AGE ESTIMATION IN ARCHAEOLOGICAL SKELETAL REMAINS: EVALUATION OF FOUR NON-DESTRUCTIVE AGE CALCULATION METHODS.

M. Vodanović,[a] J. Dumančić,[a] I. Galić,[b] I. Savić Pavičin,[a] M. Petrovečki,[b] R. Cameriere,[c] H. Brkić.[a]

[a] *Department of Dental Anthropology, School of Dental Medicine, University of Zagreb, Croatia*
[b] *Medical School, University of Zagreb, Zagreb, Croatia*
[c] *Instituto di Medicina Legale, Universita di Macerata, Italy*

ABSTRACT

Estimation of age at death is an essential part of reconstructing information from skeletal material. The aim of the investigation was to reconstruct the chronological age of an archaeological sample from Croatia using cranial skeletal remains as well as to make an evaluation of the methods used for age estimation. For this purpose, four age calculation methods were used: palatal suture closure, occlusal tooth wear, tooth root translucency and pulp/tooth area ratio. Cramer's V test was used to test the association between the age calculation methods. Cramer's V test showed high association (0.677) between age determination results using palatal suture closure and occlusal tooth wear, and low association (0.177) between age determination results using palatal suture closure and pulp/tooth area ratio. Simple methods like palatal suture closure can provide data about age at death for large number of individuals, but with less accuracy. More complex methods which require qualified and trained personnel can provide data about age for a smaller number of individuals, but with more accuracy. Using different (both simple and complex) age calculation methods in archaeological samples can raise the level of confidence and percentage of success in determining age.

(J Forensic Odontostomatol 2011;29:2:14-21)

Keywords: Archaeology; paleodontology; palatal suture closure; occlusal tooth wear; tooth root translucency; pulp/tooth area ratio; age estimation; Croatia.

Running title: Age estimation in archaeological skeletal remains.

INTRODUCTION

There are three main elements in the procedure of anthropological investigation and the identification of exhumed human remains: race determination, sex determination and age determination at the time of death. The most difficult one to determine is the age. Age estimation is a sub-discipline of the forensic sciences and should be an important part of every identification process, especially when information relating to the deceased is unavailable.[1] There are forensic[2, 3] and archaeological reasons for age determination of human skeletal remains.[4] Age estimation is of broader importance in forensic medicine, not only for identification purposes of the deceased, but also in connection with crimes and accidents.[1] According to the growing interest in vital statistics of past populations and palaeodemography (for example: age-group composition, sex ratios and the reasons for mortality in a community), procedures of sexing and ageing of skeletal remains are considered as a very important part of bioarchaeological investigations.[5]

Dental and bone material from each exhumed body or parts of the body are helpful in the age estimation process. There is more or less interdependence between time and many natural changes of the human body which can be used for determination of age at death. Patterns of aging are detected on both macroscopic (direct observation and radiological examination) and microscopic levels.[6, 7] The ageing of human remains is based upon a detailed knowledge of biological changes that occur during development, growth and maturation.[8] The exact chronology of these changes is dependent upon physiological variations in any one individual.[9] Skulls and teeth can provide a lot of information about

age at death and that is the reason why there are many age determination methods based on cranial and dental features. Techniques for chronological age estimation in children based on dental maturity may be divided into those using the atlas approach[10-12] and those using scoring systems.[13,14] Once the development of crowns and roots is completed and the teeth are in functional occlusion, age determination using dental findings becomes more difficult. After the age of about 24 years dental estimates depend upon subtle changes in the teeth which are dependent not only upon increasing age but also upon the effects of wear.[9] Age determination methods applicable in adults could be divided into morphological[15-17] and radiological techniques.[14,18-20] Although there are many methods available, only methods based on non-destructive examination of the sample are recommended to use in bioarchaeological investigations. Therefore the methods for age estimation most often used by anthropologists and bioarchaeologists are macroscopic.

Given that skeletal remains coming from archaeological series are very often poorly preserved and fragmentary and demand careful handling to prevent further damage, age determination can be particularly complex. Assessments of age based on skeletal remains are most likely to be fairly accurate with immature or young adult individuals. Remains of older persons present more of a problem, and when dealing with earlier populations, it is difficult to be sure that significant age-changes took place at the same time, and that they showed the same group variability, as in modern populations.[7] For this reason it is best to combine several methods in order to raise the level of confidence and the percentage of success in determining age.

The aim of this investigation was to reconstruct the chronological age of the archaeological sample from Croatia using cranial skeletal remains as well as to make an evaluation of four non-destructive age estimation methods applicable in bioarchaeological investigations.

