JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, 2017
doi: 10.1111/1556-4029.13505
Available online at: onlinelibrary.wiley.com

PAPER

ANTHROPOLOGY

Joan Viciano,[1] Ph.D.; Stefano De Luca,[2] Ph.D.; Javier Irurita,[3] Ph.D.; and Inmaculada Alemán,[3] Ph.D.

Age Estimation of Infants Through Metric Analysis of Developing Anterior Deciduous Teeth

ABSTRACT: This study provides regression equations for estimation of age of infants from the dimensions of their developing deciduous teeth. The sample comprises 97 individuals of known sex and age (62 boys, 35 girls), aged between 2 days and 1,081 days. The age-estimation equations were obtained for the sexes combined, as well as for each sex separately, thus including "sex" as an independent variable. The values of the correlations and determination coefficients obtained for each regression equation indicate good fits for most of the equations obtained. The "sex" factor was statistically significant when included as an independent variable in seven of the regression equations. However, the "sex" factor provided an advantage for age estimation in only three of the equations, compared to those that did not include "sex" as a factor. These data suggest that the ages of infants can be accurately estimated from measurements of their developing deciduous teeth.

KEYWORDS: forensic science, forensic anthropology, dental age, deciduous dentition, developing teeth, infants, odontometrics

The field of forensic anthropology is steadily growing, and methods for reconstruction of the biological profiles of skeletal remains are constantly being re-examined and improved upon for application to paleoanthropological, archeological, and forensic studies. However, there remain several areas that have not seen such expansion. Most research and methods of identification have been targeted toward older juveniles and adults, and thus, for fetal and infant remains, little has been studied. Furthermore, the results obtained tend to be highly contested and are subjected to constant evaluation by physical anthropologists and forensic scientists (1).

Several fetal and infant osteological collections have been established around the world (e.g., [2–6]). These can thus provide great sources of information for the development of methods that might yield a high degree of certainty and offer optimal discriminating capacity. This is particularly true in the forensic setting, such as for the estimation of the age at death. On this basis, this study was conducted on developing deciduous teeth from the Granada osteological collection of identified infants and young children.

Evaluation of the age of immature individuals has wide applications in several scientific and forensic fields. For clinical purposes, orthodontists can use age assessment to decide on the timing of a particular treatment, and pediatricians might be interested to know whether the dental maturity of a child with a certain disease is delayed or advanced (7,8). For forensic purposes, it would be useful to estimate the age of a child whose birth date is not known, or whose birth certificate might be false (9).

The main methods to evaluate the age of immature individuals are based on the study of skeletal growth (10–14). However, several studies have demonstrated that skeletal growth has disadvantages compared to other methods that are based on the analysis of dentition (1,10,15). Methods based on developing teeth appear to be more suitable for the assessment of age than those based on skeletal development, because they can offer certain advantages, such as (i) they are the only methods that can be applied from a prenatal age to adolescence; (ii) dental maturation is controlled by genetics rather than by environmental factors (such as nutritional, hormonal, and pathological changes), thus showing less variability in comparison with skeletal development and increasing the analytical precision (10,16–18); and (iii) teeth are one of the most resistant tissues in the human body, even relative to bone tissue, and they are often the only physical evidence available for study in burned individuals or in an archeological setting, where they can remain well preserved even under bad burial conditions (19–21).

The main dental techniques for estimating the age of immature individuals are based on observations of the degree of dental maturation and eruption, using charts or atlases (e.g., [22,23]), or a scoring system (e.g., [24–28]). However, in recent years, more reliable techniques have been developed that are based on metric analyses of the developing teeth (e.g., [29–33]). These metric techniques are considered to be more accurate and valid than traditional techniques using charts, atlases, or scoring systems, which tend to use more subjective criteria and require minimal experience of the observer, as it is often difficult to discriminate between different stages of dental mineralization and development.

[1]Operative Unit of Anthropology, Department of Medicine and Ageing Sciences, 'G. d'Annunzio' University of Chieti–Pescara, Piazza Trento e Trieste 1, Chieti 66100, Italy.

[2]Unidad Especial de Identificación Forense, Servicio Médico Legal, Avenida La Paz 1012, Comuna de Independencia, Santiago de Chile, Chile.

[3]Laboratory of Anthropology, Department of Legal Medicine, Toxicology and Physical Anthropology, University of Granada, Avenida de la Investigación 11, Granada 18071, Spain.

Received 30 Nov. 2016; and in revised form 8 Feb. 2017; accepted 2 Mar. 2017.

On this basis, the goals of this study were to develop regression equations for estimation of the age at death of infants and young children through metric analysis of the developing anterior deciduous teeth, and to evaluate the reproducibility of these formulae through analysis of intra-observer and inter-observer variability.

Materials and Methods

Sample

This study was conducted on a sample that is part of the Granada osteological collection of identified infants and young children (6), which includes 230 identified individuals in a perfect state of preservation who were exhumed from the San José Municipal Cemetery of Granada (Spain). Reliable *antemortem* information was obtained from the burial records of the San José Municipal Cemetery, the death certificates in the Registry Office, and in cases of judicial death, from forensic reports in the Granada Institute of Legal Medicine. The key data that were available from these records included sex, date of birth and death, and immediate and underlying cause of death, among other information. These remains are kept in the Laboratory of Anthropology of the University of Granada.

The exclusion criteria were for unknown age at birth or death, presence of disease that might have affected dental development (e.g., hydrocephaly, anencephaly, cleft palate, amelogenesis imperfecta), and death described on the death certificate as due to "premature delivery," "congenital weakness, or "lack of development," because of the consequent lack of correspondence between chronological age and degree of skeletal development. After application of these criteria, 97 individuals (62 boys, 35 girls) aged between 2 days and 1,081 days formed the final study sample. Fig. 1 illustrates the distribution of this sample according to age and sex. The birth years of these individuals ranged from 1914 to 2000, and their death years range from 1915 to 2001. The great majority of these births (72%) and deaths (73%) were between 1950 and 1975, which means that this sample largely dates from the third-quarter of the 20th century. Fig. 2 illustrates the distribution of the sample by decade of birth and decade of death.

Measurements Taken

Five measurements of the anterior deciduous teeth were taken (in millimeters) according to the definitions of Aka et al. (32). The measurements included the following, as illustrated in Fig. 3:

- Mesiodistal width: maximum dimension between the mesial and distal surfaces.
- Buccolingual width: maximum measure between the buccal and lingual surfaces at the mid-sagittal location.
- Crown height: maximum measure from the cervical to the incisal edges on the mid-sagittal line.
- Crown thickness: measure from the inner to outer surfaces of the teeth.
- Root height: measure from the mid-sagittal line of the buccal root surface, between the cervical line and the edge of the developing root.

Depending on the tooth development, the mesiodistal width, buccolingual width, crown height, and crown thickness measurements can be taken until root development initiates, and the root height can be measured after this period. Except for the crown thickness, the measurements were collected using digital dental calipers (Masel Orthodontics Inc., Carlsbad, CA, USA), to a precision of 0.01 mm. The measurement of the crown thickness was taken using special thickness-measuring compasses, with an accuracy to 0.1 mm (Iwanson Calipers, Salvin Dental Specialities, Zossen, Germany). Teeth with signs of anomalies in volume or shape, hypoplastic defects, fractures, or taphonomic/diagenetic effects were excluded from the analysis. The measurements were performed on the teeth of either the left side or the right side of the dental arches, depending on their availability. If both contralateral teeth were available, the mean was calculated for the measured values.

