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Human Femoral Head Dimorphism Compared to Sex Differences in the Diaphysis of the Femur

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Abstract

Thibault, Alyssa (Georgia State University) *Human Femoral Head Dimorphism Compared to Sex Differences in the Diaphysis of the Femur*. The femur is the largest bone in the body, and one of the most common bones found at crime scenes and archaeological sites. This study focused on measuring multiple femoral morphological structures. After collecting the measurements and morphology scores, SPSS was used to analyze the data. These analyses included a measurement error study, correlations of femoral head to other measurements of the femur, multiple linear regression, and bivariate graphs. Independent sample t-tests were utilized to determine whether the means of the two sexes, estimated using femoral head diameter, differ with respect to the variation with each group and number of individuals for each femoral diaphyseal and neck measurement. The femoral neck provided the most reliable sex information, suggesting the proximal aspect may be more dimorphic than the distal femur.

Introduction

The femur is the largest and least fragile bone in the body and, for this reason, it is the most common bone found in archeological and forensic settings, which leads to the femoral head being used as a typical method of identifying the sex of individuals. However, this does not mean the femur is always found complete. There are several factors to keep in mind that could potentially lead to fragmentary or distorted femoral remains, such as postmortem trampling, handling, maceration, degradation processes of decay, diseases such as syphilis and tuberculosis, and other alterations perpetrated by humans, animals, and other organisms. Measurements of the femoral head can aid in identifying individuals, but what if the sample does not have the femoral head, or it is damaged? Is there another way to determine the sex of an individual by using the femur? Furthermore, are the other measurements more accurate, or should they be used alongside the measurement of the femoral head? This study will focus on measuring multiple femoral morphological structures, such as the head, neck, lesser-greater trochanter, length, shaft, lateral-medial condyle, and intercondylar fossa using digital calipers and qualitative notes. The purpose of this study is to determine whether there are any measurements that are significantly correlated with sex as estimated using the standard femoral head measurements, and whether specific morphological nuances characterize one sex or the other.

The femoral head is part of the pelvis. Sexual dimorphism of the pelvis due to reproductive considerations leads to multiple sex differences in the femur, which can then be measured to determine sex. It is expected that more sex-relevant traits will occur on the proximal femoral head and neck region than on the distal condylar area. However, it is also possible that the proximal head region places considerable biomechanical demands on the distal femur such that it conforms to the expectations of sexual dimorphism. A third possibility is that none of the traits measured or observed will present any discernable correlation with femoral head diameter and that the breadth dimensions of this particular surface, which after all joins to the acetabular region of the pelvis, is the only accurate predictor of sex in the femur. These scenarios were evaluated from data collection and analysis using statistical tools.

There are multiple factors that could explain why the femur is possibly sexually dimorphic, one being that it articulates with the pelvis and angle of the bone. To better understand this, one must first examine the pelvis and why it would have an impact on the femur. The pelvis is sexually dimorphic due to the fact that females need to be able to give birth, causing the female pelvis to be wide and short, while the male pelvis is narrow and long (Steele and Bramblett, 1988).

This would affect how the femur interacted with the tibia, leading to differences in the distal end of the femur. Some studies have suggested that the quadriceps angle is different on males and females due to the shape of the pelvis. Males usually fall into the lower range whereas females fall into the higher range (Khasawneh, 2019). This would suggest that the female femur is angled more than that of males, indicating that the distal end of the femur might be sexually dimorphic as well to account for the angle differences.

Materials and methods

The equipment used to conduct this research included a pair of digital sliding calipers, dental floss, an osteometry board, and a measuring tape. All materials were provided by the Georgia State University Bioarchaeology Teaching Lab, except for the dental floss and measuring tape which were brought from outside. In the study, Excel was used to keep track of all the data that had been collected while the analysis of the data was done using the Statistical Package for the Social Sciences (SPSS) that was provided by Georgia State University. The project objective was to observe femora (n = 20), curated in the Georgia State University Bioarcheology Teaching Laboratory in the Department of Anthropology, in order to gather more information on potential sex indicators.

