forensic sciences

MDPI

Article

Alveolar Measurements in Dental Anthropology: An Alternative Metric Technique in Cases of Postmortem Missing Teeth

Carmen Tanga [1,*] and Joan Viciano [2]

[1] Department of Legal Medicine, Toxicology and Physical Anthropology, University of Granada, Avenida de la Investigación 11, 18071 Granada, Spain
[2] Independent Researcher in Physical and Forensic Anthropology, Via Borgo Malan 15, 10062 Luserna San Giovanni, Italy; joanviciano@gmail.com
* Correspondence: carmentanga@correo.ugr.es

Abstract: Background/Objectives: The aim of this study was to examine the relationship between the mesiodistal and buccolingual alveolar diameters and the usual crown and cervical diameters and to test the reliability of these alveolar measurements for their application in dental anthropology in cases of missing teeth. **Methods**: A total of 127 skeletal individuals from the identified osteological collection of Certosa Cemetery (Bologna, Italy) were used in this study. After the evaluation of limiting factors, only the central incisor to the second premolar was analysed due to a null or small sample size for the molars. The mesiodistal and buccolingual diameters were measured at the level of the crown, cervix and alveolus. The relationship between the mesiodistal and buccolingual crown or cervical diameters and the alveolar measurements was assessed. **Results**: The buccolingual alveolar diameters showed consistently significant relationships with their equivalent cervical and crown diameters, while the mesiodistal alveolar diameters did not show consistent relationships. Furthermore, the patterns of phenotypic variation were similar for the alveolar, cervical and crown areas. Thus, the alveolar areas appear to show similar levels of variability compared with the equivalent crown and cervical areas. **Conclusions**: Alveolar measurements may serve as suitable proxies in comparative phenotypic variation studies and can be considered a useful supplement to the standard odontometric data collection strategy. The measurements proposed in this study for the evaluation of the alveoli are a valid alternative in situations in which teeth are not available for measurement, such as in forensic and archaeological contexts.

Keywords: dentoalveolar structures; dental metrics; alveolar metrics; dentoalveolar size; postmortem missing teeth; dental anthropology; forensic contexts; archaeological contexts

check for updates

Academic Editor: Hugo Cardoso

Received: 7 November 2024
Revised: 13 January 2025
Accepted: 14 January 2025
Published: 16 January 2025

Citation: Tanga, C.; Viciano, J. Alveolar Measurements in Dental Anthropology: An Alternative Metric Technique in Cases of Postmortem Missing Teeth. *Forensic Sci.* **2025**, *5*, 4. https://doi.org/10.3390/forensicsci5010004

1. Introduction

The oral cavity represents one of the most valuable sources of information in various scientific disciplines, such as biological anthropology, clinical odontology, the forensic sciences and archaeology. Of all oral structures, teeth constitute the most frequently investigated physical evidence because, due to their anatomical characteristics and position in the oral cavity, they represent the structures that are best preserved after the death of an individual [1]. The high degree of mineralisation of dental tissues in comparison to bone tissue gives them considerable hardness and resistance against a range of possible mechanical, chemical, physical and thermal post-depositional alterations [2].

Odontometrics, the study of human tooth size variation, is a valuable technique that plays a critical role in dental anthropology (e.g., for reconstructing a biological profile from skeletal remains: population affinity, sex and age-at-death) [3–5] and routine clinical practices (e.g., in orthodontic treatment planning) [6]. In odontometrics, the most common measurements are the mesiodistal (MD) and buccolingual (BL) crown diameters [7]. However, to circumvent or minimise the effects of several limiting factors that may compromise the collection of crown measurements (e.g., advanced dental wear, calculus deposits, carious lesions, enamel hypoplastic defects, orthodontic or restorative treatments), Hillson et al. [8] proposed the use of alternative measurements focused on obtaining dimensions at the cervical level. Several studies have shown that the cervical area is influenced to a lesser extent by the limiting factors that affect the crown and that measurements taken at the cervical level are reliable [9,10], which makes it possible to solve the problem of crown-related limitations and to increase the sample size of collected dental measurements [11]. Furthermore, several studies have demonstrated that cervical diameters display varying rates of relationship with crown diameters, so cervical measurements record information similar to those of the crown [8,12–14]. Hence, they may be the best choice if the dental crown is not available for measurement. However, postmortem missing teeth are a common phenomenon in archaeological and forensic contexts, thus compromising the application of odontometrics [15–17]. Because teeth are frequently lost during the process of skeletonisation or due to careless handling during the collection, transportation, preparation or examination in the laboratory of human skeletal remains, in the context of dental anthropology, tooth alveoli are often measured, and these could provide reliable information on dental dimensions when teeth are not available for measurement [18,19]. A dental alveolus is a socket in the maxilla/mandible in which the roots of a tooth are held in the alveolar process by the periodontal ligament [20], constituting the impression of the intra-alveolar morphology and, consequently, a size component of the root.

The present study investigated whether alveolar measurements are a valid alternative to usual dental dimensions in cases where teeth are missing. Although crown and cervical diameters are clearly controlled by a complex interaction between genetic and environmental factors [21], which allows one to investigate phenomena such as sexual dimorphism, dental evolution or the relationships of past populations, the alveolus could provide similar information and could be as useful as the dimensions at the cervical or crown level for these purposes, as long as they can be recorded in a reliable way. Thus, the aims of the study were (i) to examine the relationship between the MD and BL alveolar diameters and the usual crown and cervical diameters and (ii) to test the reliability of alveolar measurements as substitutes for crown and cervical diameters.

2. Materials and Methods

2.1. Study Sample

A total of 127 skeletal individuals from the identified osteological collection of Certosa Cemetery (Bologna, Italy) were used in this study [22]. These skeletal individuals are housed at the Museum of Anthropology of the Alma Mater Studiorum University of Bologna. The study sample consisted of 64 males (mean age-at-death: 28.62 $\pm$ 9.36 years) and 63 females (mean age-at-death: 31.13 $\pm$ 8.78 years).

2.2. Data Collection

Before the numerous dentoalveolar measurements were taken, each tooth and alveolus was examined for various limiting factors that could have an adverse effect on the metric study, including dental pathological processes like caries, hypoplastic defects, calculus deposits, periodontal disease and traumatic injuries; dental anomalies including the number, volume and shape; dental wear; local alveolar bone resorptions such as dehiscence and fenestration; and taphonomic/diagenetic effects. Regarding dental wear, for crown measurements, the MD diameter was measured to a maximum stage of 3 of incisal wear (according to the scoring system by Smith [23]) for the incisors, and to a maximum stage of 4 of incisal/occlusal wear for the canines and posterior teeth. The BL crown diameter was measured for teeth with a maximum stage of 5 of incisal/occlusal wear. For alveolar measurements, the MD and BL diameters were measured to a maximum stage of 2 on the interdental walls of the alveolar process (according to Kerr [24]; stage > 2 indicates 'periodontitis' following this scoring system).

Following the evaluation of the diverse limiting factors and the exclusion of the measurements affected by each dentoalveolar structure under examination, the crown, cervical and alveolar measurements of the permanent dentition were taken using an electronic digital pointed-jaw dental calliper (Masel Orthodontics Inc., Carlsbad, CA, USA) to an accuracy of 0.01 mm. Measurements were taken on the left side of the dental arch. If this was not available, then the right side was measured. When possible, and without forcing the teeth, they were removed for the alveolar measurements (Figure 1). Due to a null or small sample size for the molars (n = 0 for the maxillary and mandibular first and third molars and the maxillary second molar; n = 2 for the mandibular second molar), they were not considered in this study. Therefore, only the teeth from the central incisor to the second premolar were analysed.

