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Sex and stature estimation on the tibia: a virtual pilot study on a contemporary Hispanic population

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Sex and stature estimation represent two pillars in the creation of the biological profile, providing crucial demographic information that forensic anthropologists use for the identification of unknown skeletonized remains. This pilot study evaluates population data proposing a virtual sex and stature estimation method for a Hispanic population using the tibia. Ninety-two CT scans from the New Mexico Decedent Image Database were used to generate 3D models of the left tibia (forty-seven males, forty-five females). Tibial length, proximal and distal breadth were the parameters taken. Intra-observer error was assessed using an intra-class correlation coefficient. Sex differences were explored, and discriminant function and regression analysis used to develop sex and stature estimation formulae, respectively. High repeatability was demonstrated. Sex estimation accuracies ranged between 83.7 per cent and 93.5 per cent, with proximal and distal breadth showing the highest correct classification rates. Stature estimation produced errors between 5.51 cm and 7 cm, with the validation test providing errors falling within the predicted standard error of the estimate reported by the original equations. This study suggests the potential for accurate sex and stature estimation in the Hispanic sample. Although a larger sample is needed to corroborate the preliminary results, the proposed methods might assist in the identification of future forensic cases.

The forensic anthropologist plays an important role in the identification process of unknown skeletonized remains (Ubelaker, Shamlou & Kunkle 2019). One of the aims of their assessment is the creation of the biological profile, which involves the estimation of four pieces of demographic information through osteological evidence: population affinity, sex, age-at-death, and stature (Latham, Bartelink & Finnegan 2018). Stature and sex estimation entail useful evidence for narrowing down the search for missing persons, as these two pieces of information are mostly recalled by, for example, relatives (Menéndez Garmendia, Gómez-Valdés, Hernández, Wesp & Sánchez-Mejorada 2014; Rainio, Lalu, Ranta & Penttilä 2001).

When evaluating the stature of an individual, three different types of data for estimation can be gathered. Living stature is measured in a standing position by medical personnel, and it is considered to be the most accurate; nevertheless, it is subject to

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small physiological variations during the day and it is affected by age (Giles 1991). The other types of data are cadaveric and forensic stature, with the first being highly variable within individuals and with inconsistent data collection protocols, and with the second being possibly unreliable as it is often self-reported, hence accounting for inaccuracies (Bidmos 2005; Giles 1991; Ousley 1995; Trotter & Gleser 1977).

Overall, stature estimation is a relatively simple and straightforward assessment due to the fact that parameters are often easily measured by the analyst without the need for experience and most measurements are standardized. The methods are, however, greatly affected by intrinsic and extrinsic factors such as genetics, age-at-death, population affinity, and sex (Rainio *et al.* 2001; Zeman & Beňuš 2020*b*). For example, different correlations between long bones and stature have been observed between males and females (Ramezani, Shokri, Ghanbari, Salehi & Niknami 2019). Extrinsic factors appear to also have a great impact on stature. A study on Andean populations found that the relationship between long bones and stature is strongly correlated with the individuals' geographical area, with population groups sharing common geographical environments having similar average stature (Anzellini & Toyne 2020). Nutrition can have a major influence in skeletal growth and development, as individuals with a low body mass index – being considered an indicator of poor health – might present shorter height (Bogin, Smith, Orden, Varela Silva & Loucky 2002; Kumar, Kumar & Kumar 2020).

Over the years, multiple techniques have been developed to estimate stature either through the anatomical method, which involves the use of measurements from multiple bones with the addition of correction factors (Fully 1956; Fully & Pineau 1960; Raxter, Auerbach & Ruff 2006; Raxter & Ruff 2010), or the generation of regression equations, which require the collection of measurements from single or multiple bones (Dupertuis & Hadden 1951; Menéndez Garmendia, Sánchez-Mejorada & Gómez-Valdés 2018; Ramezani *et al.* 2019; Steele & McKern 1969; Zhang *et al.* 2021). The recovery and state of preservation of the remains will dictate the choice of the methods for stature estimation, as, for example, taphonomic factors can prohibit the collection of specific parameters (Giurazza *et al.* 2012).

Sex estimation, on the other hand, can be complex and often requires a high level of experience to reach accurate outcomes through the morphological assessment of different skeletal elements (Krishan *et al.* 2016; Ritz-Timme *et al.* 2011; Spiegler & Monson 2010). Sexual dimorphism refers to the differences in size and shape between females and males of the same species; whether it is derived genetically or it is a consequence of nutritional and environmental factors, this difference can be assessed in skeletal remains (Nikitovic 2018; Ruff 1987). Morphological approaches are less time consuming, but some of them are highly dependent on the experience of the observer (Krishan *et al.* 2016). On the other hand, metric analysis can be useful when the remains are taphonomically affected and bone surfaces appear eroded, with some methods offering the possibility of performing the assessment on fragmented remains (Lachenbruch & Goldstein 1979; Ramsthaler, Kettner, Gehl & Verhoff 2010).