Measurements were taken at least twice on all the bones, and even four times on some of them, to validate the observations were as accurate as possible. The measurements were also spread out in different trials to increase precision. Measurements began in October and finished at the end of November. The method of measuring was intended to reduce human error that occurs when using the femur to determine sex: measurements have to be taken multiple times, nonconsecutively, and compared to increase repeatability which reduces error as much as possible. Simply taking measurements in the wrong manner, slight movements in the instrument, or instrument errors can imperil the accuracy of data. After all the data were collected and recorded into spread sheets, the study used SPSS to determine the standard deviation between trials and to determine the accuracy of the measurements. Prior to formal data collection, a measurement error study was conducted whereby the same individuals were measured and described (n = 10). The subsequent data were analyzed using t-tests and percent difference between the two trials.

Feature	Shorthand	Method of Measurement
Head	H	From the edge of the epiphyseal line of the head to the other side
Neck	N	The widest part of the neck closest to the trochanters
Lesser - Greater Trochanter	LGT	The most proximal end to the most distal end of the trochanters
Shaft	S	Shaft circumference taken from the middle section
Length	L	From the head to the condyles
Lateral-Medial condyle	LMC	The edge of the epicondyles of the posterior side of the lateral to medial condyle
Intercondylar fossa	IF	The widest inner part between the lateral and medial condyles
Head-Greater trochanter	Ha-Gt	From the fovea capitis of the head to the greater trochanter

Table 1 shows the shorthand that will be used throughout the paper along with the method of measurements used.

Bones

The femora were acquired from the Georgia State University Bioarchaeology Teaching Laboratory in the Department of Anthropology. The collection included 20 femora of unknown provenance. All 20 bones suffered from at least one pathology; this can be seen in *Table 2*, which lists all the bones and their current condition. Most of the bones suffered from either osteoporosis, osteoarthritis, or other pathologies. **Osteoporosis** is a condition where the total bone mass is reduced causing the bone to weaken. This is common with age and some diseases (Ortner, 2019). Osteoporosis can lead to fractures along the distal portion of the femur due to minor stress on the bone. These bones, when examined, were noticeably lightweight and tended to be more eroded in the distal end and in the proximal end around the head (Aufderheide, 2000). **Osteomyelitis** refers to any kind of infection that affects the bone or the bone marrow and causes swelling of the bone. Osteomyelitis can develop from a compound fracture, surgery, or injury to the femur. This is more common in people older than 40, but can be seen in any age group (Aufderheide, 2000). **Osteoarthritis** is the most common type of degenerative joint disease. Osteoarthritis is identified by the deterioration of the cartilage that is found in the joints between two bones. Along with the deterioration of cartilage, it is also accompanied by the formation of bony spurs and by lipping along the joint (White, 2005).

Bone Number	Notes	Pathology	Color
GSU 5.1	Missing the distal end of the bone. Cut right in the middle of the shaft; the break point is rounded not sharp suggesting it may have happened during life.	Osteonecrosis	Tan
GSU 5.2	In extremely poor condition, missing most of the key parts needed for this research. Missing the distal end of the femur along with the proximal end, and portions of the head, neck, and the lesser and greater trochanter are also damaged.	Osteoporosis	Tan
GSU 5.3	Missing part of the left condyle and severe lipping on the right condyle. Part of the head and neck appear swollen together.	Osteomyelitis, eburnation	Light tan and some darker areas
GSU 5.4	Severe lipping on the condyles, eburnation on the right lateral condyle, and some lipping on the head.	Osteoarthritis, osteomyelitis, periostitis, eburnation	Reddish tint, but mostly tan
GSU 5.5	Missing part of the fovea capitis, which is on the head; this does not affect the data. Part of the epicondyle on the left is missing, but again this should not have a significant effect on the data.	Osteoarthritis	Light tan