To determine possible intra-observer error, these measurements were obtained from the teeth of 35 randomly selected individuals by the principal observer at different times. To evaluate the inter-observer error, another 33 randomly selected individuals were re-measured by a second observer. The same calipers were used in both cases.

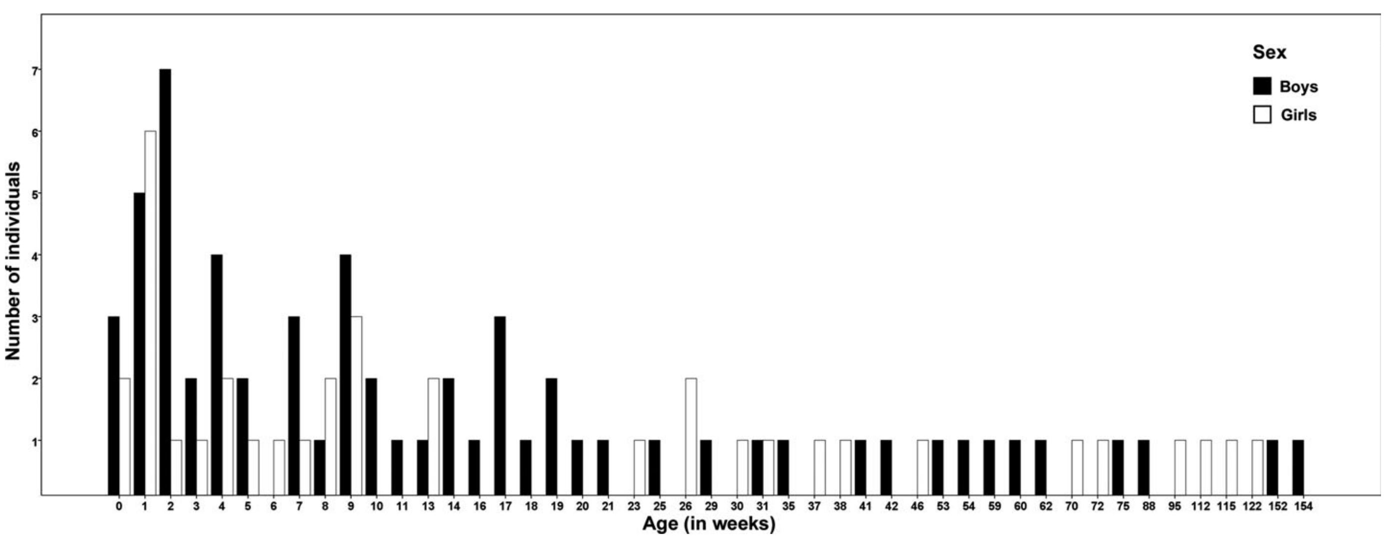

FIG. 1—*Distribution of the sample by age and sex.*

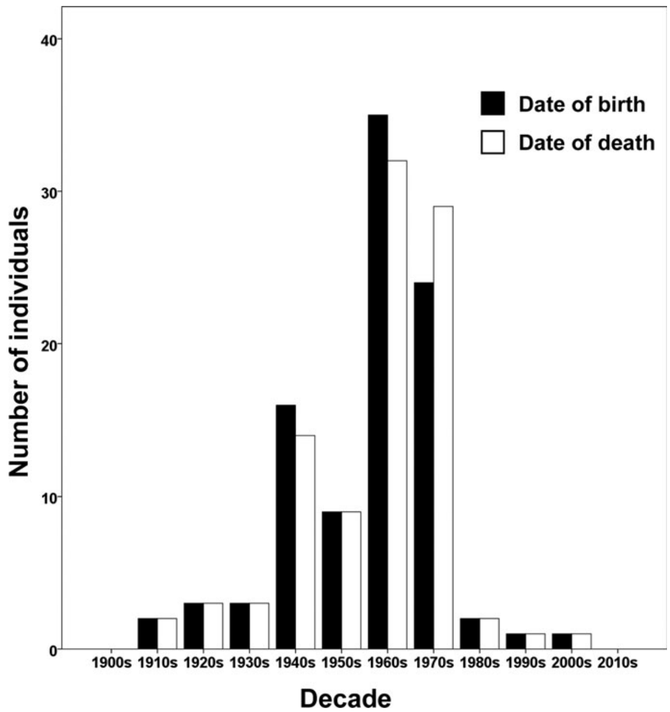

FIG. 2—*Distribution of the sample by decades of birth and death.*

Statistical Analysis

The relationships between the chronological age (measured in weeks postbirth) and the different tooth measurements were investigated through Pearson's product-moment correlations. Then, linear regression analysis was performed to obtain single (i.e., with one explanatory variable) or multiple (i.e., with two explanatory variables) regression equations for the dental age calculations, with the chronological age as the dependent variable and the different tooth measurements as the independent variables. The regression equations were calculated for a maximum combination of two measurements, to maximize the applicability in cases where the dental remains were fragmented. Correlation coefficients (r) and coefficients of determination (r^2) were computed, whereby the best predictors are those with the highest r and r^2 values. The regression equation parameters were calculated for the combined sexes and for each sex separately including the "sex" factor as an independent variable ("sex" factor: 1 for boys, 2 for girls). The hypothesis of normality, homoscedasticity, and no autocorrelation of residuals was checked. Only the regression equations that showed minimum r and r^2 coefficients of 0.7 were selected.

The intraclass correlation coefficients (ICCs) were computed to determine the levels of agreement between the repeated measurements collected by the same observer and by the different observers. To determine the degree of agreement for any given set of data, the computed ICCs were compared to the strengths of agreement criteria proposed by Fleiss (34), which defined five levels of qualitative assessment: "very good," for ICCs >0.90; "good," for ICCs from 0.71 to 0.90; "moderate," for ICCs from 0.51 to 0.70; "poor," for ICCs from 0.31 to 0.50; and "little or no agreement" for ICCs <0.30.

All of the statistical analyses were performed using the IBM® SPSS® Statistics 22.0 software (SPSS Inc., Chicago, IL, USA). A p-value <0.05 was considered significant for all of the statistical data.

Results

In the intra-observer error analysis (Table 1), for the maxilla, the ICCs with the central incisors ranged from 0.887 to 0.997 (i.e., "good" to "very good"), with slightly higher ICCs with the lateral incisors (0.929–0.999; "very good") and canines (0.986–0.998; "very good"). For the mandible, the ICCs with the central incisors were slightly higher, at 0.984–0.999 ("very good"), with the lateral incisors at 0.955–0.999 ("very good"), and the canines at 0.967 to 0.998 ("very good"). In addition, the differences between the means of the repeated measurements did not exceed 0.054 mm for the maxillary teeth and 0.062 mm for the mandibular teeth. For the inter-observer error analysis (Table 2), the maxillary and mandibular teeth generally showed similar ICCs. With the maxilla, the ICCs with the central incisors

