Cranial and Postcranial Metric Sex Determination Between Modern Thai and Native American Populations

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Introduction

One of the most important components of the biological profile (sex, age, ancestry, and stature of skeletonized remains) established by bioarchaeologists and forensic anthropologists is sex estimation, as it dictates the methods used in age, ancestry, and stature. Two types of methods exist for determining sex; morphological and metric, both of which can be applied to cranial and postcranial elements. Nonmetric methods are based on visual observations of the sexually dimorphic features of the skull, pelvis, and other postcranial elements (Phenice 1969; Walker 2008). Metric techniques rely on standardized measurements that are entered into regression formulae or subjected to discriminant function analysis (Spradley and Jantz 2011). Historically, nonmetric methods of the pelvis and cranium have dominated sex assessment (Garvin *et al.* 2014; Klales *et al.* 2012; Spradley and Jantz 2011). However, in forensic or archaeological contexts, the pelvis or cranium may be missing or damaged, and methods derived from long bones are needed.

Current metric and morphological methods used to estimate sex were largely developed on modern and historic African and European Americans. For example, Spradley and Jantz (2011) provide cranial and postcranial discriminant function sex estimation equations for modern American Black and White individuals with correct classifications from 71.88% to 94.34%. Importantly, they found that postcranial measurements are superior at predicting sex compared to cranial metric or morphological approaches. Additionally, precontact archaeologically derived Native Americans historically served as biological proxies for modern Asian individuals due to their shared, yet distant, genetic history. As such, it is unlikely that the majority of extant sex estimation methods can be accurately applied to underrepresented modern populations, including Asian individuals. Further, research has demonstrated that certain Asian populations, including Japanese, Pilipino, and Thai are less sexually dimorphic than non-Asian populations (Tallman and Go 2017; Tallman 2016).

Materials and Methods

This study investigates the metric differences in sexual dimorphism between precontact Native Americans and modern Thai individuals and establishes population-specific discriminant function equations to assist in sex estimation. The Native American sample is comprised of 102 adult individuals (f = 49; m = 53) from the American Museum of Natural History. The Thai sample is comprised of 100 individuals (f = 50; m = 50) from Khon Kaen University who were 17-96 years old (see Techataweewan *et al.* 2017). A total of 36 skull and 57 postcranial measurements were taken following Langley *et al.* (2016) and analyzed with independent t-tests to determine if differences exist between the Native American and Thai individuals. Further, select measurements were tested in Spradley and Jantz's (2011) American Black and White sex estimation equations to see how equations derived from non-Asian populations perform on Native American and Thai individuals. Lastly, population-specific linear regression classification equations were developed for the Native American and Thai individuals.

Results

Table 1. Number of measurements that are statistically different between modern Thai and Native American individuals.

Element	Males (%)	Females (%)
Cranium	12/29 (41.4)	12/29 (41.4)
Mandible	7/9 (77.8)	5/9 (55.6)
Clavicle	2/3 (66.7)	2/3 (66.7)
Scapula	0/4 (0.0)	3/4 (75.0)
Humerus	4/5 (80.0)	2/5 (40.0)
Radius	3/4 (75.5)	0/4 (0.0)
Ulna	1/6 (16.7)	2/6 (33.3)
Sacrum	1/4 (25.0)	0/4 (0.0)
Os Coxa	4/11 (36.4)	3/11 (27.3)
Femur	2/11 (18.2)	0/11 (0.0)
Tibia	4/6 (66.7)	4/6 (66.7)
Fibula	0/2 (0.0)	1/2 (50.0)
Calcaneus	0/2 (0.0)	0/2 (0.0)

Results, contd.

Table 2. Spradley and Jantz's (2011) American Black (B) and White (W) equation comparisons. Those in red fall below 80% correct classification.

