J Forensic Sci, May 2008, Vol. 53, No. 3
doi: 10.1111/j.1556-4029.2008.00699.x
Available online at: www.blackwell-synergy.com

Douglas H. Ubelaker,[1] *Ph.D. and Roberto C. Parra,*[2] *B.A.*

Application of Three Dental Methods of Adult Age Estimation from Intact Single Rooted Teeth to a Peruvian Sample

ABSTRACT: Methods of estimating adult age at death from such dental features as root translucency, root length, and the extent of periodontosis in intact single rooted teeth have proven useful in studies of modern individuals, especially in estimating age in older adults. Questions remain however, concerning the impact of regional and population variation on accuracy. To examine this issue, three approaches to age estimation were applied to a diverse sample of 100 individuals from Peru. Mean errors of estimation for all three approaches were similar to those originally reported, suggesting minimal impact of population variation of the features measured. A new regression equation, specifically for Peruvian samples, is provided.

KEYWORDS: forensic science, skeletal age at death, adults, teeth, root transparency, Lamendin, Peru

In 1992, Lamendin et al. (1) published a technique for estimating age at death in human adults using two dental criteria, the extent of root translucency and periodontosis height (PH) on the labial surfaces of intact single rooted teeth. In this approach, root translucency is measured from the apex of the root using a strong backlight. The extent of periodontosis is measured from the cemento-enamel junction. Both variables are expressed in relation to total root length. In their French samples of teeth from individuals of known age at death, the technique produced a mean error of about 10 years in the study sample and about 8.4 years in a control sample derived from forensic cases. This technique has received considerable attention because of its simplicity, accuracy (especially in older adults), and the fact that it does not require histological sections (observations are made from intact teeth).

In a separate test of the Lamendin et al. technique on another French autopsy sample of individuals of known age at death (2), the method produced more accurate estimates than the other individual techniques employed such as estimating age from sternal rib ends (3–7), the pubic symphysis (8), and long bone cortical histology (9–11). The study suggested that experience with the technique was a minimal factor in accuracy in contrast to more complex techniques such as those utilizing cortical histology.

Although the procedure appears to be useful for estimating age at death in modern autopsy samples, it may have limited application to those from other contexts in which diagenesis may be a factor. When the technique was applied to two historic 18th and 19th century samples from London, the mean error increased substantially (12).

As with most methodology aimed at estimating age at death, a major concern with this technique involves the impact of population variation. To what extent can this method developed from a relatively homogeneous French sample be applied to forensic cases originating from other regions and populations? In a partial response to this question, in 2002, Prince and Ubelaker (13) applied the technique to the Terry Collection, curated at the Smithsonian Institution in Washington, D.C. They found that in spite of the differences between the French and American samples, the mean error was actually slightly lower in the application to the latter and could be further reduced with consideration given to sex and ancestry.

The Lamendin technique and its modifications have attracted considerable scientific attention for the reasons discussed above. However, the two variables in the technique, root transparency, and the extent of periodontosis previously have been considered in numerous other studies. In fact, these two variables were among the six features of Gustafson's (14) classic 1950 study assessing age at death from dental sections. The key study by Bang and Ramm (15) involving assessment of dental age changes from both intact teeth and dental sections included root transparency. The Bang and Ramm study focused on a very large sample of 450 extracted teeth from 201 patients and 476 teeth from 64 individuals removed at autopsy.

In 1975, Vlĉek and Mrklas (16) modified the original Gustafson procedure to consider applications to samples from archeological contexts. They excluded both of the variables of the Lamendin technique in this modification arguing that periodontosis and root transparency could not be observed accurately in such material. In contrast, in a forensic oriented study, Maples (17) introduced multiple regression analysis and reduced the number of variables used by Gustafson but included root transparency in the modified approach.

In 1989, Solheim (18) studied age changes in a sample of 1000 teeth and found a high correlation of dental root transparency with age at death and suggested that the variable was not affected by periodontal destruction. In the same year, Lorentsen and Solheim (19) suggested that root transparency was caused by mineral deposition within the dentinal tubules and that a sex difference existed in the rate of such deposition. Drusini et al. (20) revealed that the accuracy of assessing root transparency was about the same for simple caliper measurement versus more complex computerized densitometric approaches. Sengupta et al. (21) found that sectioning of teeth of considerable antiquity could be enhanced with first infiltrating and embedding them in methyl methacrylate and that in

[1]Department of Anthropology, Smithsonian Institution, NMNH, MRC 112, Washington, DC 20560-0112.
[2]Departamento de Antropología, Instituto de Medicina Legal del Perú, Av. Abancay 491, 6to Piso, Lima-01, Peru.

