

# Geometric Morphometric Analysis of the Human Innominate for Sex Estimation



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## Introduction

The human innominate has been cited as the most accurate bone for sex estimation (Stewart 1979). Due to this, the morphological and size differences have been captured by numerous metric and nonmetric methods. The current study is a validation of the applicability of a newly developed method by Klales *et al.* (2009) and Vollner (2009) to more modern contexts.

The aforementioned studies designed and modified a set of 21 three-dimensional landmarks and used geometric morphometric analysis (GMA) to estimate sex and ancestry for a sample taken from the 20<sup>th</sup> century Hamann-Todd Osteological Collection (HTH). This study was completed in order to develop landmarks that could be easily identified and replicated. The high percentage of correctly classified individuals (94% of females and 97% of males) prompted the current validation study which uses a modern sample from the William M. Bass Donated Skeletal Collection (WBDC).

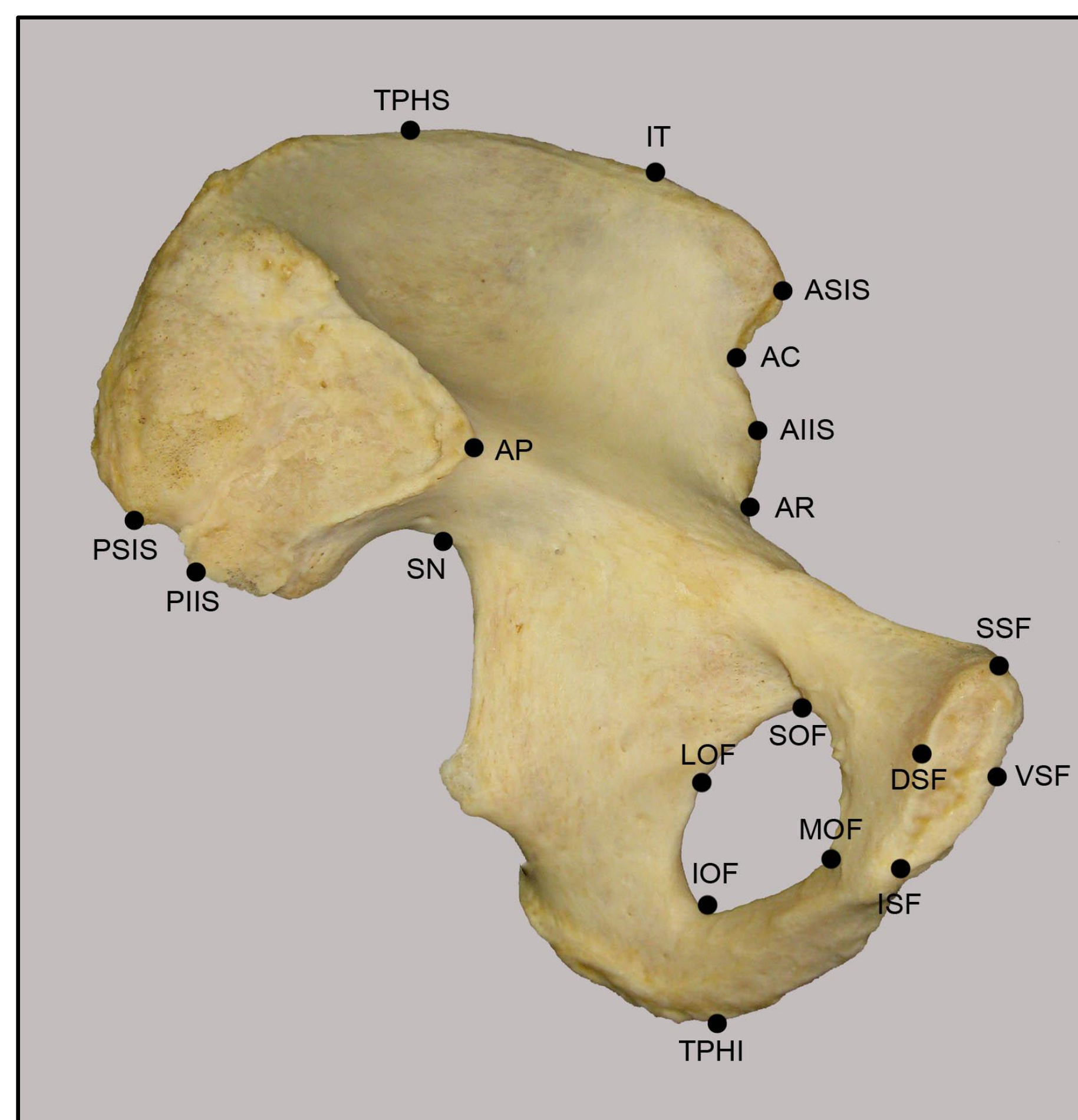


Figure 1. Medial view of the innominate with landmarks.

Table 1. Abbreviations for landmarks.

Landmark Abbreviation	Landmark Name
AC	Anterior Curvature
AIIS	Anterior Inferior Iliac Spine
AP	Auricular Point
AR	Acetabular Rim
ASIS	Anterior Superior Iliac Spine
DSF	Dorsal Symphyseal Face
IC	Iliac Crest
IOF	Inferior Obturator Foramen
ISF	Inferior Symphyseal Face
