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TECHNICAL NOTE

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Recalibration of the Klales et al. (2012) method of sexing the human innominate for Mexican populations

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Abstract

Objectives: The aim of this study was to test the accuracy of the Klales et al. (2012) equation for sex estimation in contemporary Mexican population.

Materials and Methods: Our investigation was carried out on a sample of 203 left innominates of identified adult skeletons from the UNAM-Collection and the Santa María Xigui Cemetery, in Central Mexico. The Klales' original equation produces a sex bias in sex estimation against males (86–92% accuracy versus 100% accuracy in females). Based on these results, the Klales et al. (2012) method was recalibrated for a new cutt-of-point for sex estimation in contemporary Mexican populations.

Results and Discussion: The results show cross-validated classification accuracy rates as high as 100% after recalibrating the original logistic regression equation. Recalibration improved classification accuracy and eliminated sex bias. This new formula will improve sex estimation for Mexican contemporary populations.

KEYWORDS
nonmetric sex estimation, pelvis, Phenice traits, visual sex estimation

1 | INTRODUCTION

In skeletal biology and especially in forensic anthropology, accurate sex estimation is a critical step in establishing the biological profile, a crucial element in achieving positive identification. While the usefulness of almost every part of the skeleton has been tested for sex estimation, it is well known that the innominate bone is perhaps the most accepted and accurate element for sexing skeletal remains. Unlike metric methods, morphological methods are relatively quick and easy to perform; they do not require any specialized equipment and are able to examine features often not easily captured with metric methods (Klales, Ousley, & Vollner, 2012).

The Klales et al. (2012) method modified the Phenice (1969) technique to include ordinal scoring of three pubic traits and statistical classification based on logistic regression analysis. The method achieved classification accuracy of 94.5% in the original sample and 86.2% in the validation sample (Klales et al., 2012). Since the Scientific Working Group for Forensic Anthropology (www.swganth.org) and the Latin American Forensic Anthropology Association (www.alafforense.org) recommend a population-specific approach to improve sex assessment, and there are no available data for the Klales et al. (2012) method in Mexican populations, the goal of this work is to apply the original Klales et al. (2012) method in two Mexican skeletal series, Otomí from

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the Mezquital Valley and Mestizos from Mexico City, and carry out the statistical analysis to recalibrate population specific logistic regression equations for sexing the innominate bones in contemporary Mexican populations.

2 | MATERIALS AND METHODS

2.1 | Reference samples

The study was based on Klales et al. (2012) modification of Phenice's (1969) traits, namely the ventral arc (VA), the subpubic contour (SPC), and the medial aspect of the ischio-pubic ramus (MA) traits in two Mexican samples of known sex and age-at death adult skeletons. Each individual was scored by one of the authors (JAGV) on a five-point ordinal scale based on the figures and descriptions presented by Klales et al. (2012).

The first sample consists of 57 human innominates (29 females and 28 males) of Otomí indigenous from Santa María Xigui, Alfajayucan, Hidalgo, Mexico pertaining to the Mezquital Valley. The Mezquital Valley is a cultural and geographical region consisting of 27 Municipal localities characterized by semi-arid climate. This valley is subdivided into five sub-regions of which Alfajayucan is one of its main plains. The Mezquital Valley has been inhabited by different Native American groups that share a common genetic origin, with the Otomí population being the first to separate from the others in the late Early Preclassic period (2500–1200 YBP) (Gorostiza et al., 2012). In 2010, Santa Maria Xigui had a total population of 1,104 inhabitants (564 females and 540 males) of whom 37.93% were Otomí (hñähñu) language speakers (www.inegi.org.mx). Skeletal data was obtained with informed consent from relatives during relocation of the Nuestro Señor San Isidro Labrador cemetery, located in Alfajayucan, Hidalgo; in December 2013. Sex and age data were obtained from cemetery records. The sample cover the period between 1960 and 2010. The age-at-death distribution of the Santa María Xigui ranges between 19 and 108 years. The female mean is 64.94 years with a standard deviation of 19.19 years and male mean is 49.38 years with a standard deviation of 17.39 years.

The second sample consists of 146 adult human innominates (62 females and 84 males) of Mestizo individuals from Mexico City from the Osteological Collection of the National Autonomous University of Mexico (UNAM-Collection), in the Physical Anthropology Laboratory, Department of Anatomy, School of Medicine. The UNAM-Collection is comprised from contemporary skeletons (1990–2010 chronological range of the years of death) from unclaimed bodies from forensic institutes, public hospitals, psychiatric institutions, and shelters. Some of the individuals have recorded antemortem data, like sex and age; and in some cases, we have also name, death cause and provenance (Gómez-Valdés et al., 2012; Menéndez et al., 2014). The UNAM-Collection individuals range between 20 and 89 years. The female mean is 53.1 years with a standard deviation of 17.4 years and male mean is 49.4 years with a standard deviation of 18.18 years. The study of the UNAM-Collection was carried out following the established norms in Items 4 and 5 from the Third Chapter of the Regulations for Safety and Coordination of Health Research of the National Autonomous University of Mexico Legislation (http://info4.juridicas.unam.mx/unijus/unv/20/) (Supporting Information Figures S1 and S2).