Element	Sex	Spradley and Jantz (2011) Accuracy (%)		Native American Accuracy (%)		Thai Accuracy (%)	
		B	W	B	W	B	W
Humerus	F	94.1	95.2	100.0	94.0	93.8	92.0
	M	93.6	90.9	58.0	73.0	90.0	82.0
Clavicle	F	93.9	97.2	100.0	100.0	100.0	100.0
	M	92.9	90.0	12.5	35.0	57.0	68.0
Scapula	F	91.7	95.2	100.0	100.0	100.0	100.0
	M	92.1	90.9	43.0	44.0	48.0	44.0
Femur	F	90.9	95.9	100.0	100.0	98.0	100.0
	M	92.3	91.2	56.0	45.0	86.0	60.0
Cranium	F	90.7	88.5	9.0	56.0	64.6	87.5
	M	90.6	91.5	100.0	93.8	97.8	83.0
Ulna	F	92.9	91.8	13.0	100.0	100.0	100.0
	M	88.2	93.9	100.0	26.0	15.0	45.0
Os Coxa	F	90.0	90.7	--	39.0	15.0	52.0
	M	90.6	87.9	--	100.0	100.0	100.0
Tibia	F	89.3	91.4	100.0	100.0	90.0	100.0
	M	87.9	91.9	82.0	50.0	98.0	82.0
Calcaneus	F	88.9	81.9	96.5	--	96.0	--
	M	87.8	83.5	46.0	--	36.0	--
Radius	F	83.9	96.4	100.0	100.0	100.0	100.0
	M	87.5	92.2	4.0	12.5	26.0	68.0
Fibula	F	88.5	81.1	100.0	100.0	100.0	100.0
	M	82.8	81.5	0.0	23.0	4.0	32.0
Mandible	F	75.5	85.9	54.0	84.0	30.0	70.0
	M	81.0	75.7	89.0	79.0	100.0	90.0
Sacrum	F	77.3	73.8	33.0	--	50.0	--
	M	66.7	69.9	85.0	--	82.0	--

Table 3. Sex estimation linear regression classification equations for modern Thai individuals.

Element	Equations
Cranium	= (-0.030*Nasion-Occipital)+(0.076*Maximum Cranial Length)+(0.057*Upper Facial Height)+(0.011*Basion Bregma)+(-0.027*Cranial Base Length)+(-0.070*Biorbital Breadth)+(0.001*Frontal Chord)+(0.005*Bizygomatic Breadth)+(-0.034*Interorbital Breadth)+(-0.008*Bimaxillary)+(-0.002*Partial Chord)+(-0.013*Maximum Alveolar Breadth)+(0.007*Minimum Frontal Breadth)+(-0.005*Biauricular Breadth)+(0.062*Nasion Prosthion)+(-0.003*Biasterionic)+(-7.975)
Mandible	= (0.037*Mandibular Angle)+(0.012*Mandibular Length)+(0.050*Maximum Ramus Height)+(0.017*Minimum Ramus Breadth)+(-8.542)
Clavicle	= (0.072*Maximum Diameter)+(0.047*Minimum Diameter)+(0.025*Length)+(-4.270)
Scapula	= (0.011*Scapula Height)+(0.004*Scapula Breadth)+(0.29*Glenoid Cavity Breadth)+(0.064*Glenoid Cavity Height)+(-4.476)
Humerus	= (0.037*Epicondylar Breadth)+(0.058*Maximum Vertical Head Diameter)+(0.017*Maximum Diameter at Midshaft)+(-4.439)
Radius	= (0.134*Minimum Midshaft Diameter)+(0.112*Maximum Head Diameter)+(0.005*Maximum Length)+(-4.419)
Ulna	= (-0.009*Maximum Length)+(0.102*Maximum Diameter at Midshaft)+(0.145*Minimum Diameter at Midshaft)+(0.019*Psysiological Length)+(-4.471)
Sacrum	= (0.003*Anterior Height of Sacrum)+(0.005*Transverse Diameter of S1)+(0.073*Anterior-Posterior Diameter of S1)+(-2.319)
Os Coxa	= (0.014*Maximum Innominate Height)+(0.036*Ischial Length)+(0.052*Minimum Iliac Breadth)+(0.006*Minimum Ischial Length)+(-0.033*Maximum Iliac Breadth)+(-4.131)
Femur	= (0.059*Epicondylar Breadth)+(0.004*Maximum Anterior-Posterior Length of Medial Condyle)+(0.008*Circumference at Midshaft)+(-4.962)
Tibia	= (0.010*Circumference at Midshaft)+(0.032*Distal Epiphyseal Breadth)+(0.048*Maximum Proximal Epiphyseal Breadth)+(-5.397)
Fibula	= (0.014*Maximum Length)+(0.003*Maximum Midshaft Diameter)+(-4.330)
Calcaneus	= (0.028*Maximum Length)+(0.062*Middle Breadth)+(-4.072)

Results, contd.