Received 17 May 2007; and in revised form 14 Sept. 2007; accepted 14 Oct. 2007.

assessing root dentine translucency, the mandibular canine was the tooth of choice. Soomer et al. later (22) noted that sectioning of teeth improved accuracy.

In 1995, Lucy et al. (23) stressed the potential impact of diagenesis on root transparency with possible obliteration of sclerotic dentin. They also raised the key question of the impact of population variation on the accuracy of the Gustafson variables. The effect of diagenesis and postmortem interval on the accuracy of age estimates from root translucency were further addressed by Mandojana et al. (24), Kvaal and During (25), and Sengupta et al. (26). Sengupta et al. (26) examined root translucency in the 19th century Spitalfields sample in London. They noted that most of the dentition presented a "chalky" appearance which negatively impacted age assessment. Microscopic examination of the affected teeth revealed areas of mineralization and concentrations of "filiform structures" associated with the dentinal tubules. Kvaal and During (25) suggested that the taphonomic introduction of iron molecules in the dentine and pulp-canal could be a factor as well.

Intra-observer and inter-observer errors have been examined thoroughly with the variables of root length, periodontosis, and translucency and found to be minimal (1,13,27).

One of the key issues emerging from the literature discussed above is the impact of population variation on the Lamendin technique. The study on the Terry Collection (13) suggested that the impact may be minimal; however some population variation was noted within that study. The research reported here presents the application of the Lamendin technique, as well as the Bang and Ramm method for assessing root transparency in intact teeth to a diverse sample from Peru. This application further examines the impact of population variation in these variables because the composition of the Peruvian sample is dramatically different from those of the French and American samples tested previously.

Materials and Methods

Methodological approaches proposed by Bang and Ramm (15), Lamendin et al. (1), and Prince and Ubelaker (13) (formulae for white males and white females) were applied to a sample of 100 single rooted teeth (24 maxillary and 76 mandibular) extracted from 100 contemporary cadavers from 17 different regions of Peru (Table 1). These individuals consisted of 28 females ranging in age from 23 to 80 years and 72 males ranging in age from 21 to 87 years. Table 2 presents the age range by decade of both the male and female samples utilized in this study. The female mean age was 48.8 years with a standard deviation of 19.2 years. The male mean age was 47.3 years with a standard deviation of 15.8 years. The sample was compiled at the Medical Legal Institute in Lima, Peru and represented individuals of known age and sex. The 100 teeth utilized consisted of 21 mandibular right lateral incisors, seven maxillary right lateral incisors, 32 mandibular right central incisors, nine mandibular left lateral incisors, five mandibular right canines, nine maxillary left lateral incisors, three maxillary left central incisors, nine mandibular left central incisors, one maxillary right canine, three maxillary right central incisors, and one maxillary left canine.

Variables defined in the studies of Bang and Ramm (15), Lamendin et al. (1), and Prince and Ubelaker (13) were utilized and measured according to procedures defined in these studies. The variables of total root height (RH), PH, and root transparency height (RTH) were measured with the use of a digital caliper (values recorded in millimeters) and a light box to provide backlighting, facilitating evaluation of root transparency (Fig. 1). All

TABLE 1—*Area of origin within Peru of the male and female individuals in the sample.*

	Sex					
	Female		Male		Total	
Region	*n*	%	*n*	%	*n*	%
Amazonas	1	1	0	0	1	1
Apurimac	1	1	4	4	5	5
Arequipa	1	1	6	6	7	7
Ayacucho	3	3	13	13	16	16
Cusco	0	0	7	7	7	7
Huanuco	1	1	3	3	4	4
Ica	1	1	0	0	1	1
Iquitos	1	1	3	3	4	4
Junin	4	4	5	5	9	9
La Libertad	0	0	4	4	4	4
Lambayeque	1	1	0	0	1	1
Lima	12	12	16	16	28	28
Madre de	0	0	2	2	2	2
Piura	0	0	1	1	1	1
Puno	0	0	5	5	5	5
Tacna	1	1	3	3	4	4
Tumbes	1	1	0	0	1	1
Total	28	28	72	72	100	100