MATERIALS AND METHODS

The research was carried out on a total of 192 skulls from excavations of the crypt at St. Theresa's Cathedral in Požega in Croatia. The exhumation of the remains was done in 2004. The skeletal remains were dated from 18th and 19th centuries. The age and sex of the skulls at the time of death was unknown. During the investigation the skulls were stored in the Department of Dental Anthropology, School of Dental Medicine University of Zagreb.

For the purpose of this investigation, four age calculation methods were used: palatal suture closure, occlusal tooth wear, tooth root translucency and pulp/tooth area ratio. Suture closure and tooth wear were chosen because they are simple methods with a long tradition of usage for age estimation purposes. Tooth root translucency and pulp/tooth area ratio are more complex and more time consuming methods but probably giving more reliable results. All of these methods are non-invasive methods and this is very important in the examination of ancient bones and teeth.

The median palatine suture was examined on each skull in order to determine the amount of obliteration. Obliteration was defined as any portion of a suture no longer visible. If the obliteration of the suture was completed (Fig. 1), it was considered that the person at the time of death was older than 35 years. If the suture was open or partially open (Fig. 2), it was considered that the person was younger than 35 years at the time of death.

Age estimation by occlusal tooth wear was done according to Lovejoy`s method.[21] All teeth present in both jaws were used for this examination.

Single-rooted teeth with minimal or no caries, mostly upper canines, were used for age determination using tooth root translucency. A sliding calliper was used to measure the length of translucent dentine. The age was calculated according to Bang and Ramm.[17]

Radiographic images of upper canines were used for age determination using pulp/tooth area ratio according to Cameriere et al.[22] Twenty points from each tooth outline and ten points for each pulp outline were identified and used to evaluate tooth and pulp areas (Figure 3).

Examinations of palatal suture closure, occlusal tooth wear and tooth root translucency were carried out by one observer (MV) and age determination using pulp/tooth area ratio was performed by another observer (RC).

Cramer's V test was used to test the strength of association between the age calculation methods in a contingency table. The closer V is to 0, the smaller the association between the variables. On the other hand, V being close to 1 is an indication of a strong association between variables. Statistical analysis was performed with Statistica 5.0 statistical program.

RESULTS

Out of the total of 192 skulls, males presented 50.5% (97 skulls), females 41.7% (80 skulls) and children presented 7.8% (15 skulls with mixed or deciduous dentition). Skulls with mixed or deciduous dentitions were excluded from further investigation.

Age estimation using palatal suture closure was possible on 148 individuals (83.6%). More than a half (51.4%) of the population was younger than 35 years at the time of death.

Using occlusal tooth wear age could be determined on 113 individuals (63.8%), Table 1. An average age at death was 31.4 years. The majority of the sample (46.0%) was between 31 and 40 years at the time of death.

Age estimation using root dentine translucency was performed on 77 individuals (43.5%), Table 2. An average, age at death was 51.0 years. Almost all the individuals in the sample (94.8%) were older than 40 years.

Age estimation using pulp/tooth area ratio was performed on 88 individuals (49.7%), Table 3. An average age at death was 48.0 years. The majority of the sample (72.8%) was older than 40 years.

Cramer's V test showed high association (V = 0.677) between age determination results using palatal suture closure and occlusal tooth wear. This suggests that from the biological point of view these two processes are closely linked; palatal suture closure takes place simultaneously and almost in the same correlation to the chronological age as occlusal tooth wear. Association between age determination results using occlusal tooth wear and pulp/tooth area ratio was V = 0.241. There was low association (V = 0.177) between age determination results using palatal suture closure and pulp/tooth area ratio. According to the results of Cramer's V test the biological relationship between occlusal tooth wear and pulp/tooth area ratio and between palatal suture closure and pulp/tooth area ratio is not obvious. Although all of these processes are correlated to the chronological age, there are no reciprocal links between them as was found between palatal suture closure and occlusal tooth wear. Calculation of the association between age determination results using root dentine translucency and other age estimation methods could not be calculated because there was no root dentine translucency found on individuals younger than 35 years.

On a repeated random sample, performed after three weeks, identical findings were observed, so kappa value was 1, confirming intra- and inter-examiner reliability.

DISCUSSION

This research used four non-destructive age calculation methods based on four different tissues: bone, dental enamel, dentine and pulp. This provides a wide spectrum of information about age changes in a human body. Such approach is common in recent populations, but quite rare in archaeological investigations because it is time-consuming and expensive, additionally highly trained personnel are necessary.