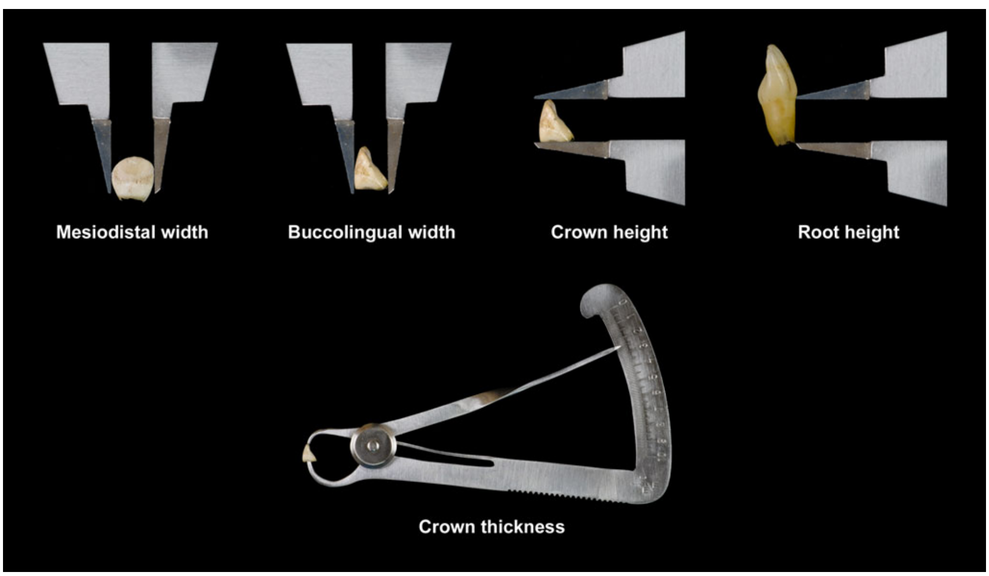

FIG. 3—*Illustrations of the measurements taken for the deciduous dentition.*

TABLE 1—*Intra-observer error analysis for the maxilla and mandible measurements.*

		Maxilla								Mandible							
			Measurement 1		Measurement 2						Measurement 1		Measurement 2				
Measurement	Tooth	*n*	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Diff (mm)	ICC	Strength of Agreement	*n*	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Diff (mm)	ICC	Strength of Agreement
Mesiodistal width	Central incisor	10	6.063	0.438	6.052	0.459	0.011	0.995	Very good	10	3.818	0.291	3.821	0.294	−0.003	0.995	Very good
	Lateral incisor	15	4.709	0.648	4.680	0.385	0.029	0.994	Very good	15	4.052	0.345	4.067	0.338	−0.015	0.993	Very good
	Canine	14	5.575	0.711	5.542	0.702	0.033	0.997	Very good	11	4.417	0.503	4.423	0.498	−0.006	0.991	Very good
Buccolingual width	Central incisor	10	3.963	0.567	3.970	0.565	−0.007	0.996	Very good	10	3.061	0.424	3.049	0.451	0.012	0.993	Very good
	Lateral incisor	15	3.693	0.648	3.715	0.671	−0.022	0.998	Very good	15	2.841	0.555	2.855	0.565	−0.014	0.992	Very good
	Canine	14	3.409	1.014	3.396	0.986	0.013	0.998	Very good	10	2.758	0.618	2.754	0.621	0.004	0.998	Very good
Crown height	Central incisor	10	5.750	0.578	5.729	0.562	0.021	0.991	Very good	10	4.968	0.674	5.026	0.688	−0.058	0.995	Very good
	Lateral incisor	15	4.770	0.695	4.801	0.702	−0.031	0.996	Very good	16	4.671	0.669	4.640	0.626	0.031	0.960	Very good
	Canine	14	4.439	1.279	4.469	1.276	−0.030	0.998	Very good	11	3.823	0.665	3.866	0.675	−0.043	0.997	Very good
Crown thickness	Central incisor	10	2.550	0.178	2.510	0.160	0.040	0.887	Good	10	2.560	0.366	2.500	0.400	0.060	0.984	Very good
	Lateral incisor	15	2.273	0.252	2.273	0.294	0.000	0.929	Very good	16	2.525	0.277	2.463	0.303	0.062	0.955	Very good
	Canine	14	2.100	0.404	2.107	0.441	−0.007	0.986	Very good	11	2.100	0.283	2.046	0.238	0.054	0.967	Very good
Root height	Central incisor	10	2.350	1.274	2.349	1.289	0.001	0.997	Very good	12	2.245	1.425	2.223	1.403	0.022	0.999	Very good
	Lateral incisor	6	2.007	1.379	2.062	1.446	−0.054	0.999	Very good	4	2.545	1.323	2.498	1.305	0.047	0.999	Very good
	Canine	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

n, number of teeth; Mean, overall measurement mean; SD, standard deviation; Diff, mean difference between repeated measurements; ICC, intraclass correlation coefficient.

TABLE 2—*Inter-observer error analysis for the maxilla and mandible measurements.*

		Maxilla								Mandible							
			Measurement 1		Measurement 2						Measurement 1		Measurement 2				
Measurement	Tooth	*n*	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Diff (mm)	ICC	Strength of Agreement	*n*	Mean (mm)	SD (mm)	Mean (mm)	SD (mm)	Diff (mm)	ICC	Strength of Agreement
Mesiodistal width	Central incisor	12	5.885	0.426	5.841	0.435	0.044	0.998	Very good	6	3.770	0.262	3.750	0.263	0.020	0.989	Very good
	Lateral incisor	14	4.607	0.299	4.599	0.288	0.008	0.989	Very good	15	4.152	0.453	4.150	0.426	0.002	0.993	Very good
	Canine	11	5.903	0.645	5.902	0.662	0.001	0.998	Very good	13	4.457	0.774	4.452	0.772	0.005	0.998	Very good
Buccolingual width	Central incisor	12	3.868	0.710	3.888	0.743	−0.020	0.997	Very good	5	2.882	0.344	2.906	0.408	−0.024	0.980	Very good
	Lateral incisor	14	3.610	0.729	3.617	0.748	−0.007	0.998	Very good	15	3.029	0.669	3.015	0.724	0.014	0.996	Very good
	Canine	11	3.681	1.071	3.661	1.032	0.020	0.997	Very good	13	2.970	0.913	2.915	0.934	0.055	0.999	Very good
Crown height	Central incisor	12	5.505	0.782	5.506	0.750	−0.001	0.997	Very good	6	4.670	0.577	4.725	0.584	−0.055	0.992	Very good
	Lateral incisor	14	4.710	0.789	4.786	0.756	−0.076	0.999	Very good	15	4.857	0.969	4.897	0.963	−0.040	0.999	Very good
	Canine	11	4.778	1.289	4.825	1.297	−0.047	0.998	Very good	13	3.997	1.208	4.060	1.208	−0.063	0.999	Very good
Crown thickness	Central incisor	12	2.428	0.179	2.418	0.252	0.010	0.953	Very good	6	2.367	0.266	2.350	0.295	0.017	0.982	Very good
	Lateral incisor	14	2.286	0.232	2.264	0.271	0.022	0.927	Very good	15	2.513	0.354	2.487	0.385	0.026	0.977	Very good
	Canine	11	2.218	0.384	2.191	0.401	0.027	0.980	Very good	12	2.075	0.409	2.058	0.440	0.017	0.977	Very good
Root height	Central incisor	10	2.267	1.512	2.255	1.526	0.012	0.999	Very good	10	2.644	1.846	2.608	1.878	0.036	1.000	Very good
	Lateral incisor	4	2.168	0.910	2.150	0.878	0.018	1.000	Very good	2	3.580	0.622	3.725	0.601	−0.145	1.000	Very good
	Canine	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

n, number of teeth; Mean, overall measurement mean; SD, standard deviation; Diff, mean difference between repeated measurements; ICC, intraclass correlation coefficient.

ranged from 0.953 to 0.998 ("very good"), with the lateral incisors from 0.927 to 1.000 ("very good"), and the canines from 0.980 and 0.998 ("very good"). The results were similar with the mandible, where the ICCs with the central incisors were 0.980–1.000 ("very good"), with the lateral incisors 0.977–1.000 ("very good"), and with the canines 0.977–0.999 ("very good"). The differences between the means of the repeated measurements did not exceed 0.076 mm for the maxillary teeth, and 0.145 mm for the mandibular teeth. In both the intra-observer and inter-observer analyses, the ICCs for the root height in the canines could not be calculated, as it was not possible to take this measurement in these randomly selected individuals.

