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Age estimation of adults from dental radiographs

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Abstract

Previous studies have shown that with advancing age the size of the dental pulp cavity is reduced as a result of secondary dentine deposit, so that measurements of this reduction can be used as an indicator of age. The aim of the present study was to find a method which could be used to estimate the chronological age of an adult from measurements of the size of the pulp on full mouth dental radiographs. The material consisted of periapical radiographs from 100 dental patients who had attended the clinics of the Dental Faculty in Oslo. The radiographs of six types of teeth from each jaw were measured: maxillary central and lateral incisors and second premolars, and mandibular lateral incisors, canines and first premolars. To compensate for differences in magnification and angulation on the radiographs, the following ratios were calculated: pulp/root length, pulp/tooth length, tooth/root length and pulp/root width at three different levels. Statistical analyses showed that Pearson's correlation coefficient between age and the different ratios for each type of tooth was significant, except for the ratio between tooth and root length, which was, therefore, excluded from further analysis. Principal component analyses were performed on all ratios, followed by regression analyses with age as dependent variable and the principal components as independent variables. The principal component analyses showed that only the two first of them had significant influence on age, and a good and easily calculated approximation to the first component was found to be the mean of all the ratios. A good approximation to the second principal component was found to be the difference between the mean of two width ratios and the mean of two length ratios, and these approximations of the first and second principal components were chosen as predictors in regression analyses with age as the dependent variable. The coefficient of determination (r^2) for the estimation was strongest when the ratios of the six teeth were

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included ($r^2 = 0.76$) and weakest when measurements from the mandibular canines alone were included ($r^2 = 0.56$). Measurement on dental radiographs may be a non-invasive technique for estimating the age of adults, both living and dead, in forensic work and in archaeological studies, but the method ought to be tested on an independent sample.

Keywords: Age determination by teeth; Dental radiographs; Dental pulp; Secondary dentine

1. Introduction

Age estimation is one of several indicators employed to establish identity in forensic cases. Such estimations of living individuals are made for refugees or other persons who arrive in a country without acceptable identification papers and may require a verification of age, in order to be entitled to civil rights and/or social benefits in a modern society. In archaeological research estimation of age at death for skeletal remains has been a technique employed in describing the palaeodemography of populations [1].

Age estimations from teeth are frequently used, because teeth may be preserved long after all other tissues, even bone, have disintegrated, but unlike bone they can also be inspected directly in living individuals. The dental age estimation methods most frequently referred to require extraction, and some of them preparation of microscopic sections of at least one tooth [2,3,4]. These methods are time-consuming and expensive, and a destructive approach may not be acceptable for ethical, religious, cultural, or scientific reasons.

Among living humans dental age estimation has had to be based on clinical experience as well as evidence of attrition, darker colour or periodontal recession in extracted teeth [5,6,7]. All these three factors are strongly influenced by habits and pathological processes [8], and age estimations based on these factors are in many ways uncertain.

A study of radiographs of the teeth is a non-destructive, simple method to obtain information and is a technique used daily in most dental surgeries, but it is rarely employed in methods of age estimation. An attempt [9] has been made to estimate age from radiographs, using the criteria and scoring system devised by Gustafson [4]. Secondary dentine deposits have been regarded as a valuable age factor [10], and measurements of the pulp on radiographs from mandibular incisors have shown a significant difference in direct measurements between 10-year age groups [11]. Secondary dentine has also been measured indirectly on radiographs of extracted teeth; such measurements, together with direct measurements of a single tooth, were suggested for use in a non-destructive method to predict age [12]. So far we have not found any reports of age estimation methods based on measurements from radiographs of several teeth from the same dentition.

The purpose of the present investigation was to find a method for estimating the chronological age of adults without tooth extraction and destruction, by examining the relationship between age and the pulpal size on periapical dental radiographs.

2. Material and methods

Full mouth dental radiographs were collected from the records of the Department of Oral Radiology, Dental Faculty, University of Oslo. The radiographs were from 100 individuals, ranging from 20–87 years with a mean age of 42.6 years. The age and gender distribution of the material is shown in Table 1. The paralleling technique had been used to take the radiographs, employing the Eggen filmholder [13].

