THE FEMORAL BICONDYLAR ANGLE AS A TOOL FOR SEX DETERMINATION

IN UNIDENTIFIED FORENSIC HUMAN REMAINS

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INTRODUCTION

The femur is used by anthropologists for many different applications. Paleoanthropologists use the femur to determine stature and locomotion patterns (Cartmill and Smith, 2009; Conroy, 1997; Gruss, 2007; Heiple and Lovejoy, 1971; Jungers, 1988; Ruff, 1995; Stanford et al., 2006; Tattersall, 1999; Walmsley, 1933; Ward, 2002). Forensic anthropologists use the femur to assist in identification of unknown modern deceased individuals through the analysis of the biological profile. More specifically, because the femur shows 75% variation between individuals, it has been useful for stature and sex determination (Van Gerven, 1972). While measurement of the maximum length of the femur has been the primary method for estimation of stature (Bass, 1995; Black and Ferguson, 2011; Burns, 1999; Howells, 1973; Klepinger, 2006; Moore-Jansen, 1994; Nafte, 2000; Ousley and Jantz, 2006; Rathbun and Buikstra, 1984; Reichs, 1998; Schmitt et al., 2006; Steadman, 2009; White 2000), sex determination has been accomplished using a variety of femoral dimensions. For example, sex estimation has been determined using the femur head diameter (Albanese, 2003; Jantz et al., 2008; King et al., 1998; Spradley and Jantz, 2011; Trancho et al., 1996;), femur head angle (Albanese et al., 2008), the femur maximum length (Spradley and Jantz, 2011), epicondylar breadth (Spradley and Jantz, 2011), bicondylar length (Spradley and Jantz, 2011), circumference at the midshaft (Spradley and Jantz, 2011), bicondylar breadth (Spradley and Jantz, 2011), and neck diameter (Alunni-Perrett, 2003; Frutos, 2003; Stojanowski and Seidemann, 1999).

Many of the above methods for sex determination from the femur are dependent on the presence of well-preserved (mostly complete) femora; unfortunately, this is often not seen in badly decomposed forensic remains. Femoral shafts are most commonly encountered in forensic situations. In addition, accuracy of many of the above methods has not been determined—known error rates for forensic methods are critical for effective courtroom testimony following Daubert (1993) guidelines. These guidelines state that in order for a method to be accepted by the court during an expert
testimony, the method must (1) follow the scientific method, (2) must undergo peer review and publication, (3) be consistent with reliable standards of testing with known error rates, and (4) must be generally accepted by the scientific community. The third criterion is where most sex determination methods fail Daubert’s guidelines. It is clear that alternative methods for determination of the sex from the femur need to be explored.

The bicondylar angle of the femur is the angle of inclination from the knee to the hip. The presence of the bicondylar angle is a trait only present in hominids. The bicondylar angle is only present in modern humans who learned to walk before their distal epiphyses fused to the distal end of the femur shaft (Tardieu and Trinkhaus, 1994). Stewart (1979), in his classic volume Essentials of Forensic Anthropology: Especially as Developed in the United States, stated that the bicondylar angle was sexually dimorphic because of the differing morphology of the pelvis between sexes. Because the female pelvic region is broader, the femur must articulate to the acetabulum at a different angle than in a male. In order for females to still perform bipedal locomotion, the angle needed for the valgus knee must be variable between males and females. However, the amount of variation between male and female femoral angles and whether this variation is great enough to determine sex is unknown.

The purpose of the research presented here is to explore the potential of the femoral bicondylar angle for determining sex from forensic human remains. This exploration will first involve a literature review of prior attempts at measuring the bicondylar angle. These prior methods will be compared and evaluated for their accuracy, consistency, and ease of use by applying each of them to a sample of both forensic and prehistoric known-sex femora. Investigation of alternative methods for bicondylar angle measurement will be undertaken, with the main goal being the delineation of a consistent method of measuring the bicondylar angle. Finally, analysis of femoral bicondylar angle variation will be examined to determine whether the observed variation is great enough to be used as a tool for determining sex.
PRIOR RESEARCH ON THE BICONDYLAR ANGLE

The femoral bicondylar angle has been widely studied in Paleoanthropology in terms of the locomotion patterns of early hominids like Lucy (Conroy, 1997; Jungers, 1988; Ward 2002). However, the bicondylar angle has not been applied to modern forensic analyses. Standard measurements currently taken with forensic human remains do not include the bicondylar angle (Bass, 1995; Black and Ferguson, 2011; Burns, 1999; Howells, 1973; Klepinger, 2006; Moore-Jansen, 1994; Naft, 2000; Ousley and Jantz, 2006; Rathbun and Buikstra, 1984; Reichs, 1998; Schmitt et al., 2006; Steadman, 2009; White 2000). While a literature search produced a voluminous number of references on the femoral bicondylar angle, only three sources presented explicit methodology for the measurement of this angle in hominids. These included two methods applied to paleontological remains and one applied to a prehistoric bioarchaeological sample.