Virtual anthropology is an ever-expanding field in forensic and biological anthropology as it allows the assessment of skeletal remains without the need for maceration, as well as the possibility of accessing and sharing virtual data from any location (Brough, Rutty, Black & Morgan 2012; Mullins & Albanese 2018; Robinson *et al.* 2008; Sidler, Jackowski, Dirnhofer, Vock & Thali 2007). Research has demonstrated that there is no significant difference between measurements collected from dry bone and those obtained from three-dimensional (3D) models (e.g. computer tomography [CT] scans), and also that the data collected from 3D images have higher accuracy than those from conventional two-dimensional (2D) scans (Hildebolt, Vannier & Knapp 1990; Robinson *et al.* 2008).

As research has advanced, it has become evident that population-specific methods are necessary (Galeta & Brůžek 2020; Kranioti & Apostol 2015; Kranioti *et al.* 2019; Zeman & Beňuš 2020*b*). Migration has always been and still is a key element in the global history of populations, with different population groups being subjected to mass migration due to internal conflicts, climate crisis, and extreme poverty (Fisher 2014; Hudson, Peckmann, Logar & Meek 2016). For example, the Hispanic population – a term used for the first time by the US Census body to identify all individuals who were born or descended from countries in Central and South America – has increasingly been affected by emigration, currently accounting for 13 per cent of the migrants worldwide (European Commission 2006). In addition, such countries have seen and are currently suffering violent situations such as internal conflicts, military dictatorships, and forced disappearance, which often lead to casualties, thus making it crucial to achieve accurate outcomes in the identification process (Bogin *et al.* 2002; Menéndez Garmendia *et al.* 2018). The aim of this study is to explore the development of sex and stature estimation methods from a contemporary Hispanic sample, contributing to the generation of population-specific standards from populations that are under-represented in the current literature (Plens, Górka & Lopez Quintero 2022). The tibia was selected as the optimal skeletal element as it demonstrated the highest correlation with stature in previous studies conducted on similar populations (Genovés 1967; Menéndez Garmendia *et al.* 2018), as well as showing a significant degree of sexual dimorphism (González-Reimers, Velasco-Vázquez, Arnay-de-la-Rosa & Santolaria-Fernández 2000; Spradley & Jantz 2011).

Materials and methods

Sample group

The data for this study consist of CT scans from the left tibia which were acquired from the New Mexico Decedent Image Database (NMDID). Most individuals recorded in the NMDID have information available such as origin, age-at-death, sex, stature, pathologies, and, in some cases, cause of death (Edgar *et al.* 2020).

A total of ninety-two CT scans (forty-seven males and forty-five females) were selected from the database, targeting those individuals who are identified by the medical examiner and through next-of-kin interviews as either Hispanic, Latino, Spanish, New Mexican, Chicano, Mexican American, or Mexican (Edgar *et al.* 2020). Sex refers to the biological sex of the decedent as recorded in the medical examiner NMDID. The demographic data for stature (living height) consist of the information provided by the next of kin. In addition, all CT scans were selected based on the absence of any pathology and any sign of trauma which could influence the measurements. Only individuals between 18 and 60 years of age were selected in order to avoid any bias due to developmental and/or degenerative processes (Cline, Meredith, Burger & Burrows 1989) (Table 1).

CT scan data acquisition

The NMDID consists of CT scans with 1 mm slice thickness and 0.5 mm overlap (Edgar *et al.* 2020). The CT scan from the tibia for each subject was uploaded and viewed on

Table 1. Demographic information for the sample under study.

Sample	*N*	Minimum age	Maximum age	Mean age	SD
Males	47	21	60	38.23	12.54
Females	45	19	59	37.42	11.80
Total	92	19	60	37.84	12.13

N = number of individuals; SD = standard deviation.

the 3D Slicer software (Fedorov *et al.* 2012). A 3D model of the left tibia was created following the standardized procedure presented by Robles, Carew, Morgan, and Rando (2020). This includes the preparation of the cropped volume in order to isolate the bone of interest; the selection of the most appropriate threshold effect (>200.00); and the elimination of any background noise which could affect the final model. Following the creation of the 3D model, the landmarks were selected for the three measurements collected in this study: total bone length (the distance between the most proximal point on the intercondylar tubercle and the most distal point on the medial malleolus); distal breadth (the maximum distance between the most medial point on the medial malleolus and the most projecting point on the lateral surface of the fibular notch); and proximal breadth (maximum distance between the most projecting point of the medial and lateral condyles, respectively) (Langley, Jantz, Ousley, Jantz & Milner 2016). The distance between the landmarks was measured using the 'line markup' function of the markup module in the 3D Slicer software.

Data analysis

Data analysis was performed using SPSS.V28. Intra-observer error was assessed using intraclass correlation coefficient (ICC) with a two-way mixed-effect model under absolute agreement, with threshold for assessment being 0.80 and 0.90 for good and excellent agreement, respectively (Haber & Barnhart 2006). Ten individuals were used for this analysis with measurements being taken two weeks after original data collection.

All measurements are presented in cm. Descriptive statistics were calculated for the total sample, and the sample divided into males and females. The distribution of the data was assessed using the Shapiro-Wilk test for normality and kurtosis and skewness, as well as graphical representation through the generation of histograms, Q-Q plots, and boxplots (Cramer 1997; Shapiro & Wilk 1965; Tabachnick & Fidell 2007).

