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TECHNICAL NOTE

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A Test of the Differential Accuracy of the Maxillary Versus the Mandibular Dentition in Age Estimations of Immature Skeletal Remains Based on Developing Tooth Length

ABSTRACT: Liversidge and colleagues developed a method for predicting the age of immature skeletal remains based on the length of developing teeth. This quantitative method combines dental data from both jaws, except for the permanent lateral incisor, and because there are reasons to suspect that these two types of data are not identical and should not be combined, it raises concerns regarding the accuracy of the technique when applied differently to each jaw. In this study, the differential accuracy of the method was test when applied to the maxillary and mandibular dentition. The test sample is comprised of 57 Portuguese subadult skeletons of known age at death. Results suggest an overall high consistency between estimates obtained from both jaws, but for the permanent dentition only. In the deciduous dentition the age estimates obtained from the maxillary teeth tend to be greater than the age estimates obtained from the mandibular pair, and the differences are significant for the incisors and canine. Additionally, ages obtained from the maxillary deciduous canine also differ significantly from true chronological age. In the permanent dentition there were no differences between the ages provided by both jaws but both the maxillary and mandibular second molars show a significant tendency to underestimate true chronological age. Although this study cannot validate completely the method presented by Liversidge and colleagues, it does provide an important test to its accuracy and calls for further research into its overall performance, particularly with respect to the results obtained from both jaws.

KEYWORDS: forensic science, forensic odontology, age determination by teeth, subadults, tooth length, permanent dentition, deciduous dentition

The accuracy of subadult age estimation methods based on dental development has been subjected to constant evaluation by skeletal biologists and forensic scientists. Because most methods rely on schedules of tooth formation, such evaluation has been based on radiographic studies of living children (1–3) or of identified immature skeletal material (4–6). The main difficulties in testing such methodologies comprehensively is that radiographic studies of living children are usually limited to older children and adolescents and collections of identified immature skeletons are extremely rare. Despite some limitations in reference material, the testing of age estimation methods through utilization of diverse samples is fundamental to address the problem of uncertainty when a method is applied to an individual originating from a population that differs from the one that contributed to the development of the method.

Liversidge and colleagues (7,8) have developed a quantitative method of age estimation based on the length of the developing dentition and this technique has several advantages over methods that rely on schedules of tooth formation. Being a quantitative method it is more objective than methods that rely on subjective assessments of fractional stages of dental development. Making use of regression equations, the technique was also specifically designed to predict age, something that most methods are not designed for. Another major advantage is that, because the sex of immature skeletal remains cannot be easily determined, age estimates based on this technique are not affected by methodological considerations of sex. Although other quantitative methods have been developed for the deciduous (9) and permanent dentition (10–12), they vary in measuring technique and applicability to tooth type and age interval. The regression formulae developed by Liversidge and colleagues (7,8) is the most comprehensive technique for estimating age from tooth length because it relies on a single measurement of the tooth, it can be applied to the whole deciduous and permanent dentition and to the entire postnatal growth period, from birth to 20 years of age. Liversidge and colleagues technique has the additional advantage of allowing age to be estimated from both the maxillary and mandibular teeth. Despite the promise of greater accuracy in quantitative methods, Liversidge et al. technique has only been evaluated once (13). Although this study represents a very important effort of accuracy testing, it only relied on a sample of mandibular radiographs of living children between the ages of 8 and 14 years and the study did not include the deciduous dentition or the permanent incisors. One problem with Liversidge and colleagues' technique that also has not been dealt with is that, except for the permanent lateral incisor, maxillary and mandibular tooth length data were combined. In their study, Liversidge and Molleson (8) point to the fact that, except for the permanent lateral incisor, maxillary and

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mandibular permanent tooth length data did not differed between the jaws but they do not present statistical information to support the statement. Additionally, in the earlier study (7) crown height of permanent central incisors differed significantly between the jaws and differences between maxillary and mandibular teeth were tested using an inappropriate test (unpaired *t*-test). Despite significant differences between deciduous first molars in crown height and between deciduous central incisors in tooth length, data from both jaws was still combined for developing the regression equations. In this context, there seems to be some problems with the combination of data from both jaws and, consequently, some concerns may be raised regarding the accuracy of the technique when applied differently to each jaw. This is particularly important as it is not uncommon for skeletal remains to be represented by only one jaw. The goal of this study is to test the differential accuracy of Liversidge and colleagues (7,8) method on the maxillary and mandibular dentition of a sample of 20th-century Portuguese identified immature skeletons. Identified samples of subadults are extremely rare and, although the Portuguese sample is relatively small in size, it allows for an important test of the accuracy of age estimation methods that otherwise could not have been performed.

