the lower jaw (Figs. 15 and 16).

The material contained few upper first premolars. Similarly, there were relatively few molars. In the latter the mesial and distal roots usually showed quite good correlation in the degree of root transparency. There was, however, often a marked but not significant difference ($P>0.05$) in the degree of root transparency between mesial and distal roots compared to the palatinal roots of upper molars from one person. The highest correlation coefficients were obtained when grouping corresponding roots from the 6 upper molars and corresponding roots from the 6 lower molars, separately. For practical purposes the results from the present material indicated that when several teeth from one individual are available, one will probably arrive at the best estimation of age by excluding upper first premolars and all the molars.

Of all the 12 variables the following 4 usually gave the highest empirical correlation with age: IT TM, IT 100•TM/RL, SS TM and SS 100•TM/RL. The relative values usually did not give any higher correlations than the absolute values and IT TM and SS TM exhibited about the same correlation *indi-*

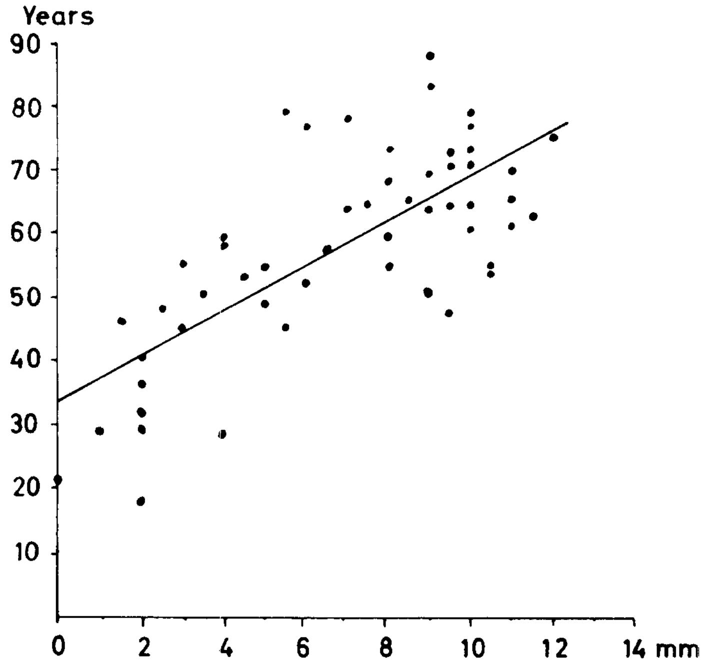


Fig. 16. The extent of transparent root dentin at various ages in intact roots of 56 lower, left lateral incisors. Correlation coefficient = 0.73. Y = 33.65 + 3.53 · X (Table X)

ces. Therefore, measuring the transparency on the intact root would often be sufficient. For values of transparent length less than or equal to 9.0 mm, estimating age, A, from a single root with chosen variable = X, the following equation (second degree polynome) should be used:

$$B_0 + B_1 \cdot X + B_2 \cdot X^2 = A \text{ (Equation 1)}$$

employing the coefficients and the standard deviation on the estimated age, S_A, presented in Tables VIII and IX.

If the length of root transparency is in excess of 9.0 mm, the following equation (first degree polynome) usually will give the best results (example given in Fig. 13):

$$B_0 + B_1 \cdot X = A \text{ (Equation 2)}$$

employing the coefficients and the standard deviation on the estimated age, SA, presented in Tables X and XI.

In cases with several (n) roots available from one individual age should be determined for each root separately following the same procedure:

$$a_i = \text{age},\ S_{a_i} = \text{standard deviation},\ i = 1, \cdots\cdots, n$$

Table VIII

Reference table for age estimation using second degree polynomial regression of mean transparent length on intact roots (IT, TM)

Type of tooth	Number of teeth	Constant term B_0	Regression coefficient B_1	Regression coefficient B_2	Standard deviation S_A	Correlation index r_2
Upper right central incisor	32	20.3	5.74	0.000	10.42	0.80
Upper left central incisor	29	24.3	6.22	—0.119	9.71	0.83
Upper right lateral incisor	31	18.8	7.10	—0.164	10.83	0.84
Upper left lateral incisor	26	20.9	6.85	—0.223	9.77	0.83
Upper right cuspid	33	26.2	4.64	—0.044	12.59	0.67
Upper left cuspid	32	25.27	4.58	—0.073	13.80	0.64
Upper first premolars	25	23.91	3.02	0.203	11.62	0.78
Upper right second premol.	23	23.78	5.06	—0.064	11.21	0.82
Upper left second premol.	28	25.95	4.07	—0.067	9.48	0.80
Lower right central incisor	50	9.80	12.61	—0.711	10.91	0.76
Lower left central incisor	60	23.16	9.32	—0.539	12.27	0.61
Lower right lateral incisor	58	26.57	7.81	—0.383	11.95	0.65
Lower left lateral incisor	56	18.58	10.25	—0.538	10.08	0.79
Lower right cuspid	57	23.30	8.45	—0.348	10.52	0.73
Lower left cuspid	50	27.45	7.38	—0.289	10.22	0.73
Lower right first premol.	37	24.83	6.85	—0.237	9.53	0.82
Lower left first premol.	37	29.17	5.96	—0.173	10.13	0.74
Lower right second premol.	33	29.42	4.49	—0.065	13.00	0.73
Lower left second premol.	35	18.72	5.79	—0.082	11.52	0.82
Upper 6 molars root no. 1	38	30.25	3.23	—0.018	10.22	0.83
Lower 6 molars root no. 1	29	27.39	6.25	—0.239	10.49	0.82
Upper 6 molars root no. 2	27	34.73	0.67	0.211	10.68	0.79
Lower 6 molars root no. 2	47	30.21	5.52	—0.181	10.69	0.76
Upper 6 molars root no. 3	105	27.43	3.64	0.039	10.02	0.82