TABLE 2—*Age and sex distribution of individuals in the sample.*

	Sex					
	Female		Male		Total	
Age category (years)	*n*	%	*n*	%	*n*	%
20–29	6	6	10	10	16	16
30–39	6	6	14	14	20	20
40–49	2	2	22	22	24	24
50–59	6	6	11	11	17	17
≥60	8	8	15	15	23	23
Total	28	28	72	72	100	100

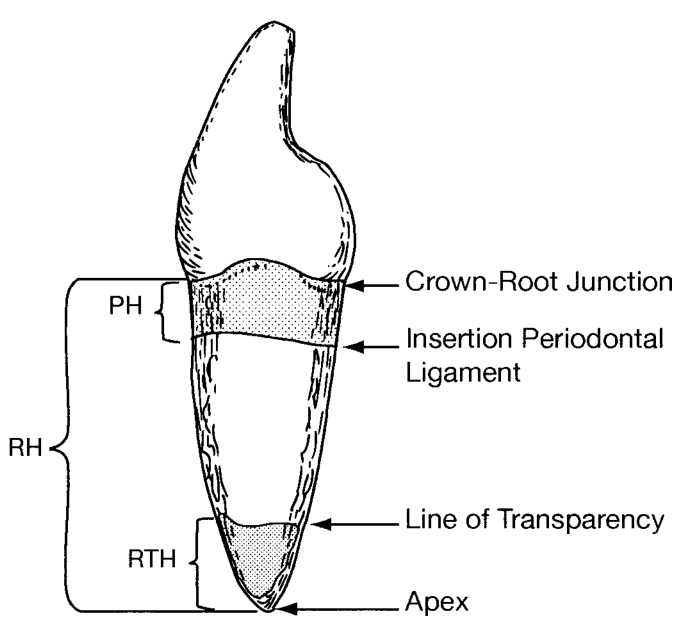

FIG. 1—*Dental features utilized to estimate age at death.*

data were analyzed using the statistical package SPSS, version 12. Two independent observers, both with considerable previous experience with the technique, collected data. All measurements and age calculations were conducted without knowledge of actual age at death.

Results

Table 3 presents the mean errors of age estimation with sexes reported separately when the three methods were applied to the Peruvian sample. The mean error refers to the difference between estimated age and actual age. Overall, all of the methods performed well with total mean errors of 8.3 years for Lamendin et al. (1), 7.6 years for Prince and Ubelaker (13), and 8.8 years for Bang and Ramm (15). These values compare favorably with those reported in the original publications of these studies and argue for minimal population variation in the variables addressed. In all three methods, ages were assessed slightly more accurately in males than females, although sample size could be a contributing factor.

Errors of estimation broken down by categories of age at death are presented in Table 4. These results reveal elevated levels of error in the application of all three methods in the oldest age category, 60 years and greater. The Lamendin et al. (1) and Prince and Ubelaker (13) methods were most accurate when applied to individuals in the 30–39 year age category. The Bang and Ramm (15) approach was most accurate for those between the ages of 50 and 59 years.

TABLE 3—*Analysis of male and female differences in mean error in the estimation of age at death using four methods.*

Method	Sex	*n*	Mean Error	SD
New Peruvian equation	Female	28	6.8352	6.31738
	Male	72	6.0767	5.85826
	Total	100	6.2891	5.96777
Bang and Ramm (15)	Female	28	8.9813	6.52483
	Male	72	8.6917	6.73634
	Total	100	8.7728	6.64621
Prince and Ubelaker (13)	Female	28	8.7468	6.50099
	Male	72	7.1908	6.57317
	Total	100	7.6265	6.55788
Lamendin et al. (1)	Female	28	9.4864	7.96957
	Male	72	7.8040	7.16600
	Total	100	8.2751	7.39772

TABLE 4—*Analysis of age variation of mean errors of age estimation using four methods.*