Material and Methods

The material selected for this study consists of juvenile skeletons of known sex and age at death from the Lisbon identified skeletal collection. This collection derives from modern cemetery sources and encompasses around 1700 skeletons, of which 700 are fully identified (14). Remains originate from temporary graves and are identified through coffin plates and burial records. Most of the individuals represent the middle to low social class of the city of Lisbon, Portugal. The study sample consists of 57 individuals aged from birth to 19 years. Individuals were interred between 1913 and 1974. Specimens were included if the available teeth could be paired for the mandible and the maxilla. That is, each specimen had to have at least one superior–inferior pair of matched loose teeth (e.g., both upper and lower loose M1s). Exact calendar age was obtained from civil records of birth and death and was converted to decimal age.

Developing mandibular and maxillary deciduous and permanent teeth were measured according to Liversidge and colleagues (7,8), as the distance from the cusp-tip to the developing edge of crown or root in the midline, parallel to the long axis of the tooth. In teeth with more than one cusp or root, the maximum length was measured. Measurements were taken on isolated teeth using a standard digital caliper and recorded to the nearest tenth of a millimeter. Owing to the problems of image distortion and superimposition in maxillary radiographs only loose teeth were used and no measurements were taken on X-ray film. Because no maxillary radiographs were taken, the available sample was limited to the ability to pair loose maxillary teeth with their corresponding mandibular match. Both left and right teeth were measured when available and the average length calculated, otherwise only the available tooth was measured. Owing to some problems of preservation and absence of radiographic data, some specimens were represented by only one pair of matched teeth whereas in other cases one individual had more than one pair of teeth. A total of 52 pairs of deciduous and 63 pairs of permanent teeth were included in the analysis.

Intraexaminer agreement was estimated by comparing tooth lengths obtained in two separate measuring sessions of 20 uniradicular and 20 multiradicular teeth. The amount of variance in tooth length in the two sessions that is accounted for examiner error was quantified by calculating the intraclass correlation coefficient.

Age was estimated for each individual tooth from the regression formulae developed by Liversidge et al. (7) for the deciduous dentition and by Liversidge and Molleson (8) for the permanent dentition. Differential accuracy of each jaw was tested by examining consistency between estimated ages obtained from upper and lower teeth and by comparing each of the estimated ages with true chronological age. First the age estimated from each maxillary tooth was compared with the age estimated to the corresponding mandibular tooth in each individual using the nonparametric Wilcoxon Matched Pairs Test and then each of those individual tooth ages were compared with chronological age using the same nonparametric test. Owing to small sample sizes, the analogous and more robust parametric paired *t*-test could not be used.

Results

The intraclass correlation coefficient was -0.77 for uniradicular teeth and -0.06 for multiradicular teeth. Because variation, by definition, is positive this cannot logically be taken as indicating that -77% and -6% of the variation on tooth length is accounted for by the examiner. It is instead taken as indicating that the variance component for the examiner is zero, and that 0% of the variation on tooth length is accounted for by the examiner, indicating a very good intraexaminer agreement.

The regression formulae for the deciduous dentition provided estimated ages that differed between the jaws when using the central and lateral incisors and canine (see Table 1). Although not all deciduous teeth provided significant discrepant age estimates between the jaws, all maxillary teeth show a tendency to overestimate age relative to the mandibular teeth. This is particularly true for the canine where the maxillary tooth also differed significantly from true chronological age. Age estimates provided by all the other teeth did not differ from true chronological age.