Table 4. Sex estimation linear regression classification equations for Native Americans.

Element	Equations
Cranium	= (0.019*Biauricular Breadth)+(0.020*Bimaxillary Breadth)+(-0.007*Maximum Cranial Breadth)+(0.009*Bizygomatic Breadth)+(0.023*Basion-Bregma Height)+(10.088*Nasal Height)+(-0.006 Frontal Chord)+(0.037*Foramen Magnum Breadth)+(0.063*Nasion-Prosthion Height)+(0.027*Mastoid Height)+(0.003*Upper Facial Breadth)+(-8.548)
Mandible	= (0.028*Bicondylar Breadth)+(0.010*Bigonial Breadth)+(0.025*Maximum Ramus Height)+(-4.697)
Clavicle	= (0.088*Maximum Diameter)+(0.052*Minimum Diameter)+(0.026*Maximum Length)+(-4.556)
Scapula	= (0.030*Height of Scapula)+(0.011*Breadth of Scapula)*(-4.877)
Humerus	= (0.003*Maximum Length of the Humerus)+(0.029*Epicondylar Breadth of Humerus)+(0.071*Maximum Vertical Diameter of Head of Humerus)+(-5.068)
Radius	= (0.020*Maximum Length)+(0.73*Maximum Diameter of Radial Head)+(-5.592)
Ulna	= (-0.028*Maximum Length of Ulna)+(0.050*Physiological Length)+(0.080*Olecranon Breadth)+(-5.651)
Sacrum	= (-0.015*Transverse Diameter of S1)+(0.116*Anterior-Posterior Diameter of S1)+(0.009*Anterior Height of Sacrum)+(-3.363)
Os Coxa	= (0.022*Ischial Length)+(0.021*Maximum Innominate Height)+(-0.031*Maximum Iliac Breadth)+(-0.014*Minimum Ischial Length)+(0.056*Minimum Iliac Breadth)+(-3.613)
Femur	= (0.130*Maximum Diameter of Femur Head)+(0.030*Epicondylar Breadth of Femur)+(-0.016*Maximum Antero-Posterior Length of Medial Condyle)+(-0.025*Maximum Antero-posterior Length of Lateral Condyle)+(-4.696)
Tibia	= (0.009*Circumference at Midshaft)+(0.015*Maximum Midshaft Diameter)+(0.083*Distal Epiphysis Breadth)+(-4.683)
Fibula	= (0.012*Maximum Length)+(0.093*Maximum Midshaft Diameter)+(-4.902)
Calcaneus	= (0.039*Maximum Length)+(0.036*Middle Breadth)+(-3.805)

Table 5. Classification accuracies for the Native American and Thai linear regression classification equations. Those in red fall below 80% correct classification.

Element	Native American Accuracy (%)		Thai Accuracy (%)	
	Male	Female	Male	Female
Cranium	100.0	95.5	88.2	94.4
Mandible	95.5	82.8	90.0	74.0
Clavicle	84.4	93.1	83.7	94.0
Scapula	87.0	81.3	97.9	94.0
Humerus	96.7	93.5	98.0	90.0
Radius	84.4	83.3	90.0	92.0
Ulna	85.7	88.9	91.8	94.0
Sacrum	73.7	82.4	74.4	67.7
Os Coxa	76.2	90.0	91.8	91.8
Femur	96.0	92.3	88.0	95.9
Tibia	85.7	86.7	89.9	90.0
Fibula	85.5	80.8	76.0	78.0
Calcaneus	--	--	80.0	80.0