Degree of obliteration of cranial sutures can be used to estimate the actual age of a person at death.[23] At birth, the secondary palate is composed of right and left maxilla and the right and left palatine, joined by broad sutures. With increasing age, the gaps visible between suture edges decrease, fuse and ultimately obliterate. Mann et al.[24] showed that obliteration of these sutures could be used as an estimator of biological age. They found that

suture closure and age are correlated, but they concluded that this method can be used to sort commingled skeletons and corroborate age estimates based on other ageing techniques.[24] A problem with this method can appear if the cranial remains are fragmented and poorly preserved. This was the reason why 16.4% of skeletal remains examined in this investigation could not be involved in this age calculation method. Sutures may also be of help in determining the number of individuals represented by a series of skull fragments. For example, if we compare a fragment showing a part of the suture nearly completely obliterated, with another displaying the suture completely open, it may usually be concluded that more than one person is represented.[7]

Tooth wear may be defined as the wearing away of tooth substance during mastication by the rubbing of one tooth surface against another, together with the abrasive effect of any hard material present in the food. Most normal teeth show some degree of tooth wear, but this is less marked in recent civilized groups than in ancient and modern primitive populations.[7] Tooth wear has been frequently used as a tool of age estimation.[25] Lovejoy`s method[21] used in this study is a simple, not time-consuming method based on comparison of a degree of a tooth wear. This method is not population specific and this must be taken into consideration during the age estimation of different populations particularly in archaeological investigations. Dental attrition can provide a population-specific means of age estimation; but archaeologically relevant reference samples, that is, samples of skeletons of known age and sex coming from a population with the same way of living as any given archaeological sample of skeletons, are virtually nonexistent. Therefore, age estimation of ancient individuals from dental attrition is difficult.[26]

The increase in size of the apical zone of sclerotic dentine in human teeth has been used in forensic science as a method of age assessment, either as one of several regressive changes related to age, or as the sole variable since the finding that the increase in apical translucency was the factor most closely linked to age.[27] Measuring the length of translucency in millimetres provides accuracy and a high degree of objectivity.[17] The most reliable way to measure the dentine translucency is to measure on sections of the teeth. This is impossible if a unique archaeological sample is examined where the preparation of sections of the teeth is not allowed. When a section of a tooth is made, the tooth is permanently destroyed and cannot be used for other investigations - in this case the only way to study the dentinal translucency is the use of strong light and intact teeth. Sengupta et al.[28] studied difficulties in estimating age using root dentine translucency in human teeth of varying antiquity and found that the majority of the archaeological sample was affected by a morphological change creating a "chalky'" appearance to the dentine. Removal of the obviously affected teeth did not improve the correlation coefficients to any useful degree.[28] "Chalky" dentine appeared under the light microscope to be composed of large fenestrations, islands of mineralized tissue and masses of filiform structures that appeared to be following the path of the dentinal tubules in their invasion of the peripheral dentine. Whittaker and Bakri[29] studied racial variations in the extent of tooth root translucency and concluded that factors other than age may be important in the formation of sclerotic apical dentine in teeth of different racial origin. The effect of racial origin should be considered when using sclerosis as a means of age determination in forensic cases.[29]

Pulp/tooth area ratio as an indicator of age is quite a new age estimation method presented by Cameriere.[22] This method requires a radiographic image of an examined tooth, computer-aided drafting software and trained personnel. In extensive archaeological investigations where age estimation is only one of many parameters which must be determined, there is often no time, money and knowledge to perform such age assessments. This method, which is for a beginner time-consuming, is recommended in individual cases where a reliable and accurate age assessment is necessary both for living and deceased persons.[22] We used this method in our investigation in order to test the reliability and accuracy of the other three methods which are easier to perform and less time-consuming.

Cameriere at al[30] tested the reliability in age determination by pulp/tooth ratio in upper canines in historical samples of known age and found that the pulp/tooth ratio method is not only a useful technique to assess the chronological age of living persons, but it is also a reliable tool in the determination of age at death in skeletal remains.[30]

It should be noted that in the age estimation the term "accuracy of an age estimation method" is the degree of closeness of the estimated age to the true (chronological) age. The term "precision of an age estimation method" is the degree to which repeated age estimations under unchanged conditions show the same results. Our specimens were of unknown age, therefore, there is no 'gold standard' against which the 'accuracy' of the methods can be gauged.

CONCLUSION

Using four adult age calculation methods in our investigation, age determination was possible in 100% of individuals, but with different levels of accuracy. The more methods used promised a higher level of accuracy. Number of used age estimation methods was dependent of the state of preservation of the skeletal remains.