Van Gerven (1972) explored the degree of intrapopulation variation in a multitude of femoral dimensions (including the bicondylar angle) in a sample of prehistoric Native Americans from Illinois. The method for measuring the bicondylar angle devised by this researcher uses the maximum length and the bicondylar length to estimate the angle (Figure 1). Van Gerven never described what he did with these measurements. However, the angle measured forms an acute angle but because of where the bicondylar length and the maximum length meet, a right angle is being created; since a right angle is created, we are allowed to use the math function of cosine, which is:

\[
\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}
\]

For our purposes, the equation by Van Gerven (1972) would be:

\[
\cos\theta = \frac{\text{maximum length}}{\text{bicondylar length}}
\]
The second method to configure the bicondylar angle was proposed by Heiple and Lovejoy (1971) (Figure 2). These researchers were analyzing distal femur fragments from the early Pleistocene Sterkfontein hominids in an attempt to characterize their locomotion patterns. They determined that the length of the bicondylar angle that should be measured is the line connecting the midpoint of the shaft just below the lesser trochanter with the midpoint of the shaft at 25% of the maximum length from the distal end (around 20-30mm from the distal femoral condyles). The other line of measurement, femur length, is perpendicular to the table, from which the femur is being measured upon, meeting up with the midpoint beneath the lesser trochanter. This article also did not give a formula to use for measuring the angle, so the law of cosine will be applied again.
The equation using measurement markers by Hieple and Lovejoy (1971):

\[
\cos \theta = \frac{\text{femur length}}{\text{bicondylar angle length}}
\]

**Figure 2 – Image of the measurements taken when using the Heiple and Lovejoy method:**

The third method of measuring the bicondylar angle is depicted in research described by Ruff (1995) (Figure 3). Ruff utilizes a biomechanical model to investigate the relationship between the femur and the pelvis in Early Pleistocene *Homo erectus* fossils and its implications for hominid gait, parturition, as well as hominid taxonomy. Ruff uses the measurements for the bone length and the line perpendicular from the table, in which the bone is resting on, that is level with the superior surface of the femur neck to create the bicondylar angle. “Bone length” refers to the measurement of the long axis of the shaft from the center of the epicondylar breadth to the superior surface of the femur neck just medial to the greater trochanter (Ruff, 1995). The line perpendicular to the table combined with bone length creates a right angle, which allows for the use of cosine again.
For our purposes, the equation by Ruff (1995) would be:

\[ \cos \theta = \frac{\text{line perpendicular to the table}}{\text{bone length}} \]

Figure 3 – Image of the measurements taken when using the Ruff method:

Ruff (1995) did not directly give the formula for measuring the bicondylar angle, but he did use the cosine of the bicondylar angle as part of a formula to measure the mediolateral position for the insertion of the gluteus medius and minimus muscles. This suggested that the lines that are being measured to obtain the bicondylar angle articulate to make a right angle. He did not use the bicondylar length or the maximum length, as described in Moore-Jansen et al. (1994), because those measurements are affected by the size of the femur head and the angle and length of the femur neck in relationship with the shaft. All three of these have been regarded as sexually dimorphic and, therefore, adding bias to the measurement of the bicondylar angle.
These equations will give the angle of inclination of the knee. If one of these methods is consistent in measuring the bicondylar angle, the sample will be divided by sex to determine if there is enough statistical difference to use the bicondylar angle to determine sex from an unknown sample. The angle that is expected is between 9° and 15° with 15° being very high because it is the maximum reported for any early hominid and modern human populations have a smaller bicondylar angle than early hominids (Tardieu and Trinkaus, 1994).

MATERIALS AND METHODS

A sample of nine prehistoric and modern (forensic) femora is used to test the three methods for bicondylar angle measurement discussed above. Since this is exploratory research to assess the potential of the bicondylar angle for sex determination, sample sizes are small. These samples include three femora from the Radford University Forensic Science Institute’s prehistoric (Native American) collection, three from the Institute’s modern (cadaver) collection, and two modern forensic cases from the Virginia Office of the Chief Medical Examiner (Western District, Roanoke). The final femur represented an anatomical model housed within the Forensic Science Institute. The three methods of measuring the bicondylar angle are applied to these samples in an attempt to assess each method for its accuracy and consistency in measuring the bicondylar angle. When the Van Gerven method was performed, the osteometric board was used. A tape measure and a level (to ensure the measurement from the table was truly perpendicular) were used for the Heiple and Lovejoy method and the Ruff method.