Discussion and Conclusions

The results of this study indicate that: 1) there are statistically significant cranial and postcranial metric differences between the Native American and Thai individuals (Table 1); 2) discriminant function equations developed on non-Asian populations perform poorly when classifying the sex of the Native American and Thai individuals (Table 2); and 3) population-specific discriminant function equations developed on the Native American and Thai samples greatly improve correct classification accuracies (Tables 3 – 5). In particular, all elements except for the scapula, radius, sacrum, femur, and calcaneus exhibit statistically different dimensions between the Native American and Thai individuals. In general, the modern Thai individuals are smaller in size compared to Native Americans. This indicates that sex estimation methods developed on Native American individuals should not be applied to modern Asian individuals. The differences between the Native American and Thai individuals can be attributed to divergent and unique population histories. The ancestors of Native Americans developed the unique Amerindian mtDNA in Berinigia roughly 21,000 years BP (Mazières 2011). However, it was not until roughly 12,000 years ago that Native American populations began to present derived craniofacial morphology, thus differentiating them from their Asian ancestors.

Discussion and Conclusions, contd.

While some correct classifications achieved 100% when Spradley and Jantz's (2011) American Black and White equations were applied to the Native American and Thai individuals, 22 Native American and 18 Thai applications exhibited correct classifications below 80% (Table 2). However, only six equations fell below 80% for Spradley and Jantz (2011). The majority of these equations misclassified Thai and Native American males as females. Native American and Thai individuals are more gracile than the American Black and White individuals, since the majority of those misclassified were males. Therefore, the application of sex estimation methods developed on non-Asian individuals results in reduced discriminatory power because the Native Americans and Thai are less sexually dimorphic than African and European American individuals. The differences in sexual dimorphism are due to differing environmental and genetic factors between African and European American populations compared to the Native American and modern Thai individuals. In particular, nutritional intake is significantly different, and impacts the development of skeletal structures.

The population-specific equations developed on Native Americans resulted in correct classification rates ranging from 73.7% to 100.0%, and Thai equations resulted in correction classification rates ranging from 67.7% to 98.0%; which are significantly higher than classification rates derived from Spradley and Jantz's (2011) equations (Tables 3 – 5). Unlike Spradley and Jantz's (2011) results, the cranium performed best for Native Americans, with an overall correct classification rate of 97.8%. The humerus and femur also performed well, resulting in Native American correct classification rates in excess of 92%. For the Thai, the best elements and equations for predicting sex are the scapula, humerus, and ulna, which resulted in correct classification rates in excess of 90%. Moreover, the slightly reduced performance of the Thai equations in comparison to those of the Native Americans suggests that the Thai are less sexually dimorphic than the Native Americans.

In the absence of modern Asian remains available for study, Native Americans have been used as proxies for Asian populations; however, the results of the current study indicate that this practice is inaccurate. The Native Americans and Thai differ in their expressions of sexual dimorphism, and the two groups are likewise dissimilar to non-Asian populations. Therefore, the population-specific sex estimation equations presented here are better suited for estimating the sex of Native American and Thai individuals in bioarchaeological and forensic contexts.

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References

Garvin HM, Sholts SB, Mosca LA. 2014. Sexual dimorphism in human cranial trait scores: Effects of population, age and body size. *American Journal of Physical Anthropology* 154:259-269.

Klales AR. 2016. Secular change in morphological pelvic traits used for sex estimation. *Journal of Forensic Sciences* 61(2):295-301.

Mazières 2011

Phenice TW. 1969. A newly developed visual method of sexing the Os Pubis. *American Journal of Physical Anthropology* 30:297-302.

Spradley MK, Jantz RL. 2011. Sex estimation in forensic anthropology: skull versus postcranial elements. *Journal of Forensic Sciences* 56(2): 289-296.

Tallman SD. 2016. The evaluation and refinement of nonmetric sex and ancestry assessment methods in modern Japanese and Thai individuals. Unpublished dissertation, University of Tennessee, Knoxville, TN.

Tallman SD, Go M. 2017. Application of the Optimized Summed Scored Attributes Method to Sex Estimation in Asian Crania. *Journal of Forensic Sciences* doi: 10.1111/1556-4029.13644.

Techataweewan N, Tuamsuk P, Toomsan Y, Woraputtaporn W, Prachaney P, Tayles N. 2017. A

Walker PL. 2008. Sexing skulls using discriminant function analysis of visually assessed traits. *American Journal of Physical Anthropology* 135:39-50.

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