Comparatively, estimated ages obtained from the regression formulae for the permanent maxillary dentition did not differ from mandibular estimated ages (see Table 2). Only the age estimates obtained from the maxillary and mandibular second molars differed significantly from true chronological age, where it was consistently underestimated. Contrary to deciduous teeth, in the permanent dentition there was no tendency for one jaw to provide overestimates or underestimates compared with the other jaw. In three of the tooth pairs (M3, PM1, and I1) maxillary age tended to overestimate mandibular age, whereas in the remaining five (M2, M1, PM2, C, and I2) maxillary age tended to underestimate mandibular age. Although the age estimates obtained from the maxillary and mandibular lateral incisors do not differ significantly, regression formulae were developed separately for both jaws and, therefore, results for this tooth would not originate from inappropriate combination of maxillary and mandibular data.

Discussion

The first observation is that Liversidge and colleagues' (7,8) method for age estimation using developing tooth length is quite accurate overall. Only the deciduous maxillary canine and the permanent maxillary and mandibular second molars provided age estimates significantly different from true chronological age. Results also indicate that combination of maxillary and mandibular teeth for developing regression formulae did not affect their

TABLE 1—*Deciduous dentition. Summary statistics for difference between age estimated from maxillary teeth and age estimated from mandibular teeth, and Wilcoxon marched pairs test values by tooth type pair.*

Tooth Pairs	*N*	Mean Age	SD	Diff	Min Diff	Max Diff	*T*	*p*
dm^2	8	1.11	0.9257	0.0164	– 0.2891	0.2424	17.00	0.8886
dm_2		1.09	0.8483					
dm^1	6	0.98	0.7823	0.0224	– 0.1887	0.1532	7.00	0.4631
dm_1		0.96	0.8297					
dc′	14	2.14*	0.9332	0.2101	– 0.0546	0.5135	1.00	0.0012
dc‚		1.93	0.8653					
di^2	18	1.10	0.6090	0.0504	– 0.0574	0.2096	25.00	0.0084
di_2		1.05	0.6326					
di^1	6	0.91	0.5997	0.1424	0.0418	0.2945	0.00	0.0277
di_1		0.77	0.5449					

N, number of teeth; Mean age, mean age obtained from each tooth type; SD, standard deviation of mean age; Diff, mean difference between maxillary and mandibular age; Min diff, minimum difference between maxillary and mandibular age, Max diff, maximum difference between maxillary and mandibular age; *T*, Wilcoxon marched pairs test; *p*, probability that the observed difference between the age obtained from the maxillary tooth and the age obtained from the mandibular tooth is not zero due to chance alone.

*Differs significantly from true chronological age at $p<0.01$.

differential performance, as age estimates do not differ between the jaws but this is only true for the permanent dentition. In deciduous teeth, age estimates obtained from the anterior dentition (i1, i2, and c) differed significantly between maxillary and mandibular pairs. In addition, all deciduous maxillary teeth tend to provide overestimates compared with mandibular teeth, despite both not differing from true chronological age.

In the deciduous dentition, results for the central incisor are not surprising given that Liversidge et al. (7) had already detected significant differences in tooth length between maxillary and mandibular measurements. However, one problem with Liversidge and colleagues' study, that may have prevented detection of further significant differences between teeth of both jaws, is that the differences were tested using an unpaired *t*-test. This test examines the differences between maxillary and mandibular teeth in the entire sample as if both sets of measurements were completely independent. In fact, when using this test mandibular observations could actually be from completely different individuals from the maxillary observations, thus providing no meaningfully information on the differences between the jaws in the same individual. Only intraindividual differences in tooth measurements are relevant for the accuracy of the method. If not, a good accuracy of both jaws in estimating age could simply be the result of maxillary age estimates being obtained from individuals other than the ones that provided the mandibular age estimates. Although not all deciduous teeth provided age estimates that differed significantly between the jaws, all maxillary teeth tended to provide older ages compared with mandibular teeth suggesting a faster growth rate for the upper teeth. Such faster growth rate of the anterior upper teeth is confirmed by other studies (9,15).