Root no. 1 = mesial root
Root no. 2 = distal root
Root no. 3 = palatinal root

the estimated average age being the aritmetic mean of the ages thus determined:

$$\frac{1}{n}(a_1 + \cdots\cdots + a_n) = A$$

The standard deviation on the estimated average age being

$$S_A = \frac{1}{n}\sqrt{S_{a_1}^2 + \cdots\cdots\cdots + S_{a_n}^2 + 85 \cdot n(n-1)}$$

Confidence intervals for the real age could be computed from Table XII.

Table IX

Reference table for age estimation using second degree polynomial regression of mean transparent length on longitudinal root sections (SS, TM)

Type of tooth	Number of teeth	Constant term Bo	Regression coefficient B_1	Regression coefficient B_2	Standard deviation SA	Correlation index r_2
Upper right central incisor	32	21.02	6.03	—0.060	11.43	0.76
Upper left central incisor	29	26.84	6.00	—0.155	11.03	0.77
Upper right lateral incisor	31	23.09	7.04	—0.197	11.25	0.82
Upper left lateral incisor	26	24.62	5.18	—0.077	9.40	0.84
Upper right cuspid	33	21.52	6.49	—0.171	13.29	0.62
Upper left cuspid	32	24.64	5.22	—0.143	13.78	0.64
Upper first premolars	25	29.98	2.73	0.107	13.17	0.71
Upper right second premol.	23	24.76	4.81	0.000	10.43	0.83
Upper left second premol.	28	22.34	7.59	—0.393	6.88	0.90
Lower right central incisor	50	13.63	12.11	—0.683	11.01	0.75
Lower left central incisor	60	26.46	8.79	—0.511	11.74	0.65
Lower right lateral incisor	58	21.77	10.19	—0.581	11.26	0.70
Lower left lateral incisor	56	22.22	9.07	—0.444	10.78	0.75
Lower right cuspid	57	24.34	8.38	—0.358	10.74	0.72
Lower left cuspid	50	23.88	8.76	—0.388	9.96	0.75
Lower right first premol.	37	21.54	8.63	—0.395	10.19	0.79
Lower left first premol.	37	26.02	7.00	—0.234	8.39	0.83
Lower right second premol.	33	14.90	9.93	—0.451	9.05	0.88
Lower left second premol.	35	23.87	5.50	—0.098	10.85	0.85
Upper 6 molars root no. 1	38	28.22	4.82	—0.101	6.85	0.93
Lower 6 molars root no. 1	29	33.42	5.18	—0.302	15.76	0.50
Upper 6 molars root no. 2	27	20.43	6.09	—0.182	10.85	0.79
Lower 6 molars root no. 2	47	29.91	4.97	—0.102	11.10	0.74
Upper 6 molars root no. 3	105	25.15	4.34	—0.032	10.20	0.81

Root no. 1 = mesial root
Root no. 2 = distal root
Root no. 3 = palatinal root

The results of evaluating age on a new material consisting of 168 teeth from 24 persons by means of the method outlined above are shown in Table XIII. Up to about 75 years age was determined with good accuracy and even studying the whole sample revealed that 14 out of 24 cases, 58.3 %, came within the theoretical 35 % confidence interval, ranging from ± 4.2 to ± 4.7 years. Nineteen or 79.2 % fell within the theoretical 65 % confidence interval corresponding to ± S_A ranging from 9.2 to 10.5. In older people, however, there seemed to be a tendency for underestimation of age.

Table X

Reference table for age estimation using first degree polynomial regression of mean transparent length on intact roots (IT, TM)

Type of tooth	Number of teeth	Constant term B_0	Regression coefficient B	Standard deviation S_A	Correlation coefficient r
Upper right central incisor	32	20.34	5.74	10.42	0.80
Upper left central incisor	29	26.78	4.96	9.58	0.82
Upper right lateral incisor	31	22.06	5.36	10.73	0.83
Upper left lateral incisor	26	25.57	4.38	9.81	0.82
Upper right cuspid	33	28.13	4.01	12.39	0.67
Upper left cuspid	32	27.59	3.65	13.60	0.64
Upper first premolars	25	18.42	5.40	11.41	0.78
Upper right second premol.	23	25.33	4.28	10.96	0.82
Upper left second premol.	28	26.92	3.37	9.32	0.80
Lower right central incisor	50	29.00	4.23	11.85	0.70
Lower left central incisor	60	37.56	2.94	12.84	0.55
Lower right lateral incisor	58	38.81	2.81	12.43	0.60
Lower left lateral incisor	56	33.65	3.53	11.12	0.73
Lower right cuspid	57	37.80	3.50	11.24	0.68
Lower left cuspid	50	41.50	2.84	10.74	0.69
Lower right first premol.	37	30.83	4.05	9.73	0.80
Lower left first premol.	37	34.97	3.74	10.14	0.73
Lower right second premol.	33	30.68	3.76	12.82	0.73
Lower left second premol.	35	20.87	4.79	11.38	0.82
Upper 6 molars root no. 1	38	30.56	3.00	10.08	0.83
Lower 6 molars root no. 1	29	30.32	3.66	11.04	0.79
Upper 6 molars root no. 2	27	29.49	3.32	11.09	0.77
Lower 6 molars root no. 2	47	31.46	3.77	10.89	0.74
Upper 6 molars root no. 3	105	26.81	4.07	9.98	0.82