A preliminary study on radiographs from 20 individuals showed that measurements from mandibular lateral incisors, canines and first premolars and maxillary central and lateral incisors and second premolars were most strongly correlated with age, so these teeth were selected for the investigation. A paired *t*-test on these measurements showed that there were no significant differences between teeth from the left and the right side of the jaw. Consequently, in the present study teeth from either the left or the right side were chosen, whichever were best suited for measurement. Reliable measurements could not be made on teeth which were impacted, had vestibular radio-opaque fillings, crowns, pathological processes in the apical bone visible on the radiographs or had already been root-filled, or which had the mesio-distal plane of the tooth not parallel to the film, and only those cases where all measurements on the six selected teeth could be made, were selected in this study.

Not knowing the age and gender of the individual, the following measurements were carried out on the radiographs of all six types of teeth with a pair of vernier callipers: the maximum tooth length, the pulp length and root length on the mesial surface from the enamel-cementum junction (ECJ) to the root apex. A stereomicroscope with a measuring eyepiece to the nearest 0.1 mm was employed to measure the root and pulp width both at the ECJ (level A) and at the midroot level, i.e. halfway between the ECJ and the apex of the root (level C), as well as at the midpoint between the ECJ and midroot level (level B) (Fig. 1).

To test for reproducibility of the measurements, they were repeated on the radiographs from ten individuals by the first observer (KMK) and by a second observer (SIK).

Table 1
Age and gender distribution of the 100 individuals in the material

Age (years)	No. of females	No. of males	Total no.
20–29	17	16	33
30–39	4	8	12
40–49	12	7	19
50–59	9	9	18
60–69	8	4	12
70–87	6	0	6
Total	56	44	100

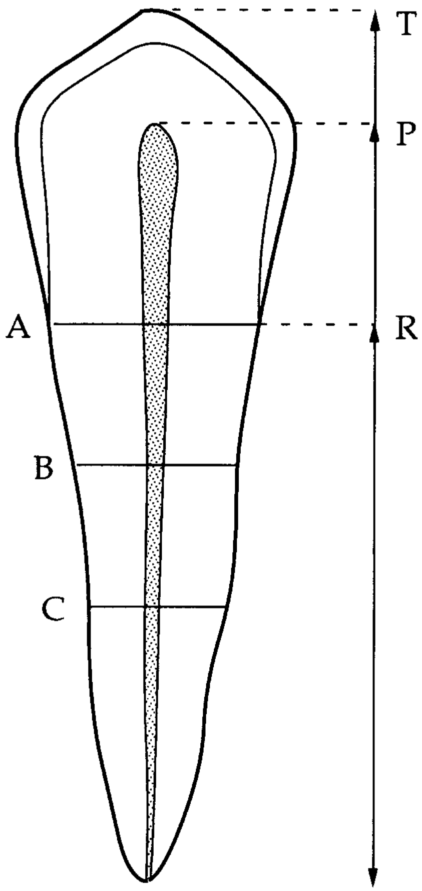

Fig. 1. Diagram showing the measurements made on the radiographs of each tooth. T, maximum tooth length; R, root length on the mesial surface; P, maximum pulp length; A, root and pulp width at enamel-cementum junction (ECJ); B, root and pulp width midway between measurement levels A and C; C, root and pulp width midway between apex and ECJ.

2.1. Statistical analyses

All measurements were entered into an IBM/AT computer and the statistical calculations carried out, using the SPSS/PC+ [14] and SAS [15] statistical programs. The gender of the patient and the age when the radiographs were taken were entered as additional information. The ratios between the tooth and pulp measurements were calculated and used in the analyses, in order to reduce the effect of a possible variation in the magnification and angulation of the radiographs. The following ratios were calculated: the tooth/root length, the pulp/root length, and the pulp/tooth length, as well as the pulp/root width at the three levels. The correlation coefficients were calculated between age and the ratios and the various mean values of the ratios. A paired *t*-test and the correlation coefficients were used to investigate intra- and inter-observer variations.

As more than one predictor is available from which to estimate age, more than one might be employed. Two questions then arise. Are there marked differences in the estimating power of the various predictors? To what extent is the accuracy of the age estimation improved by sequential addition of ratios from all six types of teeth? These two questions cannot be answered by comparing bivariate correlations. In order to find the 'best' subset of predictors, a combination of regression analyses and principal component analyses was used [15]. First, a principal component analysis of the predictors was performed and thereafter a regression analysis was made, employing age as the dependent variable and the principal components and gender as independent variables in the stepwise procedure, with inclusion level at $P < 0.05$ and exclusion level at $P > 0.06$ [16]. A prediction which included measurements of teeth from both jaws was calculated, as were also separate predictions restricted exclusively to either maxillary or mandibular teeth. Separate predictions were also calculated for each of the six types of teeth included in the study.