Sex differences were explored using an independent *t*-test, and the assumptions of normality and outliers for each group and homogeneity of variances through Levene's test were checked for the statistical analysis performed on each parameter (Sheskin 2011). When the homogeneity of variance assumption was violated, the interpretation of the results was conducted using Welch's test (Welch 1951). The non-parametric alternative Mann-Whitney U test was used if the assumptions were not met (Mann & Whitney 1947). The generation of sex estimation equations was performed using discriminant function analysis (DFA). The assumptions were tested on the data under study (Hahs-Vaughn 2016; Tabachnick & Fidell 2007). Univariate DFA was conducted, first, for each of the tibial variables separately, and then multivariate DFA was conducted with all possible combinations of parameters. The results were assessed according to Wilk's Lambda, eigenvalues, group centroids and sectioning points, canonical discriminant function coefficients, within-groups correlation matrices, and both original and cross-validated classification accuracies, with the latter being performed through leave-one-out classification strategies (Hair, Black, Babin & Anderson 2018; Tabachnick & Fidell 2013).

For stature estimation, linear regression analysis was performed. First, the relationship between the parameters was assessed for linearity using scatterplots. A developmental set was used to generate the regression equations (80 per cent of the total sample with equal number of males and females, $N = 74$). Owing to limitations in sample size and to avoid the risk of losing statistical power, the stature regression equations were not generated for the sexes separately. Simple regression models were generated using just one single parameter, and then multiple regression was conducted to test the accuracy of stature estimation based on different combinations of parameters. The assumptions were tested for simple and multiple linear regression in relation to homoscedasticity, multicollinearity, and normality of the residuals as well as outliers, and R^2, adjusted R^2, and the standard error of the estimate (SEE) were reported to assess the model fit and accuracy (Kim 2015; Kutner, Nachtsheim, Neter & Li 2005). A validation set (20 per cent of the total sample with equal number of males and females, $N = 18$) was used to validate the generated equations calculating absolute minimum, maximum, and mean error between known stature and estimated stature. Both developmental and validation sets had similar mean age and similar age distribution.

Results

ICC results demonstrate high repeatability for the three tibial parameters, with the average ICC values ranging from 0.95 to 0.99, indicating an excellent agreement, and the 95 per cent ICC confident intervals ranging from 0.80 to 0.99, suggesting good and excellent agreement.

Descriptive statistics for the total sample, and for males and females separately, are presented in Table 2. The total sample presents an average tibia length of 37.53 cm with proximal breath and distal breadth reporting average values of 7.19 cm and 5.10 cm, respectively. Males present higher values than females for tibia length, having 39.28 cm and 35.69 cm, respectively. The same pattern is seen for proximal and distal breadth.

Table 2. Descriptive statistics for the total sample, and for males and females for the tibial parameters.

		Minimum	Maximum	Mean	*SD*	*SE*	*SW*
Total	Tibia L	30.84	44.14	37.53	2.60	0.271	0.096
	Proximal B	5.91	8.76	7.19	0.64	0.067	0.029
	Distal B	4.13	6.264	5.10	0.45	0.047	0.385
	Stature	149.86	193.00	167.45	10.16	1.05	0.017
Males	Tibia L	34.43	44.14	39.28	2.23	0.325	0.824
	Proximal B	6.57	8.76	7.69	0.43	0.063	0.204
	Distal B	4.72	6.26	5.42	0.36	0.053	0.826
	Stature	152.40	193.00	174.32	8.57	1.24	0.965
Females	Tibia L	30.84	38.53	35.69	1.45	0.216	0.147
	Proximal B	5.91	7.45	6.66	0.34	0.050	0.859
	Distal B	4.13	5.242	4.77	0.26	0.039	0.671
	Stature	149.86	173.00	160.27	5.81	0.865	0.033

*All measurements in cm; L = length; B = breadth; *SD* = standard deviation; *SE* = standard error; *SW* = Shapiro-Wilk *p*-value.

Table 3. Results of independent samples *t*-test and Welch's test for sex differences.

	F value	*t* (*df*)	*p*-value	Mean difference	*SED*	95% *CID*	
						Lower	Upper
Tibia L	7.468	9.20 (79.32)	< 0.001	3.591	0.390	2.814	4.367
Proximal B	1.036	12.75 (90)	< 0.001	1.028	0.081	0.868	1.189
Distal B	4.512	9.88 (84)	< 0.001	0.648	0.066	0.517	0.778

L = length; B = breadth; *SED* = standard error of the difference; CID = confidence interval of the difference.

Regarding stature, the overall average stature for the total sample is 167.45 cm, with males presenting higher height than females (174.32 cm ($SD = 1.24$) and 160.27 cm ($SD = 0.86$), respectively).

The Shapiro-Wilk test demonstrated that the tibial parameters were normally distributed for males and females, while proximal breadth was the only parameter non-normally distributed for the total sample (Table 2). Regarding stature data, the total sample and female individuals presented a non-normal distribution. Overall, no significant outliers were identified through the assessment of boxplots.

The differences between males and females for the tibial parameters were analysed using an independent samples *t*-test. The assumption for normality and absence of outliers were met, and the homogeneity of variance Levene's test demonstrated that tibia length and distal breadth violated this assumption (p-value < 0.05), and thus, Welch's test was interpreted for these two parameters (Table 3). All three tibial parameters were statistically significantly different between males and females. Man-Whitney *U* results demonstrated a statistically significant difference between the sexes for stature ($U = 184.5, z = -6.828, p < 0.001$).