2.2 | Statistical methods

In keeping with the original Klales et al. (2012) method, classification accuracy was tested using logistic regression in SPSS 17.0 (SPSS, Inc., 2008). The statistical analysis was carried out in two stages; the first tested the accuracy of the original Klales et al. (2012) equation through cross-tabulations of documented and predicted sex in both samples. Taking into account the bias in sex estimation, the second stage consisted of recalibrating the original equation for each sample and the combined samples. The classification accuracy of each trait was also examined and compared to the original Klales et al. (2012) publication.

Logistic regression was preferable to other classification methods, such as discriminant function analysis, because the method is more appropriate in situations where the data violate assumptions of normality, variations in group composition and when variables are qualitative rather than quantitative (Halperin, Blackwelder, William, & Verter, 1971; Press & Wilson, 1978). Trait frequencies and correlations were also calculated in accordance with Klales et al. (2012).

3 | RESULTS

Table 1 displays the results of the original Klales et al. (2012) equation in two documented Mexican skeletal series. Achieving the 100% correct sex classification of females and about 86–92% correct classification of males in both series. When both samples were combined, classification accuracy was 95%, again in favor of females. The fact that females showed a rate of over-classification in relation to the males suggests that the location of the original cut-off-point needs to be recalibrated for the Mexican population.

After the logistic regression equation was recalibrated, accuracy for the UNAM collection was 100% using all three traits (Table 2). The

TABLE 1 Cross-tabulation of sex after the application of Klales et al. (2012) method in two modern Mexican samples

		Estimated		
Sample	Documented	Female	Male	Total
XIGUI	Female	29	0	29
	Male	4	24	28
	%	100	86	
UNAM	Female	62	0	62
	Male	7	77	84
	%	100	92	
Combined	Female	91	0	91
	Male	11	101	112
	%	100	90	

TABLE 2 Percent (%) correct classification for individual traits and combined traits using the recalibrated equation

Trait (s)	Females	Males	Combined	Sex bias
VA, SPC, MA	100	100	100	0
VA, MA	100	100	100	0
MA, SPC	98.9	100	99.5	1.1
VA, SPC	98.9	99.1	99	0.2
VA	97.8	99.1	98.5	1.3
SPC	96.7	100	98.5	3.3
MA	91.2	100	96.1	8.8

new calibrated logistic regression equation for the UNAM collection is: 16.370 (VA) + 15.842 (MA) + 14.978 (SPC) − 125.185. Classification accuracy for the XIGUI collection was also 100%. The new calibrated logistic regression equation for the XIGUI collection is: 18.120 (VA) + 31.830 (MA) + 13.771 (SPC) − 175.245. Classification remained high with a combined correct classification of 100% when all three traits were used in combination and when both samples were combined (Table 2). Using all three trait scores, the new logistic regression equation for combined modern Mexican populations is:

$$18.667(\mathrm{VA})+30.361(\mathrm{MA})+12.334(\mathrm{SPC})-168.376$$

If the logistic regression equation score for an unknown individual is less than zero, the individual will classify as a female. In this manner, the probability of being female can be calculated through the equation $p_f = 1/(1 + e^{score})$ and the probability for males $p_m = 1 - p_f$ (Press & Wilson, 1978).

Classification was equally high and sex bias was equally low when using the ventral arc in combination with the medial aspect of the ischio-pubic ramus (Table 2). When traits were analyzed individually, classification accuracy was highest with the ventral arc (98.5%) and subpubic contour (98.5%), followed by the medial aspect of the ischio-pubic ramus (96.1%; Table 2). The ventral arc had the lowest sex bias (1.3) of the three traits, while the medial aspect of the ischio-pubic ramus had the highest sex bias (8.8).

Score frequencies were more variable for males than females. Females were predominantly grouped into the lower scores (Scores 1 and 2), while males predominantly grouped into the higher scores (Scores 3–5) (Figure 1, Table 3).

4 | DISCUSSION

The recalibrated logistic regression equation using the Collection-UNAM and XIGUI data greatly increased correct sex classification from the original equation provided by Klales et al. (2012). Furthermore, sex bias was eliminated with the recalibrated equation. Additionally, classification accuracy in the present research was higher (100%) than in the Hamann-Todd sample (94.5%) used in the original study by Klales et al. (2012). Higher classification accuracy in the present research is consistent with tests in a modern South African sample (99.2%; Kenyhercz 2012; Stull, Kenyhercz, & L'Abbe, 2013). Despite the same combined correct classification accuracy, females classified higher in the South

