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Sex estimation by odontometrics of nonadult human remains from a contemporary Italian sample

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Abstract

Objectives: The objective was to develop an odontometric technique for sex estimation based on dental measurements from adult individuals, and to evaluate its applicability and reliability for diagnosis of sex of nonadult skeletal remains.

Materials and methods: This study was conducted on the permanent dentition of 132 individuals (70 males, 62 females) from the identified human skeletal collection of the Certosa Cemetery (Bologna, Italy) of the University of Bologna. Binary logistic regression equations were developed based on dental measurements of the permanent teeth of the adult individuals, and these equations were subsequently applied to the permanent dentition of nonadult individuals to estimate their sex.

Results: These data show that the canine teeth of both the maxilla and mandible are the most sexually dimorphic teeth in adults, followed by the mandibular second molar, maxillary and mandibular second and first premolars, and mandibular first molar. These data provided correct assignment of sex in 80.4–94.9% of cases, which depended on the measurements used. Of the 26 nonadult individuals of the experimental sample, sex diagnosis was possible for 22, which represented an applicability rate of 84.6% of the individuals. Comparing the sex of these 22 nonadult individuals estimated by odontometrics with the known biological sex, correct assignment was obtained in 90.9% of cases.

Conclusion: As a method of sex estimation, odontometric analysis of permanent dentition can be used successfully for nonadult human skeletal remains in both forensic and archeological contexts.

KEYWORDS

binary logistic regression, odontometry, sexual dimorphism, subadults, tooth size

1 INTRODUCTION

Sex estimation of nonadult human skeletal remains with satisfactory accuracy is a recognized problem in physical anthropology. This represents a challenge in medico-legal assessments, as well as in other studies of both ancient and recent skeletal remains. The problem arises because expression of sex-related skeletal characteristics is mainly due to the changes in hormone levels at puberty. Thus, in individuals who have not yet reached puberty and have not yet matured sexually, the discernment of sexual skeletal characteristics is minimal (Cardoso, 2008; Lewis, 2006).

Estimation of sex of nonadult skeletal remains has been reported, with this most frequently being based on the use of the same skeletal characteristics known to be accurate for sex assessment in adults, as mainly morphological traits of the pelvis (Irurita & Alemán, 2016; Luna, Aranda, & Santos, 2017; Schutkowski, 1993; Sutter, 2003; Vlak,

Roksandic, & Schillaci, 2008; Weaver, 1980) and the cranium (Franklin, Oxnard, O'Higgins, & Dadour, 2007; Irurita & Alemán, 2016; Loth & Henneberg, 2001; Molleson, Cruse, & Mays, 1998; Schutkowski, 1993).

However, as some subjectivity is involved in such descriptive skeletal morphology because of the difficulty to consistently assign a score to a specific feature, these methods have been criticized for high rates of intraexaminer and interexaminer errors (Cardoso & Saunders, 2008; Krishan et al., 2016). To circumvent these complications, studies have been designed to develop further skeletal metric methods for sex estimation (Stull & Godde, 2013; Stull, L'Abbé, & Ousley, 2017). Although these metric methods have been reported to be more repeatable than descriptive morphological methods (Bartlett & Frost, 2008; Ulijaszek & Kerr, 1999), they have proven to be of limited use for accurate sex estimation. Such metric methods depend on the integrity of the skeletal remains under the usual circumstances of the fragmented state of preservation of fragile remains of nonadult individuals recovered in forensic and archeological contexts. In addition, these measurements tend to be population specific.

Odontometrics is a valuable technique for sex estimation, particularly as teeth are often better preserved than bone tissue due to their hardness, durability and resistance to postdepositional processes (Duckworth, 2006; Gouveia, Oliveira Santos, Santos, & Gonçalves, 2017; Schmidt & Symes, 2015). Therefore, teeth are often more represented in human skeletal samples when the bones are in decayed and/or fragmented conditions (Hillson, 1996). Over the last 60 years, following the study of Hunt Jr and Gleiser (1955) about sex estimation from osseous and dental remains of nonadult individuals, analyses have been carried out to determine a reliable method for sex estimation from teeth. Thus, numerous studies have quantified sexually dimorphic differences between males and females through odontometric techniques, with the demonstration that sexual dimorphism results in larger teeth in males than females in permanent dentition (Adams & Pilloud, 2019; Angadi, Hemani, Prabhu, & Acharya, 2013; Capitaneanu, Willems, Jacobs, Fieuws, & Thevissen, 2017; Hassett, 2011; Kazzazi & Kranioti, 2017, 2018; Khamis, Taylor, Malik, & Townsend, 2014; Luna, 2019; Peckmann, Logar, Garrido-Varas, Meek, & Pinto, 2016; Peckmann, Meek, Dilkie, & Mussett, 2015; Shaweesh, 2017; Sonika, Harshaminder, Madhushankari, & Sri Kennath, 2011; Tardivo et al., 2015; Viciano, Alemán, D'Anastasio, Capasso, & Botella, 2011; Viciano, D'Anastasio, & Capasso, 2015; Viciano, López-Lázaro, & Alemán, 2013; Yong et al., 2018; Zorba, Moraitis, Eliopoulos, & Spiliopoulou, 2012; Zorba, Moraitis, & Manolis, 2011; Zorba, Vanna, & Moraitis, 2014) and deciduous teeth (López-Lázaro, Alemán, Viciano, Irurita, & Botella, 2018; Paknahad, Vossoughi, & Ahmadi Zeydabadi, 2016; Shankar et al., 2013; Singh, Bhatia, Sood, & Sharma, 2017; Viciano et al., 2013; Ządzińska, Karasińska, Jedrychowska-Dańska, Watala, & Witas, 2008).

Although the deciduous dentition shows significant sexual dimorphism (De Vito & Saunders, 1990; Viciano et al., 2013), its application for sex estimation in nonadult individuals has been relatively limited, for three main reasons: (a) the low levels of minerals in the deciduous dentition mean that it is frequently in a worse state of conservation in comparison to the permanent dentition (De Menezes Oliveira et al., 2010; Wilson & Beynon, 1989); (b) the early age at which the deciduous teeth exfoliate means that they are recovered less frequently (Hillson, 1996); and (c) the typical small sample size of deciduous teeth in osteological collections significantly reduces the statistical power required for the development of reliable sex diagnosis methods (Garcia-Godoy, Michelen, & Townsend, 1985; Ządzińska et al., 2008).

On the basis of these limitations, odontometric techniques for sex estimation developed on the permanent dentition might be applied not only to adult individuals, but also to nonadult individuals. As the permanent teeth develop early and remain unchanged throughout life once they have formed (except in cases where specific changes and disorders of function, pathology or nutrition have an effect on the normal size of teeth), any effects on sexual dimorphism in the permanent teeth that can be observed in adults should also apply to nonadult individuals (Cardoso, 2008). Thus, to estimate sex using odontometrics, the permanent dentition from adult individuals can be used to develop the equations, which can then be applied to the permanent dentition of nonadult individuals. This methodology has been used with satisfactory results (Aris, Nystrom, & Craig-Atkins, 2018; Beyer-Olsen & Alexandersen, 1995; Okazaki, 2005; Rösing, 1983; Thompson, 2013; Viciano et al., 2011, 2015). However, all of these studies except Aris et al. (2018) were carried out using skeletal samples of archeological origins. Here the biological sex of the adult and/or nonadult individuals was unknown, and the sex was previously estimated by descriptive methods using pelvic and/or cranial features. Therefore, in these studies there remains uncertainty of the reliability of the skeletal sex estimation, as it first depends on the integrity and state of preservation of the bone remains. The reliability of the odontometric technique developed using the sample of adult individuals is thus may have been compromised. Moreover, as the biological sex of the nonadult individuals is not known, reliable comparisons with the estimated odontometric sex cannot be made to establish the rate of correct sex assignment. In contrast, Aris et al. (2018) used an osteological collection of identified adult and nonadult individuals to develop the odontometric technique for sex estimation. However, their study was limited to the analysis of only the maxillary first molar, which greatly reduces the applicability of the odontometric technique when other teeth are available.

With this background, the present study aimed to evaluate the complete permanent dentition of an identified osteological collection to develop an odontometric technique for sex estimation, and evaluate its applicability and reliability for sex estimation of nonadult individuals.

2 | MATERIALS AND METHODS

2.1 | Study sample

This study was based on the identified human skeletal collection of the Certosa Cemetery (Bologna, Italy). These individuals are housed at the Museum of Anthropology of the Alma Mater Studiorum University of Bologna. Reliable antemortem information obtained from the cemetery archives and death certificates provided detailed data on

their sex, place and date of birth and death, date of burial, occupation, and cause of death, among other information (Belcastro et al., 2017).

The study sample consisted of 132 individuals (70 males, 62 females). The age at death of these individuals was from 8 years to 87 years (mean age at death, 38.93 ± 18.61 years). Figure 1a shows the distribution by age at death and by sex of the sample. The deaths occurred during the six decades from 1898 to 1944, with 82.6% of the deaths before 1933, which means that this sample largely dates from the first third of the 20th century. Figure 1b shows the distribution by decade of death. According to the ages at death, the individuals were divided into two age groups following conventional anthropological categories (modified from Vallois, 1960): nonadult individuals (from birth to 20 years), and adult individuals (≥21 years).

The sample was divided into two subsamples: (a) the *reference subsample*, which comprised 106 adult individuals aged from 21 years to 87 years (53 males, 53 females); and (ii) the *experimental subsample*, which comprised 26 nonadult individuals aged from 8 years to 20 years (17 males, 9 females; Table 1). The *reference subsample* provided the odontometric data used for the binary logistic regression analysis. The equations calculated from these data were then applied to the *experimental subsample* to estimate the sex.

2.2 | Inclusion criteria and measurement procedure

Prior to the collection of the different dental measurements, all of the teeth were examined for various limiting factors that might negatively affect the subsequent odontometric analysis. The limiting factors for exclusion from the analysis included: (a) pathological processes, such as caries, hypoplastic defects and traumatic injuries; (b) dental anomalies, such as anomalies in number, volume and shape; (c) taphonomic/diagenetic effects; and (d) notably wear. For the crown measurements (see details below), the mesiodistal diameter was measured for the incisors to a maximum stage of 3 of incisal wear (according to Smith, 1984), and for the canines, premolars and molars to a maximum stage of 4 of incisal/occlusal wear. Buccolingual and diagonal crown diameters of the molars were taken for teeth to a maximum stage of 5 of occlusal wear.

After evaluation of the diverse limiting factors and exclusion of the measurements affected for each tooth examined, the crown and cervical measurements of the permanent dentition were collected. Four measurements were taken for incisors, canines and premolars, and eight measurements for molars, which for the "ideal" permanent dentition provided 88 measurements for both dental arches for each individual (i.e., those with all of the teeth present and without any limiting factors).