Root no. 1 = mesial root
Root no. 2 = distal root
Root no. 3 = palatinal root

The 62 root-filled teeth exhibited considerable variance in the extent of root transparency. This material was considered too small and heterogenous for statisctical evaluation but it was noteworthy that many of these non-vital teeth from adult persons showed no sign of transparency of the roots (Fig. 17), the dentin appearing very dense and opaque.

The 14 impacted teeth also seemed to vary somewhat in the degree of root transparency but, except for one tooth from a 34 year old person, they all showed marked transparency of the root dentin (Fig. 18).

Table XI

Reference table for age estimation using first degree polynomial regression of mean transparent length on longitudinal root sections (SS, TM)

Type of tooth	Number of teeth	Constant term B_0	Regression coefficient B	Standard deviation S_A	Corelation coefficient r
Upper right central incisor	32	22.36	5.39	11.25	0.76
Upper left central incisor	29	30.18	4.30	10.93	0.76
Upper right lateral incisor	31	25.55	5.23	11.20	0.82
Upper left lateral incisor	26	25.90	4.39	9.24	0.84
Upper right cuspid	33	28.01	4.23	13.12	0.61
Upper left cuspid	32	29.41	3.32	13.70	0.63
Upper first premolars	25	28.44	3.81	12.93	0.71
Upper right second premol.	23	24.75	4.81	10.43	0.83
Upper left second premol.	28	26.21	4.03	7.62	0.87
Lower right central incisor	50	31.78	4.19	12.09	0.69
Lower left central incisor	60	37.89	3.08	12.31	0.60
Lower right lateral incisor	58	38.49	3.03	12.42	0.60
Lower left lateral incisor	56	35.19	3.49	11.46	0.71
Lower right cuspid	57	40.32	3.05	11.77	0.64
Lower left cuspid	50	42.07	2.73	10.88	0.68
Lower right first premol.	37	33.10	3.66	11.08	0.73
Lower left first premol.	37	32.79	4.11	8.71	0.81
Lower right second premol.	33	27.46	4.17	11.23	0.80
Lower left second premol.	35	25.60	4.41	10.77	0.84
Upper 6 molars root no. 1	38	30.03	3.48	7.11	0.92
Lower 6 molars root no. 1	29	35.27	2.78	15.74	0.47
Upper 6 molars root no. 2	27	26.89	3.55	10.92	0.77
Lower 6 molars root no. 2	47	30.31	4.22	11.00	0.74
Upper 6 molars root no. 3	105	25.83	3.95	10.16	0.81

Root no. 1 = mesial root
Root no. 2 = distal root
Root no. 3 = palatinal root

Table XII

Showing the confidence intervals for real age at different significance levels)*

Significance level	Lower limit	Real age	Upper limit
Ca. 35 %	$A-0.45 \cdot S_A$	age	$A+0.45 \cdot S_A$
Ca. 65 %	$A-S_A$	age	$A+S_A$
Ca. 95 %	$A-2.S_A$	age	$A+2S_A$

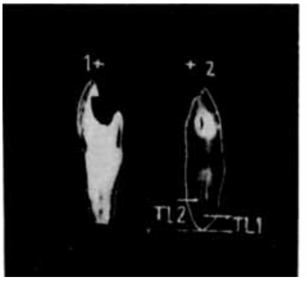
*) i.e. if estimated age = A and standard deviation = S_A, there is a 35, 65 or 95% probability that the real age of the person will be within the ranges $A \pm 0.45 \cdot S_A$, $A \pm S_A$ or $A \pm 2S_A$, respectively.

Table XIII

Showing the results of estimating age on a new material consisting of 168 teeth from 24 persons by means of the method outlined in the text (IT, TM, Equation 1)