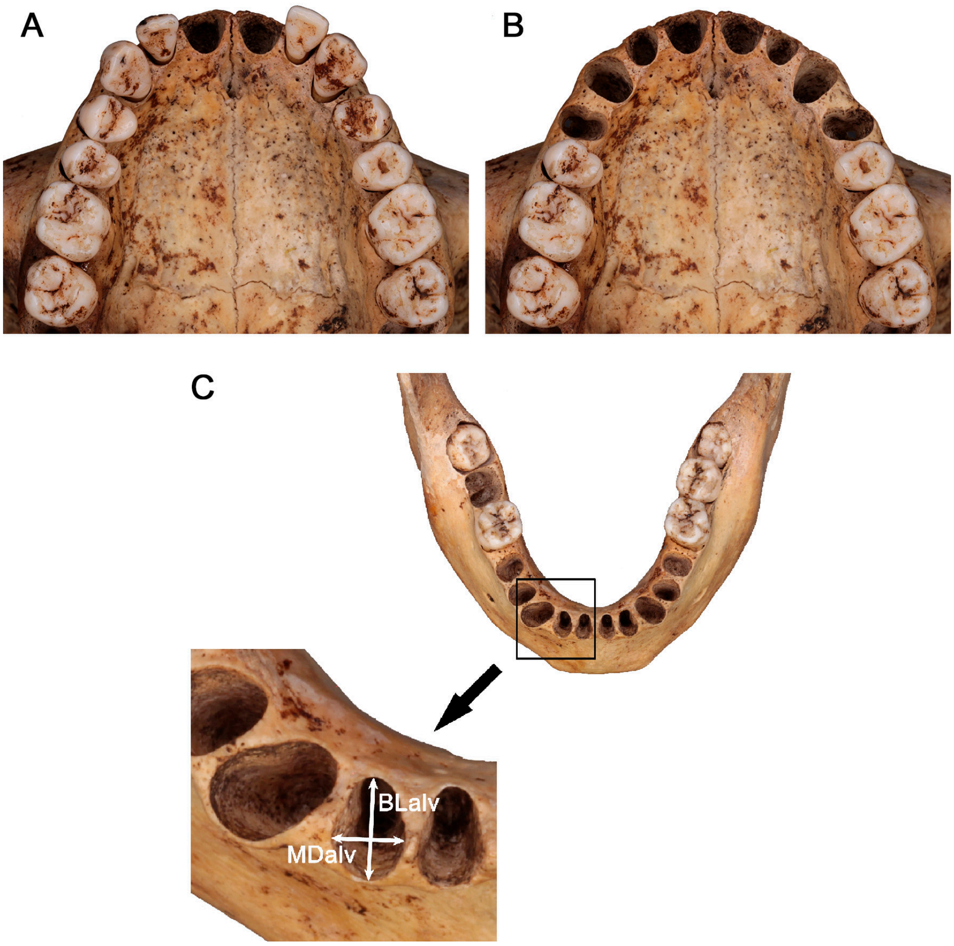

Figure 1. Maxilla showing the dentoalveolar structures useful for measurement (**A**) before and (**B**) after removing the teeth from their alveoli. (**C**) Example of the location of the alveolar measurements in the right second incisor of the mandible. MDalv, maximum mesiodistal alveolar diameter; BLalv, buccolingual alveolar diameter.

Except for the MD cervical diameter, which was measured using the criteria of Vodanović et al. [25], the crown and cervical measurements were taken in accordance with the definitions of Hillson et al. [8] using the modifications detailed by Aubry [26]. For alveolar measurements, the following definitions are proposed (Figure 1C):

> The *maximum MD alveolar diameter* is the maximum distance between two parallel planes, tangentially to the most mesial and most distal points of the alveolar bone crest;
>
> The *maximum BL alveolar diameter* is the maximum distance between two parallel planes, one tangential to the most lingual/palatal point of the alveolar bone crest, and the other tangential to a point on the buccal/labial alveolar bone crest.

The maximum MD and BL alveolar diameters were measured in the internal wall of the alveolar bone crest using the internal jaws of the calliper.

Numerous studies multiply the MD and BL diameters to generate an approximation of the occlusal crown area, which is sometimes referred to as the 'robustness index'. In the current study, the 'maximum crown area' was calculated by multiplying the maximum crown diameters, the 'maximum cervical area' by multiplying the cervical diameters and the 'maximum alveolar area' by multiplying the alveolar diameters.

Finally, the crown, cervical and alveolar diameters were remeasured at different times by the principal examiner (C.T.) to evaluate the intra-examiner error. Twenty-eight skeletal individuals were selected randomly for this endeavour. The measurements were spaced out by a minimum of 2 weeks and a maximum of 1 month and used the same set of callipers. When present in these skeletal individuals, measurements were taken for both contralateral teeth. Because of this, the *n* values in Tables 1–3 indicate the total number of teeth measured rather than the number of individuals under study.

2.3. Statistical Analysis

SPSS Statistics 25.0 for Windows (IBM Corp., Armonk, NY, USA) was used for statistical analysis. Initially, descriptive statistical analysis was conducted for each tooth to obtain the sample size, mean, standard deviation and minimum and maximum values for each dentoalveolar diameter. Next, different regression models (i.e., linear, logarithmic, inverse, quadratic, power and exponential) were checked to evaluate the relationships between the crown or cervical diameters and the alveolar diameters separately for the maxillary and mandibular teeth. To select the regression model that best explains the variability in the data with the highest accuracy, the coefficient of determination (R^2) and the standard error of the estimate (SEE) were examined. R^2 indicates the proportion of the variance in the dependent variable (i.e., the crown or cervical diameter) that is predictable from the independent variable (i.e., the alveolar diameter). A higher R^2 suggests that the model explains more of the variability in the data. The SEE measures the accuracy of the predictions made by the regression model, representing the typical distance between the observed and predicted values. A lower SEE indicates that the predictions are closer to the actual values. The model with the highest R^2 was selected. If multiple regression models had the same R^2, then the model with the lowest SEE was selected. Finally, diagnostic plots were generated to check whether the regression models worked well for the data. Q–Q plots were used to assess whether the residuals were normally distributed. Residual plots were examined to assess the appropriateness of the linear or non-linear regression models.

The differences in the means of all the measurements taken at the two different times were quantified to examine potential intra-examiner error before any statistical analysis was performed. The intraclass correlation coefficient (ICC) was computed to determine the degree of agreement between repeated measurements taken by the same examiner. Because of the nature of the data, the 'two-way mixed-effects absolute-agreement' model was utilised to calculate the ICC. The ICC for a given data set was compared with the four levels of qualitative assessment established Koo and Li [27] to determine the degree of agreement: 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. For all the statistical results, the level of significance was set at $p < 0.05$.

3. Results

Tables 1–3 show the results of the intra-examiner error analyses evaluating the repeated measurements taken by the principal examiner for the crown, cervical and alveolar measurements. In the intra-examiner error analysis for crown measurements (Table 1), the MD and BL diameters showed high ICCs. For the maxilla, the ICCs for the MD diameters were 0.970–0.994 (excellent agreement), with slightly higher ICCs for the BL diameters (0.981–0.997; excellent agreement). For the mandible, the ICCs for the MD diameters were 0.974–0.998 (excellent agreement), with slightly higher ICCs for the BL diameters (0.986–0.996; excellent agreement).

Table 1. Comparisons of differences in the means for maxillary and mandibular crown metrics between repeated measurements collected by the principal examiner (intra-examiner error analysis).