All of the measurements were taken with digital dental calipers (Masel Orthodontics Inc., USA) to an accuracy of 0.01 mm. Measurements were taken on either the left or right side, depending on the tooth availability. If both contralateral teeth were available, the mean of the measurements were calculated. In the nonadult individuals in the *experimental subsample*, the measurements were only taken for the teeth that had a completely formed crown and showed initial root development. All of the crown and cervical measurements were taken according to the definitions of Hillson, FitzGerald, and Flinn (2005) (using the modifications outlined by Aubry, 2014), except for the mesiodistal cervical diameter, which was measured following the criteria of Vodanović, Demo, Njemirovskij, Keros, & Brkić (2007). For the dental crown, the measurements collected were maximum

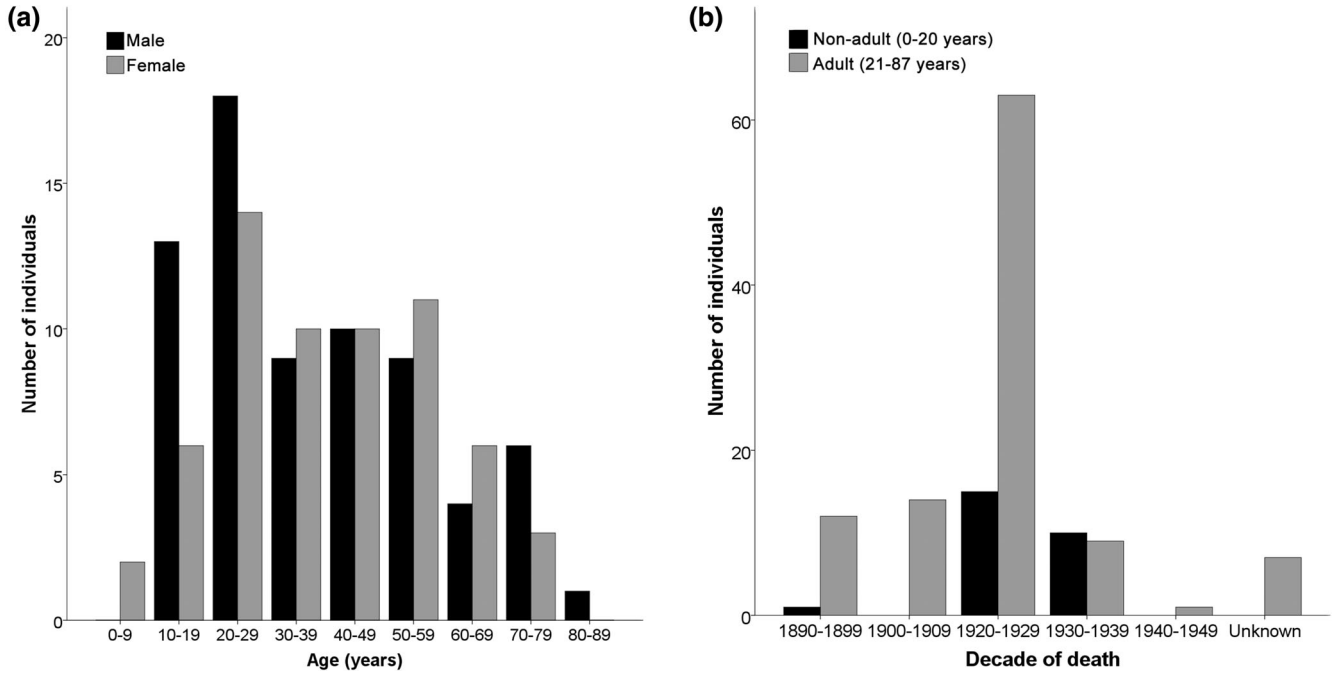

FIGURE 1 Distributions of the entire sample of 132 individuals by sex and age at death (a) and by decade of death (b)

TABLE 1 Distribution of the two subsamples (*reference subsample* and *experimental subsample*) according to sex and age group

	Nonadult individuals			Adult individuals			
Subsample	**Birth–6 years**	**7–12 years**	**13–20 years**	**21–40 years**	**41–60 years**	**>60 years**	**TOTAL**
Reference subsample							
Male	0	0	0	24	19	10	53
Female	0	0	0	24	20	9	53
Subtotal	0	0	0	48	39	19	106
Experimental subsample							
Male	0	2	15	0	0	0	17
Female	0	2	7	0	0	0	9
Subtotal	0	4	22	0	0	0	26

Note: Modified from Vallois, 1960.

mesiodistal crown diameter (MDcrn), maximum buccolingual crown diameter (BLcrn), mesiobuccal–distolingual crown diameter (MBDLcrn), and mesiolingual–distobuccal crown diameter (MLDBcrn). At the level of the cement–enamel junction, the measurements collected were mesiodistal cervical diameter (MDcerv), buccolingual cervical diameter (BLcerv), mesiobuccal–distolingual cervical diameter (MBDLcerv), and mesiolingual–distobuccal cervical diameter (MLDBcerv). The further coding of the teeth defined them also as molar (M3/2/1), premolar (PM2/1), canine (C), or incisor (I2/1).

To evaluate the intraexaminer error, 25 randomly selected individuals from the original sample (17 adults, 8 nonadult individuals) were remeasured at different times by the principal examiner (J.V.; highly experienced in odontometrics). Moreover, to assess interexaminer error, a further 13 randomly selected individuals (8 adults, 5 nonadult individuals) were re-measured by a second examiner (C.T.; previous knowledge in dental morphology; trained in tooth measurements by the principal examiner over 3 months prior to the present study using a separate dental sample). In both situations, the same set of calipers was used, with a minimum period of 2 weeks and a maximum of 1 month between the two measurements. As both contralateral teeth were measured when present in these individuals, the numbers in Tables 2 and 3 do not represent the number of individuals studied, but rather the total number of teeth measured.

2.3 | Statistical analysis

Data were subjected to several statistical analyses using the statistical package for social sciences software IBM SPSS Statistics 22.0 (IBM Corp., 2013) for Windows.

The data were first assessed as the pooled samples for normality using Kolmogorov–Smirnov one-sample tests, and for homogeneity of variance using Levene tests, with $p \leq .05$ defining statistical significance. These analyses characterized the samples, allowed detection of any major errors in the database collection or in the data processing, and helped with the data distribution and homogeneity of variance. This last information was necessary for acceptance/rejection of assumptions to apply later tests.

Before any statistical analysis was carried out, the differences between the means in all of the dimensions collected at the two different times were quantified to examine possible intraexaminer and interexaminer error. To determine the level of agreement between repeated measurements collected by the same examiner and by different examiners, the intraclass correlation coefficient (ICC) was calculated. The ICC is an index that reflects both the degree of correlation and the agreement between the measurements. As the ICC is a flexible statistical model that can be applied to many different circumstances, it comprises a total of 10 different variants (Koo & Li, 2016; Perinetti, 2018). According to the nature of these data and the composition of the group of examiners, the ICC calculations were performed using the "two-way mixed-effects absolute-agreement" model, for both the intraexaminer and interexaminer errors. To determine the degree of agreement for a given set of data, the ICC calculated was compared to the criteria proposed by Koo and Li (2016), which establishes four levels of qualitative assessment: ICC <0.5 indicates "poor" reliability; ICC from 0.5 to 0.75 indicates "moderate" reliability; ICC from 0.75 to 0.9 indicates "good" reliability; and ICC >0.9 indicates "excellent" reliability.

Next, for both the *reference* and *experimental subsamples*, descriptive analysis was performed to calculate the sample size and the mean and standard deviation for each measurement. Measurements of the *reference* and *experimental subsamples* were tested using independent Student's *t*-tests (where normality and homoscedasticity were fulfilled) or nonparametric Mann–Whitney *U*-tests (for the other cases).

For the *reference subsample*, independent Student's *t*-tests were performed to explore potential significant differences between means of males and females when assumptions for normality and homoscedasticity were fulfilled ($p > .05$), and nonparametric Mann–Whitney *U*-tests when they were not. As the multiple statistical tests were performed on the same dataset, the Bonferroni correction was applied to the *P* estimates. Thus, the level of significance was set at $p = .05/88 = .00057$ ($p = .05/N$, where N represents the number of different variables tested). The magnitudes of the sexual differences

TABLE 2 Comparisons of differences in the means for maxi ary and mandibu ar denta metrics between repeated measurements co ected by the principa examiner (i.e., intraexaminer error ana ysis)

	Maxillary teeth								Mandibular teeth							
		Measurement 1		Measurement 2						Measurement 1		Measurement 2				
Tooth measurement	*n*	Mean	SD	Mean	SD	Diff	ICC	Strength of agreement	*n*	Mean	SD	Mean	SD	Diff	ICC	Strength of agreement
Denta crown																
MDcrnM3	18	8.916	0.786	8.918	0.820	−0.003	0.988	Exce ent	11	10.780	1.305	10.742	1.228	0.038	0.996	Exce ent
MDcrnM2	23	9.524	0.688	9.502	0.663	0.023	0.983	Exce ent	16	10.764	0.662	10.726	0.618	0.039	0.988	Exce ent
MDcrnM1	23	9.931	0.746	9.971	0.755	−0.040	0.984	Exce ent	22	10.967	1.113	10.916	1.091	0.052	0.996	Exce ent
MDcrnPM2	20	6.877	0.454	6.754	0.443	0.123	0.986	Exce ent	29	7.359	0.311	7.346	0.311	0.014	0.962	Exce ent
MDcrnPM1	19	7.135	0.324	7.129	0.334	0.006	0.960	Exce ent	27	7.126	0.414	7.124	0.426	0.002	0.968	Exce ent
MDcrnC	22	7.776	0.331	7.793	0.347	−0.017	0.975	Exce ent	15	6.891	0.452	6.850	0.430	0.041	0.989	Exce ent
MDcrn 2	20	6.459	0.631	6.419	0.607	0.040	0.979	Exce ent	19	6.153	0.413	6.177	0.447	−0.025	0.979	Exce ent
MDcrn 1	7	8.327	0.413	8.344	0.423	−0.017	0.977	Exce ent	15	5.584	0.577	5.601	0.586	−0.017	0.985	Exce ent
BLcrnM3	16	11.339	1.128	11.255	1.087	0.084	0.996	Exce ent	12	9.959	1.077	9.986	1.107	−0.028	0.995	Exce ent
BLcrnM2	31	11.741	0.772	11.735	0.770	0.007	0.992	Exce ent	26	10.043	0.755	10.054	0.737	−0.011	0.987	Exce ent
BLcrnM1	28	11.603	0.701	11.549	0.703	0.054	0.984	Exce ent	25	10.322	0.999	10.275	0.916	0.047	0.991	Exce ent
BLcrnPM2	25	8.839	0.645	8.858	0.661	−0.018	0.988	Exce ent	29	8.237	0.541	8.258	0.586	−0.021	0.982	Exce ent
BLcrnPM1	24	8.728	0.571	8.735	0.592	−0.008	0.982	Exce ent	26	7.839	0.560	7.824	0.580	0.015	0.986	Exce ent
BLcrnC	23	8.329	0.614	8.333	0.628	−0.004	0.986	Exce ent	20	8.015	0.627	7.981	0.657	0.034	0.993	Exce ent
BLcrn 2	20	6.383	0.532	6.326	0.504	0.057	0.986	Exce ent	25	6.648	0.427	6.622	0.461	0.026	0.981	Exce ent
BLcrn 1	22	7.577	0.359	7.559	0.374	0.018	0.966	Exce ent	22	6.056	0.540	6.044	0.521	0.012	0.979	Exce ent
MBDLcrnM3	16	11.422	1.205	11.416	1.156	0.006	0.978	Exce ent	12	10.876	1.339	10.862	1.291	0.014	0.995	Exce ent
MBDLcrnM2	31	11.987	0.818	11.963	0.805	0.025	0.993	Exce ent	25	11.539	0.762	11.506	0.781	0.032	0.993	Exce ent
MBDLcrnM1	27	12.411	0.710	12.364	0.717	0.047	0.991	Exce ent	23	11.921	0.779	11.808	0.767	0.113	0.989	Exce ent
MLDBcrnM3	16	9.751	1.101	9.766	1.128	−0.017	0.992	Exce ent	10	11.092	1.047	11.068	1.004	0.024	0.990	Exce ent
MLDBcrnM2	31	10.645	0.860	10.646	0.833	−0.001	0.992	Exce ent	25	11.161	0.800	11.104	0.784	0.058	0.974	Exce ent
MLDBcrnM1	27	11.059	0.804	10.988	0.782	0.070	0.992	Exce ent	23	11.430	0.739	11.344	0.728	0.086	0.988	Exce ent
Denta cervix																
MDcervM3	15	7.163	0.919	7.139	0.923	0.025	0.991	Exce ent	5	9.626	1.236	9.652	1.167	−0.026	0.997	Exce ent
MDcervM2	33	7.906	0.530	7.908	0.523	−0.002	0.978	Exce ent	21	9.224	0.772	9.216	0.762	0.008	0.989	Exce ent
MDcervM1	27	7.966	0.467	7.976	0.461	−0.009	0.974	Exce ent	26	9.022	0.567	9.044	0.578	−0.023	0.982	Exce ent
MDcervPM2	26	4.707	0.449	4.716	0.415	−0.009	0.962	Exce ent	32	5.114	0.424	5.141	0.421	−0.027	0.964	Exce ent
MDcervPM1	23	4.720	0.544	4.760	0.527	−0.040	0.986	Exce ent	34	4.961	0.534	4.976	0.512	−0.015	0.980	Exce ent