For the generation of sex estimation models, DFA was performed first on single parameters. As seen in Table 4, the lowest classification accuracy from the univariate DF is produced by tibia distal breadth with an overall cross-validated correct classification of 83.7 per cent, with the females showing a higher correct classification than males (88.9 per cent and 78.7 per cent, respectively). The highest accuracy is provided by proximal breadth with an overall correct classification of 92.4 per cent, producing similar accuracy rates for males and females. From the multivariate DF generated, the highest classification accuracy is produced by the combination of proximal and distal breadth, which provided a correct classification of 93.5 per cent, presenting higher rates for females than for males (95.6 per cent and 91.5 per cent, respectively).

Regarding the generation of stature estimation models, a linear relationship between stature and the parameters was first corroborated by the scatterplots. Table 5 shows the results for the simple and multiple regression models. Model assumptions were tested with no unusual points being observed through scatterplots and through standardized residual case-wise diagnosis, and independence of the residuals was corroborated through the Durbin-Watson test. No multicollinearity was reported according to the multicollinearity diagnosis values. Simple and multiple linear regression model diagnostic plots can be found in the supplementary material in the appendix.

Regarding the models' performance, all simple models are statistically significant, with the model including tibia length and the model including proximal breadth

Table 4. Sex estimation univariate and multivariate discriminant functions, sectioning points, and classification results.

				Discriminant function				Original %			Cross-validated %		
		Wilk's Lambda	Group centroid M/F (sectioning points)[a]	Constant	Unst. coefficient/s			Male	Female	Total	Male	Female	Total
Univariate DF	Tibia L	0.52^{**}	0.930/−0.972 (−0.021)	−19.88	0.53			80.9	88.9	84.8	80.9	88.9	84.8
	Proximal B	0.357^{**}	1.298/−1.356 (−0.029)	−18.543	2.58			91.5	93.3	92.4	91.5	93.3	92.4
	Distal B	0.483^{**}	1.001/−1.046 (−0.0225)	−16.13	3.16			78.7	88.9	83.7	78.7	88.9	83.7
Multivariate DF	Tibia L + proximal_B	0.343^{**}	1.339/−1.399 (−0.06)	−21	0.15	2.138		85.1	93.3	89.1	85.1	93.3	89.1
	Proximal B + distal B	0.346^{**}	1.329/−1.388 (−0.0295)	−19.476	2.11	0.845		91.5	95.6	93.5	91.5	95.6	93.5
	Tibia L + distal B	0.435^{**}	1.104/−1.153 (−0.0245)	−20.223	0.265	2.017		83	93.3	88	80.9	93.3	87
	Tibia L + proximal_B + distal_B	0.339^{**}	1.352/−1.412 (−0.03)	−21.105	0.118	1.918	0.566	87.2	95.6	91.3	85.1	95.6	90.2

$^{**}p$-value < 0.001

L = length; B = breadth; unst. = unstandardized

[a] Discriminant score less than sectioning point is female.

Table 5. Simple and multiple regression analysis for stature estimation.

		ANOVA			Parameter estimates			Model summary		
	Model	*F* (*p*-value)	Pr > *F*	Unst. coefficients	*SE*	*t*	*p*-value	R^2	R^2 adj.	*SEE*
Simple regression models	*Constant*	124.727	< 0.001	49.815	10.522	4.734	<0.001	0.634	0.629	6.3
	Tibia L			3.127	0.28	11.168	<0.001			
	Constant	126.049	<.0001	74.116	8.309	8.92	<.0001	0.636	0.631	6.28
	Proximal B			12.968	1.155	11.227	<0.001			
	Constant	86.074	<0.001	83.896	8.999	9.323	<0.001	0.545	0.538	7.03
	Distal B			16.31	1.758	9.278	<0.001			
Multiple regression models	*Constant*	93.297	<0.001	47.304	9.21	5.136	<.001	0.724	0.717	5.51
	Tibia L			1.772	0.372	4.759	<.001			
	Proximal B			7.438	1.542	4.825	<.001			
	Constant	67.506	<0.001	70.144	8.392	8.359	<.001	0.655	0.646	6.16
	Proximal B			9.663	2.022	4.779	<.001			
	Distal_B			5.426	2.749	1.973	0.05			
	Constant	74.023	<0.001	49.551	9.972	4.969	<.001	0.676	0.667	5.97
	Tibia L			2.188	0.408	5.364	<.001			
	Distal B			6.953	2.296	3.028	0.003			
	Constant	61.614	<0.001	47.446	9.264	5.121	<.001	0.725	0.714	5.54
	Tibia L			1.7	0.403	4.222	<.001			
	Proximal B			6.868	1.935	3.55	<.001			
	Distal B			1.306	2.658	0.492	0.62			

L = length; B = breadth; Unst. = unstandardized; adj. = adjusted; SEE = standard error of the estimate.

Table 6. Absolute minimum, maximum, and mean errors of the generated formulae tested on the validation set.