				Crown Measurements					
					95%CI				
Arch	**Measurement**	**Tooth**	***n***	**ICC**	**Lower**	**Upper**	***F***	***p***	**Strength of Agreement**
Maxilla	Mesiodistal	I^1	6	0.976	0.826	0.997	41.161	0.000	Excellent
		I^2	16	0.990	0.971	0.996	97.902	0.000	Excellent
		C′	18	0.987	0.965	0.995	76.977	0.000	Excellent
		P^1	17	0.977	0.937	0.992	43.723	0.000	Excellent
		P^2	15	0.992	0.976	0.997	123.816	0.000	Excellent
	Buccolingual	I^1	17	0.981	0.948	0.993	53.107	0.000	Excellent
		I^2	17	0.994	0.984	0.998	176.546	0.000	Excellent
		C′	18	0.990	0.973	0.996	98.038	0.000	Excellent
		P^1	20	0.990	0.975	0.996	100.306	0.000	Excellent
		P^2	20	0.992	0.979	0.997	123.083	0.000	Excellent
Mandible	Mesiodistal	I_1	13	0.993	0.977	0.998	140.056	0.000	Excellent
		I_2	18	0.989	0.972	0.996	95.094	0.000	Excellent
		C,	14	0.995	0.984	0.998	190.358	0.000	Excellent
		P_1	20	0.982	0.954	0.993	55.055	0.000	Excellent
		P_2	19	0.974	0.933	0.990	38.646	0.000	Excellent
	Buccolingual	I_1	17	0.986	0.960	0.995	69.384	0.000	Excellent
		I_2	20	0.992	0.980	0.997	123.879	0.000	Excellent
		C,	16	0.995	0.987	0.998	216.445	0.000	Excellent
		P_1	22	0.991	0.979	0.996	117.268	0.000	Excellent
		P_2	22	0.991	0.978	0.996	108.516	0.000	Excellent

n, number of teeth; ICC, intraclass correlation coefficient; 95%CI, 95% confidence interval; *F*, *F*-statistic; *p*, *p*-value (values statistically significant at $p < 0.05$ level).

In the intra-examiner error analysis for cervical measurements (Table 2), the MD and BL diameters showed high ICCs. For the maxilla, the ICCs for the MD diameters were 0.978–0.998 (excellent agreement), with slightly higher ICCs for the BL diameters (0.988–0.998; excellent agreement). For the mandible, the ICCs for the MD measurements were 0.950–1.000 (excellent agreement), with slightly higher ICCs for the BL diameters (0.985–0.998; excellent agreement).

Table 2. Comparisons of differences in the means for maxillary and mandibular cervical metrics between repeated measurements collected by the principal examiner (intra-examiner error analysis).

			Cervical Measurements						
					95%CI				
Arch	**Measurement**	**Tooth**	***n***	**ICC**	**Lower**	**Upper**	***F***	***p***	**Strength of Agreement**
Maxilla	Mesiodistal	I^1	17	0.997	0.992	0.999	334.967	0.000	Excellent
		I^2	19	0.992	0.980	0.997	126.823	0.000	Excellent
		C′	21	0.990	0.977	0.996	105.151	0.000	Excellent
		P^1	20	0.993	0.983	0.997	152.189	0.000	Excellent
		P^2	21	0.978	0.946	0.991	45.411	0.000	Excellent
	Buccolingual	I^1	16	0.992	0.978	0.997	133.021	0.000	Excellent
		I^2	20	0.994	0.986	0.998	175.357	0.000	Excellent
		C′	22	0.988	0.972	0.995	85.027	0.000	Excellent
		P^1	22	0.997	0.993	0.999	366.635	0.000	Excellent
		P^2	21	0.997	0.993	0.999	358.999	0.000	Excellent
Mandible	Mesiodistal	I_1	21	0.970	0.927	0.988	33.861	0.000	Excellent
		I_2	23	0.950	0.883	0.979	20.120	0.000	Excellent
		C,	22	0.992	0.981	0.997	125.933	0.000	Excellent
		P_1	23	0.987	0.968	0.994	74.697	0.000	Excellent
		P_2	23	0.981	0.954	0.992	51.573	0.000	Excellent
	Buccolingual	I_1	21	0.985	0.964	0.994	68.268	0.000	Excellent
		I_2	20	0.987	0.966	0.995	74.696	0.000	Excellent
		C,	23	0.993	0.983	0.997	137.061	0.000	Excellent
		P_1	20	0.993	0.981	0.997	136.539	0.000	Excellent
		P_2	24	0.991	0.980	0.996	115.231	0.000	Excellent

n, number of teeth; ICC, intraclass correlation coefficient; 95%CI, 95% confidence interval; *F*, *F*-statistic; *p*, *p*-value (values statistically significant at $p < 0.05$ level).

Table 3 shows the results of the intra-examiner analysis for the alveolar measurements. For the maxilla, the ICCs for the MD diameters were 0.796–0.974 (good-to-excellent agreement), with higher ICCs for the BL diameters (0.918–0.990; excellent agreement). For the mandible, the ICCs for the MD diameters were 0.887–0.951 (good-to-excellent agreement), with higher ICCs for the BL diameters (0.917–0.961; excellent agreement). Overall, the ICCs showed high reproducibility in the intra-examiner error analyses (good-to-excellent agreement) for the crown, cervical and alveolar measurements. However, the crown and cervical measurements showed slightly higher ICCs (excellent agreement) than the alveolar measurements (good-to-excellent agreement). These results indicated that the repeated measurements taken by the principal examiner were particularly reliable.

Table 3. Comparisons of differences in the means for maxillary and mandibular alveolar metrics between repeated measurements collected by the principal examiner (intra-examiner error analysis).

			Alveolar Measurements						
					95%CI				
Arch	**Measurement**	**Tooth**	***n***	**ICC**	**Lower**	**Upper**	***F***	***p***	**Strength of Agreement**
Maxilla	Mesiodistal	I^1	24	0.973	0.937	0.988	37.998	0.000	Excellent
		I^2	27	0.974	0.944	0.988	38.251	0.000	Excellent
		C′	26	0.959	0.904	0.982	26.850	0.000	Excellent
		P^1	14	0.796	0.371	0.934	4.781	0.004	Good
		P^2	13	0.841	0.477	0.951	5.999	0.002	Good

Table 3. *Cont.*

				Alveolar Measurements					
					95%CI				
Arch	**Measurement**	**Tooth**	***n***	**ICC**	**Lower**	**Upper**	***F***	***p***	**Strength of Agreement**
	Buccolingual	I^1	13	0.953	0.800	0.987	28.676	0.000	Excellent
		I^2	18	0.962	0.901	0.986	27.029	0.000	Excellent
		C′	18	0.990	0.974	0.996	100.524	0.000	Excellent
		P^1	11	0.918	0.703	0.978	11.669	0.000	Excellent
		P^2	13	0.961	0.873	0.988	24.050	0.000	Excellent
Mandible	Mesiodistal	I_1	25	0.946	0.873	0.977	20.535	0.000	Excellent
		I_2	26	0.943	0.873	0.974	17.447	0.000	Excellent
		C,	28	0.951	0.895	0.978	21.405	0.000	Excellent
		P_1	26	0.931	0.845	0.969	13.938	0.000	Excellent
		P_2	16	0.887	0.678	0.960	8.514	0.000	Good
	Buccolingual	I_1	10	0.924	0.694	0.981	12.157	0.000	Excellent
		I_2	14	0.961	0.882	0.987	25.100	0.000	Excellent
		C,	14	0.961	0.880	0.987	24.463	0.000	Excellent
		P_1	15	0.918	0.756	0.972	11.604	0.000	Excellent
		P_2	14	0.917	0.737	0.973	13.677	0.000	Excellent

n, number of teeth; ICC, intraclass correlation coefficient; 95%CI, 95% confidence interval; *F*, *F*-statistic; *p*, *p*-value (values statistically significant at $p < 0.05$ level).