(Continues)

TABLE 2 (Continued)

	Maxillary teeth								Mandibular teeth							
		Measurement 1		Measurement 2						Measurement 1		Measurement 2				
Tooth measurement	*n*	Mean	SD	Mean	SD	Diff	ICC	Strength of agreement	*n*	Mean	SD	Mean	SD	Diff	ICC	Strength of agreement
MDcervC	27	5.945	0.637	5.930	0.614	0.015	0.982	Exce ent	33	5.510	0.785	5.532	0.724	−0.021	0.987	Exce ent
MDcerv 2	24	4.693	0.515	4.700	0.503	−0.007	0.980	Exce ent	32	3.780	0.279	3.779	0.298	0.001	0.942	Exce ent
MDcerv 1	22	6.849	0.503	6.793	0.518	0.056	0.994	Exce ent	28	3.473	0.227	3.492	0.232	−0.020	0.945	Exce ent
BLcervM3	17	10.508	1.081	10.502	1.048	0.006	0.996	Exce ent	10	9.220	1.032	9.222	1.027	−0.002	0.995	Exce ent
BLcervM2	33	11.222	0.947	11.199	0.947	0.023	0.994	Exce ent	30	9.104	0.849	9.158	0.865	−0.054	0.993	Exce ent
BLcervM1	24	10.969	0.739	10.939	0.703	0.030	0.990	Exce ent	27	9.231	0.706	9.190	0.718	0.041	0.986	Exce ent
BLcervPM2	26	8.189	0.973	8.182	0.986	0.007	0.997	Exce ent	34	7.332	0.690	7.321	0.710	0.011	0.987	Exce ent
BLcervPM1	26	7.853	0.969	7.804	0.979	0.049	0.995	Exce ent	29	7.073	0.655	7.041	0.640	0.033	0.989	Exce ent
BLcervC	27	7.973	0.665	7.943	0.698	0.030	0.986	Exce ent	32	7.902	0.617	7.885	0.670	0.017	0.988	Exce ent
BLcerv 2	24	5.896	0.745	5.843	0.685	0.053	0.990	Exce ent	29	6.341	0.437	6.274	0.399	0.067	0.970	Exce ent
BLcerv 1	20	6.763	0.509	6.719	0.492	0.044	0.971	Exce ent	26	5.771	0.537	5.729	0.522	0.043	0.969	Exce ent
MBDLcervM3	16	10.696	1.038	10.648	1.037	0.048	0.995	Exce ent	9	9.818	1.149	9.814	1.172	0.003	0.994	Exce ent
MBDLcervM2	33	11.529	0.935	11.498	0.936	0.031	0.993	Exce ent	29	10.362	0.911	10.329	0.883	0.033	0.992	Exce ent
MBDLcervM1	25	11.577	0.741	11.541	0.752	0.036	0.985	Exce ent	26	10.835	0.735	10.826	0.750	0.009	0.991	Exce ent
MLDBcervM3	17	9.027	0.769	8.985	0.728	0.042	0.985	Exce ent	3	10.810	1.637	10.800	1.594	0.010	0.999	Exce ent
MLDBcervM2	33	10.044	0.814	10.055	0.841	−0.011	0.988	Exce ent	18	10.201	1.041	10.141	1.034	0.060	0.995	Exce ent
MLDBcervM1	24	10.112	0.681	10.085	0.652	0.027	0.984	Exce ent	27	9.974	0.782	9.930	0.786	0.044	0.986	Exce ent

Abbreviations: BL, bucco ingua C, canine cerv, cervica crn, crown *Diff*, mean difference between repeated measurements of principa examiner , incisor CC, intrac ass corre ation coefficient M, mo ar MBDL, mesiobucca –disto ingua MD, mesiodista MLDB, mesio ingua –distobucca *n*, number of teeth PM, premo ar SD, standard deviation.

TABLE 3 Comparisons of differences in the means for maxi ary and mandibu ar denta metrics between repeated measurements co ected by the principa and the secondary examiner (i.e., interexaminer error ana ysis)

	Maxillary teeth								Mandibular teeth							
		Examiner 1		Examiner 2						Examiner 1		Examiner 2				
Tooth measurement	*n*	Mean	SD	Mean	SD	Diff	ICC	Strength of agreement	*n*	Mean	SD	Mean	SD	Diff	ICC	Strength of agreement
Denta crown																
MDcrnM3	10	8.615	0.781	8.457	0.855	0.158	0.943	Exce ent	5	11.178	0.866	10.936	0.824	0.242	0.978	Exce ent
MDcrnM2	11	9.320	0.482	9.316	0.435	0.005	0.893	Good	5	10.430	0.699	10.344	0.542	0.086	0.944	Exce ent
MDcrnM1	8	10.021	0.453	10.115	0.454	−0.094	0.846	Good	12	11.435	0.672	11.211	0.615	0.224	0.981	Exce ent
MDcrnPM2	11	6.851	0.462	6.610	0.461	0.240	0.937	Exce ent	15	7.358	0.358	7.117	0.436	0.241	0.836	Good
MDcrnPM1	10	7.210	0.382	7.044	0.478	0.166	0.920	Exce ent	12	7.086	0.435	6.963	0.581	0.122	0.795	Good
MDcrnC	9	7.718	0.386	7.652	0.441	0.066	0.903	Exce ent	10	6.991	0.471	6.842	0.486	0.149	0.937	Exce ent
MDcrn 2	11	6.871	0.485	6.669	0.554	0.202	0.927	Exce ent	11	6.173	0.533	6.190	0.575	−0.017	0.982	Exce ent
MDcrn 1	4	8.598	0.270	8.550	0.366	0.048	0.890	Good	9	5.804	0.651	5.768	0.604	0.037	0.970	Exce ent
BLcrnM3	12	11.220	0.979	10.970	0.772	0.250	0.945	Exce ent	5	10.178	0.338	10.290	0.219	−0.112	0.884	Good
BLcrnM2	15	11.710	0.967	11.158	0.757	0.552	0.882	Good	15	10.045	0.766	10.018	0.673	0.026	0.951	Exce ent
BLcrnM1	13	11.805	0.693	11.573	0.781	0.231	0.948	Exce ent	16	10.642	0.696	10.448	0.514	0.194	0.886	Good
BLcrnPM2	13	9.005	0.716	9.022	0.790	−0.017	0.987	Exce ent	16	8.270	0.609	8.303	0.723	−0.033	0.966	Exce ent
BLcrnPM1	14	8.833	0.528	8.872	0.584	−0.039	0.974	Exce ent	14	7.916	0.622	7.731	0.657	0.184	0.888	Good
BLcrnC	11	8.467	0.756	8.438	0.804	0.029	0.991	Exce ent	13	8.163	0.716	8.019	0.857	0.144	0.954	Exce ent
BLcrn 2	11	6.382	0.643	6.203	0.557	0.178	0.951	Exce ent	12	6.661	0.565	6.546	0.663	0.115	0.953	Exce ent
BLcrn 1	7	7.384	0.240	7.380	0.229	0.004	0.900	Exce ent	10	6.259	0.717	6.194	0.634	0.065	0.964	Exce ent
MBDLcrnM3	12	11.346	1.044	10.878	1.169	0.468	0.938	Exce ent	5	11.400	0.796	11.296	0.610	0.104	0.883	Good
MBDLcrnM2	12	12.113	0.812	11.682	0.804	0.432	0.907	Exce ent	11	11.486	0.819	11.142	0.682	0.344	0.973	Exce ent
MBDLcrnM1	13	12.720	0.459	12.431	0.423	0.289	0.924	Exce ent	16	12.079	0.712	11.761	0.736	0.318	0.961	Exce ent
MLDBcrnM3	12	9.579	1.143	9.817	0.643	−0.238	0.779	Good	6	11.597	0.533	11.362	0.648	0.235	0.833	Good
MLDBcrnM2	13	10.619	0.954	10.400	0.772	0.218	0.961	Exce ent	12	11.298	0.728	11.013	0.542	0.286	0.946	Exce ent
MLDBcrnM1	8	10.970	0.574	10.848	0.418	0.123	0.945	Exce ent	15	11.590	0.627	11.313	0.535	0.277	0.929	Exce ent
Denta cervix																
MDcervM3	11	7.017	0.975	6.881	0.840	0.136	0.947	Exce ent	2	10.265	1.393	10.295	1.280	−0.030	0.996	Exce ent
MDcervM2	18	7.892	0.556	7.928	0.515	−0.036	0.835	Good	8	8.848	0.463	8.818	0.533	0.030	0.897	Good
MDcervM1	14	8.100	0.573	8.218	0.632	−0.118	0.864	Good	16	9.094	0.586	9.170	0.648	−0.076	0.904	Exce ent
MDcervPM2	12	4.729	0.460	4.838	0.332	−0.109	0.886	Good	17	5.268	0.597	5.262	0.396	0.006	0.804	Good
MDcervPM1	13	4.762	0.607	4.903	0.562	−0.142	0.798	Good	15	5.036	0.689	5.078	0.457	−0.042	0.879	Good

(Continues)

TABLE 3 (Continued)