Method	Age (years)	*n*	Mean error	SD
New Peruvian equation	20–29	16	5.6680	3.72763
	30–39	20	3.8043	3.20709
	40–49	24	5.0469	3.74039
	50–59	17	4.0255	2.13491
	≥60	23	11.8510	8.94930
	Total	100	6.2891	5.96777
Bang and Ramm (15)	20–29	16	11.0609	7.61626
	30–39	20	8.5145	7.69664
	40–49	24	6.9417	5.54425
	50–59	17	5.2602	3.13591
	≥60	23	11.9127	6.43490
	Total	100	8.7728	6.64621
Prince and Ubelaker (13)	20–29	16	8.1524	3.75171
	30–39	20	3.9986	3.74662
	40–49	24	4.8339	2.98622
	50–59	17	4.5004	3.16944
	≥60	23	15.6400	7.73407
	Total	100	7.6265	6.55788
Lamendin et al. (1)	20–29	16	6.5819	2.96523
	30–39	20	3.3090	3.74427
	40–49	24	5.4520	3.20120
	50–59	17	6.8636	5.67600
	≥60	23	17.7603	8.07613
	Total	100	8.2751	7.39772

TABLE 5—*Correlation coefficients between the variables and actual age with TR representing root transparency.*

Variable	Observer	Tooth Surface	Correlation coefficient
Combined	1	Buccal	0.86
TR	1	Buccal	0.79
Combined	1	Lingual	0.85
TR	1	Lingual	0.76
Combined	2	Buccal	0.75
TR	2	Buccal	0.69
Combined	2	Lingual	0.76
TR	2	Lingual	0.68

Analyses of the correlation of age at death within the Peruvian sample with the variables of RH, translucency height and PH combined and translucency height presented independently for each of the two observers on the labial and lingual sides of the teeth are presented in Table 5. This analysis reveals relatively high correlation coefficients for all of the variables, but especially for the multiple regression of variables measured from the buccal side of the tooth by observer 1 (0.86). Comparison of the values in Table 5 suggests minimal differences between observers. The most accurate regression equation for the Peruvian sample is that generated from measurements taken by observer number 1.

The new Peruvian equation is as follows:

$$\text{Age} = 31.71 - 1.18\text{RH} + 5.81\text{PH} + 3.14\text{RTH}$$

All measurements are in millimeters (mm). In this equation, RH, PH, and RTH are measured on the buccal side of the tooth. This new formula was applied by observer number 1 to the same samples as those utilized in the application of the three methods from the published literature. The mean errors were 6.8352 with a standard deviation of 6.31738 when applied to the female sample, 6.0767 with a standard deviation of 5.85826 with the male sample, and 6.2891 with a standard deviation of 5.96777 for the combined sample. These errors are slightly lower than those generated from the three approaches from the published literature.

Oral hygiene, dental pathology, and cultural influences such as the chewing of coca leaves may impact the accuracy of these methods in estimating adult age at death. In particular, variance in oral hygiene logically would affect the extent of periodontosis. However, testing on diverse samples of the Lamendin approach, of which the extent of periodontosis is a major factor, has revealed generally similar degrees of error.

Conclusions

Of the three methods tested on the Peruvian sample, the Prince and Ubelaker study (13) based on the U.S. sample (Terry Collection) offered the most accurate results. This suggests that considering the dental features examined, the Peruvian sample has more in common with individuals in the Terry Collection than with the samples underlying the Lamendin (1) and Bang and Ramm (15) studies. As expected, an equation developed from the Peruvian sample itself produced the most accurate results and now represents the method of choice in applications to individuals from similar populations.

This study adds to the growing literature suggesting that population and regional differences have minimal impact on the accuracy of the Lamendin technique and root transparency considered independently. However, maximum accuracy is obtained with population specific formulae, such as that suggested above, and using aging methodology incorporating multiple variables.

Acknowledgments

The authors thank José Vela and Sandra Ibarra for their assistance in data collection, and Nawreen Kahn for her assistance with manuscript preparation.