Table 3 shows the regression equation parameters for the relationships between age and root height of the maxillary and mandibular teeth. The equations with the sexes combined showed that root development of the central incisors initiated at 3.01 weeks for the maxilla, and 4.06 weeks for the mandible. For the lateral incisors, the root development initiated at 3.30 weeks for the maxilla, and at 10.62 weeks for the mandible. Finally, for the canines, the root development initiated at 23.96 weeks for the maxilla, and at 29.17 weeks for the mandible. The correlation coefficients (r) and the coefficients of determination (r^2) of the regression equations were higher for the maxillary teeth than the mandibular teeth. The r ranged from 0.843 to 0.883 for the maxilla, and from 0.661 to 0.763 for the mandible. The r^2 ranged from 0.710 to 0.779 for the maxilla, and from 0.437 to 0.582 for the mandible. Here, the root heights of the maxillary teeth were better predictors for age than those for the mandibular teeth. Similar r and r^2 were obtained when the "sex" factor was included in these equations. Thus, including the "sex" as a separate factor did not provide any particular advantage for the age estimations through these equations.

Table 4 shows the regression equation parameters that indicate the relationships between the age and the mesiodistal width, buccolingual width, crown height, and thickness of the dental crown of the maxillary and mandibular teeth. Here, the r and r^2 of these regression equations were higher for the mandibular teeth than the maxillary teeth. The r ranged from 0.854 to 0.864 in the maxilla, and from 0.836 to 0.950 in the mandible, depending on the particular measurements used in the regression equations.

TABLE 3—*Regression equation parameters for age (in weeks) versus sex and root height for the maxilla and mandible anterior teeth.*

						95% Confidence Interval					
Location	Tooth (n)	Equation	Model	Estimator	SE	Lower	Upper	t	Sig.	r	r^2
Maxilla	Central incisor (54)	1a								0.883	0.779
			Constant	3.006	2.847	−2.707	8.719	1.056	0.296		
			Root height	8.037	0.593	6.847	9.226	13.556	0.000		
		1b								0.891	0.794
			Constant	−5.547	5.306	−16.200	5.105	−1.045	0.301		
			Root height	7.975	0.580	6.812	9.139	13.760	0.000		
			Sex	6.330	3.346	−0.386	13.047	1.892	0.064		
	Lateral incisor (39)	2a								0.850	0.723
			Constant	3.301	5.557	−7.957	14.560	0.594	0.556		
			Root height	10.897	1.109	8.650	13.144	9.826	0.000		
		2b								0.861	0.741
			Constant	−8.905	9.384	−27.938	10.127	−0.949	0.349		
			Root height	10.449	1.122	8.173	12.724	9.311	0.000		
			Sex	9.337	5.847	−2.521	21.196	1.597	0.119		
	Canine (23)	3a								0.843	0.710
			Constant	23.957	10.234	2.675	45.239	2.341	0.029		
			Root height	14.200	1.979	10.085	18.314	7.177	0.000		
		3b								0.872	0.760
			Constant	−6.604	17.867	−43.874	30.667	−0.370	0.716		
			Root height	14.895	1.879	10.976	18.814	7.928	0.000		
			Sex	18.527	9.153	−0.566	37.620	2.024	0.057		
Mandible	Central incisor (54)	4a								0.763	0.582
			Constant	4.058	4.729	−5.431	13.546	0.858	0.395		
			Root height	8.375	0.984	6.400	10.351	8.507	0.000		
		4b								0.766	0.587
			Constant	−0.810	7.924	−16.718	15.099	−0.102	0.919		
			Root height	8.264	0.999	6.259	10.269	8.273	0.000		
			Sex	3.835	4.999	−6.201	13.872	0.767	0.447		
	Lateral incisor (37)	5a								0.661	0.437
			Constant	10.615	10.133	−9.957	31.186	1.048	0.302		
			Root height	9.112	1.748	5.565	12.660	5.214	0.000		
		5b								0.726	0.527
			Constant	−11.569	12.842	−37.667	14.529	−0.901	0.374		
			Root height	7.656	1.723	4.154	11.158	4.443	0.000		
			Sex	20.141	7.920	4.045	36.237	2.543	0.016		
	Canine (21)	6a								0.697	0.486
			Constant	29.173	16.688	−5.756	64.102	1.748	0.097		
			Root height	14.563	3.437	7.369	21.757	4.237	0.000		
		6b								0.745	0.555
			Constant	−12.182	29.366	−73.877	49.514	−0.415	0.683		
			Root height	16.057	3.403	8.908	23.206	4.719	0.000		
			Sex	22.800	13.596	−5.763	51.364	1.677	0.111		

n, number of teeth; SE, standard error; t, Student's t-test; Sig., significance; r, coefficient of correlation; r^2, coefficient of determination.

TABLE 4—*Regression equation parameters for age (in weeks) versus sex, mesiodistal width, buccolingual width, crown height, and crown thickness for the maxilla and mandible anterior teeth.*