Table 4 shows the descriptive results for the total tooth sample size.

Table 4. Descriptive analysis for the total tooth sample size.

			Maxilla					Mandible				
Region	**Measurement**	**Tooth**	***N***	**Mean**	**SD**	**Min**	**Max**	***N***	**Mean**	**SD**	**Min**	**Max**
Crown	Mesiodistal	I1	44	8.333	0.400	6.94	9.41	78	5.360	0.542	3.37	6.66
		I2	71	6.550	0.620	5.19	7.95	80	6.022	0.548	3.84	7.25
		C	78	7.668	0.477	5.99	9.01	69	6.833	0.485	5.89	8.21
		P1	75	7.050	0.409	5.87	8.04	94	7.015	0.459	5.43	8.06
		P2	71	6.903	0.508	5.77	8.06	93	7.331	0.462	5.44	8.09
	Buccolingual	I1	77	7.359	0.424	6.65	8.42	74	6.017	0.437	5.20	6.97
		I2	79	6.351	0.462	4.99	7.57	73	6.487	0.413	5.53	7.73
		C	83	8.339	0.608	7.26	10.28	66	7.762	0.689	5.20	9.58
		P1	92	8.846	0.570	7.68	10.75	87	7.756	0.454	6.92	9.12
		P2	98	9.106	0.675	7.85	11.11	102	8.267	0.556	6.68	9.97
	Area	I1	41	60.055	5.208	46.85	76.50	57	32.782	4.750	24.25	44.43
		I2	65	41.515	6.038	26.15	53.50	56	38.651	4.952	28.20	51.52
		C	71	64.103	8.194	48.57	86.66	52	53.025	7.282	36.61	69.92
		P1	71	62.515	7.357	49.01	86.43	73	54.639	6.232	40.95	70.32
		P2	62	63.153	9.427	45.29	87.30	81	60.958	7.266	41.79	79.16
Cervical	Mesiodistal	I1	91	6.556	0.663	3.35	8.03	96	3.459	0.263	2.86	4.38
		I2	94	4.784	0.666	3.52	6.65	109	3.795	0.353	3.01	5.02
		C	105	5.829	0.580	4.50	7.05	119	5.305	0.626	3.92	6.82
		P1	94	4.774	0.572	3.66	6.22	120	4.863	0.441	3.95	6.46
		P2	90	4.800	0.477	4.10	6.05	119	5.152	0.480	4.28	6.665
	Buccolingual	I1	91	6.544	0.504	5.54	7.89	86	5.698	0.545	3.18	7.00
		I2	95	5.810	0.667	4.53	9.19	90	6.183	0.626	3.43	7.45
		C	107	7.944	0.687	6.83	9.93	104	7.751	0.751	4.42	9.78
		P1	91	8.052	0.647	4.45	9.49	102	6.900	0.561	4.96	8.45
		P2	93	8.296	0.719	6.63	10.72	102	7.388	0.652	5.30	9.45

Table 4. *Cont.*

			Maxilla					Mandible				
Region	**Measurement**	**Tooth**	***N***	**Mean**	**SD**	**Min**	**Max**	***N***	**Mean**	**SD**	**Min**	**Max**
	Area	I1	82	43.735	6.140	27.81	57.49	80	19.779	3.015	10.11	26.09
		I2	82	27.910	5.634	18.37	41.85	85	23.541	4.023	11.76	37.05
		C	98	46.632	8.143	31.46	66.48	96	41.522	8.495	19.54	62.70
		P1	83	38.381	6.986	19.05	56.98	93	33.673	5.437	24.60	52.65
		P2	78	40.134	7.122	27.78	62.60	96	38.325	6.508	27.45	62.51
Alveolus	Mesiodistal	I1	116	6.468	0.604	4.86	7.90	111	2.71	4.58	3.607	0.347
		I2	105	4.853	0.539	3.61	6.65	118	2.93	4.76	3.941	0.362
		C	89	5.915	0.626	4.31	7.26	112	4.32	6.66	5.390	0.573
		P1	39	4.522	0.451	3.44	5.51	100	3.94	5.96	4.790	0.378
		P2	34	4.772	0.398	4.05	5.65	61	4.08	6.05	5.109	0.379
	Buccolingual	I1	63	6.354	0.493	5.40	7.28	52	4.85	6.82	5.766	0.499
		I2	67	5.864	0.521	4.67	7.21	65	5.14	7.58	6.274	0.545
		C	58	7.943	0.898	6.34	10.01	37	6.12	10.15	7.644	0.845
		P1	33	7.818	0.585	6.70	9.53	47	5.73	7.98	6.538	0.492
		P2	35	7.934	0.654	6.60	9.28	53	6.02	8.49	7.070	0.567
	Area	I1	59	41.905	5.843	30.62	55.84	47	21.107	3.010	15.15	27.75
		I2	63	28.039	5.100	19.64	39.72	61	24.419	3.432	18.46	35.25
		C	56	46.954	9.661	30.51	70.30	36	41.002	8.690	29.80	64.60
		P1	29	35.337	5.850	27.67	50.70	47	31.249	3.919	24.58	41.18
		P2	33	38.145	5.840	27.52	47.85	51	36.348	5.064	26.36	49.61

N, number of teeth; Mean, overall measurement mean; SD, standard deviation; Min, minimum value; Max, maximum value; I1, central incisor; I2, lateral incisor; C, canine; P1, first premolar; P2, second premolar.

The results of the main regression models evaluating the relationships between cervical and alveolar measurements are presented in Table 5. Analysis of the cervical measurements revealed notable differences between the maxillary and mandibular arches. Across the different regression models, the maxillary arch generally showed stronger relationships, as indicated by higher R^2 values, compared with the mandibular arch. In the maxilla, the highest R^2 values were observed for the BL diameter, particularly for the canine and the first premolar, where the linear (for the canine) and quadratic (for the first premolar) models provided R^2 values as high as 0.916 and 0.842, respectively. The MD diameter also showed strong relationships, with R^2 values reaching 0.790 for the canine and 0.744 for the lateral incisor. The area measurements in the maxilla also showed strong relationships for all teeth, particularly for the canine, the first premolar and the lateral incisor, with R^2 values of 0.944, 0.831 and 0.818, respectively, in the quadratic models. The mandible generally presented lower R^2 values for all measurements compared with the maxilla. The MD diameter showed the weakest relationships, with R^2 values for the second premolar, the first premolar and the central incisor as low as 0.204, 0.239 and 0.253, respectively. In contrast, the BL diameters showed better fits, especially for the central incisor, with R^2 values reaching up to 0.841. Overall, the cervical measurements demonstrated that the maxilla tends to have stronger and more consistent relationships between the cervical and alveolar measurements than the mandible.

Table 6 shows the relationships between the crown and alveolar measurements. The crown measurements also revealed distinct patterns between the maxillary and mandibular arches, with the maxilla consistently showing better model fits than the mandible. For the maxilla, the BL diameter once again exhibited the highest R^2 values, with the canine and the first premolar reaching values of 0.891 and 0.825, respectively, with quadratic models. The MD diameter displayed moderate R^2 values, with the second premolar achieving an R^2 of 0.484. The area measurements in the maxilla also showed strong relationships, particularly for the central incisor and canine, with R^2 values of 0.765 and 0.761, respectively, in the quadratic models. For the mandible, the crown measurements followed a similar trend to the cervical measurements, with generally lower R^2 values. The MD diameter was the least predictive, with the first and second premolars showing R^2 values as low as 0.036 and 0.038, respectively. However, the BL diameter provided better fits, particularly for the central incisor, where the quadratic model reached an R^2 of 0.798. The crown measurements confirmed the trend observed in the cervical measurements: the maxillary arch consistently showed better fits across various measurements and regression models compared with the mandibular arch. This suggests that compared with the mandibular teeth, the variability in the maxillary teeth is captured more effectively by these models.