IT	Iliac Tubercle
LOF	Lateral Obturator Foramen
MOF	Medial Obturator Foramen
PIIS	Posterior Inferior Iliac Spine
PSIS	Posterior Superior Iliac Spine
SN	Sciatic Notch
SOF	Superior Obturator Foramen
SSF	Superior Symphyseal Face
TPHI	Total Pelvic Height - Inferior
TPHS	Total Pelvic Height - Superior
VSF	Ventral Symphyseal Face

## Materials and Methods

Innominate bones were selected from the WBDC, housed at the University of Tennessee, Knoxville, based on the following criteria: individuals were at least 19 years old at the time of death with a left innominate complete enough for all landmarks to be taken and with no apparent pathological conditions affecting the bone. A sample of 133 left innominates (53 females and 80 males) were digitized with a Microscribe digitizer and 3Skull software (Ousley 2004) to capture 21 three-dimensional landmarks (Figure 1, Table 1).

The resulting three dimensional data were analyzed using MorphoJ (Klingenberg 2008). A Procrustes' fit analysis was run to eliminate size in order to focus on the shape differences. To test preliminary accuracy rates, discriminant function analysis (DFA) was conducted on these raw shape variables and cross validated accuracies were evaluated. Due to the limitations of the statistical capabilities in MorphoJ, most notably the absence of the stepwise function, the Procrustes' coordinates were exported to SPSS. The data were then subjected to DFA with the forward Wilks' stepwise option selected.

