

Sex Estimation Using Metric and Geometric Morphometric Analyses of the Adult Human Talus

INTRODUCTION:

Estimating biological sex is an essential first step when analyzing human remains in both forensic and archaeological contexts. While the human pelvis and skull provide the most accurate sex estimation due to their significant degree of sexual dimorphism, they are not always present or sufficiently preserved to permit analysis. **The talus** is a tarsal bone (in the foot / ankle) which articulates with the tibia and fibula (lower leg bones) and the calcaneus and navicular (other tarsals). Existing research has demonstrated that the talus is **sexually dimorphic**, making it useful for sex estimation. Additionally, it is very dense (Harris and Case, 2012) and therefore **preserves well** over time and in diverse contexts.

The present study utilizes **linear measurements** and **geometric morphometric (GM) analyses** of adult human tali from diverse populations for the purpose sex estimation. This study aims to refine existing methodologies and address the current lack of standardization for the purpose of sex estimation.

RESEARCH QUESTIONS:

- Q1:** Does side asymmetry exist in the talus?
Q2: What combination of linear measurements achieves the most accurate sex estimation?
Q3: Does GM analysis provide more accurate sex estimation than linear measurements?

MATERIALS AND METHODS:

Data include ancient Egyptian individuals from Sai Island (**n=19, 7 for GM**), ancient Maya individuals from Lamanai (**n=35, 9 for GM**), and modern white Americans from the New Mexico Decedent Image Database (NMDID; **n=9 (L&R) for GM**). This represents a preliminary subset of the final study samples.

Seven linear measurements were collected: maximum width (**TW**), maximum length (**TL**), maximum height (**TH**), overall volume (**V**), trochlear length (**TrL**), trochlear breadth (**TrB**), and head height (**HH**). Set points were developed for each measurement for each sample group. 3D surface scans or CT scans were collected and **29 landmarks** were placed following the protocol of Harcourt-Smith (2002). All data were collected from both left and right tali (when possible) to assess the degree of side asymmetry present.

All data were analyzed using **R and R Studio**. Linear measurement data were analyzed using ANOVAs, LDAs, and set points. For the GM data, a Generalized Procrustes Analysis was performed, followed by a Principal Component Analysis in shape space, Canonical Variate Analysis with the first five principal components in shape space and form space, and Procrustes ANOVAs in shape space and form space to assess side asymmetry. Finally, mean shapes were calculated for males and females separately and wireframes were created.

Figure 1: Left Talus with Landmarks & Linear Measurements

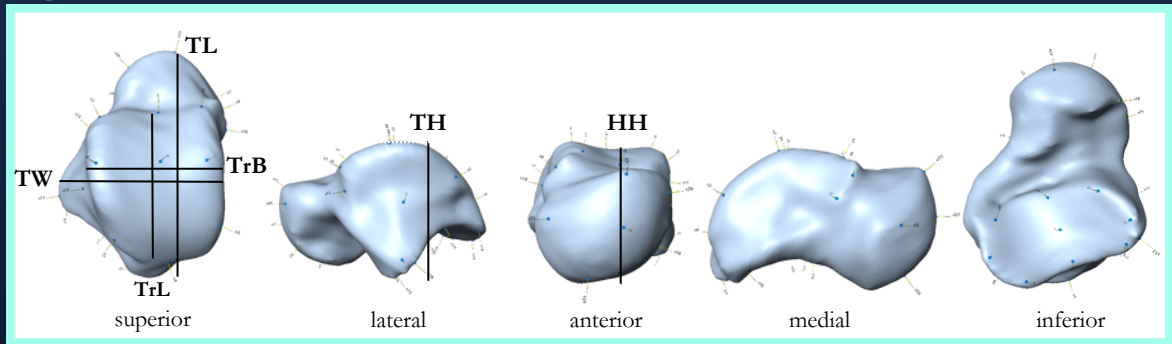
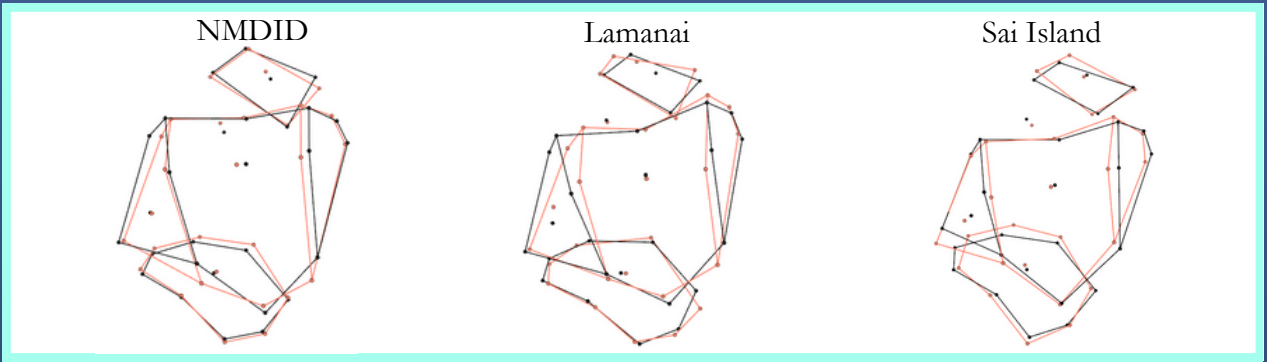