Bone Number	Notes	Pathology	Color
GSU 5.6	Missing the left and right epicondyle, along with some of the greater trochanter.	Osteoarthritis, infection, periostitis	Tan
GSU 5.7	Missing part of the epicondyle on the left side along with a bit on the right. There is discoloration in the intercondylar fossa, head, and neck. Lipping on the head. The bone has some discoloration, possibly due to conditions of preservation.	Osteoarthritis	Rust color with dark areas
GSU 5.8	Some damage around the head exists, but not to the degree that would hinder an accurate measurement. Missing parts of the epicondyle on both sides	Osteoporosis	Tan
GSU 5.9	Lipping on the condyles. Discoloration of the head, neck, and the condyles.	Osteoarthritis	Tan
GSU 5.10	Some wear on the head, neck, condyles	None observed	Red tint
GSU 5.11	Missing part of the head, along with the epicondyle. Odd bend in the proximal portion of the shaft that looks like it was possibly from development and not from an infection.	Possible rickets	Yellowish white
GSU 5.12	Missing the distal part of the bone and seems to be where the epiphyseal plate would be. Possibly a young adult age from 16-19.	None observed	Tan
GSU 5.13	Unusual bend on the proximal end of the shaft; there is also a distinct color change in the area. Some bony overgrowth along the Linea aspera, lesser and greater trochanter present. The only measurement the bony overgrowth should affect is the circumference of the shaft, but only slightly.	Osteoarthritis	Tan and white
GSU5.14	Swelling of the shaft due to infection, along with small pin holes and linear lines. There are two small brown spots that are also slightly indented on the proximal end of the shaft. Discoloration around the head with the fovea capitis area missing. The medial epicondyle is missing and has a large hole in it.	Osteomyelitis, osteoarthritis, infections, periostitis	White with black areas
GSU 5.15	Overgrowth of the linea aspera and the pectineal line. There is also an unusual bend in the proximal end of the shaft.	None observed	Tan
GSU 5.16	Missing part of the head and has a screw sticking in the missing section, which seems to have been put there when the individual was alive because the growth of bony tissue surrounding the intrusive object is visible. There is another screw with two holes that traverses through the intertrochanteric crest. There is also some lipping on the condyles.	Osteoporosis	Dark tan

Bone Number	Notes	Pathology	Color
GSU 5.17	Oddly, short neck. Discoloration in the proximal half of the shaft compared to the rest of the bone. Some postmortem damage present.	None observed	Tan and white
GSU 5.18	Remodeling on the shaft with some swelling of the proximal end. This is most likely due to an infection of the bone. There is also some damage to the inferior surface of the head.	Osteomyelitis	Light tan
GSU 5.19	The femur is in relatively decent shape, but missing most of the epicondyle.	None observed	Dark tan
GSU 5.20	Very swollen and a lot of remodeling of the bone. The shaft is swollen to the extent that it is not possible to see any features like the linea aspera and intertrochanter crest. The proximal end just blends in with the shaft and the only features that are noticeable are the neck and head. The distal end has the same issue with the shaft just blending in, with only the medial and lateral condyle noticeable. Overall, the diaphysis has the appearance of a French baguette.	Osteomyelitis, periostitis	White

Table 2 shows the bone notes, pathology, and color that were observed during research.

For the final data set, the second set of measurements from a measurement error study was used because they were taken after more experience in measuring had been acquired, and therefore would be more likely to accurately represent the morphology. *Table 3* shows all the final measurements and the estimated sex membership that was used in this study. In *Table 3*, not all measurements were able to be obtained due to the pathology and condition of the bones; the measurements that could not be obtained are marked with a 0 (zero). *Table 3* also shows the estimated stature of the individual. The formulae used included Y=61.41+(2.38*Length) +/-3.27 for males and Y=54.10+(2.47*Length) +/- 3.27 for females (White,2005). Note: Before inputting the length, it is important to make sure that the measurements are in centimeters instead of millimeters.