						95% confidence Interval					
Location	Tooth	Equation (*n*)	Model	Estimator	SE	Lower	Upper	*t*	Sig.	*r*	r^2
Maxilla	Central incisor			–	–	–	–	–	–	–	–
	Lateral incisor			–	–	–	–	–	–	–	–
	Canine	7a (39)								0.854	0.730
			Constant	−13.648	2.532	−18.778	−8.517	−5.390	0.000		
			Crown height	5.676	0.568	4.525	6.827	9.994	0.000		
		7b (39)								0.855	0.732
			Constant	−12.027	4.005	−20.149	−3.904	−3.003	0.005		
			Crown height	5.557	0.617	4.306	6.808	9.012	0.000		
			Sex	−0.883	1.679	−4.287	2.521	−0.526	0.602		
		8a (40)								0.860	0.739
			Constant	−10.400	5.637	−21.822	1.022	−1.845	0.073		
			Mesiodistal width	−0.743	1.576	−3.936	2.449	−0.472	0.640		
			Buccolingual width	7.528	1.283	4.928	10.128	5.867	0.000		
		8b (40)								0.861	0.741
			Constant	−8.600	6.736	−22.261	5.061	−1.277	0.210		
			Mesiodistal width	−0.821	1.599	−4.065	2.423	−0.513	0.611		
			Buccolingual width	7.430	1.311	4.772	10.089	5.668	0.000		
			Sex	−0.820	1.639	−4.143	2.503	−0.500	0.620		
		9a (39)								0.855	0.731
			Constant	−15.662	5.346	−26.504	−4.820	−2.930	0.006		
			Mesiodistal width	0.609	1.419	−2.269	3.488	0.429	0.670		
			Crown height	5.357	0.939	3.453	7.262	5.705	0.000		
		9b (39)								0.856	0.733
			Constant	−13.903	6.572	−27.244	−0.562	−2.116	0.042		
			Mesiodistal width	0.525	1.446	−2.411	3.460	0.363	0.719		
			Crown height	5.293	0.959	3.346	7.240	5.518	0.000		
			Sex	−0.806	1.713	−4.282	2.671	−0.471	0.641		
		10a (39)								0.864	0.746
			Constant	−13.750	2.490	−18.800	−8.699	−5.521	0.000		
			Buccolingual width	3.782	2.504	−1.296	8.859	1.510	0.140		
			Crown height	2.743	2.021	−1.356	6.841	1.357	0.183		
		10b (39)								0.864	0.747
			Constant	−12.392	3.951	−20.411	−4.372	−3.137	0.003		
			Buccolingual width	3.714	2.537	−1.435	8.864	1.464	0.152		
			Crown height	2.695	2.047	−1.460	6.850	1.317	0.196		
			Sex	−0.739	1.656	−4.100	2.622	−0.446	0.658		
		11a (39)								0.856	0.733
			Constant	−13.732	3.640	−21.115	−6.350	−3.772	0.001		
			Buccolingual width	6.746	1.235	4.242	9.250	5.464	0.000		
			Crown thickness	0.888	2.984	−5.163	6.939	0.298	0.768		
		11b (39)								0.857	0.735
			Constant	−12.063	5.197	−22.613	−1.513	−2.321	0.026		
			Buccolingual width	6.706	1.252	4.165	9.247	5.358	0.000		
			Crown thickness	0.618	3.075	−5.623	6.860	0.201	0.842		
			Sex	−0.785	1.725	−4.287	2.717	−0.455	0.652		
		12a (39)								0.860	0.740
			Constant	−10.375	3.775	−18.030	−2.719	−2.748	0.009		
			Crown height	6.966	1.243	4.444	9.487	5.603	0.000		
			Crown thickness	−4.335	3.722	−11.885	3.214	−1.165	0.252		
		12b (39)								0.862	0.744
			Constant	−7.632	5.256	−18.302	3.038	−1.452	0.155		
			Crown height	6.950	1.251	4.410	9.489	5.556	0.000		
			Crown thickness	−4.861	3.809	−12.594	2.872	−1.276	0.210		
			Sex	−1.278	1.693	−4.714	2.159	−0.755	0.455		
Mandible	Central incisor	13a (51)								0.878	0.771
			Constant	−19.187	2.017	−23.240	−15.135	−9.514	0.000		
			Crown thickness	10.778	0.840	9.089	12.466	12.827	0.000		
		13b (51)								0.888	0.789
			Constant	−15.676	2.599	−20.902	−10.451	−6.032	0.000		
			Crown thickness	10.742	0.814	9.105	12.379	13.192	0.000		
			Sex	−2.534	1.237	−5.021	−0.048	−2.049	0.046		
	Lateral incisor	14a (0)								–	–
			Constant	–	–	–	–	–	–		
			Crown height	–	–	–	–	–	–		
		14b (59)								0.842	0.709
			Constant	−12.723	2.195	−17.120	−8.326	−5.797	0.000		
			Crown height	4.844	0.424	3.994	5.694	11.413	0.000		

TABLE 4—*Continued.*

Location	Tooth	Equation (n)	Model	Estimator	SE	95% confidence Interval Lower	Upper	t	Sig.	r	r^2
		15a (60)	Sex	−1.935	0.812	−3.562	−0.309	−2.384	0.021	0.937	0.878
			Constant	−24.808	1.637	−28.084	−21.532	−15.158	0.000		
			Crown thickness	13.449	0.658	12.132	14.766	20.444	0.000		
		15b (60)								0.942	0.888
			Constant	−21.597	2.120	−25.843	−17.352	−10.187	0.000		
			Crown thickness	13.347	0.637	12.072	14.623	20.953	0.000		
			Sex	−2.255	0.992	−4.242	−0.268	−2.273	0.027		
		16a (57)								0.836	0.700
			Constant	−34.646	4.393	−43.452	−25.839	−7.887	0.000		
			Mesiodistal width	8.081	1.394	5.287	10.875	5.798	0.000		
			Buccolingual width	2.930	0.840	1.246	4.614	3.488	0.001		
		16b (57)								0.846	0.715
			Constant	−31.142	4.782	−40.734	−21.550	−6.512	0.000		
			Mesiodistal width	7.454	1.418	4.610	10.299	5.256	0.000		
			Buccolingual width	3.252	0.847	1.554	4.951	3.840	0.000		
			Sex	−1.455	0.854	−3.169	0.258	−1.704	0.094		
		17a (57)								0.864	0.747
			Constant	−30.601	4.217	−39.054	−22.147	−7.257	0.000		
			Mesiodistal width	5.814	1.463	2.881	8.748	3.974	0.000		
			Crown height	3.058	0.616	1.822	4.294	4.961	0.000		
		17b (57)								0.872	0.761
			Constant	−27.316	4.541	−36.425	−18.208	−6.015	0.000		
			Mesiodistal width	5.259	1.470	2.310	8.208	3.577	0.001		
			Crown height	3.225	0.612	1.997	4.453	5.267	0.000		
			Sex	−1.355	0.772	−2.904	0.194	−1.755	0.085		
		18a (58)								0.862	0.743
			Constant	−18.082	1.946	−21.982	−14.182	−9.292	0.000		
			Buccolingual width	2.839	0.750	1.337	4.341	3.788	0.000		
			Crown height	3.618	0.521	2.574	4.663	6.942	0.000		
		18b (58)								0.885	0.784
			Constant	−15.293	2.004	−19.310	−11.276	−7.633	0.000		
			Buccolingual width	3.061	0.698	1.663	4.460	4.388	0.000		
			Crown height	3.526	0.484	2.557	4.495	7.292	0.000		
			Sex	−2.278	0.715	−3.712	−0.844	−3.184	0.002		
		19a (0)								–	–
			Constant	–	–	–	–	–	–		
			Buccolingual width	–	–	–	–	–	–		
			Crown thickness	–	–	–	–	–	–		
		19b (58)								0.857	0.734
			Constant	−17.489	2.501	−22.504	−12.475	−6.993	0.000		
			Buccolingual width	3.504	0.768	1.964	5.045	4.560	0.000		
			Crown thickness	7.292	1.265	4.755	9.828	5.763	0.000		
			Sex	−2.502	0.792	−4.090	−0.915	−3.161	0.003		
		20a (0)								–	–
			Constant	–	–	–	–	–	–		
			Crown height	–	–	–	–	–	–		
			Crown thickness	–	–	–	–	–	–		
		20b (59)								0.850	0.723
			Constant	−14.716	2.481	−19.689	−9.744	−5.931	0.000		
			Crown height	3.688	0.820	2.045	5.332	4.498	0.000		
			Crown thickness	3.102	1.893	−0.692	6.897	1.639	0.107		
			Sex	−1.979	0.800	−3.583	−0.375	−2.473	0.017		
	Canine	21a (46)								0.941	0.886
			Constant	−20.239	1.728	−23.722	−16.756	−11.711	0.000		
			Crown height	7.820	0.423	6.968	8.672	18.489	0.000		
		21b (46)								0.941	0.886
			Constant	−20.160	2.761	−25.728	−14.592	−7.301	0.000		
			Crown height	7.814	0.462	6.882	8.746	16.908	0.000		
			Sex	−0.042	1.131	−2.322	2.238	−0.037	0.971		
		22a (45)								0.840	0.705
			Constant	−9.381	7.029	−23.565	4.804	−1.335	0.189		
			Mesiodistal width	−3.878	2.595	−9.115	1.359	−1.494	0.143		
			Buccolingual width	12.608	2.057	8.458	16.759	6.131	0.000		
		22b (45)								0.840	0.705
			Constant	−9.948	9.359	−28.849	8.952	−1.063	0.294		
			Mesiodistal width	−3.810	2.724	−9.312	1.691	−1.399	0.169		
			Buccolingual width	12.615	2.082	8.409	16.820	6.058	0.000		
			Sex	0.191	2.043	−3.935	4.316	0.093	0.926		