Supplementary Figure S1 shows the Q–Q plots for the best-fit regression models that were developed; the data points closely follow the straight line at a 45° angle upwards (left to right). These graphs show significant deviations from the diagonal line, suggesting that the residuals were not normally distributed. Because the assumption of normality was not met for some of the linear regressions (i.e., for the models evaluating the BL crown diameter of the mandibular canine, the crown area of the mandibular first premolar, the MD cervical diameter of the maxillary and mandibular canines and the BL cervical diameter of the maxillary canine), non-linear regression models would be more appropriate than linear regression models (see Tables 5 and 6). Supplementary Figure S2 shows the residual plots; the residuals were randomly dispersed around the horizontal axis and, therefore, the non-linear regression models are appropriate for the data. These plots confirm that the development of non-linear regression models are suitable for establishing the relationship between the alveolar measurements and the crown or cervical measurements. Supplementary Tables S1 and S2 show the parameters of the best-fit regression models for the relationships between the crown (Supplementary Table S1) or cervical (Supplementary Table S2) diameters and the alveolar diameter reported in Tables 5 and 6.

Table 5. Principal regression models evaluating the relationships between the cervical and the alveolar measurements.

						Non-Linear Models									
				Linear		Logarithmic		Inverse		Quadratic		Power		Exponential	
Measurement	**Arch**	**Tooth**	***n***	**R^2**	**SEE**	**R^2**	**SEE**	**R^2**	**SEE**	**R^2**	**SEE**	**R^2**	**SEE**	**R^2**	**SEE**
Mesiodistal	Maxilla	I^1	64	0.565	0.466	0.551	0.473	0.530	0.484	**0.573**	**0.465**	0.460	0.090	0.469	0.090
		I^2	61	0.727	0.348	0.721	0.352	0.706	0.362	0.727	0.351	**0.744**	**0.071**	0.739	0.072
		C′	61	* **0.790**	* **0.294**	0.783	0.299	0.766	0.310	** **0.790**	** **0.297**	0.784	0.052	0.784	0.052
		P^1	23	0.537	0.437	0.506	0.452	0.468	0.468	**0.607**	**0.413**	0.498	0.095	0.528	0.092
		P^2	21	0.454	0.373	0.429	0.382	0.404	0.390	**0.588**	**0.333**	0.447	0.074	0.470	0.073
	Mandible	I_1	62	0.249	0.244	0.244	0.245	0.236	0.247	0.251	0.246	0.248	0.071	**0.253**	**0.070**
		I_2	70	0.477	0.266	0.449	0.273	0.418	0.281	**0.541**	**0.251**	0.450	0.070	0.475	0.069
		C,	75	* **0.638**	* **0.421**	0.636	0.422	0.631	0.425	** **0.638**	** **0.424**	0.634	0.079	0.633	0.079
		P_1	72	0.229	0.339	0.233	0.338	0.235	0.338	0.239	0.340	**0.239**	**0.070**	0.234	0.070
		P_2	48	0.201	0.325	0.200	0.325	0.198	0.326	0.201	0.328	**0.204**	**0.063**	**0.204**	**0.063**
Buccolingual	Maxilla	I^1	37	0.788	0.210	0.782	0.213	0.773	0.217	**0.790**	**0.212**	0.772	0.034	0.775	0.033
		I^2	47	0.528	0.539	0.527	0.539	0.524	0.541	0.528	0.545	**0.582**	**0.082**	0.580	0.082
		C′	43	* **0.916**	* **0.233**	0.914	0.235	0.906	0.245	** **0.916**	** **0.235**	0.909	0.030	0.906	0.030
		P^1	19	0.841	0.233	0.839	0.235	0.833	0.239	**0.842**	**0.240**	0.836	0.029	0.834	0.030
		P^2	23	0.703	0.287	0.676	0.300	0.645	0.314	**0.785**	**0.251**	0.673	0.037	0.699	0.035
	Mandible	I_1	23	0.794	0.271	0.778	0.282	0.760	0.293	**0.841**	**0.244**	0.788	0.046	0.802	0.045
		I_2	34	0.727	0.247	0.715	0.252	0.700	0.259	**0.739**	**0.245**	0.704	0.041	0.712	0.040
		C,	27	0.796	0.339	0.783	0.350	0.758	0.370	**0.798**	**0.345**	0.778	0.046	0.785	0.045
		P_1	31	0.631	0.367	0.627	0.369	0.621	0.372	**0.633**	**0.372**	0.559	0.061	0.562	0.061
		P_2	36	0.806	0.209	0.794	0.216	0.779	0.223	**0.821**	**0.204**	0.797	0.028	0.807	0.028
Area	Maxilla	I^1	35	0.753	2.602	0.727	2.739	0.687	2.930	**0.768**	**2.561**	0.709	0.066	0.726	0.064
		I^2	37	0.817	2.655	0.809	2.719	0.786	2.874	**0.818**	**2.693**	0.804	0.103	0.801	0.104
		C′	40	0.937	2.511	0.942	2.416	0.923	2.782	**0.944**	**2.414**	0.936	0.054	0.914	0.062
		P^1	15	0.813	3.771	0.791	3.994	0.761	4.268	**0.831**	**3.732**	0.779	0.104	0.791	0.101
		P^2	21	0.607	3.623	0.557	3.845	0.503	4.070	**0.751**	**2.959**	0.591	0.092	0.639	0.087
	Mandible	I_1	23	0.767	1.623	0.731	1.743	0.689	1.873	**0.839**	**1.382**	0.729	0.085	0.759	0.080
		I_2	33	0.778	2.097	0.729	2.314	0.670	2.553	**0.833**	**1.847**	0.707	0.095	0.737	0.090
		C,	25	0.752	4.582	0.753	4.574	0.741	4.688	**0.754**	**4.671**	0.751	0.110	0.733	0.114
		P_1	31	0.650	3.343	0.649	3.349	0.644	3.376	**0.651**	**3.401**	0.626	0.102	0.625	0.102
		P_2	34	0.585	3.425	0.560	3.526	0.527	3.654	**0.620**	**3.331**	0.570	0.089	0.593	0.086

n, sample size for comparison; R^2, coefficient of determination; SEE, standard error of the estimate. The best-fit regression model for each tooth is highlighted in **bold**. * Since the assumption of normality was not met, this linear model is not adequate in favour of a non-linear model. ** Next non-linear model selected with the highest R^2 over the linear model because the normality requirement was not met.

Table 6. Principal regression models evaluating the relationships between the crown and the alveolar measurements.