Contrary to the deciduous dentition, results for the permanent dentition do not suggest significant differences between age estimates provided by both jaws. There was also no tendency for teeth in one jaw to provide consistent older or younger ages than the other jaw. In fact, the only problem with the permanent dentition was that both the maxillary and the mandibular second molars gave age estimates significantly different from true chronological age. Although this finding may result from random variation due to a small test sample, the original regression formulae in

TABLE 2—*Permanent dentition. Summary statistics for difference between age estimated from maxillary teeth and age estimated from mandibular teeth, and Wilcoxon marched pairs test values by tooth type pair.*

Tooth Pairs	*N*	Mean Age	SD	Diff	Min Diff	Max Diff	*T*	*p*
M^3	4	18.22	2.2255	0.4475	– 1.5032	1.3999	4.00	0.7150
M_3		17.78	1.9798					
M^2	9	11.17*	1.3414	– 0.2963	– 1.6018	1.2949	11.00	0.1731
M_2		11.47*	1.2591					
M^1	6	1.81	0.6845	– 0.0217	– 0.3897	0.3709	8.00	0.6002
M_1		1.83	0.8075					
PM^2	15	12.71	1.4643	– 0.0783	– 1.2721	1.0900	56.00	0.8203
PM_2		12.79	1.5369					
PM^1	12	11.26	1.5057	0.1051	– 0.7443	0.9077	29.00	0.4328
PM_1		11.16	1.5020					
C′	8	8.83	4.6711	– 0.1555	– 0.9192	0.4260	12.00	0.4008
C‚		8.98	4.5957					
I^2	5	8.31	1.2484	– 0.4874	– 2.0246	0.7810	5.00	0.5002
I_2		8.79	0.1810					
I^1	4	7.54	1.6410	0.1183	– 0.2473	0.3558	3.00	0.4653
I_1		7.42	1.7590					

*Differs significantly from true chronological age at $p<0.01$.

N, number of teeth; Mean age, mean age obtained from each tooth type; SD, standard deviation of mean age; Diff, mean difference between maxillary and mandibular age; Min diff, minimum difference between maxillary and mandibular age; Max diff, maximum difference between maxillary and mandibular age; *T*, Wilcoxon marched pairs test; *p*, probability that the observed difference between the age obtained from the maxillary tooth and the age obtained from the mandibular tooth is not zero due to chance alone.

Liversidge and Molleson (8) for the second molar may have also contributed to the inaccuracy of the age estimates. The sample size for the second molar in the original study is the smallest ($n = 10$) of all teeth, suggesting not only that it may not be representative of the growth of the second molars, but also that, if the jaws are unequally represented, the sample may be more representative of maxillary or of mandibular tooth growth.

One of the limitations of the present study is that accuracy of the technique was tested in a sample of limited age range. Because most loose teeth tend to be the ones that have pierced the alveolar bone and therefore tend to be the teeth in more advanced stages of development, the accuracy of most teeth could not be tested in their entire developmental age range. This may partly explain the accuracy results for the second molar as the mean age for this tooth coincides with the age interval ($\sim$ 6–15 years) less represented by the original data of Liversidge and colleagues. This may suggest, instead, that the original regression formulae may not be adequate for this age interval.

Another obvious limitation of this study is sample size. Characteristics of the sample and of the individuals selected did not provide sample sizes to allow for more meaningful results. Particularly, sample sizes did not allow for the use of more powerful statistical tests, such as the parametric paired *t*-test. Although this study cannot completely validate the dental age method tested here, it does provide important indications about the accuracy of this method and its potential problems. Similar judgments could also be made for Liversidge (5) and Saunders et al. (6) studies based respectively on the skeletal remains of 15 and 17 children. Because identified immature skeletal material is so rare and some problems exist with radiographs of living children, particularly the very young and infants, they provide an important basis for testing of methods, which otherwise could not be performed.

Conclusion

The major suggestion that derives from the present study is that it warrants additional research in the applicability and accuracy of Liversidge and colleagues' technique, particularly with regards to the differential performance of both jaws, as a combination of both maxillary and mandibular teeth in age estimation regression formulae may decrease the accuracy of the method. Additionally, small sizes of the original samples used to develop some of the regression formulae based on the permanent dentition may not be representative of the true growth pattern and consequently determine a decrease in accuracy. Despite some of its problems and limitations, using Liversidge and colleagues quantitative method to estimate age has several advantages: it is specifically designed to predict age; it is more objective than other methods; it can be easily applied on isolated teeth for the entire postnatal growth period; and sex does not have to be determined. It also holds the promise of higher accuracy compared with methods based on mineralization stages of formation, by providing lower confidence intervals of mean differences between estimated and chronological age.

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