	Minimum error	Maximum error	Mean error
Tibia L	0.007	11.801	4.541
Proximal B	0.189	8.919	4.261
Distal B	0.174	13.439	5.667
Tibia L + proximal B	0.174	7.586	3.901
Proximal B + distal B	0.848	8.811	4.349
Tibia L + distal B	0.257	11.505	4.594
Tibia L, proximal B + distal B	0.019	7.549	3.868

explaining similar proportions of the variance of stature as seen by the adjusted R^2, as well as producing a similar *SEE* (6.3 cm and 6.28 cm, respectively). From the multiple regression models, the lowest error and highest adjusted R^2 were produced by tibial length and proximal breadth combined, and for the model including all three parameters, producing an *SEE* of 5.51 cm and 5.54 cm, respectively.

The simple and multiple linear regression models reported in Table 5 were tested on the validation set, producing mean absolute errors ranging from a minimum of 3.86 cm to a maximum of 5.66 cm. The lowest errors, as demonstrated by the validation results, are presented by the models that include tibial length and proximal breadth, and the model including the three parameters. Overall, the errors reported in Table 6 fall within the *SEE* reported by the original models.

Discussion

The construction of the biological profile can assist in the identification process when skeletonized remains are found. Stature and sex estimation are crucial to reach a positive identification (Latham *et al.* 2018; Menéndez Garmendia *et al.* 2014; Latham *et al.* 2018; Rainio *et al.* 2001). The aim of the present research is to contribute to the generation of population-specific methods that could potentially be used for identification of Hispanic individuals. The present research used the term *Hispanic* as it embraces the origin of the individuals of the sample under study in line with the reporting terminology used by the medical examiner in the NMDID and next-of-kin information (Edgar *et al.* 2020). It is worth acknowledging the complexity of grouping individuals originating from intricate historical events and diverse population structures (Ross & Pilloud 2021). Although the term does not have a biological meaning, it is currently used by the US Census and as a self-identification term (Ross & Williams 2021; Spradley, Jantz, Robinson & Peccerelli 2008).

In this study, it was demonstrated that repeatability of the measurements collected was high. Furthermore, accuracy rates for sex estimation ranged from a minimum of 83.7 per cent to a maximum of 92.4 per cent for cross-validated correct classification, and the errors produced by the regression equations developed for stature estimation reported an *SEE* from 5.51 cm to 7.03 cm, which is in line with accuracies provided by other authors (Béguelin 2011; Bidmos 2008*a*; Ekizoglu *et al.* 2016; Kranioti & Apostol 2015). This pilot study offers not only new population data, but also the possibility of using the different formulae depending on the degree of preservation of the remains.

There are some examples in the literature which produced stature regression equations with parameters other than the total tibial length, and none of those have studied the Hispanic population (Chibba & Bidmos 2007; Fongkete *et al.* 2016). For example, Wright and Vasquez (2003) developed a method on Guatemalan individuals to estimate bone lengths from fragments but did not produce a stature estimation method. Other authors, such as Chibba and Bidmos (2007), assessed tibial proximal and distal breadth to estimate stature from South African and European individuals, with an R^2 value of 0.54 for the distal breadth and an *SEE* of 5.94 cm for female individuals, which is in agreement with the results presented here. Furthermore, Holland (1992) studied the White and Black American population with an *SEE* ranging from 4.71 cm to 4.88 cm when estimating stature using the proximal breadth. When comparing the results obtained by some methods developed using total tibial length, studies present R^2 values greater than 0.8 and error rates ranging from 2.81 cm to 3.80 cm, indicating a stronger relationship with stature than our sample (e.g. Duyar & Pelin 2003; Genovés 1967; Hasegawa, Uenishi, Fukunaga, Kimura & Osawa 2009).

The influence of genetic and environmental factors, among others, should be taken into consideration when comparing studies as this will impact the methods' performance (Anzellini & Toyne 2020; Dayal, Steyn & Kuykendall 2008). Moreover, most authors generated sex-specific stature equations, as males and females can differ greatly in their height (Bidmos 2008*b*; Gray & Wolfe 1980). Whilst presenting a pooled sample could be a pitfall of the method, it can also represent an advantage as the regression equations can be applied in circumstances where the sex of the individual is unknown. In addition, sample size differences between studies should be acknowledged as larger sample sizes might improve the error estimates (Cramer 1997). For the present study, future research will include a larger sample size with the potential of generating sex-specific stature estimation equations to test whether the accuracy improves (Albanese, Osley & Tuck 2016).

Regarding sex estimation, several studies have implemented measurements from the lower limbs, especially the tibia, often obtaining accuracies over 80 per cent, which is in agreement with the errors reported here (e.g. Akhlaghi, Sheikhazadi, Khusravi, Pournia & Anary 2011; Fasemore *et al.* 2018; Kiskira, Eliopoulos, Vanna & Manolis 2022; Kotěrová *et al.* 2017; Kranioti, García-Donas, Almeida Prado, Kyriakou & Langstaff 2017; Selliah *et al.* 2020). From the sample studied here, proximal breadth was the parameter presenting the highest sexual dimorphism providing the highest correct classification (92.4 per cent). This result largely agrees with those obtained by other authors for Spanish, Greek, Italian, Finnish, and Turkish populations (Kranioti & Apostol 2015; Kranioti *et al.* 2019; Maijanen *et al.* 2021). In addition, proximal breadth outperforms the distal breadth for sex estimation in accordance with other studies (Akhlaghi *et al.* 2011; Ekizoglu *et al.* 2016; Kranioti & Apostol 2015). The high level of this paremeter's sexual dimorphism can be explained by epiphyses functional demands of weight and musculature bearing on these parts of the bone (Dangar, Mina, Pandya, Pradip & Rathod 2015; González-Reimers *et al.* 2000).