TABLE 4—*Continued.*

Location	Tooth	Equation (n)	Model	Estimator	SE	95% confidence Interval Lower	Upper	t	Sig.	r	r^2
		23a (46)								0.948	0.899
			Constant	−12.386	3.653	−19.752	−5.020	−3.391	0.002		
			Mesiodistal width	−2.817	1.171	−5.178	−0.456	−2.407	0.020		
			Crown height	9.034	0.645	7.734	10.334	14.011	0.000		
		23b (46)								0.950	0.902
			Constant	−8.465	5.120	−18.798	1.868	−1.653	0.106		
			Mesiodistal width	−3.370	1.273	−5.940	−0.800	−2.647	0.011		
			Crown height	9.078	0.645	7.777	10.379	14.082	0.000		
			Sex	−1.259	1.155	−3.589	1.071	−1.090	0.282		
		24a (45)								0.943	0.889
			Constant	−19.478	1.881	−23.273	−15.682	−10.357	0.000		
			Buccolingual width	−1.584	1.459	−4.527	1.360	−1.086	0.284		
			Crown height	8.818	1.014	6.773	10.864	8.700	0.000		
		24b (45)								0.943	0.890
			Constant	−18.375	3.189	−24.816	−11.934	−5.761	0.000		
			Buccolingual width	−1.812	1.565	−4.973	1.349	−1.158	0.254		
			Crown height	8.881	1.034	6.793	10.969	8.590	0.000		
			Sex	−0.524	1.217	−2.982	1.934	−0.430	0.669		
		25a (45)								0.944	0.892
			Constant	−20.668	1.753	−24.206	−17.129	−11.788	0.000		
			Crown height	7.520	0.501	6.508	8.532	15.002	0.000		
			Crown thickness	0.794	0.661	−0.540	2.128	1.201	0.236		
		25b (45)								0.944	0.892
			Constant	−20.584	2.793	−26.225	−14.943	−7.369	0.000		
			Crown height	7.514	0.531	6.442	8.586	14.152	0.000		
			Crown thickness	0.792	0.670	−0.561	2.146	1.183	0.244		
			Sex	−0.044	1.132	−2.330	2.242	−0.039	0.969		

n, number of teeth; SE, standard error; t, Student's t-test; Sig., significance; r, coefficient of correlation; r^2, coefficient of determination.

The r^2 ranged from 0.730 to 0.747 in the maxilla, and from 0.700 to 0.902 in the mandible. Here, the crown measurements of the mandibular teeth were best predictors for age, compared to the maxillary teeth. Similar r and r^2 were again obtained when the "sex" factor was included in these equations; however, in contrast with the root height above, this "sex" factor did provide some advantage for the age estimation for three of these equations (Table 4, Equations 14b, 19b, 20b).

Practical Application of the Equations

An individual was randomly selected from the collection for the application of the procedure for age estimation (Table 5). Following the criteria outlined in the Materials and methods section, the anterior deciduous teeth were identified, and the different measurements were taken to calculate the age of the individual from each tooth according the different regression equations.

The following brief example illustrates the particular procedure of the regression equations developed here. For an immature individual of unknown sex, using the mandibular deciduous canine crown height (CH, 4.36 mm) and crown thickness (CT, 2.60 mm), as indicated in Table 4, Equation 25a can be applied to estimate the age of this individual. This procedure is as follows:

$$\text{Age} = -20.668 + (7.520 \times \text{CH}) + (0.794 \times \text{CT}) \qquad (25a)$$

introducing the measured data:

$$\text{Age} = -20.668 + (7.520 \times 4.36) + (0.794 \times 2.60)$$

which gives an age of 14.10 weeks (95% confidence interval, 2.82–25.39 weeks; 99 days), compared to the given age of 13.86 weeks (97 days).

Discussion

As investigations in forensic anthropology have expanded, methods for reconstruction of biological profiles of skeletal remains have been re-examined to improve their application to paleoanthropological, archeological, and forensic studies. However, several areas have seen little or no expansion, as most of these studies have focused on older juveniles and adults. Thus, as far as fetal and infant remains are concerned, little is known, and what is known tends to be highly contested by physical anthropologists and forensic scientists (1). However, with the establishing of several fetal and infant osteological collections around the world (e.g., [2–6]), these can now provide great sources of information for the development of improved methods that can offer optimal discriminating capacities while yielding a high degree of certainty. This is of particular interest in the forensic setting, such as for the estimation of age at death. Thus, the present study was conducted using anterior deciduous teeth in development from the Granada osteological collection of identified infants and young children, through which we developed an accurate method for age estimation using the odontometrics of these deciduous teeth.

The deciduous dentition develops from an early period, as the tooth germs within the sockets in the maxilla and mandible. The crown and root sizes of these teeth develop linearly up to a certain stage. This starts from initiation of the mineralization phase and continues to completion of the hard tissues, with the incremental deposition at various rates of the enamel, dentine, and cementum (35). According to Nelson and Ash (35), the completion of the crowns of the deciduous central incisors is at 1.5–2.5 months from birth; while for the roots (including the apex closure), this is at 1.5 years after birth. For the lateral incisors,

TABLE 5—*Practical application of the regression equations applied to a randomly chosen male (code: G-231) of real age 13.86 weeks (97 days).*

Location	Tooth	Equation	Estimated Age (weeks)	95% Confidence Interval (weeks) Lower	Upper
Maxilla	Central incisor	1a	14.26	6.88	21.64
	Lateral incisor	2a	13.98	0.52	27.44
	Canine	7a	11.84	1.54	22.14
		8a	8.23	−29.01	45.47
		9a	11.81	−23.75	47.39
		10a	10.03	−28.82	48.86
		11a	9.02	−21.69	39.72
		12a	9.63	−28.98	48.23
Mandible	Central incisor	4a	13.10	1.48	24.73
	Lateral incisor	14b	10.77	0.29	21.26
		15a	14.19	7.10	21.29
		16a	17.44	−13.89	41.86
		17a	13.36	−15.66	42.39
		18a	10.45	−3.98	24.88
		19b	12.93	4.97	32.06
		20b	11.66	−14.54	37.88
	Canine	21a	13.86	6.66	21.05
		22a	9.70	−42.87	62.28
		23a	13.11	−11.56	37.78
		24a	14.17	−7.46	35.81
		25a	14.10	2.82	25.39

Data for age calculation (in weeks):

Maxilla: central incisor: root height, 1.40 mm; lateral incisor: root height, 0.98 mm; canine: mesiodistal width, 5.62 mm; buccolingual width, 3.03; crown height, 4.49 mm; crown thickness, 2.60 mm.