Case no.	Number of teeth	Real age (years)	Estimated age (years)	Difference from real age	Standard deviation S_A	Level of significance 35 %	65 %	95 %
965	8	26.0	23.2	— 2.8	9.4	±4.2	± 9.4	±18.8
880	5	29.0	28.0	— 1.0	9.3	±4.2	± 9.3	±18.6
878	14	32.9	29.0	— 3.9	9.3	±4.2	± 9.3	±18.6
874	7	33.5	34.6	+ 1.1	9.3	±4.2	± 9.3	±18.6
977	11	34.0	35.6	+ 1.6	9.4	±4.2	± 9.4	±18.8
971	8	43.0	50.2	+ 7.2	10.1	±4.5	±10.1	±20.2
887	10	43.8	42.9	— 0.9	9.4	±4.2	± 9.2	±18.8
976	10	45.0	43.4	— 1.6	9.8	±4.4	± 9.8	±19.6
980	4	47.0	45.4	— 1.6	9.6	±4.3	± 9.6	±19.2
972	7	50.0	47.3	— 2.7	9.4	±4.2	± 9.4	±18.8
869	3	53.1	53.4	+ 0.3	9.6	±4.3	± 9.6	±19.2
871	6	53.1	59.8	+ 6.7	10.5	±4.7	±10.5	±21.0
979	7	57.0	54.6	— 2.4	9.4	±4.2	± 9.4	±18.8
875	5	57.4	64.2	+ 6.8	9.6	±4.3	± 9.6	±19.2
961	3	62.0	64.8	+ 2.8	9.7	±4.4	± 9.7	±19.4
877	9	65.6	59.8	— 5.8	9.4	±4.2	± 9.4	±18.8
873	8	65.8	51.0	—14.8	9.4	±4.2	± 9.4	±18.8
876	10	68.2	60.5	— 7.7	9.4	±4.2	± 9.4	±18.8
882	6	71.7	67.5	— 4.2	9.5	±4.2	± 9.5	±19.0
870	2	75.7	73.2	— 2.5	9.5	±4.3	± 9.5	±19.0
883	8	75.8	55.8	—20.0	9.4	±4.2	± 9.4	±18.8
872	6	84.7	65.7	—19.0	9.5	±4.3	± 9.5	±19.0
885	6	85.2	67.7	—17.5	9.4	±4.2	± 9.4	±18.8
884	5	85.9	65.5	—20.4	9.3	±4.2	± 9.3	±18.6

17



18

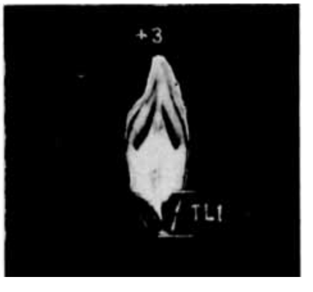


Fig. 17. Longitudinal sections of non-vital (root-filled) 1+ and vital +2 from a 42.1 year old female illustrating lack of root transparency in the non-vital tooth. Based on the tooth +2 with transparent length, TL1 = 2.0 mm, TL2=4.0 mm, TM = $\frac{2.0+4.0}{2}$ = 3.0 mm the estimated age = 39.5 years. (Table IX). (x1).

Fig. 18. Longitudinal section of impacted +3 from a 62.5 year old male illustrating a considerable extent of root transparency in a tooth that has never been in function. The mean transparent length, TM = TL1 = 6.0 mm. Estimated age = 50.8 years (Table IX). (x1).

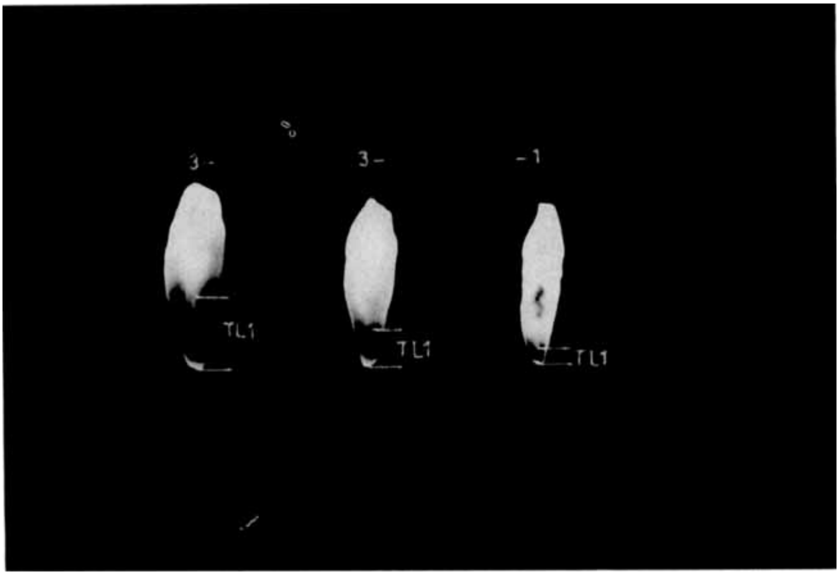


Fig. 19. Intact teeth, 3— , TLI=9.0 mm, 3—, TLI=4.5 mm, —1, TLI=1.5 mm, from a 71.1, a 53.1 and a 33.5 year old man, respectively, illustrating the possibility of measuring the length of transparent root dentin without sectioning the tooth.