TABLE 3 Score frequencies for each trait by sex and sample

		Trait score									
Sample	**Sex**	**1**		**2**		**3**		**4**		**5**	
Ventral arc (VA)											
XIGUI	Female	0.621	(18)	0.310	(9)	0.069	(2)	0.000	(0)	0.000	(0)
	Male	0.000	(0)	0.000	(0)	0.179	(5)	0.429	(12)	0.393	(11)
UNAM	Female	0.774	(48)	0.226	(14)	0.000	(0)	0.000	(0)	0.000	(0)
	Male	0.000	(0)	0.012	(1)	0.119	(10)	0.500	(42)	0.369	(31)
Subpubic contour (SPC)											
XIGUI	Female	0.724	(21)	0.207	(6)	0.069	(2)	0.000	(0)	0.000	(0)
	Male	0.000	(0)	0.000	(0)	0.214	(6)	0.429	(12)	0.357	(10)
UNAM	Female	0.629	(39)	0.274	(17)	0.097	(6)	0.000	(0)	0.000	(0)
	Male	0.000	(0)	0.000	(0)	0.179	(15)	0.488	(41)	0.333	(28)
Medial aspect (MA)											
XIGUI	Female	0.690	(20)	0.241	(7)	0.069	(2)	0.000	(0)	0.000	(0)
	Male	0.000	(0)	0.000	(0)	0.357	(10)	0.357	(10)	0.286	(8)
UNAM	Female	0.839	(52)	0.145	(9)	0.016	(1)	0.000	(0)	0.000	(0)
	Male	0.000	(0)	0.000	(0)	0.202	(17)	0.452	(38)	0.345	(29)

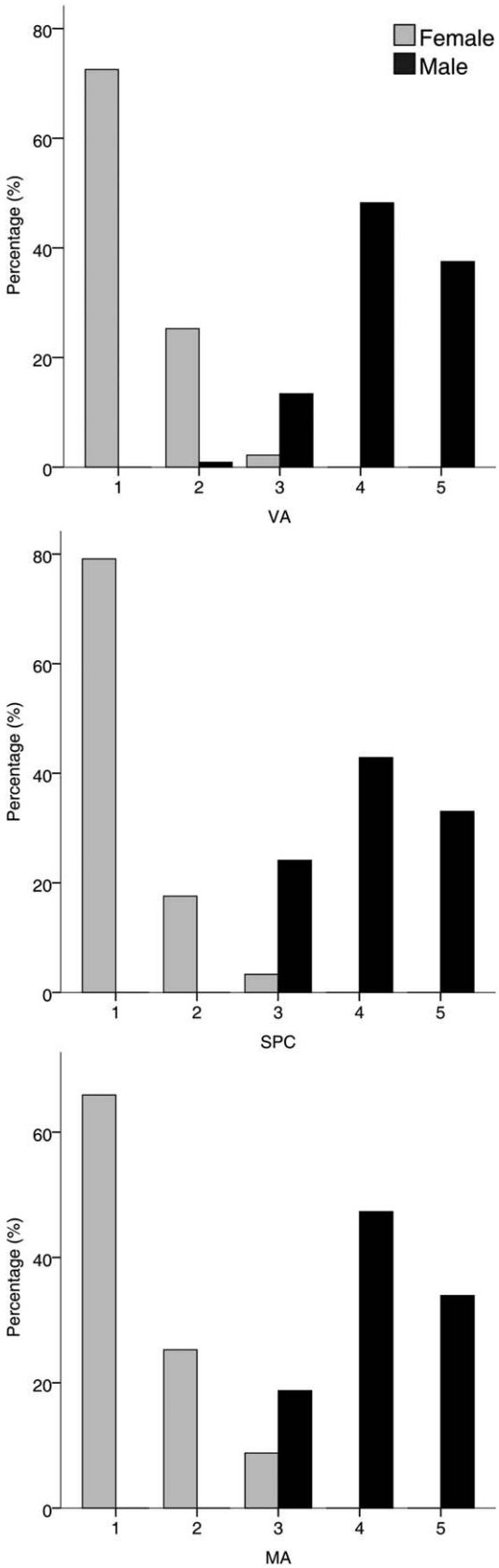

FIGURE 1 Bar graphs showing the relationship between sex and ventral arc (VA), the medial aspect of the ischiopubic ramus (MA), and the subpubic contour (SPC) on five-point ordinal scale in modern Mexican populations

African sample, while males and females classified equally as well in the Mexican sample.

Classification accuracy based on individual traits contradicts the original study by Phenice (1969) and the improved method by Klales et al. (2012). In both methods, Phenice (1969) and Klales et al. (2012) the ventral arc was the single best predictor of sex, while in the present research the classification accuracy of the subpubic contour was equally as high as the classification accuracy of the ventral arc. However, the ventral arc did have a lower sex bias than the subpubic contour. As with both original studies, the medial aspect of the ischio-pubic ramus performed the poorest of the three traits.

5 | CONCLUSIONS

The Klales et al. (2012) method combines traits from the Phenice (1969) technique with a statistical methodology that produces known error rates and results expressed in probabilistic terms. As the authors mentioned, this approach does not require special equipment and trait scoring can be done by people with different degrees of experience. Overall, the method and original equation in Klales et al. (2012) worked well, but accuracy improved and sex bias was eliminated by creating a population specific equation. Results from this study found the Klales et al. (2012) method, and the specifically the recalibration of it, is widely helpful in forensic anthropology and bioarchaeology cases in Mexico. In addition, these recalibrated equations can be applied for forensic identification cases also in the U.S., in accordance with the *Daubert* decision (Daubert v. Merrell Dow Pharmaceuticals, 1993).

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article.

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