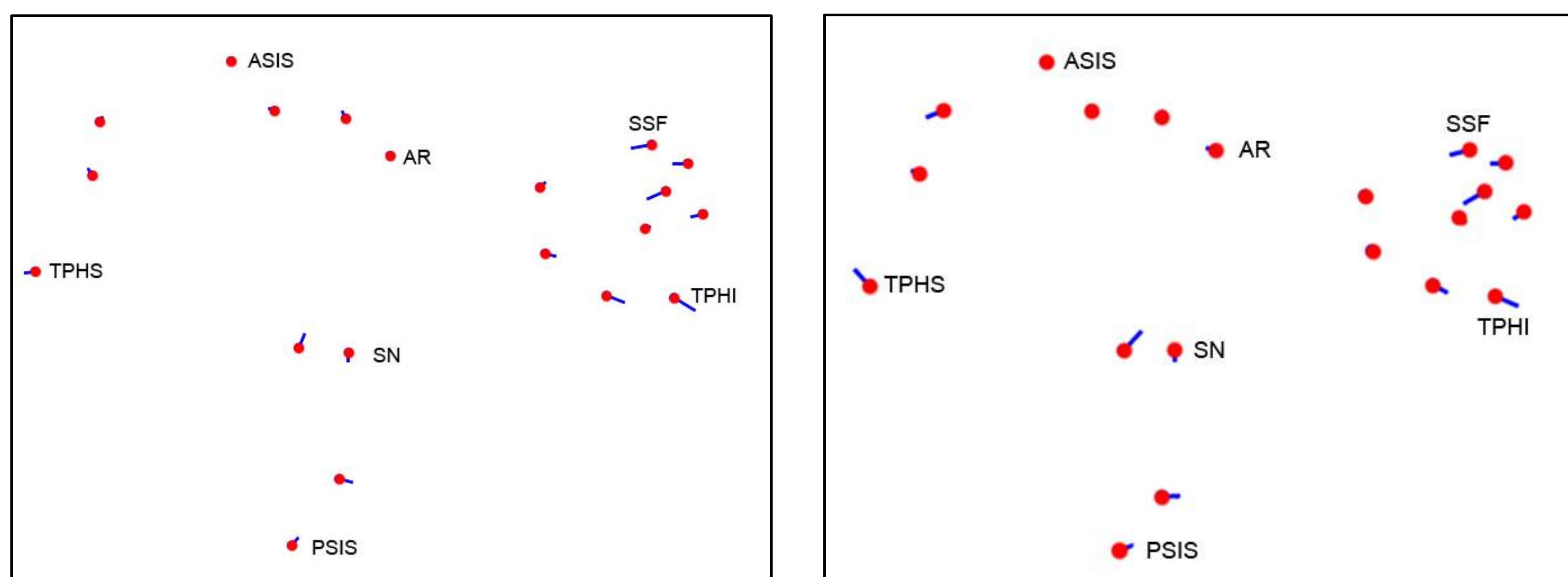


Figure 2. Mean landmark points for males and females after GMA of the WBDC (left) and HTH (right) samples. The red points represent females and the blue lines represent differences in males.

## Results

The Procrustes' fit demonstrated shape differences between males and females (Figure 2, left). These differences represent a broader and longer symphyseal face, a broader ilium and a size difference of an overall longer total length of the male innominates, all of which were also apparent in the previous study (Figure 2, right).