3. Results

The correlation coefficients between age and the calculated ratios and their mean values are shown in Table 2. The results indicated that the ratio between the length of tooth and root was only weakly or not significantly correlated with age and was excluded from further statistical calculations. All the other correlation coefficients

Table 2
Correlation coefficients between age and ratios of measurements from the dental radiographs and the mean of the ratios from each tooth, $n = 100$

Tooth	11/21	12/22	15/25	32/42	33/43	34/44
P	−0.77	−0.68	−0.54	−0.63	−0.59	−0.60
T	−0.28	−0.08(NS)	−0.09(NS)	−0.31	−0.12(NS)	−0.16
R	−0.63	−0.72	−0.56	−0.48	−0.63	−0.51
A	−0.68	−0.70	−0.70	−0.67	−0.68	−0.73
B	−0.62	−0.73	−0.56	−0.66	−0.56	−0.62
C	−0.58	−0.68	−0.55	−0.61	−0.53	−0.59
M	−0.83	−0.80	−0.75	−0.71	−0.75	−0.77
W	−0.66	−0.74	−0.60	−0.72	−0.61	−0.67
L	−0.76	−0.71	−0.60	−0.60	−0.63	−0.60
W-L	0.66	0.54	0.34	0.30	0.35	0.25

P, ratio between length of pulp and root; T, ratio between length of tooth and root; R, ratio between length of pulp and tooth; A, ratio between width of pulp and root at enamel-cementum junction (level A); B, ratio between width of pulp and root at midpoint between level C and A (level B); C, ratio between width of pulp and root at mid-root level (level C); M, mean value of all ratios (first predictor); W, mean value of width ratios from levels B and C; L, mean value of the length ratios P and R; W-L, difference between W and L (second predictor).

NS, no significance $P < 0.01$.

Table 3
The two first principal components for tooth 15/25[a]

	1st principal component	2nd principal component
P	0.43	0.51
R	0.42	0.51
A	0.50	−0.03
B	0.44	−0.51
C	0.42	−0.46

[a]These two components explain 80% of the variance.
See Table 2 for abbreviations.

between age and the ratios were negative and significant. There were no significant differences between the first and the repeated measurement by the first observer, nor when the measurements were made by a second observer.

The analyses of principal components showed that only the first two had coefficients significantly different from zero, and therefore the remaining components were disregarded. The first and second principal components for the second maxillary premolar are shown in Table 3. These two components were easily interpreted. The first one had positive signs on all coefficients, giving an overall measure of the size of the dental pulps. In addition, the weight given to each ratio was moderate, which indicated that a simple mean of all ratios could serve as a good and easily calculated approximation of the first principal component. This modified first component was therefore chosen as the first predictor for use in age estimations.

The second principal component was a little more complicated, but in most cases it assigned negative weight to the length ratios and positive weight to the width ratios, giving a measure of the shape of the dental pulp. The influence of the ratio from level A was somewhat variable and mostly negligible compared to the other four ratios; it could therefore be excluded. The numerical value of the other four ratios varied only moderately, indicating that the difference between the mean of the width ratios from levels B and C and that of the two length ratios could serve as a

Table 4
Correlation coefficients between age and the mean of ratios from teeth from both jaws (bimaxillary) and from the maxillary and the mandibular teeth separately ($n = 100$, $P < 0.001$)

Mean ratio/Jaw	Bimaxillary	Maxillary	Mandibular
M	−0.86	−0.85	−0.82
W	−0.82	−0.77	−0.80
L	−0.81	−0.80	−0.72
W-L	0.65	0.68	0.41

See Table 2 for abbreviations.

Table 5
Regression formulae for age in years based on dental radiographs from six teeth

	Equation	r^2	S.E.E. (years)
Six teeth from both jaws	Age = 129.8 – 316.4(M) – 66.8(W-L)	0.76	8.6
Three maxillary teeth	Age = 120.0 – 256.6(M) – 45.3(W-L)	0.74	8.9
Three mandibular teeth	Age = 135.3 – 356.8(M) – 82.5(W-L)	0.71	9.4
Single teeth			
11/21	Age = 110.2 – 201.4(M) – 31.3(W-L)	0.70	9.5
12/22	Age = 103.5 – 216.6(M) – 46.6(W-L)	0.67	10.0
15/25	Age = 125.3 – 288.5(M) – 46.3(W-L)	0.60	11.0
34/44	Age = 133.0 – 318.3(M) – 65.0(W-L)	0.64	10.5
33/43	Age = 158.8 – 255.7(M)	0.56	11.5
32/42	Age = 106.6 – 251.7(M) – 61.2(W-L) – 6.0(G)	0.57	11.5

r^2, coefficient of determination. S.E.E., standard error of the estimate in years.
See Table 2 for abbreviations.
G, gender: male = 1, female = 0.