Bone	Head	Neck	Lesser-greater trochanter	Shaft	Length	Lateral-Medial condyle	Inter-condylar fossa	Head-Greater trochanter	Sex	Stature
GSU 5.1	45.4	32.9	67.6	80.2	0	0	0	94	2	0
GSU 5.2	47.6	36.9	0	86.4	0	0	0	0	2	0
GSU 5.3	43	32	68.5	81.9	426	70.1	21.7	90	1	156-163
GSU 5.4	49.6	38.8	76.6	90	425	71.5	22	93.6	2	159-165
GSU 5.5	41.1	34.3	73.1	80.1	408.5	59.8	19.2	86.5	1	151-158
GSU 5.6	45.2	32.9	69.6	82.2	436	68.4	24.3	96.5	1	158-165
GSU 5.7	48.5	34.5	76.7	91.44	407	68.3	21.3	95.4	2	155-161
GSU 5.8	44.5	35.5	78.1	79.5	455	69.3	22.6	94.8	1	163-170
GSU 5.9	48	37	82.3	93.4	455	73.5	17.8	102.5	2	166-173
GSU 5.10	42.5	29.8	63	80.4	402.4	68.1	20.3	88.1	1	150-157
GSU 5.11	40.8	28.7	67	75.9	380	61	17.1	82.8	1	145-151
GSU 5.12	43	32.6	77.9	72.6	0	0	0	88.8	1	0
GSU 5.13	45.3	32.7	68	79.6	415	70.9	25.4	91.5	2	156-163
GSU 5.14	41.7	28.5	69.2	103.1	411	65.3	19.2	87.3	1	152-159
GSU 5.15	45.8	33.1	68.1	82.9	420	74.5	27.9	93.4	2	158-164
GSU 5.16	48.6	31.9	76.6	92.9	445	78.8	18.7	104	2	164-170
GSU 5.17	45.6	32.8	74.5	79.1	414	68.7	21.9	82.6	2	156-163
GSU 5.18	47	36.3	76.9	98	451	68.7	19.6	98.1	2	165-172
GSU 5.19	43.9	35.2	79.8	81	411	69.2	23.9	86.5	1	152-159
GSU 5.20	44.9	32.6	73.8	0	435	65.9	22.8	91	1	158-165

Table 3 shows measurements used to analyze data and the assigned Sex: females=1 and males=2

The femoral head has been utilized as a sex indicator to differentiate between males and females for the past 50+ years (Steele and Bramblett, 1988). The method was proposed when researchers found that measurements of the femoral head above 45 mm are male and below 45mm are female, with little overlap between the sexes (Steele and Bramblett, 1988). The most well-used method of determining the sex of an individual is by analyzing the sexual dimorphism in the skull and pelvis. However, this may not be 100% accurate because the methods used to sex an individual via the skull tend to depend on subjective categorization and the experience of the observer. The pelvis can be an accurate sex indicator, but many individuals fall in the middle of the ranges, leaving room for error, particularly in individuals with both male and female characteristics.

Bone Measurements

The areas that were chosen to be measured were based on their function relative to the pelvis and also based on previous research conducted on sexual dimorphism of the femur (Purkait, 2003; Gillespie, 2011). There are varied factors which could lead to the femur being sexually dimorphic that evolve around the sexual dimorphism of the pelvis, such as the angle of the bone and the muscle attachments and articulation to the tibia due to this angle. Starting from the proximal end of the femur and moving down to the distal end are the measurements of the head, neck, lesser-greater trochanter, shaft, greater trochanter-head distance, lateral-medial condyle, and intercondylar fossa. The proximal end of the femur articulates with the pelvis and includes the head, neck, and lesser and greater trochanter.

Head – The head of the femur is the rounded, smooth articular surface of the proximal-medial end, which is connected to the shaft by the femoral neck and articulates with the acetabulum of the pelvis. The pelvis is the most sexually dimorphic part of the skeleton; therefore, it would be understandable for the femoral head to be similarly sexually dimorphic (White, 2005).

Neck – The function of the neck is to connect the head to the shaft of the femur. The neck is slightly curved. Since the femoral head measurement is a reasonably accurate sex indicator, it can be theorized that the neck could also be sexually dimorphic. It is possible that the neck would be wider to support a larger femoral head in males and narrower for the smaller femoral head in females. One would expect the neck width to significantly correlate with femoral head breadth. It is also more common to find the femoral neck well preserved compared to the femoral head (Steele and Bramblett, 1988).

Lesser-greater trochanter – The lesser trochanter is found on the most proximal end of the posteromedial diaphysis inferior to the head and neck, while the greater trochanter is located on the lateral end of the proximal femur. Both of these points connect with ligaments from the hips. These include the pubofemoral and iliofemoral ligaments, which assist with stabilization of the hip and femur (Jones, 2019).

Head to the Greater trochanter – The measurement of the head to the greater trochanter was included due to multiple studies done on this measurement that have shown positive results. In one study done in 2016, the femoral neck width and the neck axis length were measured in 252 individuals from the National History Museum of Lisbon. Researchers examined the femoral neck axis length or FNAL: this measurement was defined as being taken from the "base of the greater trochanter to the apex of the head" (Curtate, 2016).

Length – The length of the femora was taken so that stature estimates could also be calculated. Although stature differences may reflect sex differences in extreme cases, there is always the risk that the substantial overlap in height between females and males is larger than expected for the sexes. Note: For some of the bones it was not possible to measure the entire length of the bone. (Steele and Bramblett, 1988).