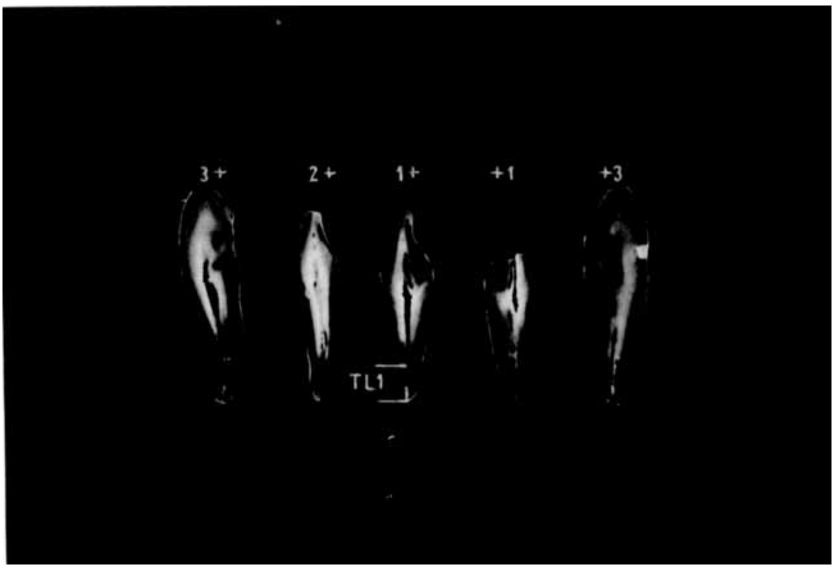


Fig. 20. Longitudinal sections of 3+, 2+, 1+, +1, +3, from a 28.0 year old male illustrating marked degree of root transparency in a young person, Case history 5, with a long standing circulatory deficiency. Estimated age utilizing 1+ only, TL=4.5 mm = 46.9 years. (Table IX). (x1).

CASE HISTORIES

1. Skeletal remains of a man found in a pile of stone in the northern part of Norway. Three teeth received for age determination.

Type of tooth	3—	—5	—8
IT TM (mm)	9.5	9.0	6.5
Estimated age (years)	72.1	64.2	57.9

Mean estimated age: 64.7 years.

This corresponded well to a 63 year old man who disappeared in that area 60 years previously.

2. Drowned man found floating in the harbor of Oslo, Norway. Five teeth received for age determination.

Type of tooth	4—	3—	—3	—4	—5
IT TM (mm)	8.5	6.5	6.0	7.5	8.5
Estimated age (years)	65.9	63.6	61.4	64.1	62.1

Mean estimated age: 63.4 years.

The man was later identified, his age being 69.7 years when he drowned.

3. Decomposed male body (suicide by hanging) found in a tree outside Bergen, Norway. Five teeth received for age determination.

Type of tooth	3+	+3	4—	3—	—3
IT TM (mm)	8.0	7.0	6.5	5.0	5.0
Estimated age (years)	60.5	57.3	59.4	56.8	57.2

Mean estimated age: 58.2 years.

The man was later identified, his age being 56.0 years at the time of death.

4. Twenty-eight year old male with marked transparency of the root dentin (Fig. 20), possibly due to a long standing circulatory deficiency also compromising the circulation in the pulp and periodontal membrane. During the last 6 years of life he had several severe respiratory tract infections, hemoptysis and dyspnea. He died from ventillatory failure and autopsy revealed bronchiectases, fibrosis of the lungs and hypertrophy of the right side of the heart.

DISCUSSION

The present material, close on 1000 teeth from 265 persons, is the largest reported to date forming a basis for an estimation of age, previous work usually comprising less than 100 teeth. Even so, it is realized that since there are many different teeth and the age of the individuals studied spans about 60 years (approximately 20—80 years) a larger material would have been preferable, especially from the lower and older age groups. Furthermore, the material included cases with several teeth obtained from one individual as well as cases with a single tooth from one person. Also, molars and some premolars contributed with two or three roots. Due respect has been paid to these facts when drawing conclusions from the results.

The method arrived at for determing age by means of measuring the extent of root transparency is comparatively simple and could easily be applied by others without previous extensive training or expensive equipment. This is especially true in the many cases where equally good results were obtained by measuring intact roots only, not necessarily, longitudinal sections.

The precision and reproducibility of the method were confirmed in the study of the error of the method.

For preservation it was necessary to keep the extracted teeth in a 10 % neutral formaldehyde solution. Possible decrease in the pH of the formaldehyde following prolonged storage with resultant decalcification of the root dentin or precipitation of protein in the dentinal tubules by the formaldehyde might have caused changes in the transparency of the root. No such effect could, however, be demonstrated. This is in keeping with the findings of *Azeroth* and *Ketterl* (1962). For practical purposes further studies should also be carried out to investigate a conceivable change in the extent of root transparency following exposure of teeth to heat, drying, burial in different types of soil, and to salt and fresh water.

Gustafson (1947) and *Nalbandian*, *Gonzales* and *Sognnaes* (1960) pointed out that the root transparency seemed to be less influenced by pathological processes than other age changes in teeth, while *Pilz* (1959) found that the pattern of extent of the root transparency was greatly influenced not only by the condition of the tooth-pulp but also by the vascular conditions in the periodontium. Inflammatory changes in the latter greatly enhanced the extent of transparency at the periphery of the root. According to *Bradford* (1960) the sclerosis of the dentin causing increased transparency begins in the narrowest tubules at the apex and periphery of the root. When this peripheral transparent zone for some reason is pronounced, especially in teeth from a young person (Fig. 5), it could easily lead to an overestimation of age. It is generally best, therefore, to disregard this zone and measure the extent of the transparency from the apex to a point approximately midway between the root-canal and the surface of the root. In many instances the proximal border-line is fairly distinct making objective measurements possible (Fig. 2). In some cases, as pointed out by *Miles* (1963), the junction is irregular and difficult to determine and the evaluation would be more or less subjective (Fig. 6). Compared with other methods, however, measuring the transparency alone seems to be by far the simplest, being at the same time a fairly objective method.

Gustafson (1947) noted that the root transparency could be seen already on extracted teeth. In the present material also it was interesting to find that in many cases good results could be obtained by measuring the transparency on intact roots only without having to destroy the teeth by sectioning, Fig. 19 and Tables VIII and IX, rendering a very expeditious age determination possible. Apparently, this potentiality has not been applied previously. Nevertheless, by making longitudinal sections the extent of root transparency could be studied in greater detail. Thus, cases that could not be evaluated on intact roots could usually be evaluated when sectioned.