RESULTS

The results of this study are showed in Table 1. Sex was determined for the all of the femora using the maximum femur head diameter (Albanese, 2003; Bass, 1995; Jantz et al., 2008; King et al., 1998; Trancho et al., 1996; Spradley and Jantz, 2011).
<table>
<thead>
<tr>
<th>Table 1 – Angle measurements recorded</th>
<th>Ruff</th>
<th>Heiple and Lovejoy</th>
<th>Van Gerven</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011-04 (Male)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>8.587°</td>
<td>13.174°</td>
<td>5.333°</td>
</tr>
<tr>
<td>Left</td>
<td>8.607°</td>
<td>12.624°</td>
<td>6.547°</td>
</tr>
<tr>
<td>H21 (Female)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>9.628°</td>
<td>12.803°</td>
<td>9.443°</td>
</tr>
<tr>
<td>HUN1 (Male)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>9.462°</td>
<td>12.695°</td>
<td>9.264°</td>
</tr>
<tr>
<td>HUNK1 (Female)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>11.940°</td>
<td>13.648°</td>
<td>6.804°</td>
</tr>
<tr>
<td>Plastic Femur (Male)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>9.650°</td>
<td>10.305°</td>
<td>6.634°</td>
</tr>
<tr>
<td>RUC1 (Female)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>7.923°</td>
<td>12.381°</td>
<td>6.772°</td>
</tr>
<tr>
<td>RUC2 (Male)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>8.746°</td>
<td>11.595°</td>
<td>5.410°</td>
</tr>
<tr>
<td>RUC3 (Female)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>8.957°</td>
<td>12.528°</td>
<td>8.787°</td>
</tr>
</tbody>
</table>

When performing the experiment, the method used by Van Gerven (1972) was the easiest to consistently measure. There was a great deal of ambiguity when following the Heiple and Lovejoy (1971) method. It was very difficult to find an acceptable feature on the bone to record the measure from. The measure was recorded at the greater trochanter because that appeared to be a consistent
feature to measure. The results when using Van Gerven’s (1972) method were lower than what is expected from the bicondylar angle; while the measurements when Heiple and Lovejoy (1971) were applied appeared to be quite larger than expected. The results when using Ruff (1995) appear to be closer to what was expected, around 9°.

Table 2 – Basic statistics for each method:

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruff</td>
<td>9.278°</td>
<td>1.147</td>
</tr>
<tr>
<td>Heiple and Lovejoy</td>
<td>12.417°</td>
<td>.9687</td>
</tr>
<tr>
<td>Van Gerven</td>
<td>7.222°</td>
<td>1.565</td>
</tr>
</tbody>
</table>

These three methods were compared using basic statistics (Table 2). The mean for the Ruff method was the closest to the mean that was expected; however, the standard deviation is large. Heiple and Lovejoy’s method has a larger than expected mean, but a low standard deviation. When looking at the box-dot-plat which shows the range and any outliers (Figure 3), the greater consistency in the Heiple and Lovejoy method is evident. The Van Gerven method has a quite large range, which is due to the biases included when the femur head and neck are included in the measurements. There are outliers present when using both the Ruff and Heiple and Lovejoy methods. These outliers were not trimmed because the sample was already very small.
Figure 4 (visual generated using PASW Statistics 18) Box-and-whiskers plot showing the range of the data recorded:

Figure 5 (visual generated using PASW Statistics 18) Error ranges for 80%, 95%, 99% for the data recorded:

Figure 5 shows the error ranges associated with 99%, 95%, and 80% confidence intervals for each method. Looking at these error ranges in the most basic sense, it can be determined that the
bicondylar angle is generally larger in females. The overlap, however, appears to be too great for the forensic application.

Analyzing each method to determine if sex differences can be deciphered using 80% confidence is depicted in Figure 6. The differences between the sexes overlap excessively for each method. These differences are not due to chance. The one observation that can be confidently made is that females consistently have a higher bicondylar angle than males. Methods by Van Gerven and Heiple and Lovejoy show the greatest chance for sexual dimorphism being statistically significant.