Regarding multivariate equations, the most accurate estimates were obtained by proximal and distal breadth (93.5 per cent); such results are linked to the coupling of the two parameters, with the nature of the proximal and distal epiphysis demonstrating a high degree of sexual dimorphism (Iscan & Miller-Shaivitz 1984). In addition, Steyn and Işcan (1997) reported a similar outcome in a study on a South African population, and other methods yield accuracies greater than 90 per cent using just three tibia parameters (Kotěrová *et al.* 2017; Kranioti *et al.* 2019; Selliah *et al.* 2020; Tise, Spradley & Anderson 2013). The evaluation of multiple parameters presents various advantages compared to equations generated through univariate analysis. Moreover, higher accuracy is usually yielded when various elements are used in conjunction, although the lack of availability of different bones might hinder the assessment (Krüger, L'Abbé & Stull 2017).

The research presented here is amongst the few studies evaluating the Hispanic population (Spradley, Anderson & Tise 2015; Tise *et al.* 2013). For example, Tise *et al.* (2013) assessed a Hispanic sample also suggesting a high degree of sexual dimorphism of the proximal tibial breadth, although the best accuracies were provided by the clavicle and the radius, and the under-representation of female individuals in this study requires further attention. When considering tibial distal breadth, O'Bright, Peckmann, and Meek (2018) obtained low accuracy (71.4 per cent) on a Chilean population, and Spradley *et al.* (2015) showed accuracies greater than 90 per cent on a Mexican sample. Thus, such differences can be linked to the methods being population-specific in respect to different biogeographical origins (Galeta & Brůžek 2020). Differences in sample size and sex distribution could have also an impact, as, for example, Spradley *et al.* (2015) used a skewed sample with more than 100 male individuals, potentially explaining the higher accuracies for this specific sex.

The present research provides further evidence for the validity of virtual identification techniques. In fact, the high repeatability obtained does show that 3D models are relatively easy to analyse. Virtual methods can be implemented in research to construct new methods based on contemporary populations and be applied in forensic investigations, with CT imaging showing high potential in metric assessment of skeletal elements (Giurazza *et al.* 2012; Hildebolt *et al.* 1990; Robinson *et al.* 2008). In future research, our sample size should be increased to better represent more populations, ideally including more individuals from Central and South America as specific criteria for individuals from these geographical areas are required (Spradley *et al.* 2008). In addition, inter-observer error must be evaluated in order to assess the reproducibility of the method (Zeman & Beňuš 2020*a*). Most importantly, investigating further the data obtained to record the stature of the individuals and testing other sources (e.g. medical records) should be considered, as the potential introduction of error relates not only to the development of the method but most importantly to the actual estimation of stature for identification (Cardoso, Marinho & Albanese 2016). Furthermore, it is suggested that additional parameters are implemented in the equations to provide the anthropologist with multiple measurements for their analysis, which can be adapted according to the conditions of the remains and context.

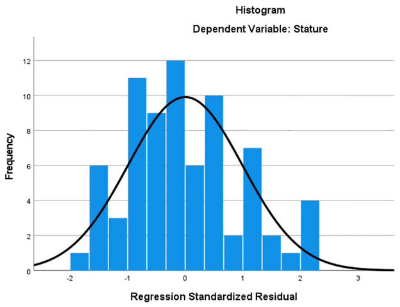
Conclusions

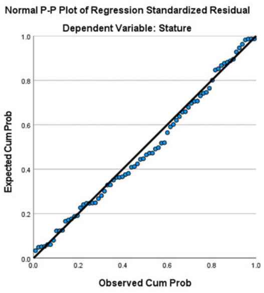
The aim of this study was to explore the possibility of developing sex and stature estimation methods using the tibia from a contemporary Hispanic sample. The results demonstrate the potential for specific-population methods for estimating those two pieces of information of the biological profile, with error rates similar to the ones reported in the literature. Moreover, the potential of using virtual methods is encouraging for the development of new techniques as stated by the literature. This study provides evidence as a tool to further investigate other tibial parameters or other skeletal elements, as well as including a larger and more diverse sample to validate the application of the formulae on other individuals with a similar biological and geographical origin.

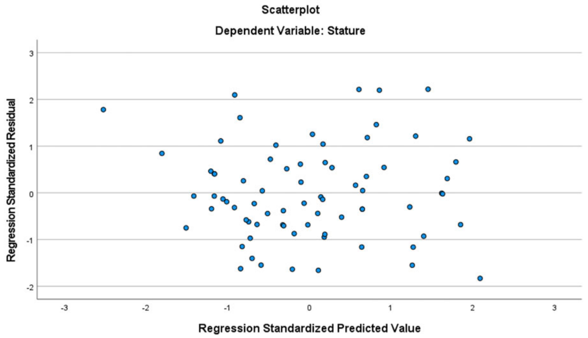
Appendix: Supplementary materials

Simple regression: stature estimation model diagnostics

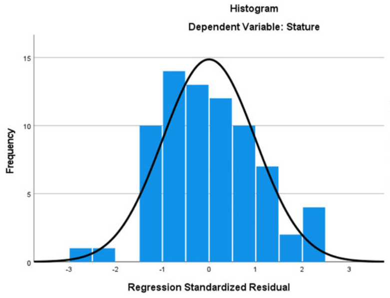
Tibia length.