Miles (1963) in his study on root transparency at various ages in longitudinal sections of 118 incisor teeth found a «loose straight-line relationship between age and transparency», $r = 0.73$, with 95 % confidence limits close to ± 22 years indicating a standard error on estimated age of about ± 11 years. This is in keeping with the present material viewed as a whole. For many of the teeth the correlation is, however, markedly improved when dividing the material in groups consisting of only corresponding roots from each subject and using second degree polynomes, Tables VIII and IX, the correlation index for many of the roots then being above 0.80.

Gustafson's method (1947, 1950) is based on a subjective evaluation of several criteria and it is therefore not directly comparable with the present method. When computing the standard error from the data given in Table V of *Gustafson*'s study (1950) on 41 teeth, however, we arrive at a value of 7.2 for the standard error on estimated age. This is twice the standard error of 3.6 presented by Gustafson as being the standard error on his own method. In our material there was a marked covariance between the length of root transparency in teeth from one person. It seems realistic to assume a similar covariance between the criteria referred to by *Gustafson* (1947, 1950). Therefore, the reduction in S_A by including several, n, teeth from one person in fact is much slighter than the reduction, $S_{An} = S_A/\sqrt{n}$, suggested by *Gustafson* (1950). Thus, the results of testing our method on a new material as well as the practical application of the method (case histories

1,2 and 3) seem to indicate that, contrary to the findings of *Johanson* (1966), root transparency could be used alone as a criterion of age and form the basis of a method for age determination.

In addition to the reservations made under *Statistical Methods* the underestimation of age evident for the older age groups could partly be due to a slowing down in the process of dentinal sclerosis in the coronal part of the root, and partly to the fact that in some cases most of the root dentin will be sclerosed at that age impeding further increase in the transparency. *Dechaume, Dérobert* and *Payen* (1960) utilizing the Gustafson method on 153 teeth from 91 persons also noted a tendency for underestimation of the real age in older adults.

The differences in results when using the absolute values, IT TM and SS TM, or the relative values, IT 100•TM/RL and SS 100•TM/RL, for root transparency were slight and do not indicate that the root transparency advances at a different rate in roots of varying sizes.

In other methods for age determinations including criteria like attrition, and secondary dentin and cementum apposition, it is possible that the fact that different teeth erupt with intervals of several years should be taken into consideration. Utilizing root transparency alone this point seems irrelevant since transparency starts after twenty years of age when all teeth, with the exception of the third molar, have been in function for many years. On the other hand, the finding of a well developed area of root transparency in impacted teeth (Fig. 15), clearly demonstrates that the transparency is not solely a results of the tooth being in function, as stated by *Azeroth* and *Ketterl* (1962), but it does suggest a relationship between the physiologic process of ageing and dentinal sclerosis.

Contrary to the statement of Gustafson (1966), transparency of the root dentin was also seen in teeth from the age group 20—29 years (Fig. 8), although usually the transparency below 30 years af age was slight or negligible, as observed by Pilz (1959). In a few cases, however, a marked transparency was seen in teeth from young persons (Fig. 20), Case history 4. In accordance with the findings of *Pilz* (1959) it is reasonable to assume that a long standing circulatory deficiency by compromising the circulation in the pulp and the periodontal membrane could enhance the sclerosis of the dentinal tubules in teeth from young persons.

The results indicated a slight difference in the linear regression coefficients between contralateral teeth, the root transparency probably increasing somewhat faster in teeth from the right side of the jaws. Similarly, teeth in the upper jaw seemed to exhibit a more rapid extension of the root transparency than teeth in the lower jaw. It is tempting to postulate that this could be a result of difference in function or in local circulatory conditions or both. Although *Schweitzer* (1961) found that chewing often took place on one side only and an individual pattern of mastication was demonstrated by *Hedegård, Lundberg* and *Wictorin* (1967), there seems to be no conclusive data on whether man uses the teeth of the right side more extensively than those on the left.

In contrast to the findings of *Azeroth* and *Ketterl* (1962) many of the non-vital teeth in the present material differed from vital teeth regarding the optical appearance of the root dentin. Thus, several non-vital teeth from adult persons exhibited no sign of transparent root dentin while vital teeth from the same subjects showed changes consistent with their respective ages. The time lapses since endodontic treatment of the teeth in question are not known. It seems reasonable to assume that the teeth void of transparent root dentin were root-filled at an age where no appreciable dentinal sclerosis had appeared, leaving the root dentin permanently opaque.

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SUMMARY

A relatively simple and objective method for age determination in adult persons by means of measuring the length of root transparency on intact roots and/or on longitudinal sections of roots is presented.

The length of transparent root dentin was measured from the apex in coronal direction on 1013 teeth comprising 132 roots. The precision and reproducibility of the method were confirmed in a study of the error of the method. A significant increase in root transparency with age was found.

It proved impossible to arrive at definite measurements of the length of transparency on 60 or 5.3 % of the intact roots and on 19 or 1.6 % of the longitudinal root sections. The present material contained relatively few molars and upper first premolars. For this reason, utilizing the suggested method for age determination when several teeth from one individual are available, one will probably arrive at the best estimation of age by excluding these types of teeth.