**Figure 6 (visual generated using PASW Statistics 18) Error ranges divided by sex for each method:**

![Error ranges divided by sex for each method](image)

**DISCUSSION AND CONCLUSION**

The initial research question was focused on determining if the bicondylar angle was sexually dimorphic enough to be used as a method for determining sex in the forensic setting. It turned out that finding a reliable method for determining the bicondylar angle is much more difficult than previously thought. Prior descriptions of measurements in the paleoanthropological and bioarchaeological literature are ambiguously explained and lack any set formulae to find the angle. What was also
challenging was the fact that there is no standard way to measure the bicondylar angle. It is clear that a consistent and reliable method for measuring the bicondylar angle is greatly needed.

Each method of measuring the bicondylar angle produced different results for what the angle was in which the difference is not due to chance alone. The femora did not even fall in the same loci in the range for each method, i.e. the lowest angle when using the Ruff method was not the lowest angle for both the Heiple and Lovejoy method and the Van Gerven method as well. This suggests that the methods vary greatly and the angle has been measured inappropriately at times depending on what method was used.

The Heiple and Lovejoy (1971) method was much more consistent in its results but the angle was far too high for what is expected for a population of prehistoric and modern Homo sapiens femora (the angle was expected to be around $9^\circ$). The Ruff (1995) method was very close to this expected value, but was much less consistent. The Van Gerven (1972) method was very inconsistent and had results that were too low.

The Van Gerven method also suffered from biases, the main bias one being inclusion of the femora head and neck when measuring the maximum length and bicondylar length. The femora head diameter, femora neck length, and femora neck angle are all sexually dimorphic and highly variable themselves. The Heiple and Lovejoy (1971) method was affected by the presence of osteoarthritis on the greater trochanter of the femur. The bicondylar angle length was often found to be measured at the superior surface of the greater trochanter. The greater trochanter is a common place for arthritis on the femur and added extra length to this measurement (Bass, 1995; White, 2000). The Ruff (1995) method had few biases included in the measurements. The only bias that I found to be a problem was the difficulty in taking the measurement; this was also an issue when using the Heiple and Lovejoy (1971) method.
Comparing the methods’ ability to decipher sex was quite ambiguous. At the 80% confidence level, all the methods showed a great overlap between sexes. This suggests that differentiation between the bicondylar angles in males and females is not great enough to be used as a sex determination tool when using one of the three methods described above. A more precise method for measuring the bicondylar angle is required for there to be any chance of using the bicondylar angle to determine sex in the forensic setting.

The large size of the error ranges for this study can be attributed to the small sample size and the large variation within the population studied. If the sample size increased and the population was more consistent, the significance in this research would increase as well. The fact that the population consisted of prehistoric and modern femora were used introduces populations that are not comparable. Secular and geographic change can attribute to the degree of sexual dimorphism.

**FUTURE RESEARCH GOALS**

There is promise in the ability to take measurements on the femur reliably and efficiently using geometric morphometrics. Geometric morphometric methods focus on the use of geometric information to provide use statistically significant analyses and relate them to physical structures (Slice, 2007). This means that the bone will be able to be digitally analyzed in a three-dimensional aspect, which would eliminate the majority of human measurement errors and provide more accurate results (Richtsmeier et al., 2002). This is currently pioneering its way through the forensic field when measuring the skull (Ousely and McKeown, 2001). This is because there are distinct and defined landmarks on the skull that can be measured by anyone with little ambiguity to produce consistent measurements and results. This method has also been applied to the mandible, with between 67%-70% accuracy (Oettlé et al., 2005; Pretorious et al., 2006). Geometric morphometrics have recently been applied to the post-cranium, mainly the pelvis (Pretorious et al., 2006). The post-cranium appears to be much more difficult
to find consistent and efficient landmarks on each bone. I believe that geometric morphometrics is the future for forensics and all of physical anthropology.

The results of this research have given evidence that the bicondylar angle of the femur is sexually dimorphic, with the angle being larger in females. Because of the great overlap between males and females, this method is likely to never be used in the forensic field since in forensics the focus is on an individual that has a good chance of lying in the overlapped range. The sex determined has to be of high probability. This method could be used on larger populations, such as in a bioarchaeological setting where the sex is determined on a general level; there is no need for it to be as precise for most questions asked. An area for future research is to test these methods with other researchers on a larger, more similar sample. This will prove how reliable each method is at determining sex. Another area for research is to find and use landmarks on the femur that can be used for geometric morphometrics. This would provide a three-dimensional image of the femur where an accurate measurement of the bicondylar angle can be taken. Once this is possible, the bicondylar angle will have the ability to be measured for paleoanthropological use to determine the bipedal status of fossil hominids accurately.
REFERENCES


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