Shaft – The shaft of the femur is located in between the proximal and distal portion of the bone. The measurement taken was the circumference of the midshaft. The midshaft diameter and circumference of the femur serve as common proxies for body mass in mammals (Jones, 2019). The linea aspera, the gluteal turbosity, and the medial-lateral supracondylar is located on the posterior side of the shaft. This is the line which runs down along the shaft and which connects to various muscles and ligament such as the gluteus maximus and adductor muscles (Low, 2019).

Distal portions of the femur articulate with the tibia and include the lateral condyle, medial condyle, and the intercondylar fossa**.**

Lateral-medial condyle – The lateral-medial condyle articulates with the lateral and medial intercondylar tubercles of the tibia, and the lateral and medial tibial condyles. (White, 2005)

Intercondylar fossa – The intercondylar fossa houses the anterior cruciate ligament and the posterior cruciate ligament that stabilize the knee joint. Other research has been done on sex difference that involved total knee surgery and which suggested that there is sexual dimorphism with the intercondylar fossa (Hirtler, 2021).

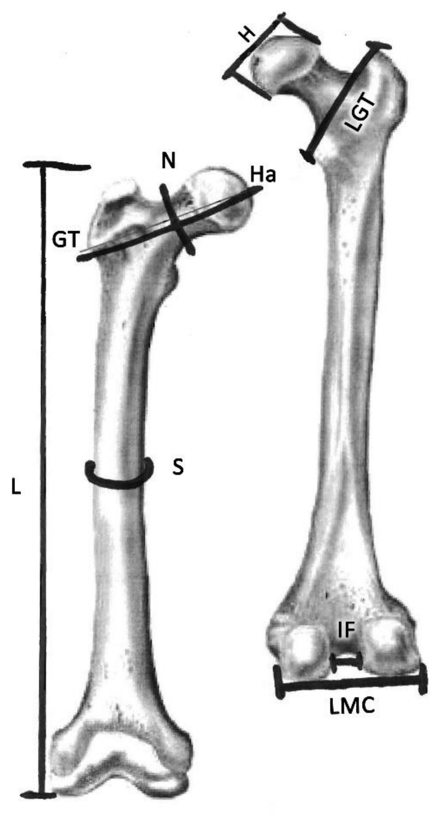


Figure 4 shows the measurements that were taken and the shorthand which the study will be using throughout this paper to refer to the measurements. Head =H, Neck=N, Lesser and Greater Trochanter= LGT, Length =L, Shaft circumference=S, Lateral and Medial Condyle=LMC, Intercondylar Fossa=IF, Head to Trochanter ridge=HaGT

The shape of the pelvis leads to another theory of the possibility of the angle of the femur varying from males to female. One theory notes how the femur in females are angled differently in order to be able to hold weight and to accommodate a wider pelvis (Purkait, 2003).

Why is this study important?

There are many ways that this research could be useful. This research should show whether there are any sex differences, even in this small sample, and whether it would be useful to conduct further research into finding ways to identify individuals more accurately, and even to help with research in the medical field on individualized treatments for the sexes based on dimorphic characteristics of the femur.

<u>Identification of individuals</u> – Much of the research on identifying individuals using the femur used the proximal portion of the femur and neglected to take into consideration the possibility of the distal end. Measuring the femoral head should, in theory, be a highly effective way to determine sex due to its proximity to the pelvis. However, the problem is that most humans tend to fall in the middle of the range, meaning that determining sex really comes down to the differential weight given to sex characteristics by examiners. Throughout this study, the decision had to made whether a person that borders slightly above 45mm should be classified as female or male, suggesting 100% accuracy in identifying sex membership may or may not have been achieved. With the addition of other measurements there is a possibility to determine sex more accurately in unknown individuals. If one can accurately assign sex, then there is a higher chance to narrow down the search of unknown individuals.

<u>Total knee replacement surgery</u> – There has been some research done previously on total knee replacement surgery and how females have seemed to continue to experience discomfort after

the procedure. The theory is that the distal portion of the femur is different on males and females. In a study conducted in 2007, which discusses how females account for two-thirds of total knee replacements, the research explored not just the measurements of the distal end of the femur but also the shape. The conclusion from this research was that the distal end of the femur is more of a trapezoid shape in females and a rectangular shape in males (Conley, 2007). This leaves the question of whether there is a way to examine dimorphism through linear measurements.