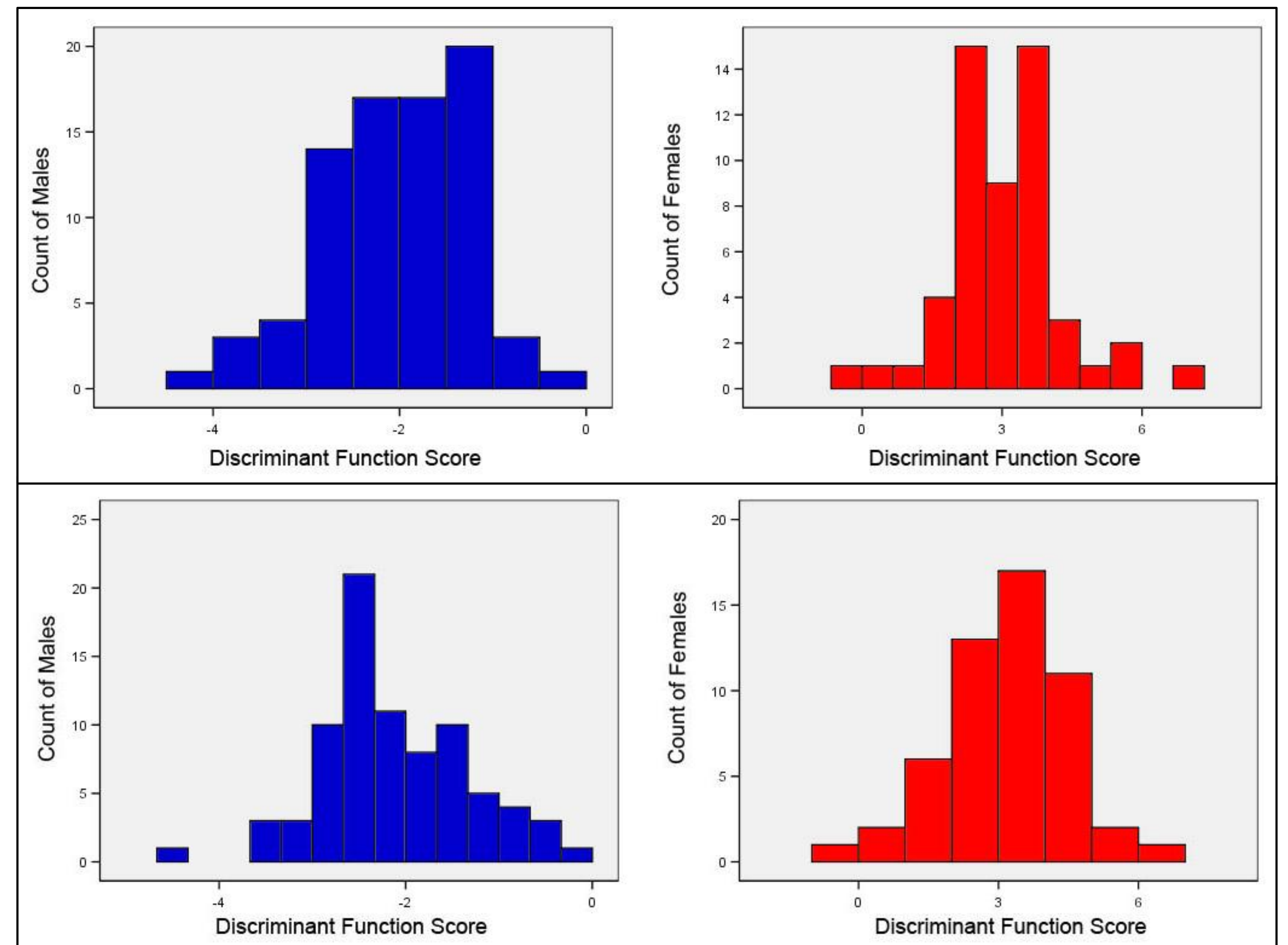


Figure 3. Two way DFA results for sex (Males: blue, Females: red) using 14 stepwise selected shape variables (top) and using 13 selected principal components (bottom).

DFA with the forward Wilks' stepwise option selected a total of 14 variables which was the maximum number of variables that this data set could support. Females were correctly classified in 51 of the 53 cases, producing an accuracy of **96.2%**. Males were correctly classified for all individuals producing **100%** accuracy. Overall accuracy for both sexes is **98.5%** (Figure 3, top). Principal component analysis (PCA) was performed in order to reduce the number of variables and was utilized for a second DFA with the forward Wilks' stepwise procedure. The PCA results for classification accuracies were equal to the original Procrustes' analysis with the exception of the selection of only 13 PCs as variables for analysis (Figure 3, bottom).

## Discussion and Conclusions

There does not appear to be any substantial differences in the sexual dimorphism represented in these two samples as shown in Figure 2. A further study on the nature of secular change, if any needs to be conducted to further explore the two samples. As hypothesized previously by the authors, the current study validated the utility of the method proposed in Klales *et al.* (2009) and Vollner (2009) for sex estimation and provided equally high classification accuracies for modern populations. However, the small sample sizes did not allow for the validation of this method in the estimation of ancestry and will be explored by the authors in the future.

The ability to study the morphological differences of the innominate can also be useful in order to determine the best two dimensional measurements to take for sex estimation. The previous studies discovered that the use of inter-landmark distances (ILDs) generated from the original dataset were able to classify individuals with high accuracy rates (99% cross-validated). Further analysis will be completed to determine if the ILDs selected for sex estimation for the HTH sample will be similar to those of the WBDC sample. This seems likely as the morphological differences appear similar.

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