good approximation to the second principal component. This modified second principal component was, therefore, chosen as the second predictor in age estimations. The two chosen predictors were included as variables in all the regression analyses.

The correlation between age and the mean of all the ratios for each type of tooth was stronger than the correlation between age and each ratio separately (Table 2). The correlation between the mean of the ratios from all six types of teeth and from maxillary and mandibular teeth separately is shown in Table 4. The correlation between age and the mean of the ratios from several teeth was stronger than that from single teeth.

The regression analyses with age as the dependent variable and the two predictors and gender as independent variables are shown in Table 5. Separate formulae are given for teeth from both jaws and from maxilla and mandible separately, as well as for single teeth. The second predictor was not included in the prediction for mandibular canines ($P = 0.06$). The gender was only included in the formulae for the mandibular lateral incisors. The coefficient of determination (r^2) for the regression was strongest when the ratio from all six types of teeth from both jaws was employed. This coefficient decreased when teeth from only one jaw were included and was weakest when only mandibular canines were measured.

4. Discussion

Examination of dental radiographs of fully developed teeth is rarely advocated for use in age estimation. It is, however, a simple, non-destructive method which can be employed both on living individuals and on the unknown dead, either in identification cases or in archaeological investigations.

The radiographs included in this study were of patients visiting the clinics of the Dental Faculty in Oslo. It was assumed that they represented a 'normal population', but it is possible that the lower socio-economic groups were over-represented because of the comparative inexpensiveness of treatment given by students. A large number of patients was not included because of missing teeth or heavily restored teeth; this applied especially to the age-group 30–39 years. Few patients from this age-group had attended the dental faculty clinics for treatment, and those few needed extensive dental treatment and were not suitable for this study. It was also difficult in the older age-groups to find patients who retained all the six teeth which were measured in this study, and it remains questionable whether older patients with small or no fillings in the six teeth are fully representative of their age-group today.

The medical history of the patients included was not taken into account, since this was not a study of biological age changes but an attempt to find an expression of pulpal changes in a normal population. It has been maintained that, to use the pulp complex as a biomarker for generalized ageing, two conditions have to be met [17]:
(1) the teeth must be in normal functional occlusion,
(2) the teeth must be free from any manifestation of pathological insults, such as dental caries, attrition, abrasion, erosion or trauma and from the effect of any dental restorations.

The second demand was not met in this survey. Physiological defence mechanisms are known to influence the pulpal morphology [17], as do also long-term corticosteroid therapy and certain systemic diseases [11], but individuals with such conditions might be found in most adult populations. The inclusion of teeth from such patients means that the predictions arrived at, while applicable to a normal population, may not give a correct expression of the biological ageing process.

The teeth were selected by the criterion that teeth from both jaws should be included. They would preferably have included molars as well, but the preliminary study clearly demonstrated that accurate measurements of multi-rooted teeth were difficult to perform, and for the same reason maxillary first premolars, which frequently have two roots, were likewise excluded. In the preliminary study, measurements from the maxillary canine demonstrated the lowest correlation coefficients with age, which is consistent with the results found when measurements were made on radiographs of extracted teeth [12]. The mandibular second premolars were frequently found to have been lost early in life, possibly as a result of orthodontic treatment. In the small preliminary sample, significant differences between the ratios from the left and right mandibular central incisors were observed. For these reasons all these three types of teeth were not included.

Full mouth dental radiographs were employed in this study. This meant that several measurements from one individual could be included, but because the teeth were still in the jawbone, additional complicating factors were encountered. The bone overshadowed the apical third of the tooth, so that the width from this area of the tooth could not be measured with sufficient accuracy. Rotated teeth were excluded, but as the curved arch of the jaws is projected on to a flat film, there will always be a certain amount of distortion when measuring the image presented there. This applies especially to the lateral incisors when the standard projections for full mouth dental radiographs are employed.