Contralateral teeth from the same individual showed a very high correlation in the extent of root transparency and there was also good over all conformity when studying many teeth from one individual.

There seemed to be no sex differences or differences between teeth from living and dead persons in the degree of root transparency.

Taking into account the age of the tooth from the time the roots are completed rather than the chronological age of the individual gave no better estimate of age when considering the material as a whole.

Testing the presented method on a new material consisting of 168 teeth from 24 persons revealed that, up to about 75 years, age could be determined with good accuracy. Fourteen out of 24 cases, 58.3 %, came within the theoretical 35 % confidence interval, ranging from ± 4.2 to ± 4.7 years. Nineteen or 79.2 % fell within the theoretical 65 % confidence interval corresponding to ± S_A ranging from 9.2 to 10.5. In older people, however, there seemed to be a tendency to underestimate age. The practical application of the method is illustrated by case histories.

Storing the teeth in a 10 % neutral formaldehyde solution for prolonged periods caused no significant changes in the transparency of the root.

Sixty-two non-vital teeth studied separately exhibited considerable variance in the extent of root transparency but it was noteworthy that many of these teeth showed no sign of transparent root dentin.

The degree of root transparency also seemed to vary somewhat in 14 impacted teeth collected from adult persons. Except for one tooth, however, they all showed a well developed area of transparency corresponding to the age of the subject in question and demonstrating a close relationship between the physiologic process of ageing and dentinal sclerosis.

RÉSUMÉ

DÉTERMINATION DE L'AGE CHEZ L'HOMME À L'AIDE DE LA TRANSPARENCE DE LA DENTINE RADICULAIRE

Les auteurs présentent une méthode relativement simple et objective pour déterminer l'âge de personnes adultes en mesurant la longueur de la zone transparente de la dentine des racines entières et/ou des coupes longitudinales de celles-ci.

La longueur de la dentine radiculaire transparente a été mesurée en partant de l'apex vers la couronne sur 1013 dents comprenant 1132 racines. La précision de la méthode et son aptitude à donner des résultats reproductibles ont été confirmées par une étude de l'erreur liée à la méthode. Une augmentation significative de la transparence radiculaire avec l'âge a été mise en évidence.

Il n'a pas été possible de mesurer exactement la longueur de la zone transparente de 60 (soit 5,3 %) des racines entières, et de 19 (soit 1,6 %) des coupes

longitudinales des racines. Le matériel considéré comportait un nombre relativement restreint de molaires et de premières prémolaires supérieures. C'est pourquoi, si on utilise la méthode proposée pour déterminer l'âge d'individus pour lesquels on a le choix entre plusieurs dents, on obtiendra de toute vraisemblance les meilleurs résultats en éliminant ces catégories de dents.

L'étendue de la zone transparente des racines des dents contro-latérales d'un même individu présentait une très forte corrélation, et il existait aussi en général une bonne conformité lorsqu'on étudiait un grand nombre de dents d'un même individu.

Il ne semblait pas exister de différences dans la transparence radiculaire entre les deux sexes, ni entre les dents provenant de vivants ou de morts.

En considérant le matériel dans son ensemble, les résultats n'étaient pas meilleurs lorsque l'évaluation de l'âge de la dent était faite en tenant compte du moment ou la formation des racines était achevée plutôt que de l'âge chronologique de l'individu.

Un essai de la méthode présentée ici sur une nouvelle série de 168 dents appartenant à 24 individus a révélé que la détermination de l'âge offrait une précision satisfaisante jusqu'à l'âge de 75 ans. Quatorze des 24 cas, (soit 58,3 %) se rangeaient dans l'*intervalle de confiance théorique* de 35 %, variant entre $\pm 4{,}2$ et $\pm 4{,}7$ ans.

Dix-neuf des cas, (soit 43,2 %) se rangeaient dans l'*intervalle de confiance théorique* de 65 %, correspondant à une $\pm S_A$ allant de 9,2 à 10,5 ans. Neanmoins, il semble exister une tendance à sous-estimer l'âge des individus âgés. L'application pratique de la méthode est illustrée par des cas individuels.

La conservation des dents dans une solution de formaldéhyde neutre à 10 %, même pendant des périodes prolongées, ne provoque pas de changements significatifs dans la transparence des racines.

Dans 62 dents dévitalisées étudiées séparément, il y avait de très grandes variations dans l'étendue de la transparence radiculaire, mais il convient de noter que beaucoup de ces dents ne présentaient aucune transparence de la dentine radiculaire.

Le degré de transparence radiculaire présentait aussi quelques variations dans 14 dents incluses provenant d'individus adultes. Cependant, à l'exception d'une des dents, on constatait sur toutes une zone de transparence bien développée, correspondant à l'âge du sujet en question, et démontrant ainsi une relation étroite entre le processus physiologique du vieillissement et la sclérose de la dentine.

ZUSAMMENFASSUNG

DIE ALTERSBESTIMMUNG DER MENSCHEN MIT HILFE VON DEM TRANSPARENZPHÄNOMEN DES DENTINS

Eine verhältnismässig einfache und objektive Methode zur Altersbestimmung erwachsener Personen vermittels Messungen des Zahnwurseltransparenz in nichtgeschnittene und in längsgeschnittene Wurzeln wird vorgelegt.