Simple methods like palatal suture closure can provide data about age at death for large number of individuals, but with less accuracy. More complex methods which require qualified and trained personnel can provide data about age for a smaller number of individuals, but with more accuracy. Using different (both simple and complex) age calculation methods for archaeological samples can raise the level of confidence and percentage of success in determining age.

ACKNOWLEDGEMENT

This research was supported by the Ministry of Science, Education and Sports of the Republic of Croatia - grant No. 065-0650445-0423.

REFERENCES

1. Willems G. A review of the most commonly used dental age estimation techniques. *J Forensic Odontostomatol*. 2001;19:9-17.
2. Schmeling A, Olze A, Reisinger W, Geserick G. Forensic age diagnostics of living people undergoing criminal proceedings. *Forensic Sci Int*. 2004 Sep 10;144(2-3):243-5.
3. Galic I, Vodanovic M, Cameriere R, Nakas E, Galic E, Selimovic E, et al. Accuracy of Cameriere, Haavikko, and Willems radiographic methods on age estimation on Bosnian-Herzegovian children age groups 6-13. *Int J Legal Med*. 2011 Mar;125(2):315-21.
4. Vodanovic M, Brkic H, Slaus M, Demo Z. The frequency and distribution of caries in the mediaeval population of Bijelo Brdo in Croatia (10th-11th century). *Arch Oral Biol*. 2005 Jul;50(7):669-80.
5. Duric M, Rakocevic Z, Rankovic N. [Age assessment at the time of death based on panoramic radiography]. *Vojnosanit Pregl*. 2005 Jul-Aug;62(7-8):557-64.
6. Iscan MY, Kennedy KAR. *Reconstruction of life from the skeleton*. New York: Alan R. Liss, Inc. 1989.
7. Brothwell DR. *Digging up bones: the excavation, treatment and study of human skeletal remains*. 3rd ed. ed. London: British Museum (Natural History): Oxford University Press 1981.
8. Spalding KL, Buchholz BA, Bergman LE, Druid H, Frisen J. Forensics: age written in teeth by nuclear tests. *Nature*. 2005 Sep 15;437(7057):333-4.
9. Whittaker DK, MacDonald DG. *A colour atlas of forensic dentistry*. Ipswich: Wolfe 1989.
10. Schour I, Massler M. Studies in tooth development: The growth pattern of human teeth. *J Am Dent Assoc*. 1940;27:1918-31.
11. Moorrees CF, Fanning EA, Hunt EE, Jr. Age variation of formation stages for ten permanent teeth. *J Dent Res*. 1963 Nov-Dec;42:1490-502.
12. Anderson DL, Thompson GW, Popovich F. Age of attainment of mineralization stages of the permanent dentition. *J Forensic Sci*. 1976 Jan;21(1):191-200.
13. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. *Hum Biol*. 1973 May;45(2):211-27.
14. Haavikko K. Tooth formation age estimated on a few selected teeth. A simple

method for clinical use. *Proc Finn Dent Soc*. 1974 Feb;70(1):15-9.
15. Solheim T. A new method for dental age estimation in adults. *Forensic Sci Int*. 1993 May;59(2):137-47.
16. Gustafson G. Age determination on teeth. *J Am Dent Assoc*. 1950 Jul;41(1):45-54.
17. Bang G, Ramm E. Determination of age in humans from root dentin transparency. *Acta Odontol Scand*. 1970 Mar;28(1):3-35.
18. Kvaal SI, Kolltveit KM, Thomsen IO, Solheim T. Age estimation of adults from dental radiographs. *Forensic Sci Int*. 1995 Jul 28;74(3):175-85.
19. Vandevoort FM, Bergmans L, Van Cleynenbreugel J, Bielen DJ, Lambrechts P, Wevers M, et al. Age calculation using X-ray microfocus computed tomographical scanning of teeth: a pilot study. *J Forensic Sci*. 2004 Jul;49(4):787-90.
20. Kvaal SI, During EM. A dental study comparing age estimations of the human remains from the Swedish warship Vasa. *Int J Osteoarchaeol*. 1999;9(3):170-81.
21. Lovejoy CO. Dental wear in the Libben population: its functional pattern and role in the determination of adult skeletal age at death. *Am J Phys Anthropol*. 1985 Sep;68(1):47-56.
22. Cameriere R, Ferrante L, Belcastro MG, Bonfiglioli B, Rastelli E, Cingolani M. Age estimation by pulp/tooth ratio in canines by peri-apical X-rays. *J Forensic Sci*. 2007 Jan;52(1):166-70.
23. Sahni D, Jit I, Neelam, Sanjeev. Time of closure of cranial sutures in northwest Indian adults. *Forensic Sci Int*. 2005 Mar 10;148(2-3):199-205.
24. Mann RW, Jantz RL, Bass WM, Willey PS. Maxillary suture obliteration: a visual method for estimating skeletal age. *J Forensic Sci*. 1991 May;36(3):781-91.
25. Kim YK, Kho HS, Lee KH. Age estimation by occlusal tooth wear. *J Forensic Sci*. 2000 Mar;45(2):303-9.
26. Boldsen JL. Analysis of dental attrition and mortality in the Medieval village of Tirup, Denmark. *Am J Phys Anthropol*. 2005 Feb;126(2):169-76.
27. Ermenc B. Metamorphosis of root dentine and age. *Int J Osteoarchaeol*. 1997;7(3):230-4.
28. Sengupta A, Whittaker DK, Shellis RP. Difficulties in estimating age using root dentine translucency in human teeth of varying antiquity. *Arch Oral Biol*. 1999 Nov;44(11):889-99.
29. Whittaker DK, Bakri MM. Racial variations in the extent of tooth root translucency in ageing individuals. *Arch Oral Biol*. 1996 Jan;41(1):15-9.
30. Cameriere R, Brogi G, Ferrante L, Mirtella D, Vultaggio C, Cingolani M, et al. Reliability in age determination by pulp/tooth ratio in upper canines in skeletal remains. *J Forensic Sci*. 2006 Jul;51(4):861-4.