References

1. Lamendin H, Baccino E, Humbert JF, Tavernier JC, Nossintchouk RM, Zerilli A. A simple technique for age estimation in adult corpses: the two criteria dental method. J Forensic Sci 1992;37:1373–9.
2. Baccino E, Ubelaker DH, Hayek LC, Zerilli A. Evaluation of seven methods of estimating age at death from mature human skeletal remains. J Forensic Sci 1999;44:931–6.
3. İşcan MY, Loth SR, Wright RK. Metamorphosis at the sternal rib end: a new method to estimate age at death in white males. Am J Phys Anthropol 1984;65:147–56.
4. İşcan MY, Loth SR, Wright RK. Age estimation from the rib by phase analysis: white males. J Forensic Sci 1984;29:1094–104.
5. İşcan MY, Loth SR, Wright RK. Age estimation from the rib by phase analysis: white females. J Forensic Sci 1985;30:853–63.
6. İşcan MY, Loth SR. Determination of age from the sternal rib in white males: a test of the phase method. J Forensic Sci 1986;31:122–32.
7. İşcan MY, Loth SR. Determination of age from the sternal rib in white females: a test of the phase method. J Forensic Sci 1986;31:990–9.
8. Brooks S, Suchey JM. Skeletal age determination based on the os pubis: a comparison of the Acsádi-Nemeskéri and Suchey- Brooks methods. Hum Evol 1990;5:227–38.
9. Kerley ER. The microscopic determination of age in human bone. Am J Phys Anthropol 1965;23:149–63.
10. Kerley ER, Ubelaker DH. Revisions in the microscopic method of estimating age at death in human cortical bone. Am J Phys Anthropol 1978;49:545–6.
11. Kerley ER. Estimation of skeletal age: after about age 30. In: Stewart TD, editor. Personal identification in mass disasters. Washington, DC: Smithsonian Institution, 1970;57–70.
12. Megyesi MS, Ubelaker DH, Sauer NJ. Test of the Lamendin aging method on two historic skeletal samples. Am J Phys Anthropol 2006;131:363–7.
13. Prince DA, Ubelaker DH. Application of Lamendin's adult dental aging technique to a diverse skeletal sample. J Forensic Sci 2002;47:107–16.
14. Gustafson G. Age determinations on teeth. J Am Dent Assoc 1950;41:45–54.
15. Bang G, Ramm E. Determination of age in humans from root dentin transparency. Acta Odontol Scand 1970;28:3–35.
16. Vlĉek E, Mrklas L. Modification of the Gustafson method of determination of age according to teeth on prehistorical and historical osteological material. Scripta Med 1975;48:203–8.
17. Maples WR. An improved technique using dental histology for estimation of adult age. J Forensic Sci 1978;23:764–70.
18. Solheim T. Dental root translucency as an indicator age. Scand J Dent Res 1989;97:189–97.
19. Lorentsen M, Solheim T. Age assessment based on translucent dentine. J Forensic Odontostomatol 1989;7:3–9.
20. Drusini A, Calliari I, Volpe A. Root dentine transparency: age determination of human teeth using computerized densitometric analysis. Am J Phys Anthropol 1991;85:25–30.
21. Sengupta A, Shellis RP, Whittaker DK. Measuring root dentine translucency in human teeth of varying antiquity. J Archaeol Sci 1998;25:1221–9.
22. Soomer H, Ranta H, Lincoln MJ, Penttilä A, Leibur E. Reliability and validity of eight dental age estimation methods for adults. J Forensic Sci 2003;48:149–52.
23. Lucy D, Pollard AM, Roberts CA. A comparison of three dental techniques for estimating age at death in humans. J Archaeol Sci 1995;22:417–28.
24. Mandojana JM, Martin-de las Heras S, Valenzuela A, Valenzuela M, Luna JD. Differences in morphological age-related dental changes depending on postmortem interval. J Forensic Sci 2001;46:889–92.
25. Kvaal SI, During EM. A dental study comparing age estimations of the human remains from the Swedish warship *Vasa*. Int J Osteoarchaeol 1999;9:170–81.
26. Sengupta A, Whittaker DK, Shellis RP. Difficulties in estimating age using root dentine translucency in human teeth of varying antiquity. Arch Oral Biol 1999;44:889–99.
27. Willems G, Moulin-Romsee C, Solheim T. Non-destructive dental-age calculation methods in adults: intra- and inter-observer effects. Forensic Sci Int 2002;126:221–6.

Additional information and reprint requests:
Douglas H. Ubelaker, Ph.D.
Department of Anthropology, NMNH, MRC 112
Smithsonian Institution
Washington, DC 20560
E-mail: ubelaked@si.edu