	Maxillary teeth								Mandibular teeth							
		Examiner 1		Examiner 2						Examiner 1		Examiner 2				
Tooth measurement	*n*	Mean	SD	Mean	SD	Diff	ICC	Strength of agreement	*n*	Mean	SD	Mean	SD	Diff	ICC	Strength of agreement
MDcervC	14	5.826	0.738	5.697	0.547	0.129	0.931	Exce ent	13	5.167	0.952	5.234	0.785	−0.067	0.965	Exce ent
MDcerv 2	14	4.851	0.561	4.823	0.547	0.028	0.975	Exce ent	16	3.769	0.249	3.859	0.284	−0.089	0.823	Good
MDcerv 1	12	6.913	0.409	6.675	0.458	0.238	0.949	Exce ent	14	3.487	0.172	3.542	0.217	−0.055	0.848	Good
BLcervM3	10	10.431	1.139	10.296	1.083	0.135	0.945	Exce ent	5	9.580	0.804	9.556	0.835	0.024	0.987	Exce ent
BLcervM2	15	11.529	1.075	11.356	0.937	0.173	0.952	Exce ent	17	9.197	0.826	9.228	0.867	−0.032	0.957	Exce ent
BLcervM1	13	11.111	0.833	11.068	0.756	0.043	0.980	Exce ent	17	9.193	0.783	9.327	0.885	−0.134	0.790	Good
BLcervPM2	15	8.227	0.965	8.201	0.984	0.026	0.993	Exce ent	18	7.420	0.805	7.291	0.953	0.129	0.894	Good
BLcervPM1	16	8.178	0.707	8.013	0.814	0.165	0.978	Exce ent	14	7.167	0.773	6.976	0.732	0.191	0.935	Exce ent
BLcervC	18	8.071	0.746	7.956	0.891	0.114	0.954	Exce ent	14	7.999	0.809	7.916	0.959	0.082	0.983	Exce ent
BLcerv 2	13	6.013	0.900	5.855	0.722	0.158	0.971	Exce ent	15	6.408	0.518	6.217	0.473	0.191	0.955	Exce ent
BLcerv 1	11	6.935	0.556	6.691	0.632	0.244	0.887	Good	11	5.997	0.611	5.842	0.531	0.155	0.982	Exce ent
MBDLcervM3	10	10.534	1.017	10.264	1.107	0.270	0.955	Exce ent	4	10.008	0.791	10.045	0.930	−0.038	0.971	Exce ent
MBDLcervM2	17	11.664	1.088	11.557	1.075	0.107	0.983	Exce ent	16	10.414	0.987	10.382	0.991	0.033	0.991	Exce ent
MBDLcervM1	14	11.766	0.778	11.688	0.793	0.079	0.989	Exce ent	17	10.841	0.756	10.802	0.755	0.039	0.983	Exce ent
MLDBcervM3	10	8.984	0.941	8.994	0.576	−0.010	0.807	Good	—	—	—	—	—	—	—	—
MLDBcervM2	16	9.943	0.728	9.876	0.952	0.067	0.910	Exce ent	9	10.113	1.198	10.006	1.198	0.108	0.999	Exce ent
MLDBcervM1	12	10.138	0.706	9.943	0.549	0.196	0.901	Exce ent	13	9.929	0.845	9.910	0.788	0.018	0.977	Exce ent

Abbreviations: BL, bucco ingua C, canine cerv, cervica crn, crown *Diff*, mean difference between repeated measurements between principa and secondary examiner , incisor CC, intrac ass corre ation coefficient M, mo ar MBDL, mesiobucca –disto ingua MD, mesiodista MLDB, mesio ingua –distobucca *n*, number of teeth PM, premo ar SD, standard deviation.

were also computed as indicators to describe the degree of differences between males and females, by calculation of the percentage of sexual dimorphism (%SD) using the Equation (1), as given by Garn, Lewis, Swindler, and Kerewsky (1967):

$$\%SD = \left(\frac{\bar{X}_m}{\bar{X}_f} \quad 1\right) \times 100 \tag{1}$$

where $\bar{X}_m$ is the mean of the male tooth measurements and $\bar{X}_f$ is the mean of the female tooth measurements. A positive result indicates larger tooth size in males, and a negative result indicates larger tooth size in females. The dimorphic ranking was then tabulated for both dental arches by allotting the first rank to the measurements with the highest percentage of sexual dimorphism, and the last rank to the those with the lowest percentage.

Finally, binary logistic regression analyses were performed for the *reference subsample* to create a set of equations for sex discrimination. Separated binary logistic regression analyses were conducted for the maxillary and mandibular teeth. To maximize the applicability of the technique for forensic and archeological cases, the equations were calculated for a maximum combination of two measurements. Binary logistic regression analysis was performed instead of the commonly used discriminant function analysis for metric sex estimation methods, as the former is more robust and usually provides better analysis with more relaxed data requirements (Albanese, 2003; Pohar, Blas, & Turk, 2004), and was therefore better suited to data in the present study. Binary logistic regression analysis produces coefficients for each measurement included in a model, as well as a constant. To use this information to estimate the sex of an individual, a logit (L_i) must first be calculated according to Equation (2):

$$L_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \tag{2}$$

where L_i is a linear function of the independent variable(s) X_n, β_0 is the constant, β_1 is the first coefficient, X_1 is the first measurement, and so on. Once L_i is calculated, it can be used to calculate the probability of the female sex (p_f) using Equation (3):

$$p_f = \frac{1}{1 + e^{-L_i}} \tag{3}$$

The probability of male sex is simply $p_m = 1 \quad p_f$. In practice, if p_f is >.5, the individual is most likely to be female, whereas if p_f is <.5, the individual is most likely to be male. In the present context, the closer p_f is to 1, the greater the probability that the individual is female, and the closer p_f is to 0, the greater the probability that the individual is male. When p_f is close to the sectioning point of .5, the probability of correct classification of an individual is lower, because this is the area of overlap between the two groups. To determine the fit of an equation to the data, a goodness-of-fit statistic was calculated, as the 2 log likelihood (2LL). The −2LL is a measure of how much unexplained information there is after the binary logistic regression equation has been fitted, whereby low values of −2LL indicate better fitting to the equations.

3 | RESULTS

3.1 | Intraexaminer and interexaminer error analyses

Following the selection criteria outlined above, the total number of teeth that comprised the random subsample for intraexaminer error analysis was 472 (225 maxillary, 247 mandibular), and the total number of teeth for the interexaminer error analysis was 278 (136 maxillary, 142 mandibular).

In the intraexaminer error analysis (Table 2), the maxillary and mandibular teeth generally showed similar ICCs. For the maxilla, the ICCs for the dental crown were 0.960–0.996 (i.e., with "excellent" agreement), with similar ICCs for the dental cervix, as 0.962–0.997 (i.e., "excellent"). For the mandible, the ICCs for the dental crown were 0.962–0.996 (i.e., "excellent"), with slightly lower ICCs for the dental cervix, as 0.942–0.999 (i.e., "excellent"). In addition, the differences between the means of the repeated measurements were 0.001–0.123 mm for the maxillary teeth, and 0.002–0.113 mm for the mandibular teeth.

For the interexaminer error analysis (Table 3), for the maxilla, the ICCs for the dental crown were 0.779–0.991 (i.e., "good" to "excellent"), with slightly higher ICCs for the dental cervix, as 0.798–0.993 (i.e., "good" to "excellent"). The data were similar for the mandible, where the ICCs for the dental crown were 0.795–0.982 (i.e., "good" to "excellent"), with slightly higher ICCs for the dental cervix, as 0.790–0.999 (i.e., "good" to "excellent"). The differences between the means of the repeated measurements were from 0.004 to 0.552 mm for the maxillary teeth, and from 0.006 to 0.344 mm for the mandibular teeth. In the interexaminer analysis, the ICC for the mesiolingual–distobuccal cervical diameter for the third maxillary molar could not be calculated, as it was not possible to take this measurement in these randomly selected individuals.

3.2 | Differences between adult and nonadult individuals

The data from the Student's *t*-tests and Mann–Whitney *U*-tests did not define any statistically significant differences between the means of the *reference subsample* and the *experimental subsample* across all of the 88 measurements ($p > .05$), as 44 for the maxillary teeth and 44 for the mandibular teeth (Table 4).

3.3 | Univariate sexual dimorphism

Table 5 gives the data for the percentages of sexual dimorphism for each dental measurement for the *reference subsample*, together with

TABLE 4 Descriptive statistics for maxi ary and mandibu ar teeth measurements and Student *t*-test and Mann–Whitney *U*-test resu ts for eva uation of differences between the *reference subsample* and the *experimental subsample*

	Maxillary teeth									Mandibular teeth								
	Reference subsample			Experimental subsample						Reference subsample			Experimental subsample					
Tooth measurement	*n*	Mean	*SD*	*n*	Mean	*SD*	*t*	*U*	*p*	*n*	Mean	*SD*	*n*	Mean	*SD*	*t*	*U*	*p*
Denta crown																		
MDcrnM3	40	8.865	0.803	10	8.712	0.711	–	176.00	.560	45	10.636	0.954	11	10.955	0.868	−1.008	–	.318
MDcrnM2	63	9.509	0.626	15	9.361	0.598	0.830	–	.409	47	10.822	0.779	13	10.899	0.583	–	278.00	.622
MDcrnM1	51	10.174	0.663	20	10.035	0.614	0.815	–	.418	50	11.227	0.641	16	11.231	0.599	−0.018	–	.986
MDcrnPM2	50	6.918	0.453	14	6.834	0.338	0.642	–	.523	62	7.331	0.421	13	7.189	0.380	1.125	–	.264
MDcrnPM1	56	7.042	0.403	16	7.041	0.380	0.008		.994	58	7.008	6.971	15	6.971	0.456	0.297	–	.767
MDcrnC	46	7.665	0.407	12	7.693	0.317	–	273.50	.962	36	6.885	0.470	14	6.906	0.457	−0.138	–	.891
MDcrn 2	44	6.577	0.569	13	6.514	0.735	0.327	–	.745	45	6.057	0.467	15	6.136	0.535	−0.547	–	.587
MDcrn 1	24	8.411	0.344	7	8.344	0.422	0.430	–	.671	39	5.442	0.435	14	5.445	0.447	−0.027	–	.979
BLcrnM3	38	11.019	0.905	10	10.847	0.934	0.532	–	.597	55	9.713	0.701	12	9.735	0.525	−0.100	–	.920
BLcrnM2	70	11.512	0.855	19	11.420	0.651	0.438	–	.663	66	10.114	0.731	15	9.945	0.387	–	458.50	.657
BLcrnM1	56	11.447	0.650	21	11.306	0.555	0.881	–	.381	61	10.380	0.817	18	10.302	0.495	0.385	–	.701
BLcrnPM2	61	9.130	0.691	17	9.121	0.521	0.050	–	.961	67	8.259	0.684	14	8.174	0.487	–	388.50	.315
BLcrnPM1	60	8.868	0.570	15	8.816	0.514	0.322	–	.749	53	7.774	0.471	14	7.719	0.369	0.406	–	.686
BLcrnC	49	8.379	0.659	12	8.241	0.532	0.669	–	.506	37	7.853	0.789	12	7.860	0.553	−0.026	–	.980
BLcrn 2	43	6.390	0.496	10	6.181	0.537	1.189	–	.240	48	6.527	0.393	14	6.498	0.396	0.238	–	.813
BLcrn 1	39	7.426	0.496	8	7.339	0.385	0.469	–	.642	41	6.053	0.444	12	6.039	0.420	0.103	–	.918
MBDLcrnM3	37	11.235	1.056	10	10.949	1.038	–	154.00	.420	53	10.745	0.890	12	10.875	0.775	−0.465	–	.643
MBDLcrnM2	65	11.861	0.830	20	11.652	0.777	0.995	–	.323	68	11.407	0.780	17	11.318	0.527	0.441	–	.660
MBDLcrnM1	58	12.265	0.593	21	12.144	0.550	0.816	–	.417	58	11.866	0.654	19	11.725	0.476	0.864	–	.390
MLDBcrnM3	41	10.010	0.769	10	9.794	0.748	–	184.50	.627	47	10.845	0.999	10	10.948	0.896	–	221.00	.769
MLDBcrnM2	69	10.620	0.826	19	10.450	0.654	0.823	–	.413	70	11.188	0.834	16	11.139	0.631	0.220	–	.827
MLDBcrnM1	59	11.221	0.665	21	11.028	0.544	–	552.50	.464	61	11.402	0.691	19	11.335	0.610	0.375	–	.709
Denta cervix																		
MDcervM3	37	7.290	0.728	8	6.844	0.693	1.580	–	.121	18	9.161	0.995	6	8.968	0.727	0.433	–	.669
MDcervM2	59	7.734	0.492	20	7.762	0.490	−0.219	–	.828	49	9.214	0.727	13	9.181	0.607	–	316.50	.972
MDcervM1	54	8.042	0.498	22	7.949	0.439	–	566.00	.748	54	9.122	0.575	19	9.047	0.506	0.505	–	.615
MDcervPM2	59	4.879	0.635	19	4.661	0.308	–	474.00	.314	74	5.198	0.475	19	5.087	0.417	–	643.50	.571
MDcervPM1	65	4.828	0.498	19	4.762	0.549	0.496	–	.621	77	4.899	0.410	20	4.774	0.437	–	619.00	.178
MDcervC	70	5.883	0.569	17	5.773	0.560	0.720	–	.473	80	5.477	0.570	21	5.420	0.561	0.405	–	.686