Other uses for this research can also benefit medical research. For example, one study examined the physical shape of the proximal end and overlay outlines of the femur to better understand why hip osteoarthritis occurs more in females than males (Frysz, 2020). They examined the femora of adolescent males and females to determine sex difference at the age of 14. The study found that the shape of the head and greater trochanter at age 14 was different in males and females. In addition, they found that females at 18 years had a narrower femoral neck width and a wider shaft (Frysz, 2020). This raises the question of whether these sex differences remain into adulthood given that the proximal end of the femur fuses between the ages of 14 to 19 years and the distal femoral between the ages of 15 to 21 (Steadman, 2009).

With evidence of a difference in the distal end of the femur, such as the lateral condyle height and the medial condyle height being slightly larger in males than females, a redesign of female-specific knee replacements has commenced (Conley, 2007). Can this information be also transferred into the field of forensic anthropology?

Other research

In 2011, Gillespie and a group of researchers searched for any sex differences in the distal portion of the femur. Their paper was used to assist in determining that the mediolateral length of the distal femur, or in this case LMC, was going to be measured and focused on in this study. Their results suggested that when the height and the mediolateral length were used to calculate the aspect ratio, there was a significant difference between males and females but with a large amount of variability between individuals (Gillespie,2011).

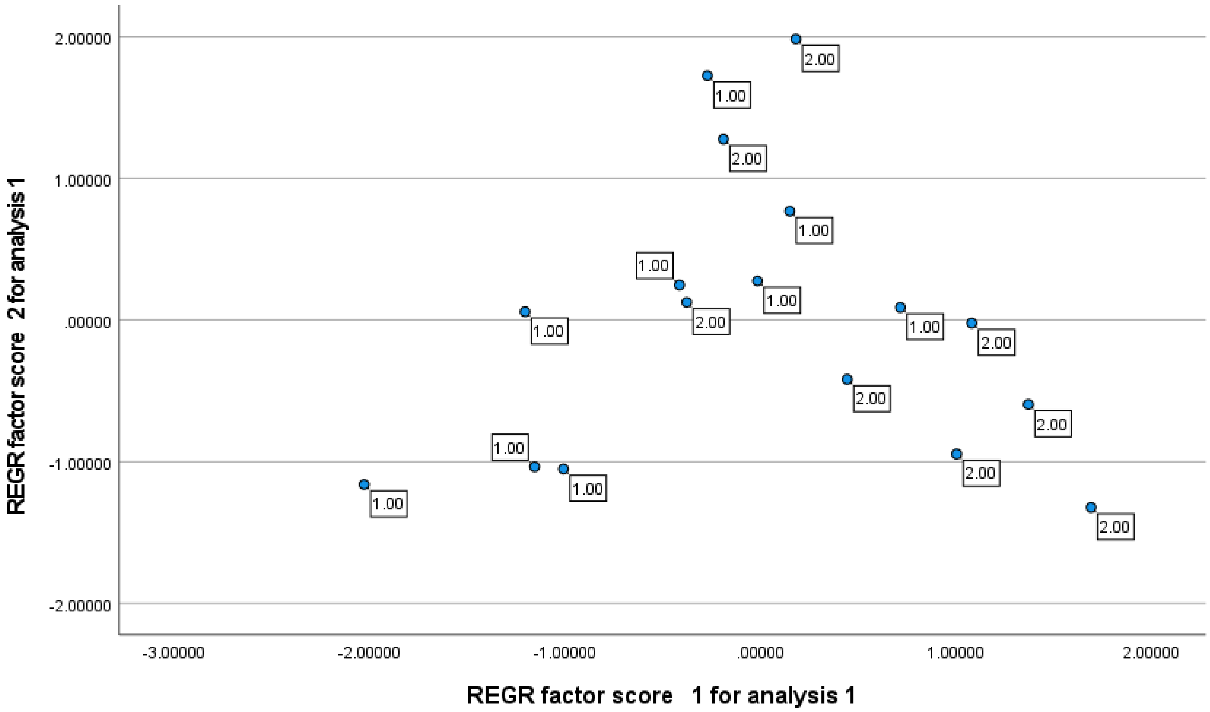
Lonner evaluated 100 male and 100 female specimens and debated whether the differences in the distal part of the femur are related to sexual dimorphism or weight. The study focused on living patients who have had a total knee replacement. It is important to look at living subjects as well to get a better understanding of whether weight could be a factor for why some of these measurements are different. Their research found that the aspect ratio was more significant in females than males along with evidence that the morphology and shape of the distal femur are also dimorphic and not just the dimensions (Lonner,2008).