The ratios between the pulp and the root have also been used in a previous study of age estimation from tooth measurements [12]. As the size of the pulp is reduced with age, the correlation coefficient between age and the ratios is negative, whereas, the inverse ratio would give a positive correlation coefficient. But, because zero, which is the measurement of an obliterated pulp, cannot be used as a denominator, the pulp/root ratio has been chosen.

The present investigation found that the correlation between age and the ratio of tooth to root length was insignificant for all types of teeth, indicating that attrition on the occlusal surface was so weak that it could not be related to age. An explanation might be that now the whole length of the tooth was measured and not only that of the crown which has been shown previously to be more strongly correlated to age [16]. Other studies of contemporary populations have found that attrition was significantly but weakly correlated to age [18,19].

The correlation coefficients between age and the ratio between the pulp and root length were compatible with the results obtained for measurements on radiographs of extracted teeth, except for maxillary lateral and central incisors, and the correlation between the pulp and root width was likewise compatible, except for maxillary central incisors at the ECJ and mandibular lateral incisors and canines at mid-root level [12]. For these ratios the correlation coefficient was much lower in the study on the extracted teeth, and it is possible that pathological processes before extraction might have influenced formation of secondary dentine. In the present study, all teeth with visible periapical pathological processes were excluded, and it is likely that the teeth from the full mouth radiographs are more representative for the teeth of a normal population than those extracted in dental surgeries.

Other studies [12,20,21] on pulpal morphology have shown that the width of the pulp is a better indicator of age than the length. The present study, where the width ratio for all teeth, except the maxillary central incisors, is found to have a stronger correlation with age than the length ratio, confirms this. Moreover, it has found that both length and width measurements have significant influence on age estimations, since the coefficient of determination (r^2) increased when the length ratios were included. An even stronger correlation with age was found by employing the mean value of all the ratios, which may be an expression of the overall size of the pulp.

The principal component analysis showed that the ratio at level A had only negligible influence on the second principal component, and it was, therefore, excluded in the second predictor. The regression analyses showed that this factor was included as significant ($P < 0.05$) in all the predictions except for the mandibular canines. It is difficult to see why the ratio at level A should be excluded, but it might be that the intercorrelation between the ratio from level A and those from levels B and C was too strong. The gender was included as a factor for the mandibular lateral incisors, and since it was negative, this result indicates that the pulpal changes occur faster in males than in females.

The coefficient of determination (r^2) was strongest when all ratios from the six teeth were included in the mean, and weakest when only the mean values of the ratios from one tooth were included. This implies that the more extensive the information obtained from an individual, the greater will be the chances of arriving at the correct age estimate. Likewise, the larger the number of observations which may be included, the smaller is the weight of each measurement. Small inaccuracies in the measurements may occur if there is a slight rotation of the tooth relative to the film or if the outlines on the film are difficult to distinguish because of superimposition on the tooth. Such small inaccuracies would induce greater error in the age estimation if the prediction was based on single, rather than on the mean of several measurements.

In age estimation studies, only dental attrition has been examined in more than one tooth from the same individual [20], but as attrition is related to diet, habits and culture [22,23], the methods presented have little application except for the population from which the measurements were collected. The measurements in the present study were made on a Norwegian population, where it is likely that secondary dentine formation does not deviate much from that of other Caucasian populations.

Differentiation between physiological secondary dentine and reparative dentine [24] cannot be made on radiographs. The method presented gives a description of the contemporary population and may have to be modified in populations with less caries and fewer dental fillings. It is, however, felt that the method, here presented, may with care be applied to other racial groups, pending the provision of predictors for such groups. Radiographs of archaeological dental material have been employed in previous studies on the size of the pulp in relation to age [25,26]. The formula, here presented, may also be used on such material, since a study of both modern and ancient material [25] and another of contemporary teeth [18] showed only a weak correlation between attrition and secondary dentine formation. Severe attrition, which is invariably found in ancient dentitions, has little influence on either the length or the width measurements of the pulp [25]. The amount of reparative dentine formation found in the ancient material may be comparable with the reparative dentine formed as a result of small carious lesions and fillings in the present material.

The formulae, here presented, for estimating chronological age in adult teeth ought to be tested on another independent sample and preferably by independent observers. It would then be interesting to find out if the prediction based on all teeth in this study could also be applied to estimate the age of adults with mean values from any number of teeth. The predictions could also be tested on panoramic radiographs (OPG).