						Non-Linear Models									
				Linear		**Logarithmic**		**Inverse**		**Quadratic**		**Power**		**Exponential**	
Measurement	**Arch**	**Tooth**	***n***	**R^2**	**SEE**	**R^2**	**SEE**	**R^2**	**SEE**	**R^2**	**SEE**	**R^2**	**SEE**	**R^2**	**SEE**
Mesiodistal	Maxilla	I^1	27	0.324	0.298	0.310	0.301	0.295	0.305	**0.372**	**0.293**	0.312	0.035	0.325	0.035
		I^2	49	0.402	0.500	0.398	0.502	0.391	0.504	**0.403**	**0.505**	0.389	0.079	0.391	0.079
		C′	48	0.432	0.375	0.424	0.377	0.413	0.381	**0.435**	**0.378**	0.426	0.049	0.431	0.049
		P^1	23	0.115	0.366	0.096	0.370	0.077	0.374	**0.263**	**0.342**	0.094	0.052	0.112	0.051
		P^2	21	0.456	0.296	0.443	0.300	0.428	0.304	**0.484**	**0.297**	0.443	0.044	0.456	0.043
	Mandible	I_1	51	0.104	0.568	0.099	0.570	0.093	0.571	**0.109**	**0.572**	0.092	0.112	0.096	0.111
		I_2	47	0.073	0.601	0.063	0.604	0.052	0.608	**0.144**	**0.584**	0.053	0.107	0.062	0.107
		C,	48	0.369	0.372	0.374	0.371	0.377	0.370	0.376	0.374	**0.378**	**0.053**	0.372	0.053
		P_1	59	0.035	0.411	0.035	0.411	0.035	0.411	**0.036**	**0.415**	0.034	0.059	0.034	0.059
		P_2	40	0.018	0.359	0.016	0.359	0.014	0.360	**0.037**	**0.360**	0.015	0.049	0.017	0.049
Buccolingual	Maxilla	I^1	34	0.728	0.192	0.725	0.193	0.719	0.195	0.728	0.195	0.728	0.026	**0.729**	**0.026**
		I^2	42	0.512	0.326	**0.513**	**0.326**	0.511	0.327	0.513	0.330	0.500	0.054	0.498	0.054
		C′	34	0.890	0.227	0.888	0.230	0.880	0.238	**0.891**	**0.231**	0.883	0.028	0.882	0.028
		P^1	20	0.804	0.310	0.788	0.323	0.769	0.337	**0.825**	**0.301**	0.795	0.035	0.807	0.034
		P^2	23	0.474	0.402	0.476	0.401	0.475	0.401	**0.478**	**0.410**	0.474	0.045	0.471	0.045
	Mandible	I_1	16	0.792	0.211	0.789	0.213	0.785	0.215	**0.798**	**0.215**	0.794	0.034	0.797	0.034
		I_2	17	0.682	0.179	0.689	0.177	**0.693**	**0.176**	0.691	0.183	0.691	0.028	0.681	0.028
		C,	14	* **0.770**	* **0.316**	0.766	0.319	0.755	0.326	** **0.770**	** **0.330**	0.742	0.044	0.744	0.044
		P_1	23	0.693	0.253	0.681	0.258	0.668	0.263	**0.725**	**0.245**	0.673	0.033	0.684	0.033
		P_2	36	0.590	0.284	0.585	0.286	0.577	0.288	0.593	0.287	0.591	0.034	**0.595**	**0.034**
Area	Maxilla	I^1	18	0.654	3.337	0.598	3.596	0.536	3.865	**0.765**	**2.842**	0.608	0.055	0.659	0.052
		I^2	35	0.586	4.205	0.569	4.286	0.543	4.413	**0.592**	**4.236**	0.528	0.113	0.539	0.112
		C′	31	0.760	4.674	0.754	4.733	0.729	4.970	**0.761**	**4.754**	0.748	0.074	0.747	0.074
		P^1	15	0.636	5.331	0.616	5.477	0.597	5.610	**0.677**	**5.222**	0.642	0.079	0.653	0.078
		P^2	20	0.451	4.651	0.458	4.622	0.457	4.626	0.465	4.721	**0.475**	**0.075**	0.468	0.075
	Mandible	I_1	13	0.579	3.331	0.593	3.272	0.603	3.234	0.614	3.343	**0.624**	**0.097**	0.607	0.099
		I_2	11	0.335	3.909	0.335	3.908	0.330	3.925	**0.338**	**4.138**	0.334	0.100	0.335	0.100
		C,	13	0.920	2.286	0.902	2.527	0.871	2.891	**0.925**	**2.314**	0.893	0.050	0.900	0.049
		P_1	22	* **0.565**	* **4.336**	0.564	4.341	0.559	4.366	** **0.565**	** **4.448**	0.543	0.082	0.543	0.082
		P_2	31	0.463	4.598	0.440	4.698	0.411	4.815	**0.504**	**4.497**	0.442	0.076	0.464	0.075

n, sample size for comparison; R^2, coefficient of determination; SEE, standard error of the estimate. The best-fit regression model for each tooth is highlighted in **bold**. * Since the assumption of normality was not met, this linear model is not adequate in favour of a non-linear model. ** Next non-linear model selected with the highest R^2 over the linear model because the normality requirement was not met.

4. Discussion

The present study is based on the hypothesis that the alveolus, representing the impression of the intra-alveolar morphology, reflects a size component of the root. Thus, the MD and BL diameters measured at the level of the alveolar bone crest should show a direct relationship with the same measurements taken at the cervical level. Overall, the results confirmed this hypothesis, as alveolar measurements showed consistently significant relationships with their equivalent cervical diameters. The BL diameters showed strong relationships, whereas the MD diameters showed moderate-to-strong relationships. When compared with crown measurements, the BL diameters showed moderate-to-strong relationships, whereas the MD diameters did not show consistent relationships (from weak-to-moderate relationships). These results are consistent with the observations of Hillson et al. [8], Stojanowski [13] and Viciano et al. [14], who only compared crown and cervical diameters but obtained higher relationships for the BL diameters compared with the MD diameters. Thus, the BL alveolar diameters may be a suitable proxy for tooth size because they seem to represent similar aspects of human dental size as do cervical and crown diameters. The observed discrepancy in the relationships between MD alveolar diameters and crown/cervical diameters likely stems from distinct anatomical and biomechanical factors influencing these dimensions. MD crown/cervical diameters may be determined mainly by genetic factors, given their critical role in maintaining occlusion and dental alignment [28,29]. In contrast, MD alveolar diameters may be influenced by functional and environmental factors. This difference can be attributed to the dynamic nature of alveolar bone since it remodels in response to masticatory forces transmitted through the periodontal ligament. These forces often result in site-specific resorption and apposition of alveolar bone, disproportionately impacting MD diameters due to their close association with occlusal loading patterns [30,31]. Conversely, BL diameters appear to maintain stronger genetic and structural correlations across alveolar, cervical and crown regions. This distinction may also be explained by evolutionary pressures supporting the stability of MD diameters, not only for functional purposes but also for aesthetics [32,33], whereas BL diameters could vary to a greater degree with biomechanical demands in activities like mastication and periodontal remodelling [7,34]. Hence, the weaker consistency of relationships concerning MD diameters reflects the complex interaction among the genetic, anatomical and biomechanical factors, highlighting the need for further research into the mechanisms underlying this variability.

On the other hand, the product of the MD and BL diameters provides an approximation of the overall tooth area (also known as the ‘robustness index’), which presumably captures similar information and gives a better approximation of tooth size with evolutionary, developmental and therapeutic relevance [8,35,36]. Our results showed similar patterns of phenotypic variations for the alveolar, cervical and crown areas. These findings suggest that when compared with equivalent crown and cervical areas, alveolar areas show similar levels of variability. As a result, these areas could be used interchangeably and serve as appropriate proxies in comparative phenotypic studies. Thus, although teeth constitute the most frequently investigated oral structures in different fields of research using metric techniques, the alveoli have great potential for obtaining reliable information on tooth size when teeth are not available for measurement [37].