Mandible: central incisor: root height, 1.08 mm; lateral incisor: mesiodistal width, 4.80 mm; buccolingual width, 3.36; crown height, 5.25 mm; crown thickness, 2.90 mm; canine: mesiodistal width, 4.93 mm; buccolingual width, 3.03 mm; crown height, 4.36 mm; crown thickness, 2.50 mm.

the crown is completed at 2.5–3.0 months, and the root again at 1.5 years, while for the canines, the crown is completed at 9 months after birth, and the root at 3.25 years. These data were obtained from living people, mainly through the use of radiographic images. Our own data regarding the completion of the crowns and the initial formation of the roots differ slightly to those of Nelson and Ash (35). According to our analysis here (see Table 3), the initial root formation is earlier for this sample, as this starts for the central incisors at 0.75–1.0 month, for the lateral incisors at 0.75–2.7 months, and for the canines at 6.0–7.30 months after birth.

It is well known that in living people, for a given chronological age, dental age is less variable than bone age (10). However, the immature individuals of the studied sample do not represent a living population, but are instead representative of infant mortality. Thus, small differences in the distributions by age of the sample might have some impact on dental development. Odontometrics has been the subject of numerous investigations to determine the patterns of variability between different teeth, and the relative influence of genetic and environmental factors. Most evidence suggests that the dimensions of the permanent and deciduous tooth crowns are, to a large extent, determined genetically (36). Unfortunately, most studies have not provided estimates of the role of common or family environments, maternal effects, or genotype–environment interactions. Several studies on familial relationships, including twins, siblings, parent–child, and cousins, have shown a significant genetic basis for crown size, with high heritability. This has been reported for permanent (37) and deciduous (38) teeth, where the estimates of heritability for deciduous crown size have ranged from 0.62 to 0.91 (36). However, differences in the quality of the environment during odontogenesis might influence tooth size and morphology, such as maternal health status during pregnancy or differential rates of fetal development. Garn et al. (39) and Seow and Wan (40) demonstrated that children with low birthweight and length as a consequence of maternal and fetal (or gestational) determinants show significantly smaller deciduous crown dimensions, compared to those for normal birth weights and lengths. The sample here was mainly composed of individuals who died in the early stages of childhood (55.7% in the first 3 months), and they might well have lived up under poor health conditions that might have affected the overall tooth dimensions of the crown. Although it would be preferable to have a more balanced age distribution, and greater representation of older children, it is currently impossible to add more identified skeletal material.

Dentition can be examined clinically either by radiographic images and/or by anatomical or dissection studies; however, these methods of data collection are not always equivalent (27). For example, initial cusp tip formation is only visible by direct observation, with mineralization defined slightly earlier on dissection than on radiography (17,27). Another stage of development that presents problems is crown completion, as the initial root formation occurs considerably earlier than true enamel completion on the lingual and labial surfaces of the root; thus, the initial root growth is easily seen directly from an isolated tooth. Aka et al. (32) developed a quantitative method for age estimation that is based on the direct observation of isolated developing deciduous teeth, the measurements of which were used in the present study (i.e., mesiodistal width, buccolingual width, crown height, crown thickness, root height). Although Aka et al. (32) provided high accuracy in their determination of the ages of fetuses and infants, they only evaluated the maxillary and mandibular central incisors. The present study represents an important effort to include the maxillary and mandibular lateral incisors and canines.

According to this method, buccolingual width, crown height, and crown thickness increase with age, as the development proceeds linearly from initial cusp formation, to extend down toward the crown, to the completion of the cingulum. However, the mesiodistal width can only be measured early in the development of a tooth (for incisors, the maximum mesiodistal width is localized in the inicisal third of the crown; in canines, it can be localized lower on the crown). Once the tooth has reached the maximum mesiodistal width, this dimension will remain unchanged during growth and development of the tooth, except in cases where specific changes and disorders of function, pathology, or nutrition have an effect on the normal dimensions of teeth. Thus, the regression equations developed here that use the mesiodistal width as an explanatory variable are limited to the initial period of development of the crown tooth.

Despite the limitations of the age/mortality bias here, the regression equations developed show high correlations with chronological age, with no significant differences between the sexes. The r^2 obtained for each regression equation indicated good fits for most of the equations obtained. The “sex” factor showed statistically significant results ($p < 0.05$) when it was included as an independent variable in a total of seven of the regression equations (5b, 13b, 14b, 15b, 18b, 19b, 20b), which indicates that the development of deciduous teeth is different in boys compared to girls. However, only in three of these equations did the “sex” factor provide an advantage for age estimation over the equations that did not include this factor (Equations 14b, 19b, 20b). It is well established that female dental development is ahead of males when considering the permanent dentition, although these data have been less clear for the deciduous dentition (16,17). Irurita et al. (33) analyzed the same osteological collection with an evaluation of the maximum tooth length, and they defined later initiation of tooth formation for the anterior deciduous teeth in boys in comparison with girls, and a higher tooth growth rate in girls than for boys. However, in an evaluation of the sexual dimorphism in odontometrics from completely formed crowns, Viciano et al. (41) reported no significant differences in any of the analyzed crown measurements for the anterior maxillary and mandibular deciduous teeth (with exception of the buccolingual diameter of maxillary central incisor). The studies of Irurita et al. (33) and Viciano et al. (41) demonstrate that there are differences in the development rate of the anterior deciduous teeth between the sexes from the Granada osteological collection, but when the teeth have completed crown formation, sexual dimorphism in the overall tooth size is not significant. Thus, the generally consistent similarities between the boys and the girls observed in the present study might suggest increased variability of the growth process in the deciduous anterior dentition due to the sex ratio of the sample, which was indeed skewed on the basis of 1.7:1 for the boys.

With identified immature skeletal material remaining rare, and with the potential problems over radiographs of living children (and particularly very young and infant children), there is the important need for the development of methods that cannot otherwise be performed. Thus, despite some of the limitations of the sample used in the present study (e.g., sample size, sex ratio), this metric analysis of the anterior deciduous teeth and the application of regression equations for infant-specific dental-age estimations will provide benefits toward the determination of the age of individuals in cases where newborn infantile teeth are present, and the skeletal remains are decomposed or not particularly well preserved.

Of note, it has been widely demonstrated that different populations can vary in dental development rates and tooth size (41–44), and numerous authors have recommended that only specific methods designed for or tested in similar study populations should be used (28,41). This is relevant because when an odontometric method is applied to a population that differs significantly from the population whose metric data were used to develop the method, the regression equations developed give poor or biased results (45).

Finally, in the inter-observer error analysis, the mean differences were in close agreement, and thus, the different measurement definitions are closely concordant between these different observers.

Final Remarks

Odontometrics represents a rapid and reliable method for the estimation of dental age in infants with an age of up to 3 years. After this age, root apical closure occurs for the deciduous canines and these regression equations developed here cannot be applied. Despite some limitations, this quantitative method to determine the age of infants has several advantages: (i) it is more objective than other methods (e.g., atlas approaches, scoring systems) and does not require experienced technicians; (ii) it can be easily applied to isolated developing deciduous teeth; and (iii) sex does not need to be determined initially.