References

[1] S. Hillson, Teeth and age. In *Teeth*, Cambridge University Press, Cambridge, 1986, pp. 176–230.

[2] G. Gustafson, Age determinations on teeth. *J. Am. Dent. Assoc.*, 41 (1950) 45–54.

[3] G. Johanson, Age determinations from human teeth. Thesis. *Odontol. Rev.*, 22, Suppl. 21 (1971) 1–126.

[4] G. Bang and E. Ramm, Determination of age in humans from root dentin transparency. *Acta Odontol. Scand.*, 28 (1970) 3–35.

[5] T. Solheim, Dental color as an indicator of age. *Gerodontics*, 4 (1988) 114–118.

[6] T. Solheim, Dental attrition as an indicator of age. *Gerodontics*, 4 (1988) 299–304.

[7] T. Solheim, Recession of periodontal ligament as an indicator of age. *J. Forensic Odontostomatol.*, 10 (1992) 32–43.

[8] W.G. Shafer, K.H. Maynard and B.M. Levy, *A Textbook of Oral Pathology*, 4th edn., W.B. Saunders Company, Philadelphia, 1983, chapters 10, 15.

[9] G. Matsikidis and P. Schultz, Altersbestimmung nach dem Gebiss mit Hilfe des Zahnfilms. *Zahnartl. Mitt.*, 72 (1982) 2524, 2527–2528.

[10] W.R. Maples, An improved technique using dental histology for estimation of adult age. *J. Forensic Sci.*, 23 (1978) 764–770.

[11] D.R. Morse, J.V. Esposito and R.S. Schoor, A radiographic study of aging changes of the dental pulp and dentin in normal teeth. *Quintessence Int.*, 24 (1993) 329–333.

[12] S. Kvaal and T. Solheim, A non-destructive method for age estimation. *J. Forensic Odentostomatol.*, 12 (1994) 6–11.

[13] S. Eggen, Simplification of radiographic technique. *Quintessence Int.*, 6 (1973) 69–71.

[14] M.J. Norusis, *SPSS/PC+ for the IBM PC/XT/AT*, SPSS Inc., Chicago, IL, 1986.

[15] SAS Institute Inc. *SAS/Stat User's Guide, Version 6, 4th edn., Vol. 2.* SAS Institute Inc., Cary, NC, 1989, pp. 1196–1210.

[16] R.F Gunst and R.L. Mason, Principal component regression (Chapter 10.1). In *Regression Analysis and its Application*, Marcel Dekker Inc., New York, 1980, pp. 317–329.

[17] D.R. Morse, Age-related changes of the dental pulp complex and their relationship to systemic aging. *Oral Surg. Oral Med. Oral Pathol.*, 72 (1991) 721–745.

[18] T. Solheim, A new method for dental age estimation in adults. *Forensic Sci. Int.*, 59 (1993) 137–147.

[19] A. Santini, M. Land and G.M. Raab, The accuracy of simple ordinal scoring of tooth attrition in age assessment. *Forensic Sci. Int.*, 48 (1990) 175–185.

[20] T. Kambe, K. Yonemitsu, K. Kibayashi and S. Tsunenari, Application of a computer assisted image analyzer to the assessment of area and number of sites of dental attrition and its use in age estimation. *Forensic Sci. Int.*, 50 (1991) 97–109.

[21] S. Prapanpoch, S.B. Dove and J.A. Cottone, Morphometric analysis of the dental pulp chamber as a method of age determination in humans. *Am. J. Forensic Med. Pathol.*, 13 (1992) 50–55.

[22] S. Molnar, Human tooth wear, tooth function and cultural variability. *Am. J. Phys. Anthropol.*, 34 (1971) 175–189.

[23] S. Molnar, Tooth wear and culture: A survey of tooth functions among some prehistoric populations. *Curr. Anthropol.*, 13 (1972) 511–526.

[24] J.K. Avery, Dentin. In S.N. Bhaskar (ed.), *Orban's Oral Histology and Embryology*, C.V. Mosby, Year Book Inc., St Louis, MO, 1991, pp. 106–138.

[25] G.G. Philippas, Influence of occlusal wear and age on formation of dentin and size of pulp chamber. *J. Dent. Res.*, 40 (1961) 1186–1198.

[26] S.I.Kvaal, B.F. Sellevold and T. Solheim, T. A comparison of different non-destructive methods of age estimation in skeletal material. *Int. J. Osteoarchaeol.*, 4 (1994) 363–370.