Although the present research showed that alveoli are a valid alternative for taking measurements when teeth are not available, they can also be subject to several limiting factors that may hinder their collection and thus significantly reduce the amount of data available for metric analysis, some of which were observed in the study sample. These factors include the following: (i) the natural presence of teeth anchored in their respective alveoli and the impossibility of their removal for analysis, because it could break the alveolar process in these important osteological collections or alter evidence in forensic cases; (ii) the presence of pathologies (e.g., periodontal diseases and abscesses) or bone defects (e.g., dehiscence) that may compromise the condition of supporting structures resulting in bone destruction [24,38–40]; (iii) biomechanical factors related to hyperactivity of the masticatory muscles (e.g., mastication, bruxism) [33]; (iv) taphonomic factors that can compromise the conservation of alveoli and their subsequent recovery in forensic and archaeological contexts and that occur already from the first phases of the decomposition of the human corpse to skeletonisation (e.g., as a result of the scavenging activity by fossorial animals in outdoor environments, described by Viciano et al. [41], and exposure of skeletal human remains to sunlight or to high temperatures) [17,19]; (v) postmortem missing alveolar processes resulting from carelessness during the recovery, transportation, storage, preparation or examination of dry skulls in the laboratory; and (vi) factors related to the careless use of the instrumentation used to collect metric data (e.g., callipers) —the alveolar bone crest is very fragile and can be damaged or broken by exerting force with the jaws of the calliper during the measurement procedure [42].

In future studies, the evaluation of biomechanical factors related to hyperactivity of the masticatory muscles should be considered, as these may affect the alveolar bone morphology. Given that the study material is skeletal remains, this assessment would be performed indirectly, evaluating diverse parameters such as the following: (i) tooth wear; (ii) mandible robustness; and (iii) musculoskeletal stress markers (entheseal changes caused by masseter, temporal, medial and lateral pterygoid muscles).

Finally, the assessment of the levels of agreement between repeated measurements taken by the same examiner is important in any metric research [43]. The evaluation of the intra-examiner error is considered fundamental as well as highly recommended because it allows one to verify that no errors have been committed from the earliest phases of the research [44]. In this study, the mean differences between repeated measurements had high ICCs (from good to excellent). The reproducibility of dental measurements, according to Harris and Smith [45], depends largely on human judgement because these measurements depend on how accessible the defining landmarks are and/or whether they are properly defined. Thus, the alveolar measurements proposed in this study and taken by the same examiner are clearly defined and completely reliable.

5. Concluding Remarks

The importance of the present study can be summarised in three points:

1. The BL alveolar diameters consistently showed a significant relationship with their equivalent cervical and crown diameters.
2. The MD alveolar diameters did not consistently show a significant relationship with their equivalent cervical and crown diameters.
3. The patterns of phenotypic variation were similar for the alveolar, cervical and crown areas. Thus, the alveolar areas appear to exhibit similar levels of variability compared with the equivalent crown and cervical areas and, therefore, they may serve as suitable proxies in comparative phenotypic variation studies.

Teeth play a significant role in human identification to estimate an individual's biological profile, such as population affinity (e.g., [12]), sex (e.g., [11]) and age-at-death (e.g., [46]). However, when teeth are missing postmortem (a common situation in forensic and archaeological settings), alveolar measurements can be considered a useful addendum to the standard odontometric data collection strategy. Thus, the MD and BL diameter definitions proposed in this study can be a valid alternative in situations in which teeth are not available for measurement to provide valuable information for human identification purposes.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/forensicsci5010004/s1. Figure S1: Q–Q plots for the best-fit regression models to assess if the set of residuals is normally distributed for the maxillary and mandibular dentoalveolar structures; Figure S2: Residuals vs. fit plots to assess if the regression models are appropriate for the data for the maxillary and mandibular dentoalveolar structures. Table S1: Regression equation parameters for the crown diameter (dependent variable) versus the alveolar diameter (independent variable). Table S2: Regression equation parameters for the cervical diameter (dependent variable) versus the alveolar diameter (independent variable).

Author Contributions: Conceptualization, C.T. and J.V.; methodology, C.T. and J.V.; validation, C.T.; formal analysis, C.T. and J.V.; investigation, C.T. and J.V.; resources, J.V.; data curation, C.T. and J.V.; writing—original draft preparation, C.T. and J.V.; writing—review and editing, C.T. and J.V.; visualisation, C.T. and J.V.; supervision, J.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

Acknowledgments: The authors of this study would like to thank Maria Giovanna Belcastro for permission to access to the identified osteological collection of Certosa Cemetery (Bologna, Italy). This work is part of the first author's PhD studies in Biomedicine at the University of Granada (Spain).

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Valenzuela-Garach, A. Forensic Odontology in Human Identification in Multiple Victims' Incidents. *Span. J. Leg. Med.* **2023**, *49*, 47–54. [CrossRef]
2. Ubelaker, D.H.; Wu, Y. Fragment Analysis in Forensic Anthropology. *Forensic Sci. Res.* **2020**, *5*, 260–265. [CrossRef] [PubMed]
3. Pilloud, M.A.; Hefner, J.T.; Hanihara, T.; Hayashi, A. The Use of Tooth Crown Measurements in the Assessment of Ancestry. *J. Forensic Sci.* **2014**, *59*, 1493–1501. [CrossRef] [PubMed]
4. Viciano, J.; De Luca, S.; Irurita, J.; Alemán, I. Age Estimation of Infants through Metric Analysis of Developing Anterior Deciduous Teeth. *J. Forensic Sci.* **2018**, *63*, 20–30. [CrossRef]
5. Viciano, J.; Tanga, C.; D'Anastasio, R.; Belcastro, M.G.; Capasso, L. Sex Estimation by Odontometrics of Nonadult Human Remains from a Contemporary Italian Sample. *Am. J. Phys. Anthropol.* **2021**, *175*, 59–80. [CrossRef]
6. Nowak, A.J.; Christensen, J.R.; Mabry, T.R.; Townsend, J.A.; Wells, M.H. (Eds.) *Pediatric Dentistry: Infancy Through Adolescence*, 6th ed.; Elsevier: Philadelphia, PA, USA, 2019. [CrossRef]
7. Kieser, J.A. *Human Adult Odontometrics: The Study of Variation in Adult Tooth Size*; Cambridge University Press: Cambridge, UK, 1990.
8. Hillson, S.; FitzGerald, C.; Flinn, H. Alternative Dental Measurements: Proposals and Relationships with Other Measurements. *Am. J. Phys. Anthropol.* **2005**, *126*, 413–426. [CrossRef]
9. Hassett, B. Technical Note: Estimating Sex Using Cervical Canine Odontometrics: A Test Using a Known Sex Sample. *Am. J. Phys. Anthropol.* **2011**, *146*, 486–489. [CrossRef]
10. Kazzazi, S.M.; Kranioti, E.F. Sex Estimation Using Cervical Dental Measurements in an Archaeological Population from Iran. *Archaeol. Anthropol. Sci.* **2018**, *10*, 439–448. [CrossRef]
11. Adams, D.; Pilloud, M. Sex Estimation from Dental Crown and Cervical Metrics in a Contemporary Japanese Sample. *Forensic Anthropol.* **2019**, *2*, 1–11. [CrossRef]
12. Pilloud, M.A.; Hillson, S. Brief Communication: The Use of Alternative Dental Measurements on Deciduous Teeth. *Am. J. Phys. Anthropol.* **2012**, *149*, 299–306. [CrossRef]
13. Stojanowski, C.M. Comment on "Alternative Dental Measurements" by Hillson et Al. *Am. J. Phys. Anthropol.* **2007**, *132*, 234–237. [CrossRef] [PubMed]
14. Viciano, J.; Alemàn, I.; D'Anastasio, R.; Capasso, L. Alternative Dental Measurements: Correlation between Cervical and Crown Dimensions. *J. Biol. Res.* **2012**, *85*, 194–200. [CrossRef]