TABLE 4 (Continued)

	Maxillary teeth									Mandibular teeth								
	Reference subsample			Experimental subsample						Reference subsample			Experimental subsample					
Tooth measurement	*n*	Mean	*SD*	*n*	Mean	*SD*	*t*	*U*	*p*	*n*	Mean	*SD*	*n*	Mean	*SD*	*t*	*U*	*p*
MDcerv 2	59	4.756	0.536	16	4.711	0.586	0.293	–	.771	71	3.870	0.331	20	3.868	0.334	–	701.50	.935
MDcerv 1	63	6.448	0.652	14	6.422	0.477	–	408.50	.668	60	3.482	0.222	18	3.452	0.238	0.505	–	.615
BLcervM3	37	10.332	1.427	8	10.038	0.896	–	124.50	.485	36	8.981	0.739	7	8.918	0.734	0.206	–	.838
BLcervM2	64	11.034	0.870	19	10.918	0.715	–	576.00	.729	58	9.122	0.818	14	8.986	0.658	0.579	–	.564
BLcervM1	55	10.810	0.742	21	10.634	0.763	0.915	–	.363	51	9.160	0.698	18	9.156	0.540	–	418.50	.580
BLcervPM2	61	8.286	0.797	16	8.240	0.695	0.213	–	.832	70	7.444	0.629	15	7.334	0.483	0.642	–	.523
BLcervPM1	63	8.093	0.639	17	7.938	0.785	0.842	–	.402	63	6.944	0.561	17	6.907	0.493	–	524.50	.897
BLcervC	68	8.008	0.749	15	7.914	0.703	–	487.50	.790	71	7.812	0.704	18	7.874	0.682	–	604.00	.721
BLcerv 2	59	5.885	0.641	13	5.701	0.588	–	314.50	.312	67	6.255	0.567	16	6.231	0.397	0.160	–	.874
BLcerv 1	58	6.540	0.528	11	6.478	0.263	–	313.50	.928	51	5.735	0.480	15	5.700	0.464	–	365.00	.789
MBDLcervM3	39	10.546	1.124	8	10.078	0.856	–	104.00	.141	41	9.437	0.879	9	9.434	0.803	0.007	–	.995
MBDLcervM2	66	11.328	0.888	20	11.153	0.752	0.799	–	.427	59	10.261	0.934	15	10.298	0.581	−0.146	–	.885
MBDLcervM1	54	11.506	0.694	20	11.397	0.588	–	508.00	.697	50	10.705	0.753	18	10.641	0.588	0.326	–	.745
MLDBcervM3	35	8.913	0.895	9	8.739	0.624	0.550	–	.585	25	9.827	0.972	4	9.441	0.573	–	41.00	.569
MLDBcervM2	65	9.898	0.732	19	9.881	0.688	0.091	–	.928	48	10.143	0.937	11	9.975	0.719	–	259.00	.922
MLDBcervM1	53	10.134	0.734	20	10.004	0.538	0.722	–	.473	52	9.997	0.745	18	9.919	0.696	0.391	–	.697

Abbreviations: BL, bucco ingua C, canine cerv, cervica crn, crown , incisor MBDL, mesiobucca –disto ingua MD, mesiodista MLDB, mesio ingua –distobucca M, mo ar PM, premo ar *n*, number of individua s *p*, *p*–va ue (none of the va ues are statistica y significant at $p \leq .05$ eve) *SD*, standard deviation *t*, Student's *t*-test *U*, Mann–Whitney *U*-test.

TABLE 5 Descriptive statistics for the maxi ary and mandibu ar teeth measurements and sexua dimorphism, *t*-test, and *U*-test resu ts for the mean differences between the sexes

	Maxillary teeth											Mandibular teeth										
	Males			Females								Males			Females							
Tooth measurement	*n*	Mean	SD	*n*	Mean	SD	*t*	*U*	*p*	%SD	Rank	*n*	Mean	SD	*n*	Mean	SD	*t*	*U*	*p*	%SD	Rank
Denta crown																						
MDcrnM3	21	8.915	0.794	19	8.810	0.831	0.407	–	.686	1.192	42	24	10.907	0.798	21	10.325	1.039	2.128	–	**.039**	5.637	24
MDcrnM2	30	9.703	0.695	33	9.332	0.504	2.439	–	**.018**	3.976	32	24	11.062	0.736	23	10.572	0.757	2.251	–	**.029**	4.635	33
MDcrnM1	24	10.402	0.628	27	9.972	0.637	2.425	–	**.019**	4.312	29	27	11.321	0.667	23	11.117	0.605	1.125	–	.266	1.835	42
MDcrnPM2	24	7.052	0.353	26	6.794	0.504	2.079	–	**.043**	3.797	34	31	7.425	0.396	31	7.237	0.429	1.791	–	.078	2.598	40
MDcrnPM1	29	7.132	0.416	27	6.944	0.372	1.774	–	.082	2.707	40	30	7.056	0.420	28	6.957	0.421	0.890	–	.377	1.423	44
MDcrnC	20	7.817	0.435	26	7.549	0.350	2.317	–	**.025**	3.550	36	16	7.034	0.503	20	6.766	0.417	1.748	–	.089	3.961	35
MDcrn 2	19	6.699	0.613	25	6.485	0.527	1.244	–	.220	3.300	37	19	6.112	0.559	26	6.017	0.394	0.670	–	.506	1.579	43
MDcrn 1	12	8.468	0.841	12	8.353	0.291	0.816	–	.424	1.377	41	17	5.508	0.404	22	5.390	0.459	0.839	–	.407	2.189	41
BLcrnM3	22	11.263	0.868	16	10.684	0.872	2.026	–	**.050**	5.419	20	33	9.917	0.724	22	9.408	0.549	2.803	–	**.007**	5.410	28
BLcrnM2	37	11.838	0.841	33	11.147	0.721	3.668	–	**.000**[a]	6.199	12	39	10.372	0.773	27	9.741	0.466	2.972	–	**.004**	6.478	21
BLcrnM1	30	11.708	0.605	26	11.146	0.574	3.545	–	**.001**	5.042	22	37	10.616	0.746	24	10.017	0.803	–	252.00	**.005**	5.980	23
BLcrnPM2	30	9.390	0.693	31	8.878	0.598	3.097	–	**.003**	5.767	15	35	8.399	0.808	32	8.106	0.483	3.631	–	**.001**[a]	3.615	36
BLcrnPM1	31	9.050	0.612	29	8.673	0.454	2.691	–	**.009**	4.347	28	27	7.982	0.449	26	7.559	0.395	–	180.00	**.002**	5.596	25
BLcrnC	25	8.757	0.650	24	7.984	0.381	5.042	–	**.000**[a]	9.682	7	16	8.394	0.648	21	7.442	0.628	4.510	–	**.000**[a]	12.792	2
BLcrn 2	16	6.608	0.610	27	6.261	0.362	–	145.00	.074	5.542	18	23	6.645	0.430	25	6.418	0.327	2.072	–	**.044**	3.537	37
BLcrn 1	19	7.549	0.599	20	7.310	0.352	–	132.50	.106	3.269	38	19	6.258	0.389	22	5.876	0.417	3.017	–	**.004**	6.501	20
MBDLcrnM3	21	11.677	0.936	16	10.654	0.935	3.294	–	**.002**	9.602	8	31	10.968	0.880	22	10.430	0.825	2.250	–	**.029**	5.158	30
MBDLcrnM2	34	12.128	0.850	31	11.568	0.711	2.866	–	**.002**	4.841	24	40	11.693	0.764	28	10.998	0.610	4.002	–	**.000**[a]	6.319	22
MBDLcrnM1	31	12.486	0.482	27	12.013	0.615	3.280	–	**.002**	3.937	33	34	12.080	0.633	24	11.563	0.566	3.195	–	**.002**	4.471	34
MLDBcrnM3	24	10.192	0.720	17	9.754	0.785	1.846	–	.073	4.490	26	27	11.095	0.923	20	10.508	1.021	2.061	–	**.045**	5.586	26
MLDBcrnM2	35	10.838	0.919	34	10.395	0.658	2.294	–	**.025**	4.262	30	40	11.498	0.788	30	10.774	0.715	3.955	–	**.000**[a]	6.720	18
MLDBcrnM1	32	11.483	0.606	27	10.909	0.602	3.638	–	**.001**	5.262	21	38	11.516	0.671	23	11.213	0.697	1.680	–	.098	2.702	39
Denta cervix																						
MDcervM3	20	7.387	0.661	17	7.175	0.805	0.881	–	.385	2.955	39	11	9.443	0.926	7	8.717	1.000	1.572	–	.135	8.329	8
MDcervM2	31	7.879	0.557	28	7.575	0.354	2.467	–	**.017**	4.013	31	27	9.532	0.725	22	8.822	0.516	3.865	–	**.000**[a]	8.048	10
MDcervM1	33	8.177	0.552	21	7.830	0.303	–	211.50	**.017**	4.432	27	34	9.297	0.543	20	8.824	0.512	3.162	–	**.003**	5.360	29
MDcervPM2	30	5.160	0.740	29	4.590	0.309	–	183.50	**.000**[a]	12.418	2	40	5.429	0.491	34	4.926	0.270	–	239.50	**.000**[a]	10.211	5
MDcervPM1	35	5.080	0.417	30	4.535	0.422	5.225	–	**.000**[a]	12.018	3	43	5.038	0.428	34	4.723	0.312	–	409.00	**.001**[a]	6.669	19
MDcervC	38	6.179	0.514	32	5.532	0.413	5.722	–	**.000**[a]	11.696	4	47	5.767	0.471	33	5.063	0.428	6.830	–	**.000**[a]	13.905	1
MDcerv 2	30	4.880	0.574	29	4.627	0.468	1.850	–	.069	5.468	19	37	3.954	0.377	34	3.778	0.247	–	439.50	**.029**	4.659	32