Address for correspondence:
Marin Vodanović
School of Dental Medicine
University of Zagreb
Department of Dental Anthropology,
Gundulićeva 5, HR-10000 Zagreb, Croatia
Telephone: +385 1 4899 214
Fax: +385 1 48 02 159
E-mail: vodanovic@sfzg.hr

TABLES and FIGURES

Table 1. *Age groups distribution according to occlusal tooth wear*

Age group (years)	N	%
<24	30	26.5
24 – 30	16	14.2
31 – 35	26	23.0
36 – 40	26	23.0
>40	15	13.3
Total	113	100.0

N = number of individuals

Table 2. *Age groups distribution according to root dentine translucency*

Age group (years)	N	%
<24	0	0.0
24 – 30	0	0.0
31 – 35	0	0.0
36 – 40	4	5.2
>40	73	94.8
Total	77	100.0

N = number of individuals

Table 3. *Age groups distribution according to pulp/tooth area ratio*

Age group (years)	N	%
<24	2	2.3
24 – 30	4	4.5
31 – 35	9	10.2
36 – 40	9	10.2
>40	64	72.8
Total	88	100.0

N = number of individuals

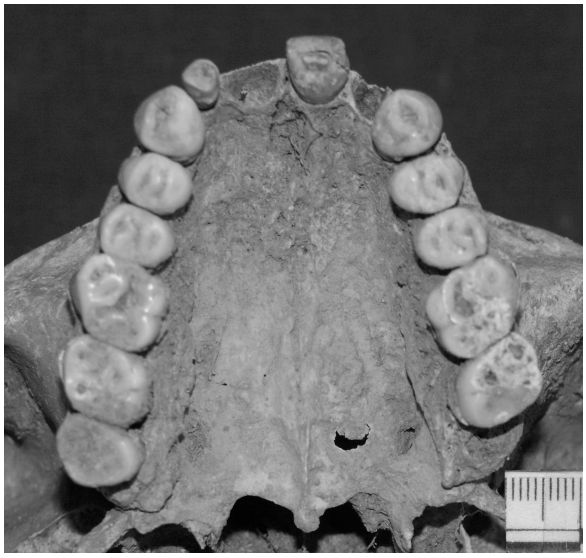

Fig.1. *Obliterated median palatine suture*

Fig. 2. *Open median palatine suture*

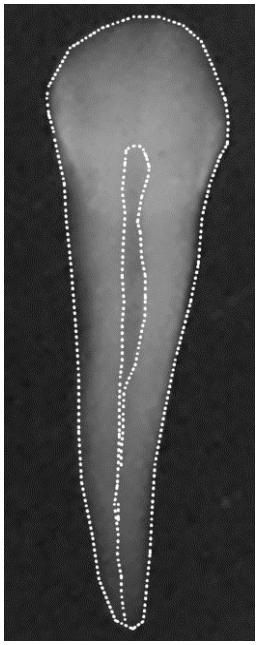

Fig. 3. *Age estimation using pulp/tooth area ratio (dotted lines on the radiograph indicate the outlines of upper canine and its pulp)*