15. Ðuric, M.; Rakocevic, Z.; Tuller, H. Factors Affecting Postmortem Tooth Loss. *J. Forensic Sci.* **2004**, *49*, 1313–1318. [PubMed]
16. Oliveira, R.N.; Melalli, R.F.H.; Autunes, J.L.F. Postmortem Tooth Loos in Human Identification Process. *J. Forensic Odontostomatol.* **2000**, *18*, 32–36. [PubMed]
17. Thompson, S. Postmortem Tooth Loss: Patterns and Indications. Senior Thesis, Projects, University of Tennessee, Knoxville, TN, USA, 2004. Available online: https://trace.tennessee.edu/utk_interstp3/42/ (accessed on 6 November 2024).
18. Cirillo, L.E.; Bartelink, E.J. Gaps in Information: What Missing Teeth Mean in Bioarchaeology. *Dent. Anthropol.* **2022**, *35*, 21–31.
19. Nayak, A.; Tamgadge, D.S. Alveolar Bone—As a Valuable Evidence in Forensic Investigations—A Review. *Acad. J. Anthropol. Stud.* **2022**, *5*, 9–14.
20. Nelson, S.J. (Ed.) *Wheeler's Dental Anatomy, Physiology, and Occlusion: 75th Anniversary; Evolve Study Resources Free with New Textbook Purchase*, 10th ed.; Saunders, Elsevier: Philadelphia, PA, USA, 2015.
21. Hillson, S. *Dental Anthropology*, 2nd ed.; Cambridge University Press: Cambridge, UK, 2024. [CrossRef]
22. Belcastro, M.G.; Bonfiglioli, B.; Pedrosi, M.E.; Zuppello, M.; Tanganelli, V.; Mariotti, V. The History and Composition of the Identified Human Skeletal Collection of the Certosa Cemetery (Bologna, Italy, 19th–20th Century). *Int. J. Osteoarchaeol.* **2017**, *27*, 912–925. [CrossRef]
23. Smith, B.H. Patterns of Molar Wear in Hunter-Gatherers and Agriculturalists. *Am. J. Phys. Anthropol.* **1984**, *63*, 39–56. [CrossRef]
24. Kerr, N. A Method of Assessing Periodontal Status in Archaeologically Derived Skeletal Material. *J. Paleopathol.* **1988**, *2*, 67–78.
25. Vodanović, M.; Demo, Ž.; Njemirovskij, V.; Keros, J.; Brkić, H. Odontometrics: A Useful Method for Sex Determination in an Archaeological Skeletal Population? *J. Archaeol. Sci.* **2007**, *34*, 905–913. [CrossRef]
26. Aubry, B.S. Technical Note: Cervical Dimensions for in Situ and Loose Teeth: A Critique of the Hillson et al. (2005) Method. *Am. J. Phys. Anthropol.* **2014**, *154*, 159–164. [CrossRef] [PubMed]
27. Koo, T.K.; Li, M.Y. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J. Chiropr. Med.* **2016**, *15*, 155–163. [CrossRef] [PubMed]
28. Dempsey, P.J.; Townsend, G.C. Genetic and Environmental Contributions to Variation in Human Tooth Size. *Heredity* **2001**, *86*, 685–693. [CrossRef] [PubMed]
29. Townsend, G.; Harris, E.F.; Lesot, H.; Clauss, F.; Brook, A. Morphogenetic Fields within the Human Dentition: A New, Clinically Relevant Synthesis of an Old Concept. *Arch. Oral Biol.* **2009**, *54*, S34–S44. [CrossRef]
30. Thongudomporn, U.; Chongsuvivatwong, V.; Geater, A. The Effect of Maximum Bite Force on Alveolar Bone Morphology. *Orthod. Craniofac. Res.* **2009**, *12*, 1–8. [CrossRef]
31. McCormack, S.W.; Witzel, U.; Watson, P.J.; Fagan, M.J.; Gröning, F. The Biomechanical Function of Periodontal Ligament Fibres in Orthodontic Tooth Movement. *PLoS ONE* **2014**, *9*, e102387. [CrossRef]
32. Garib, D.G.; Yatabe, M.S.; Ozawa, T.O. Alveolar Bone Morphology under the Perspective of the Computed Tomography: Defining the Biological Limits of Tooth Movement. *Dent. Press J. Orthod.* **2010**, *15*, 192–205. [CrossRef]
33. Scheid, R.C.; Weiss, G. *Woelfel's Dental Anatomy*, 8th ed.; Lippincott Williams & Wilkins: Philadelphia, PA, USA, 2012.
34. Harris, E.F. Where's the Variation? Variance Components in Tooth Sizes of the Permanent Dentition. *Dent. Anthropol. J.* **2003**, *16*, 84–94. [CrossRef]
35. Acharya, A.B.; Mainali, S. Are Dental Index Useful in Sex Assessment? *J. Forensic Odontostomatol.* **2008**, *26*, 53–59.
36. Schmidt, C.; Ousley, S.; Schmidt, M. Brief Communication: Correcting Overestimation When Determining Two-dimensional Occlusal Area in Human Molars. *Am. J. Phys. Anthropol.* **2011**, *145*, 327–332. [CrossRef]
37. Capeletti, L.; Franco, A.; Reges, R.V.; Silva, R.F. Technical Note: Intra-Alveolar Morphology Assessed in Empty Dental Sockets of Teeth Missing Post-Mortem. *Forensic Sci. Int.* **2017**, *277*, 161–165. [CrossRef] [PubMed]
38. Fujita, H. Periodontal Diseases in Anthropology. In *Periodontal Diseases—A Clinician's Guide*; InTech: Vienna, Austria, 2012; pp. 279–294. [CrossRef]
39. Grimoud, A.-M.; Gibbon, V.E.; Ribot, I. Predictive Factors for Alveolar Fenestration and Dehiscence. *HOMO* **2017**, *68*, 167–175. [CrossRef] [PubMed]
40. Nimigean, V.R.; Nimigean, V.; Bencze, M.A.; Dimcevici-Poesina, N.; Cergan, R.; Moraru, S. Alveolar Bone Dehiscences and Fenestrations: An Anatomical Study and Review. *Rom. J. Leg. Med.* **2009**, *50*, 391–397.
41. Viciano, J.; López-Lázaro, S.; Tanga, C. Post-Mortem Dental Profile as a Powerful Tool in Animal Forensic Investigations—A Review. *Animals* **2022**, *12*, 2038. [CrossRef]
42. Tal, H.; Artzi, Z.; Kolerman, R.; Beitlitum, I.; Goshe, G. Augmentation and Preservation of the Alveolar Process and Alveolar Ridge of Bone. In *Bone Regeneration*; Tal, H., Ed.; InTech: Vienna, Austria, 2012. [CrossRef]
43. Kieser, J.A.; Groeneveld, H.T. The Reliability of Human Odontometric Data. *J. Dent. Assoc. South Afr. = Die Tydskrif van die Tandheelkundige Vereniging van Suid-Afrika* **1991**, *46*, 267–270.
44. Pérez-Pérez, A.; Alesan, A.; Roca, L. Measurement Error: Inter-and Intraobserver Variability. An Empiric Study. *Int. J. Anthropol.* **1990**, *5*, 129–135. [CrossRef]

45. Harris, E.F.; Smith, R.N. Accounting for Measurement Error: A Critical but Often Overlooked Process. *Arch. Oral Biol.* **2009**, *54*, S107–S117. [CrossRef]
46. Garizoain, G.; Parra, R.C.; Aranda, C.; Zorba, E.; Moraitis, K.; Escalante-Flórez, K.; Retana, F.; Condori, L.; Valderrama-Leal, C.; Rodríguez, P.; et al. Root Dentin Translucency and Age at Death Estimation in Adults Using Single Rooted Teeth: Update of the Forensic International Dental Database. *Forensic Sci. Int.* **2023**, *343*, 111564. [CrossRef]