TABLE 5 (Continued)

	Maxillary teeth											Mandibular teeth										
	Males			Females								Males			Females							
Tooth measurement	*n*	Mean	SD	*n*	Mean	SD	*t*	*U*	*p*	%SD	Rank	*n*	Mean	SD	*n*	Mean	SD	*t*	*U*	*p*	%SD	Rank
MDcerv 1	34	6.447	0.763	29	6.449	0.504	−0.013	—	.989	−0.031	44	32	3.534	0.230	28	3.424	0.201	1.966	—	.054	3.213	38
BLcervM3	20	10.740	1.537	17	9.852	1.152	1.957	—	.058	9.013	9	24	9.202	0.729	12	8.537	0.549	2.782	—	**.009**	7.790	12
BLcervM2	35	11.353	0.887	29	10.650	0.685	3.487	—	**.001**	6.601	10	34	9.378	0.936	24	8.759	0.408	—	185.00	**.000**[a]	7.067	16
BLcervM1	32	10.976	0.826	23	10.578	0.543	2.020	—	**.048**	3.763	35	31	9.418	0.694	20	8.759	0.408	3.692	—	**.001**[a]	7.524	14
BLcervPM2	31	8.666	0.849	30	7.894	0.505	4.298	—	**.000**[a]	9.780	6	37	7.714	0.652	33	7.143	0.444	—	305.50	**.000**[a]	7.994	11
BLcervPM1	33	8.314	0.738	30	7.850	0.394	—	227.50	**.000**[a]	5.911	14	35	7.171	0.622	28	6.659	0.289	—	219.00	**.000**[a]	7.689	13
BLcervC	34	8.479	0.708	34	7.537	0.424	—	140.00	**.000**[a]	12.498	1	38	8.221	0.695	33	7.353	0.332	—	130.50	**.000**[a]	11.805	3
BLcerv 2	29	6.212	0.674	30	5.569	0.414	—	190.00	**.000**[a]	11.546	5	35	6.400	0.677	32	6.097	0.363	—	336.50	**.005**	4.970	31
BLcerv 1	29	6.720	0.624	29	6.360	0.333	—	266.00	**.016**	5.660	16	25	5.966	0.511	26	5.514	0.325	—	148.00	**.001**	8.197	9
MBDLcervM3	23	10.801	1.367	16	10.179	0.864	1.608	—	.116	6.111	13	27	9.721	0.908	14	8.886	0.487	—	76.50	**.002**	9.397	7
MBDLcervM2	37	11.637	0.915	29	10.933	0.683	3.456	—	**.001**	6.439	11	34	10.695	0.878	25	9.672	0.647	4.917	—	**.000**[a]	10.577	4
MBDLcervM1	31	11.739	0.703	23	11.191	0.552	3.093	—	**.003**	4.897	23	30	11.004	0.740	20	10.257	0.522	3.912	—	**.000**[a]	7.283	15
MLDBcervM3	19	8.937	1.016	16	8.886	0.759	0.166	—	.869	0.574	43	17	9.995	1.025	8	9.472	0.791	1.271	—	.216	5.522	27
MLDBcervM2	34	10.107	0.791	31	9.669	0.592	2.508	—	**.015**	4.530	25	27	10.554	0.984	21	9.615	0.534	—	107.50	**.000**[a]	9.766	6
MLDBcervM1	32	10.354	0.749	21	9.800	0.579	2.869	—	**.006**	5.653	17	32	10.255	0.714	20	9.585	0.605	3.485	—	**.001**	6.990	17

Note: BL, bucco ingua C, canine cerv, cervica crn, crown , incisor M, mo ar MBDL, mesiobucca –disto ingua MD, mesiodista MLDB, mesio ingua –distobucca *n*, number of individua s *p*, *p*–va ue (va ues statistica y significant at $p \leq .05$ are in **bold**) PM, premo ar Rank, ranking of sexua dimorphism *SD*, standard deviation *t*, Student's *t*-test *U*, Mann–Whitney *U*-test %SD, percentage of sexua dimorphism.
[a]$p \leq .00057$ (Bonferroni corrected significance).

the rankings according to magnitude, for both of the dental arches. These percentages of sexual dimorphism ranged from 0.03–12.50% for the maxillary teeth, and from 1.42–13.91% for the mandibular teeth (negative values indicate that means for females exceeded those for males, positive values show the reverse). The buccolingual cervical diameter of the canine (BLcervC') showed the greatest sexual dimorphism for the maxillary dentition, whereas the mesiodistal cervical diameter of the canine (MDcervC,) showed the greatest sexual dimorphism for the mandibular dentition.

Considering all of the measurements pooled by tooth and calculation of the mean, the greatest percentage of sexual dimorphism in the maxilla was shown by the canine (C'; $\%SD_{mean}$ = 9.36%), followed by the second premolar (PM^2; $\%SD_{mean}$ = 7.94%), the lateral incisor (I^2; $\%SD_{mean}$ = 6.46%), and the first premolar (PM^1; $\%SD_{mean}$ = 6.25%). For the mandible, the greatest percentage of sexual dimorphism was shown by the canine (C,; $\%SD_{mean}$ = 10.62%), followed by the second molar (M_2; $\%SD_{mean}$ = 7.45%), the third molar (M_3; $\%SD_{mean}$ = 6.60%) and the second premolar (PM_2; $\%SD_{mean}$ = 6.11%). In addition, it should be emphasized that the measurements collected at the cervical level showed higher percentage of sexual dimorphism than those collected at the level of the dental crown ($\%SD_{mean}$ = 7.25% vs. 4.70%; for all maxillary and mandibular measurements pooled).

Table 5 also shows the sample sizes, means and standard deviations, *t*-value, *U*-value and the degree of significance of the differences between the males and females for all of the dental measurements for the *reference subsample*. In the maxilla, 31 of the 44 measurements collected showed higher means in the males compared to the females, and in the mandible, 34 of the 44 measurements showed higher means in the males compared to the females. These differences were statistically significant at $p \leq .05$, and 25 of them (maxilla, 9; mandible, 16) were significant after Bonferroni correction, at $p \leq .00057$ (see Section 2.3 for details). There were no significant differences in the crown diameters of the maxillary central and lateral incisors (i.e., $MDcrnI^1$, $BLcrnI^1$, $MDcrnI^2$, $BLcrnI^2$), and in any analyzed diameter at the cervical level of the maxillary third molar (i.e., $MDcervM^3$, $BLcervM^3$, $MBDLcervM^3$, $MLDBcervM^3$). There was one measurement ($MDcervI^1$) that showed females with higher values than males, but this did not reach statistical significance.

Considering the dentition as a whole, the most sexually dimorphic teeth that showed statistical significance were the canines in both maxilla and mandible (C', C,), as represented by the mesiodistal and buccolingual diameters of the crown and cervix, followed by the mandibular second molar (M_2), represented by the mesiodistal, buccolingual and diagonal diameters of the crown and cervix. Next came the maxillary and mandibular second premolars (PM^2, PM_2), the maxillary and mandibular first premolars (PM^1, PM_1) and the mandibular first molar (M_1).

3.4 | Binary logistic regression analysis

The logit equations and their allocation accuracies are given in Table 6. Equations with a discriminant power <80% were excluded, and only the logit equations in which a minimum of 30 cases were used for their construction are shown.

It can be seen here that the correct allocation accuracy was from 80.0 to 100% in the females, and from 80.0 to 95.0% in the males. Therefore, the females were classified more accurately than the males for all of the logit equations. For the pooled sexes, the overall correct allocation accuracy was from 80.4 to 94.9%. Moreover, the correct allocation accuracy provided by the different logit equations was a little lower for the maxillary teeth (80.4–88.9%) than for the mandibular teeth (80.9–94.9%).

When the 40 logit equations obtained were analyzed together, this showed that the canine was the best predictor of sex in this sample, as this appeared in 33 of the 40 logit equations (maxillary teeth, 8/11; mandibular teeth, 25/29). Two of these logit equations are a combination of measurements from the same canine (i.e., L_3, L_4), while the remaining are a combination of the canine with measurements from other teeth (i.e., L_2, L_5–L_9, L_{12}–L_{36}). On the other hand, it should be emphasized that the dental cervical region was a good predictor of sex. Eighteen of the logit equations use only cervical measurements, compared with 22 equations that used a cervical measurement in combination with a crown measurement.

The following example illustrates briefly the methodological procedure used here to calculate and interpret the logit equations developed. In a hypothetical forensic/archeological case to estimate the sex of a skeletal individual, only a maxillary canine was recovered that showed moderate/severe incisal wear. As a result, only the mesiodistal and buccolingual cervical diameters could be measured. The mesiodistal cervical diameter was 6.17 mm, and the buccolingual cervical diameter was 8.36 mm. The sex can be estimated if logit equation L_4 listed in Table 6 is applied, as follows:

$$L_4 = 30.205 - 1.797\,(6.17) - 2.494\,(8.36) = -1.73233 \qquad (4)$$

The result of 1.73233 can be input into the following Equation (5) to calculate the probability of female sex (p_f):

$$p_f = \frac{1}{1 + e^{-(-1.73233)}} = .15029 \qquad (5)$$

This value is below the sectioning point of .5; thus, the p_f value indicates that there is a 15.03% probability that the individual is female. Therefore, there is an 84.97% probability that the individual is male ($p_m = 1 \quad p_f = 1 \quad .15029 = .84971$).

3.5 | Odontometric sex estimation of nonadult remains

The set of logit equations created from the *reference subsample* was then applied to the available permanent dentition of the nonadult individuals of the same population (i.e., *experimental subsample*) to estimate the sex. As the multiple logit equations were often applied to

TABLE 6 Binary logistic regression equations and assessment of the fit of each logit equation[a]