Die Länge der Transparenz wurde, von der Wurzelspitze aus, an 1013 Zähne mit insgesamt 1132 Wurzeln gemessen.

Die Genauigkeit und die Reproduzierbarkeit der Methode wurden in einer Studie der Fehlerquellen bestätigt. Es ergab sich eine deutliche Vermehrung der Transparenz mit dem Alter. Eine definitive Messung der Transparenzlänge war nicht möglich in 60 (5.3 %) der nicht geschnittene Wurzeln, auch nicht in 19 (1.6 %) der Längsschliffe. Unser Material umfasste verhältnismässig wenige Molaren und obere Erste Prämolaren. Bei Benützung der Methode zwecks Altersbestimmung verwendet man daher am besten nicht die genannten Zähne, soweit andere vorhanden sind.

Konterlaterale Zähne einer und derselben Person zeigten eine sehr hohe übereinstimmung in der Verbreitung der Wurzeltransparenz, aber es war auch eine deutliche Konformität wenn mehrere Zähne von demselben Person studiert wurden.

Transparenzunterschiede zwischen den Geschlecter, sowie zwischen Lebenden und Toten, wurden nicht gefunden.

Auf das ganze Material bezogen, ergab die Benützung der Zahnalter, vom Zeitpunkt der fertig gebildeten Wurzel gerechnet, keine bessere Resultate als die Verwendung des kronologischen Alters des Individiums.

Die erwähnte Methode, geprüft an einem neuen Material (168 Zähne von 24 Personen) zeigte gute Resultate bis zu einem Alter von 75 Jahren. Vierzehn von 24 Fällen, 58.3 %, kamen binnen «der theoretischen 35 % Grenze», zwischen ± 4.2 und ± 4.7 Jahren variierend. Neunzehn (79.2 %) kamen binnen «der theoretischen 65 % Grenze», einer $\pm$ S_A varianz zwischen 9.2 und 10.5 entsprechend. In älteren Leuten dagegen, scheint es eine Tendenz den Alter zu gering zu schätzen. Die praktische Anwändung der Methode ist mit einigen Beispielen verdeutlicht.

Zähne, die während längerer Zeit in einer 10 % neutralen Formaldehydlösung aufbewahrt wurden, zeigten keine statistisch signifikante Veränderungen der Wurzeltransparenz.

Das separate Studium von 62 nicht-vitalen Zähnen ergab einen grossen Unterschied in der Ausbreitung der Wurzeltransparenz, auch erschien es

bemerkungswehrt dass viele von diesen Zähnen keine Transparenz des Wurzeldentins zeigten.

Die Verbreitung der Wurzeltransparenz in 14 retinierten Zähnen, von erwachsene Personen gesammelt, schien auch etwas zu variieren. Mit der Ausnahme eines Zahnes, zeigten sie alle eine Transparenz dem Alter des betreffenden Individuums entsprechend; dies dürfte als eine Abhängigkeit zwischen dem physiologischen Verälterungsprozess und der dentinalen Sklerose bemessen werden.

REFERENCES

Azeroth E. & W. Ketterl, 1962: Untersuchungen über die an Zahnschliffen zu beobactende optische Inhomogenität des menschlichen Dentin. Dtsch. Zahnärztebl. *XVI:* 352—362.

Bang G., 1962: Et individs alder bestemt på tenner og tannforhold. Norske Tannlægefor. Tid. *72;* 352—359.

Bradford E. W., 1960: The dentine, a barrier to caries. Brit.dent. J. *109:* 387—398.

Dechaume M., L. Dérobert & J. Payen, 1960: De la valeur de la détermination de l'age par l'examen des dents en coupes minces. Ann. Mèd. lèg. *40:* 165—167.

Gustafson G., 1966: Forensic Odontology. American Elsevier Publishing Comp., Inc., New York.

» 1947: Åldersbestämningar på tänder. Odont. T. *55:* 556—568.

» 1950: Age determinations on teeth. J. Amer. dent. Ass. *41:* 45—54.

Hedegård B., M. Lundberg & L. Wictorin, 1967: Masticatory function — a cineradiographic investigation. Acta odont. scand. *25:* 331—353.

Johanson G. 1966: In Gustafson, G.: Forensic Odontology. American Elsevier Publishing Comp., Inc., New York p. 139.

Johnson C. C., 1968: Transparent dentine in age estimation. Oral Surg. *25:* 834—838.

Kendall M. G. & W. R. Buckland, 1960: A dictionary of statistical terms. Edinburgh, England.

Miles A. E. W., 1963: Dentition in the Estimation of Age. J. dent. Res. *42:* 255—263.

Nalbandian J., F. Gonzales & R. F. Sognnaes, 1960: Sclerotic Age Changes in Root Dentin of Human Teeth as Observed by Optical, Electron and X-Ray Microscopy. J. dent. Res. *39:*598—607.

Pedersen P. O. & S. Keiser-Nielsen, 1961: Retsodontologi. Tandlægebladet *65;* 585—644.

Pilz W., 1959: Das Transparenzphänomen der Zahnwurzel als ein Ausdruck der Biomorphose des menschlichen Dentins. Z. Alternsforsch. *13:* 139—152.

Saunders M., 1965: Dental factors in age determination. Med. Sci. Law, *5:* 34—37.

Schweitzer J. M., 1961: Masticatory function in man. J. prosth. Dent. *11:* 625—647.

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