Purkait examined 380 femurs in 2003 with known sex, age, and ethnicity. The bones were acquired from the collection at a medical institution located in India. The study had an uneven number of males to females: 200 to 80. In this paper it is discussed that other studies done on the femur did not consider the anatomical position of the bone, believing that the stress and strain is different for males and females. This can also affect the size and shape of the femoral head (Purkait,2003). Another study done by Purkait in 2005 focused on the proximal end of the femur and discussed what has become known as "Purkait's triangle." Their study noted how a single variable was only 80% accurate, but when multiple variables were combined the accuracy improved. From this study, Purkait produced 3 points that could be measured for more accuracy (Purkait, 2005).

Meeusen studied a total of 286 femurs from multiple institutions, and with various ancestry, to determine if the femoral neck axis length was a good indicator in sex determination. The femoral neck axis length is a measurement taken from the base of the greater trochanter to the apex of the head, or in this paper it is referred to as Ha-Gt. They found that out of the 286 femurs approximately 84% female and 87% males could be correctly classified using the femoral neck axis (Meeusen,2015).

Results

Each set of numbers was run through a descriptive statistical analysis to calculate the standard deviation of the trials, along with discriminant function analysis to confirm that none of the bones were mis-sexed. The discriminant function analysis demonstrates that there has been no misclassification for sex attribution. A principal components analysis was then performed on all eight traits, showing an imperfect separation of females and males, as shown in *Graph 1*.



Graph 1 shows that there is a separation between males=2 and females=1 with a few male and female outliers.

A multiple linear regression was also performed on all eight of the traits with *Table 5* showing the beta weight. The head is already the highest due to it correlating more with sex than the other variables. *Table 5* also shows that femoral midshaft circumference, labeled as S, has the highest beta weight of the other variables, implying a unique relationship between sex membership and body mass.

Bone	Beta
H	1.061
N	-0.024
LGT	-.149
S	.213
L	-.036
LMC	.093
IF	-.059
HaGt	-.300

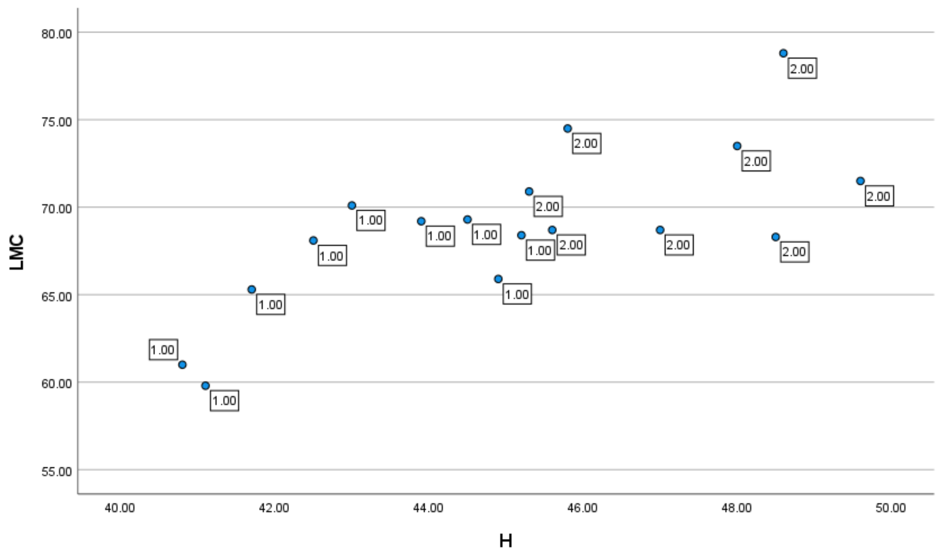
Table 5 shows the beta weight of each variable

Table 6 shows the pairs that are more relevant to sex estimation are those that correlate to the femoral head, which is utilized as a standard measure of sexual dimorphism. Shown in *Table 6* is the high and significant correlation between neck height and trochanteric ridge to the femoral head. On the other hand, LMC and IF are significantly correlated to L, showing that these factors might be more determined by height and body mass of an individual than their sex.