Dentition	Logit equation[b]	N	−2LL	Female correct		Male correct		Total
				n/N	%	n/N	%	
Maxillary teeth								
Central incisor second molar	L_1 26.710 + 0.694(BLcervI^1) 2.770 (MBDLcervM^2)	41	39.427	17/21	81.0	16/20	80.0	80.5
Lateral incisor canine	L_2 23.192 + 1.979(MDcervI^2) 4.050(BLcervC')	45	29.787	24/25	96.0	16/20	80.0	88.9
Canine	L_3 35.659 + 2.427(BLcrnC') 7.120(BLcervC')	44	30.357	22/23	95.7	17/21	81.0	88.6
	L_4 30.205 1.797(MDcervC') 2.494(BLcervC')	62	47.903	24/30	80.0	26/32	81.3	80.6
Canine first premolar	L_5 27.983 4.671(MDcervC') 0.061 (MDcrnPM^1)	43	34.383	19/22	86.4	17/21	81.0	83.7
	L_6 33.920 3.763(MDcervC') 1.348(BLcrnPM^1)	50	39.340	20/24	83.3	21/26	80.8	82.0
Canine second premolar	L_7 37.979 4.997(MDcervC') 1.158 (MDcrnPM^2)	43	26.533	21/23	91.3	17/20	85.0	88.4
	L_8 31.959 3.159(MDcervC') 1.455(BLcrnPM^2)	51	38.947	21/26	80.8	20/25	80.0	80.4
	L_9 33.332 2.778(BLcervC') 1.356(BLcervPM^2)	53	38.662	23/26	88.5	22/27	81.5	84.9
First premolar	L_{10} 15.773 + 0.108(BLcrnPM^1) 3.456 (MDcervPM^1)	52	51.245	22/26	84.6	21/26	80.8	82.7
Second premolar second molar	L_{11} 38.713 0.382(BLcrnPM^2) 3.109 (MBDLcervM^2)	45	37.600	18/22	81.8	20/23	87.0	84.4
Mandibular teeth								
Central incisor canine	L_{12} 26.362 + 1.737(MDcervI$_1$) 4.176(BLcervC,)	50	39.396	24/25	96.0	21/25	84.0	90.0
	L_{13} 29.124 1.199(BLcervI$_1$) 4.113(MDcervC,)	47	35.145	19/23	82.6	20/24	83.3	83.0
	L_{14} 54.844 + 3.282(BLcervI$_1$) 9.103(BLcervC,)	44	25.269	22/24	91.7	17/20	85.0	88.6
Lateral incisor canine	L_{15} 20.509 + 1.275(MDcrnI$_2$) 5.157(MDcervC,)	41	30.188	19/22	86.4	16/19	84.2	85.4
	L_{16} 19.444 0.116(BLcrnI$_2$) 3.446(MDcervC,)	42	37.073	16/20	80.0	19/22	86.4	83.3
	L_{17} 155.373 + 35.050(BLcrnI$_2$) 49.751 (BLcervC,)	39	7.787	18/19	94.7	19/20	95.0	94.9
	L_{18} 29.602 + 0.886(MDcervI$_2$) 4.276(BLcervC,)	59	47.724	25/29	86.2	25/30	83.3	84.7
	L_{19} 20.413 + 0.392(BLcervI$_2$) 4.232(MDcervC,)	60	46.255	23/27	85.2	30/33	90.9	88.3
	L_{20} 30.172 + 3.572(BLcervI$_2$) 6.823(BLcervC,)	58	38.730	26/28	92.9	26/30	86.7	89.7
Canine first premolar	L_{21} 24.520 3.264(MDcervC,) 1.017 (BLcervPM$_1$)	58	44.933	22/27	81.5	25/31	80.6	81.0
	L_{22} 27.091 5.229(BLcervC,) + 1.874 (MDcrnPM$_1$)	47	35.207	23/24	95.8	19/23	82.6	89.4
	L_{23} 67.561 13.020(BLcervC,) + 4.267 (BLcrnPM$_1$)	44	14.681	22/23	95.7	19/21	90.5	93.2
	L_{24} 38.655 4.780(BLcervC,) 0.419 (MDcervPM$_1$)	61	44.926	25/29	86.2	27/32	84.4	85.2
	L_{25} 42.036 7.321(BLcervC,) + 2.074 (BLcervPM$_1$)	56	32.643	23/26	88.5	25/30	83.3	85.7
Canine second premolar	L_{26} 26.776 4.861(BLcervC,) + 1.472 (MDcrnPM$_2$)	49	36.115	23/25	92.0	20/24	83.3	87.8
	L_{27} 23.240 6.642(BLcervC,) + 3.409(BLcrnPM$_2$)	54	32.975	25/26	96.2	25/28	89.3	92.6
	L_{28} 38.013 3.313(BLcervC,) 2.451 (MDcervPM$_2$)	59	42.830	26/29	89.7	24/30	80.0	84.7
	L_{29} 30.917 5.234(BLcervC,) + 1.275 (BLcervPM$_2$)	59	44.744	25/27	92.6	26/32	81.3	86.4
Canine second molar	L_{30} 27.206 3.618(MDcervC,) 0.907 (BLcervM$_2$)	49	38.198	16/20	80.0	26/29	89.7	85.7
	L_{31} 33.053 3.050(MDcervC,) 1.694 (MBDLcervM$_2$)	47	34.183	16/19	84.2	23/28	82.1	83.0

(Continues)

TABLE 6 (Continued)

Dentition	Logit equation[b]	*N*	−2LL	Female correct *n/N*	Female correct %	Male correct *n/N*	Male correct %	Total
	L_{32} 41.979 5.415(BLcervC,) 0.051 (MLDBcrnM$_2$)	47	34.319	17/21	81.0	21/26	80.8	80.9
	L_{33} 61.962 6.393(BLcervC,) 1.296 (MBDLcervM$_2$)	42	25.485	16/18	88.9	21/23	87.5	88.1
Canine third molar	L_{34} 27.443 3.598(MDcervC,) 0.871(BLcrnM$_3$)	43	32.491	14/17	82.4	22/26	84.6	83.7
	L_{35} 32.163 3.716(BLcervC,) 0.385(BLcrnM$_3$)	39	31.930	17/18	94.4	18/21	85.7	89.7
	L_{36} 33.364 4.553(BLcervC,) + 0.163 (MBDLcrnM$_3$)	39	29.506	19/19	100.0	17/20	85.0	92.3
Second premolar second molar	L_{37} 21.490 + 0.083(BLcrnPM$_2$) 2.189 (MBDLcervM$_2$)	42	38.827	16/19	84.2	21/23	91.3	88.1
First molar second molar	L_{38} 32.113 + 0.074(BLcrnM$_1$) 3.265 (MBDLcervM$_2$)	43	32.876	14/17	82.4	23/26	88.5	86.0
	L_{39} 29.705 + 0.524(MBDLcrnM$_1$) 3.521 (MBDLcervM$_2$)	42	32.288	15/18	83.3	22/24	91.7	88.1
Second molar	L_{40} 22.520 0.055(MLDBcrnM$_2$) 2.173 (MBDLcervM$_2$)	57	53.525	20/25	80.0	29/32	90.6	86.0

Abbreviations: 2LL, 2 log likelihood value; *n*, indicates the number of individuals correctly classified compared with the total of individuals used for the classification; *N*, indicates the total number of individuals used to develop the logit equations.
[a]Only logit equations with minimum of 30 cases were used for their construction, and only those with correct allocation rates >80% are presented.
[b]See Section 3.4 for example of application of a binary logistic regression equation to estimate sex.

a single individual, the following criteria were implemented to deal with conflicting sex estimates. The sex was assigned when one of the following criterions was met, while if none of them were met, the sex was assigned as uncertain:

Criterion 1. One or more estimates of the same group without any other conflicting estimates, with at least one estimate with a probability of group membership ≥80%.

Criterion 2. A probability of group membership for any estimate ≥90%, and a probability of group membership for any conflicting estimate ≤85%.

Criterion 3. The number of estimates for a given group with a probability of membership ≥80% was ≥50% higher than the conflicting estimates (i.e., the number of estimates for a given group with a probability of membership ≥80% is more than twice the conflicting estimates).

Table S1 shows the complete results for the sex assignment of each individual based on the odontometric analysis. Table 7 summarizes the data for the sex estimation for each nonadult individual, along with the comparisons with the known biological sex.

Sex was assigned for 22 of the 26 nonadult individuals using odontometrics (Figure 2). This represents an applicability rate of 84.6% of the individuals. Within these 22 nonadult individuals, 12 were classified as male (54.5%; aged 14–20 years) and 10 as female (45.5%; aged 8–20 years). For four nonadult individuals (15.4%; individuals 024F, 039M, 081M, 142M; aged between 9 and 15 years; Table 7), it was possible to collect several measurements of their available teeth, but sex could not be assigned as none of the logit equations developed in this study could be applied.

Comparison of the sex of the 22 nonadult individuals estimated by odontometrics with the known biological sex showed matches in 20 cases (90.9%), and mismatches in two cases (9.1%).

4 | DISCUSSION

Overall, dental measurements that showed the greatest percentages of sexual dimorphism clearly tended to show statistically significant differences between the two sexes. The present study shows that the canines in both the maxilla and mandible (i.e., C′, C,) were the teeth with the greatest sexual dimorphism, with larger values that were statistically significant in males compared to females. The canines also appeared in 33 out of the 40 logit equations developed, and provided percentages of correct sex assignment of 80.4–94.9% in combination with measurements from the other teeth. The canines were followed by the mandibular second molar (M_2), the maxillary and mandibular second premolars (PM^2, PM_2), the maxillary and mandibular first premolars (PM^1, PM_1), and the mandibular first molar (M_1). These data are consistent with the findings of previous studies on the greater sexual dimorphism of the canines (Acharya & Mainali, 2007; Adams & Pilloud, 2019; Angadi et al., 2013; Capitaneanu et al., 2017; De Angelis et al., 2015; Flohr, Kierdorf, & Kierdorf, 2016; Gonçalves, Granja, Cardoso, & de Carvalho, 2014; Hassett, 2011; Işcan & Kedici, 2003; Kazzazi & Kranioti, 2018; Khamis et al., 2014;

TABLE 7 Summary of the comparisons of sex assignment by odontometrics and biological sex for the *experimental subsample*

Individual	Age (years)	Biological sex	Odontometric sex[a]	Sex assignment match
011M	17	Male	Male	Match
023F	8	Female	Female	Match
024F	9	Female	[b]	
025F	18	Female	Female	Match
029M	19	Male	Female	Mismatch
039F	17	Female	Female	Match
039M	11	Male	[b]	
043M	18	Male	Male	Match
046F	16	Female	Female	Match
050M	16	Male	Male	Match
051M	20	Male	Male	Match
065M	15	Male	Male	Match
068F	18	Female	Female	Match
069M	14	Male	Male	Match
070M	20	Male	Male	Match
081M	11	Male	[b]	
091F	20	Female	Female	Match
098F	18	Female	Female	Match
099F	18	Female	Female	Match
099M	19	Male	Male	Match
110M	20	Male	Female	Mismatch
114M	18	Male	Male	Match
133M	19	Male	Male	Match
140M	20	Male	Male	Match
142M	15	Male	[b]	
165M	19	Male	Male	Match

[a]The final odontometric sex assignment was based on the criteria described in Section 3.5.
[b]None of the logit equations developed in this study could be applied.

Luna, 2019; Martins Filho, Lopez-Capp, Biazevic, & Michel-Crosato,-2016; Pereira, Bernardo, Pestana, Santos, & de Mendonça, 2010; Shaweesh, 2017; Tardivo et al., 2015; Thompson, 2013; Viciano et al., 2011, 2015, 2013; Zorba et al., 2011), and on the sexual dimorphism of both maxillary and mandibular first and second premolars (Adams & Pilloud, 2019; Kazzazi & Kranioti, 2018; Shaweesh, 2017; Yong et al., 2018; Zorba et al., 2011) and mandibular first and second molars (Acharya & Mainali, 2007; Adams & Pilloud, 2019; Angadi et al., 2013; Aris et al., 2018; Kazzazi & Kranioti, 2018; Martins Filho et al., 2016; Peckmann et al., 2015; Tuttösí & Cardoso, 2015; Viciano et al., 2015, 2013; Zorba et al., 2012, 2011). Moreover, several crown and cervical measurements of the maxillary and mandibular incisors (i.e., I^1, I_1, I^2, I_2) and third molars (i.e., M^3, M_3) also showed significant differences between males and females in the present study, and this finding is consistent with other studies (Acharya & Mainali, 2007; Adams & Pilloud, 2019; Ateş, Karaman, Işcan, & Erdem, 2006; Condon et al., 2011; Kazzazi & Kranioti, 2018; Peckmann et al., 2016, 2015; Staka, Asllani-Hoxha, & Bimbashi, 2016; Viciano et al., 2015, 2013). Measurements of the incisors and the third molars were particularly effective for sex estimation in combination with measurements from other teeth, such as the canines and the second molars, providing correct sex assignment of 80.5–94.9%.