References

1. Cardoso HFV. Environmental effects on skeletal *versus* dental development: using a documented subadult skeletal sample to test a basic assumption in human osteological research. Am J Phys Anthropol 2007;132:223–33.
2. Molleson T, Cox M, Waldron AH, Whittaker DH. The Spitalfields project, vol. 2—the anthropology, the middling sort. Research report 86. York, U.K.: Council for British Archaeology, 1993.
3. Cardoso HFV. Brief Communication: the collection of identified human skeletons housed at the Bocage Museum (National Museum of Natural History), Lisbon, Portugal. Am J Phys Anthropol 2006;129:173–6.
4. Fazekas IG, Kósa F. Forensic fetal osteology. Budapest, Hungary: Akadémiai Kiadó, 1978.
5. Dayal MR, Kegley ADT, Štrkalj G, Bidmos MA, Kuykendall KL. The history and composition of the Raymond A. Dart collection of human skeletons at the University of the Witwatersrand, Johannesburg, South Africa. Am J Phys Anthropol 2009;140:324–35.
6. Alemán I, Irurita J, Valencia AR, Martínez A, López-Lázaro S, Viciano J, et al. Brief Communication: The Granada osteological collection of identified infants and young children. Am J Phys Anthropol 2012;149:606–10.
7. Gaethofs M, Verdonck A, Carels C, de Zegher F. Delayed dental age in boys with constitutionally delayed puberty. Eur J Orthod 1999;21:711–5.
8. Lehtinen A, Oksa T, Helenius H, Rönning O. Advanced dental maturity in children with juvenile rheumatoid arthritis. Eur J Oral Sci 2000;108:184–8.
9. Thevissen PW, Kvaal SI, Willems G. Ethics in age estimation of unaccompanied minors. J Forensic Odontostomatol 2012;30:84–102.
10. Scheuer L, Black S. Developmental juvenile osteology. London, U.K.: Elsevier Academic Press, 2000.
11. Gilsanz V, Ratib O. Hand bone age: a digital atlas of skeletal maturity. New York, NY: Springer, 2005.
12. Cardoso HFV, Abrantes J, Humphrey LT. Age estimation of immature human skeletal remains from the diaphyseal length of the long bones in the postnatal period. Int J Legal Med 2014;128:809–24.
13. Cardoso HFV, Vandergugten JM, Humphrey LT. Age estimation of immature skeletal remains from the metaphyseal and epiphyseal widths of the long bones in the post-natal period. Am J Phys Anthropol 2017;162:19–35.
14. Carneiro C, Curate F, Cunha E. A method for estimating gestational age of fetal remains based on long bone lengths. Int J Legal Med 2016;130:1333–41.
15. Lewis AB. Comparisons between dental and skeletal ages. Angle Orthod 1991;61:87–92.
16. Demirjian A. Dentition. Human growth. In: Falkner F, Tanner JM, editors. Postnatal growth, 2nd edn. vol. 2. New York, NY: Plenum Press, 1986:269–98.
17. Smith BH. Standards of human tooth formation and dental age assessment. In: Kelley MA, Larsen CS, editors. Advances in dental anthropology. New York, NY: Wiley-Liss, 1991;143–68.
18. Pelsmaekers B, Loos R, Carels C, Derom C, Vlietinck R. The genetic contribution to dental maturation. J Dent Res 1997;76:1337–40.
19. Scott GR, Turner CG 2nd. The anthropology of modern human teeth: dental morphology and its variation in recent human populations. Cambridge, U.K.: Cambridge University Press, 1997.
20. Fereira JI, Fereira AE, Ortega AI. Methods for the analysis of hard dental tissues exposed to high temperatures. Forensic Sci Int 2008;178: 119–24.
21. Schmidt CW. The recovery and study of burned human teeth. In: Schmidt CW, Symes SA, editors. The analysis of burned human remains. London, U.K.: Academic Press, 2008;55–74.
22. Schour L, Massler M. The development of the human dentition. J Am Dent Assoc 1941;28:1153–60.
23. AlQahtani SJ, Hector MP, Liversidge HM. Brief Communication: The London atlas of human tooth development and eruption. Am J Phys Anthropol 2010;142:481–90.
24. Moorrees CF, Fanning EA, Hunt EE Jr. Age variation of formation stages for ten permanent teeth. J Dent Res 1963;42:490–502.
25. Moorrees CF, Fanning EA, Hunt EE Jr. Formation and resorption of three deciduous teeth in children. Am J Phys Anthropol 1963;21:205–13.
26. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol 1973;45:211–27.
27. Liversidge HM, Molleson T. Variation in crown and root formation and eruption of human deciduous teeth. Am J Phys Anthropol 2004;123:172–80.

28. Irurita J, Alemán I, López-Lázaro S, Viciano J, Botella MC. Chronology of the development of the deciduous dentition in Mediterranean population. Forensic Sci Int 2014;240:95–103.
29. Liversidge HM, Dean MC, Molleson TI. Increasing human tooth length between birth and 5.4 years. Am J Phys Anthropol 1993;90:307–13.
30. Cameriere R, Ferrante L, Cingolani M. Age estimation in children by measurement of open apices in teeth. Int J Legal Med 2006;120:49–52.
31. Cameriere R, De Angelis D, Ferrante L, Scarpino F, Cingolani M. Age estimation in children by measurement of open apices in teeth: a European formula. Int J Legal Med 2007;121:449–53.
32. Aka PS, Canturk N, Dagalp R, Yagan M. Age determination from central incisors of fetuses and infants. Forensic Sci Int 2009;184:15–20.
33. Irurita J, Alemán I, Viciano J, De Luca S, Botella MC. Evaluation of the maximum length of deciduous teeth for estimation of the age of infants and young children: proposal of new regression formulas. Int J Legal Med 2014;128:345–52.
34. Fleiss JL. The design and analysis of clinical experiments. New York, NY: Wiley, 1986.
35. Nelson SJ, Ash MM Jr. Wheeler's dental anatomy, physiology, and occlusion, 9th edn. St. Louis, MO: Saunders Elsevier, 2010.
36. Hughes T, Dempsey P, Richards L, Townsend G. Genetic analysis of deciduous tooth size in Australian twins. Arch Oral Biol 2000;45:997–1004.
37. Garn SM, Lewis AB, Walenga AJ. Genetic basis of the crown-size profile pattern. J Dent Res 1968;47:1190.
38. Townsend GC. Heritability of deciduous tooth size in Australian Aboriginals. Am J Phys Anthropol 1980;53:297–300.
39. Garn SM, Osborne RH, McCabe KD. The effect of prenatal factors on crown dimensions. Am J Phys Anthropol 1979;51:665–78.
40. Seow WK, Wan A. A controlled study of the morphometric changes in the primary dentition of pre-term, very-low-birthweight children. J Dent Res 2000;79:63–9.
41. Viciano J, López-Lázaro S, Alemán I. Sex estimation based on deciduous and permanent dentition in a contemporary Spanish population. Am J Phys Anthropol 2013;152:31–43.
42. Holman DJ, Jones RE. Longitudinal analysis of deciduous tooth emergence: II. Parametric survival analysis in Bangladeshi, Guatemalan, Japanese, and Javanese children. Am J Phys Anthropol 1998;105:209–30.
43. Reid DJ, Dean MC. Variation in modern human enamel formation times. J Hum Evol 2008;50:329–46.
44. Jayaraman J, Wong JM, King NM, Roberts GJ. The French-Canadian data set of Demirjian for dental age estimation: a systematic review and meta-analysis. J Forensic Leg Med 2013;20:373–81.
45. Teschler-Nicola M, Prossinger H. Sex determination using tooth dimensions. In: Alt KW, Rösing FW, Teschler-Nicola M, editors. Dental anthropology. Fundamentals, limits and prospects. New York, NY: Springer-Verlag Wien, 1998;479–500.

Additional information and reprint requests:
Joan Viciano, Ph.D.
Operative Unit of Anthropology
Department of Medicine and Ageing Sciences
'G. d'Annunzio' University of Chieti–Pescara
Piazza Trento e Trieste 1
66100 Chieti
Italy
E-mail: joanviciano@gmail.com