Figure 2: Mean Shape Wireframes

Mean shapes were calculated based on coordinate data for males (black) and females (red)



Q1 RESULTS:

Linear measurements: Wilcoxon Signed-Rank Test (p<0.05 = significant difference)
GM data: Procrustes ANOVA (p<0.05 = significant difference)

	Sai Island	Lamanai	NMDID
Linear meas.	no	no	NA
Shape	no	no	no
Size	no	no	no
Form space	no	no	no

Q2 RESULTS:

Sai Island LDA: all variables & cross-validation
Lamanai LDA: (TW + TL + TH) & cross-validation
Overall accuracy of sex estimation uses all set points (L & R pooled)

	Sai Island	Lamanai	NMDID
LDA	71%	64%	NA
Set points	78%	71%	NA

NA: Linear measurements mot assessed for NMDID yet

Q3 RESULTS:

CVA with first 5 PCs, with cross-validation - shape space (shape only) L & R pooled
CVA with centroid size (cs) and all coords - form space (shape & size) L & R pooled

	Sai Island	Lamanai	NMDID
Shape Space	57%	100%	78%
Form	71%	67%	83%

Acknowledgements: My sincerest thanks to Dr. Callaghan (committee), the New Mexico Decedent Image Database (NMDID), the Dayr al-Barsha Archaeological Project, the Lamanai Archaeological Project, and the UCF Anthropology Graduate program.
Ethics Statement: All human remains were treated in an ethical and respectful manner in compliance with AABA standards.

DISCUSSION:

The primary aims of this study were to determine whether side asymmetry exists in the talus, and to assess the accuracy of sex estimation using linear measurements and geometric morphometric analyses of the talus, in three diverse populations.

The preliminary results presented here represent a **subset of the final project**, and therefore results should be interpreted with some caution.

Side asymmetry was *not* identified based on the linear measurements or the GM data (shape and size separately, as well as shape and size combined in form space).

Linear discriminant analysis (LDA) achieved **71%** accuracy for the Sai Island sample and **64%** accuracy for the Lamanai sample. Set points achieved **78%** accuracy for the Sai Island sample and **71%** accuracy for the Lamanai sample.

Canonical Variate Analysis (CVA) yielded an accuracy of **57%** in shape space and **71%** in form space for the Sai Island sample; **100%** in shape space and **67%** in form space for the Lamanai sample; and **78%** in shape space and **83%** in form space for the NMDID sample.

CONCLUSION:

Side asymmetry appears to be absent in all three populations when shape, size, and both combined are considered.

Sex estimation based on set points appears to achieve higher accuracy than LDA. These accuracies are comparable to those achieved by existing studies (e.g., Barrett et al., 2001; Bidmos and Dayal, 2004; Bidmos et al., 2018; Peckmann et al., 2015).

Sex estimation using CVA in form space appears to achieve a comparable or higher accuracy compared to the other two methods. The accuracy of all three methods may be population specific.

While more conclusive results are anticipated to emerge after analysis of the full project samples, these preliminary results carry **important implications for sex estimation of archaeological and modern populations based on the talus**. Analysis of the minimum number of linear measurements necessary for accurate sex estimation has direct implications for field and time-constrained contexts. Geometric morphometric analysis utilizing three-dimensional scans has direct implications for contexts with less constrained time and resources.

References Cited:

Barrett, Ch., Cavallari, W., and Sciulli, P.W. (2001). Estimation of Sex from the Talus in Prehistoric Native Americans. *Coll. Antropol.* 25(1):13-19
Bidmos, M. A., and Dayal, M.R. (2004). Further Evidence to Show Population Specificity of Discriminant Function Equations for Sex Determination Using the Talus of South African Blacks. *Journal of Forensic Sciences* 49(6):1-6
Bidmos, M. A., Dayal, M.R., and Adegboye, O.A. (2018). Measurements of the Talus in the Assessment of Population Affinity. *Forensic Science International* 287:221.e1-221.e7
Harcourt-Smith, W. (2002). *Form and Function in the Hominoid Tarsal Skeleton* [Doctoral dissertation, University College London]. *UCL Discovery*, <https://discovery.ucl.ac.uk/id/eprint/1383046/>
Harris, S.M., & Case D.T. (2012). Sexual Dimorphism in the Tarsal Bones: Implications for Sex Determination. *Journal of Forensic Sciences*, 57(2), 295-305. <https://doi.org/10.1111/j.1556-4029.2011.02004.x>
Peckmann, T. R., Orr, K., Meek, S., and Manolis, S.K. (2015). Sex Determination from the Talus in a Contemporary Greek Population Using Discriminant Function Analysis. *Journal of Forensic and Legal Medicine* 33:14-19