The main concern in the present study was the possibility that mortality bias would affect the odontometrics of the permanent dentition. If this were the case, the sexual dimorphism of dental metrics presented by adult and nonadult individuals would be different, and therefore, would not be comparable across these individuals. The individuals studied here do not represent a single population, but are instead representative of mortality. Thus, the mortality bias of the studied sample might have some impact on differences in sizes and the sexual dimorphism for dental metrics between the adult and nonadult individuals.

Dental metrics 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 has suggested that the variation observed for tooth size of the permanent dentition is strongly genetically controlled (Alvesalo & Tigerstedt, 1974; Garn, Lewis, & Walenga, 1968; Kieser, 1990). However, differences in the quality of the environment during the complex process of odontogenesis (e.g., malnutrition, disease, climate,

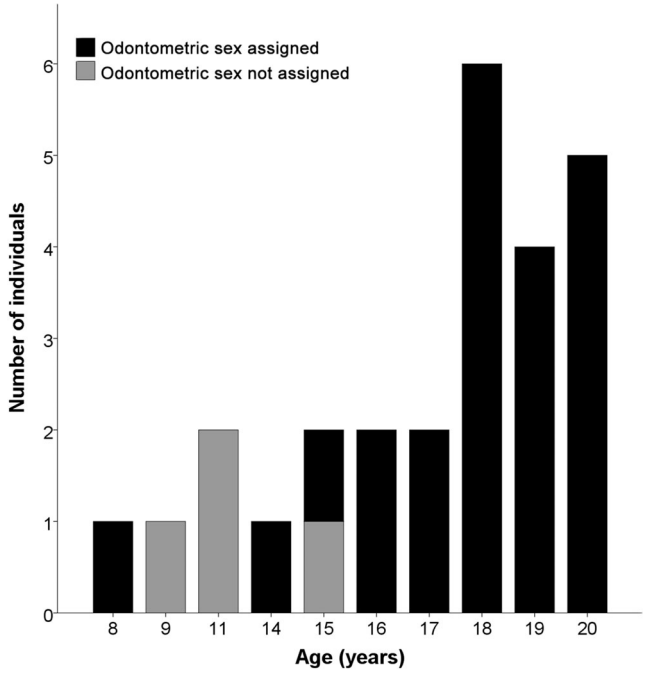

FIGURE 2 Distribution of the odontometric sex assignment of the immature individuals by age of death

subsistence patterns, other negative factors) might influence tooth size and morphology, and ultimately early death occurs among the most susceptible members of the population (Riga, Belcastro, & Moggi-Cecchi, 2014; Stojanowski, Larsen, Tung, & McEwan, 2007). Several studies have related skeletal manifestations of biological stress to the reduction in size of the permanent teeth as a result of the early deaths of nonadult individuals (Conceiçao & Cardoso, 2011; Stojanowski et al., 2007; Ządzińska, Lorkiewicz, Kurek, & Borowska-Strugińska, 2015). Although a link has been suggested between reduced tooth size and physiological stressors in nonadult individuals (Guagliardo, 1982; Simpson, Hutchinson, & Larsen, 1990; Stojanowski, 2005; Stojanowski et al., 2007), any correspondence between nonadults mortality bias and the pathological indicators of poor health has been inconsistent and sporadic between different populations (Cardoso, 2008; Stojanowski et al., 2007). For example, in an archeological context, Stojanowski (2005) documented that although the nonadult individuals from the community of San Pedro y San Pablo de Patale (in Apalachee Province, in the Florida panhandle, USA) had smaller teeth than the adults, this community appeared to be in relatively good health, which provided little evidence for increased stress or morbidity. In the present study, the analysis that was performed to evaluate differences in teeth sizes between adults and nonadult individuals did not show significant differences, which suggests that any potential impact of biological stress in early life was negligible. Thus, odontometric characteristics of the nonadult individuals appeared not to be influenced by either nutritional or physiological stressors.

Nevertheless, this statement must be interpreted with some caution, as the nonadults sample here were mainly composed of individuals who died in the last stages of adolescence (i.e., 57.69% aged 18–20 years), and only four individuals died during childhood (i.e., 15.38% aged 8–11 years), who might have lived under relatively poor health conditions that affected their teeth sizes. In the present study, after the application of the binary logistic regression equations based on dental measurements of adult individuals to the teeth of the 26 nonadult individuals of the same population, sex could be estimated in a total of 22. Comparison of the sex estimated by odontometrics with the known biological sex showed matches in 90.9% of cases. Despite the aforementioned limitations of the age/mortality bias of the nonadults sample, the high consistency of the estimated odontometric sex with the biological sex in nonadult individuals indicates that these measurements of the permanent dentition can indeed be used successfully for sex estimation of non-adult skeletal remains in this sample.

According to Nelson and Ash Jr. (2010), calcification of the permanent teeth is entirely postnatal (i.e., from birth to 10 years, including the third molar). The first molars are the first of the permanent teeth to complete crown formation (at 2.5–3.0 years old) and to emerge into the oral cavity (at 6–7 years old). These are followed by the first and second incisors (maxillary incisors: crown formation at 4–5 years old, emergence at 7–9 years old; mandibular incisors: emergence at 6–8 years old). Then the first premolars (crown formation at 5–6 years old, emergence at 10–11 years old), and canine and second premolars (canines: crown formation at 6–7 years old, emergence at 9–12 years old; second premolars: emergence at 10–12 years old). Finally, the second molars (crown formation at 7–8 years old, emergence at 11–13 years old). As a result, the logit equations developed in this study demonstrate that the odontometric characteristics of the permanent teeth can be used for sex estimation in the early stages of development of nonadult individuals. This can be seen for the early age of 5–6 years, whereby logit equation L_{10} can be applied after crown formation of the first premolar. As the individual's age progresses and dental crowns are completely formed in the tooth crypts or the oral cavity, more of the logit equations can be applied.

In addition, this study has allowed us to demonstrate the importance of the cervical dimensions of the teeth, as 18 of the logit equations developed here use only the cervical measurements, compared with 22 of these logit equations that use a cervical measurement in combination with a crown measurement. This finding is consistent with several other studies that have reported greater success for sex estimation using cervical rather than crown measurements (e.g., Adams & Pilloud, 2019; Hassett, 2011; Kazzazi & Kranioti, 2018; Viciano et al., 2013). Studies such as those of Aubry (2014), Hillson et al. (2005), Pilloud and Hillson (2012) and Viciano, Alemán, D'Anastasio, and Capasso (2012) have shown moderate to significant correlations between crown measurements with their equivalents at the cervical level of the tooth, which would indicate according to Adams and Pilloud (2019) that although similar information is conveyed in these measurements, these might represent differences due to genotype. Thus, as the dental cervical region is a good predictor of sex, its measurement allows greater applicability of the odontometric technique in cases where several limiting factors of multiple origin might

affect the available crowns of the teeth (e.g., greater dental wear, hypoplastic defects, cariogenic cavities, dental restorations), with lesser degree of involvement at the cervical level.

Although the subjectivity of descriptive morphological methods for sex estimation of nonadult individuals has led to the implementation of ordinal scoring systems and statistical analyses (Krishan et al., 2016), metric methods are favored because of the objectivity associated with metric data. However, despite there being so many diverse odon-tometric applications in clinical dentistry (e.g., prosthodontic tooth selection, implant selection) and physical anthropology (e.g., sex estima-tion, ancestry estimation), it is known that there are margins of error inherent in these methods (Perini, de Oliveira, Omelia, & de Oliveira, 2005). Thus, when dental measurements are repeated, differ-ences in the diverse measurements can occur as a result of the different sources of variation, such as: (a) biological variation of the teeth that is attributable to the diversity of the physical characteristics of a popula-tion analyzed; (b) variation due to the measuring instrument(s); and (c) variations attributable to the examiners. The first of these sources of variation cannot be avoided, while the last two sources can essentially be avoided, or at least minimized, to a large degree.

Determination of the levels of agreement between repeated mea-surements collected by the same and different examiners is an impor-tant concem in any metric study, such as the present one. Here, the I CCs showed high reproducibility in the intraexaminer error analysis (i.e., "excellent" agreements), which indicated that the repeated dental measurements collected by the principal examiner (who is highly experienced in odontometrics) were particularly reliable. For the inter-examiner error analysis, the secondary examiner had no prior experi-ence in odontometrics but was trained by the principal examiner here prior to the beginning of the present study. The overall data for inter-examiner error showed lower ICCs (which ranged from "good" to "excellent" agreement) in comparison with the intraexaminer error. The ICCs between the examiners tended to be a little lower for the molars, and to some extent for the premolars, than for the incisors and canines. For the molars, the crown diameters were more difficult to measure consistently than the cervical diameters, as it can be more difficult to measure the diagonal diameters than the mesiodistal and buccolingual diameters. The data here are consistent with those of Aubry (2014), Hillson et al. (2005) and Viciano et al. (2013), who found that the variation in the morphology of molars makes it difficult to find standard crown measurement locations. Thus, analysts are forced to consider other means of measuring teeth. For the premolars, the cervical diameters are more difficult to measure consistently than the crown diameters because the crowns do not flare out above the cement enamel-junction (which can be used as reference point for cervical measurements); this difference is less marked cervically, mak-ing it difficult to take measurements consistently. According to Harris and Smith (2009), the reproducibility of dental measurements is highly dependent on human judgment, because these measurements rely on greater or lesser accessibility of the defining landmarks, and/or if they are well delimited.

Although the level of agreement between the repeated measure-ments in the present study showed that dental measurements are reproducible and concordant within and between examiners, the slight differences between the different examiners can be attributed to the difficulties for the measurements of certain tooth dimensions. Thus, to improve the accuracy of the methodological procedures and the correct use of the binary logistic regression equations developed for odontometric sex estimation, it is mandatory that the examiners have knowledge in dental morphology as well as minimal training in the correct localization of the landmarks for the collection of the dif-ferent dental measurements.

In summary, all these considerations emphasize the importance of the present study for sex estimation of nonadult human skeletal remains. This study reinforces and extends previous studies that have proposed that when completely formed dental crowns are present in the tooth crypts or the teeth have emerged into the oral cavity, odon-tometric analysis of the permanent dentition is an objective and rapid technique for sex estimation of nonadult skeletal remains in forensic cases and in archeological settings. Therefore, odontometrics benefit from the advantages of lack of expression of sex-related skeletal char-acteristics in sexually immature individuals, better preservation of teeth than bone tissue, and metric approaches. Moreover, this tech-nique is easier to apply in situations where preservation of skeletal remains is not optimal and/ or only the dentition is recovered.

AUTHOR CONTRIBUTIONS

Joan Viciano: Conceptualization; data curation; formal analysis; investigation; methodology; supervision; validation; visualization; writing-original draft; writing-review and editing. Carmen Tanga: Conceptualization; data curation; formal analysis; investigation; methodology; validation; visualization; writing-original draft; writing-review and editing. Ruggero D'Anastasio: Writing-original draft; writing-review and editing. Maria Giovanna Belcastro: Writing-original draft; writing-review and editing. Luigi Capasso: Writing-original draft; writing-review and editing.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not pub-licly available due to privacy or ethical restrictions.

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