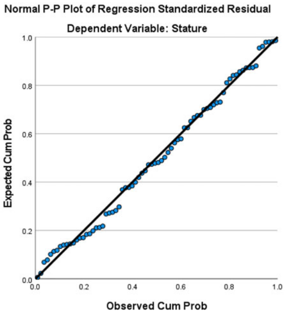


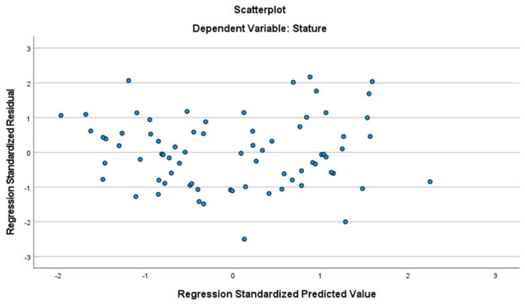




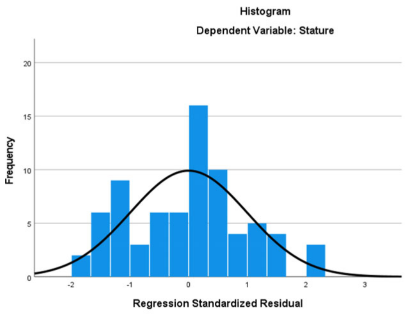
Proximal breadth.

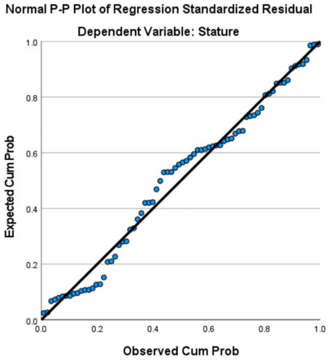


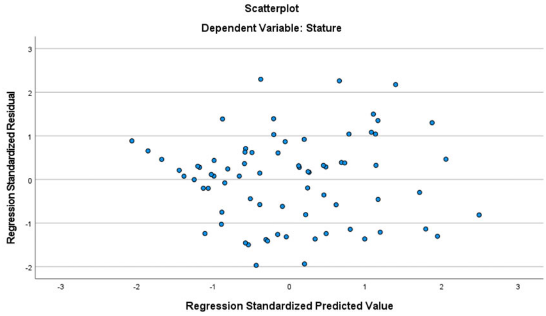




Distal breadth.

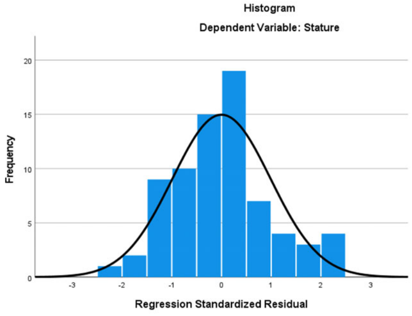


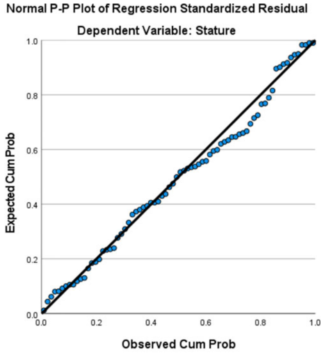


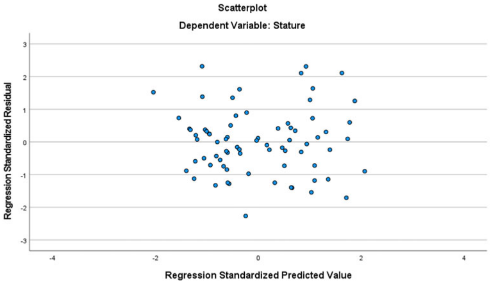


Multiple regression: stature estimation model diagnostics

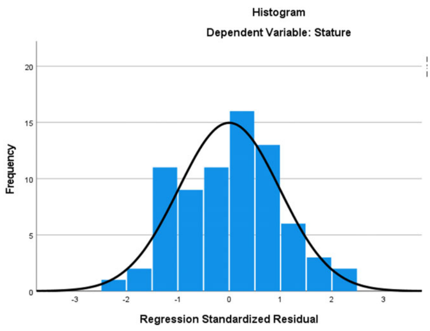
Proximal breadth and tibia length.

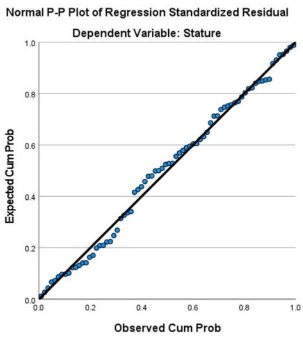


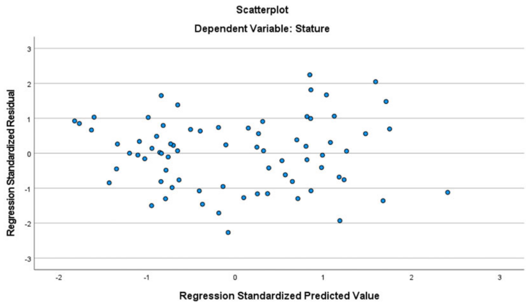




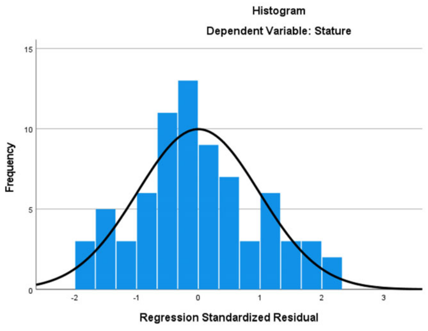
Proximal breadth and distal breadth.

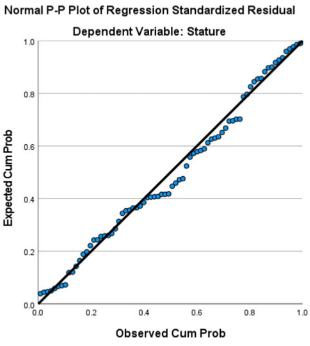


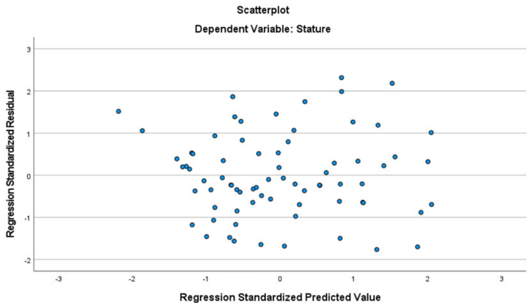




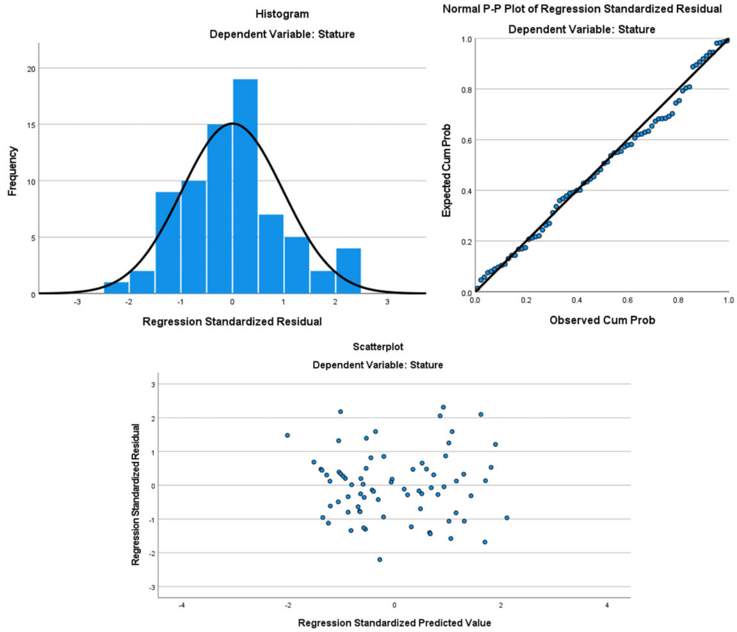
Tibia length and distal breadth.







Tibia length, proximal breadth, and distal breadth.



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Estimation du sexe et de la stature à partir du tibia : étude pilote virtuelle sur une population hispano-américaine contemporaine

Résumé

L'estimation du sexe et de la stature forme le double pilier du profil biologique et apporte des informations démographiques cruciales que les anthropologues légistes utilisent pour identifier les restes osseux de personnes inconnues. L'étude pilote présentée ici évalue des données de population en proposant une méthode d'estimation virtuelle du sexe et de la stature d'une population hispano-américaine à l'aide du tibia. Des images tomographiques de 92 sujets (47 hommes, 45 cinq femmes), issues de la New Mexico Decedent Image Database, ont été utilisées pour générer des modèles 3D du tibia gauche. La longueur du tibia et sa largeur proximale et distale ont été relevées. L'erreur pour un même observateur a été évaluée à l'aide d'un coefficient de corrélation intra-classe. Les différences entre les sexes ont été explorées et une fonction discriminante et une analyse de régression ont été utilisées pour développer, respectivement, des formules d'estimation du sexe et de la stature. La très bonne répétabilité de la méthode a été démontrée. L'exactitude d'estimation du sexe variait entre 83,7 % et 93,5 %, avec un maximum de classifications correctes pour la largeur proximale et distale. L'estimation de la stature a produit des erreurs de 5,51 cm à 7 cm et le test de validation a donné des erreurs dans les limites de l'erreur-type prédite de l'estimation rapportée par les équations d'origine. Cette étude suggère un potentiel d'estimation exacte du sexe et de la stature dans un échantillon hispano-américain. Bien qu'un plus grand échantillon soit nécessaire pour corroborer ces résultats préliminaires, les méthodes proposées pourraient aider à l'identification des sujets dans de futurs cas médicolégaux.

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