Pair	R	P
H-N	0.684	<.001
H-HaGt	0.899	<.001
N-HaGt	0.595	0.041
LGT-L	0.542	0.014
LGT-LMC	0.532	0.016
LGT-IF	0.641	0.003
L-LMC	0.99	<.001
L-IF	0.923	<.001
LMC-IF	0.933	<.001
LMC-L	0.99	<.001
IF-LGT	0.641	0.003
IF-L	0.923	<.001
IF-LMC	0.933	<.001
HaGt-H	0.899	<.001
HaGt-N	0.595	0.041

Table 6 shows the pairs that are highly correlated

For this study, the LMC was considered when determining if the distal end of the femur showed any sexual differences. When analyzing the correlation in *Table 6* and the beta weights in *Table 5* it appears that the LMC is not sexually dimorphic but related to height. It also appears that the LMC in females was slightly lower than males, with some outliers.



Graph 2 shows LMC on the Y- axis and Head (which correlates to sex) on the x- axis.

As shown in *Graph 2*, the LMC measurements for both male and female hover around 68-70. According to this data set, females did not go above 70 and males did not go below 68, indicating that any LMC that measures above 70 are male and any below 68 are female.

A t-test was also conducted for all factors, with the p-value shown in *Table 7*. When looking at the p-value, a number lower than < 0.005 is more statistically significant while a number higher than >0.005 is not statistically significant. *Table 7* shows that none of the factors have a p-value lower than 0.005 other than the femoral head measurement. The t-tests demonstrated that no significant difference existed between trials.

	P- Value
H	<.001
N	0.018
LGT	0.506
S	0.132
L	0.646
LMC	0.952
IF	0.669
HaGt	0.706

Table 7 shows the p-value of each factor

Interpretation of results and comparison to other studies

The findings from *Table 6*, which showed the correlations between two variables, is consistent with the research found in another study that used the femoral neck width and the neck axis length of 252 individuals from the National History Museum of Lisbon. In this study researchers examined the femoral neck axis length, which is from the head to right below the HaGt, and the femoral neck width (Curate,2016).

Another study done by researchers in Chile was conducted with the intent to help find if there were any additional measurements that should be used on the proximal end for identifying sex. The article explains how the femur contributes to forensic anthropology. They examined a total of eight measurements on the proximal end of the femur, including the femoral neck, along with the measurements from the greater trochanter and the head. The study found that all the measurements they had taken showed a significant difference between males and females, with the males showing higher variables than the females (Carvollo,2020). The study concluded that the femoral neck measurements might be a better sexing method.

A third study also examined measurements taken from the super-inferior neck of the femur to understand if they could get an accurate sex estimation from these measurements. They studied a total of 270 individuals, finding that the femoral neck measurements were more accurate than any of the other measurements (Seidmann,1998). The femoral neck being an accurate way to determine the sex of an individual is not particularly surprising since the neck attaches the head to the body of the femur, making it more likely for the size of the femoral neck to correlate to the size of the femoral head.

This study analyzed the length, head, transverse head diameter, distal breadth, and proximal breadth from 100 different individuals of known sex, noting that out of all the different factors that were examined they found that all measurements were higher for males than females (Kumari,2019). For the seven variables they conducted a statistical analysis that showed the mean and max of males and females. These two charts showed that the male minimum measurements overlapped with the female maximum measurements. This showed that even though males have higher measurements than females there is still an overlapping where other studies suggest that most humans full within the same range.

One other study found that the femoral head and the anteroposterior diameter of the shaft were more accurate together than alone and were more accurate in females than males, with a 92.5% accuracy in females and 82.5% in males. The sample size included 40 males and 40 females showing that out of the 80 bones males had a high variation in all the measurements, excluding the measurements that were taken of the epicondyle length which was higher in females. (Soni,2010). This correlates with *Graph 2* which shows how the LMC measurements for males and females have a distinct separation with some overlap. Comparing this study to theirs, it would point to the epicondyle being more sexually dimorphic than the LMC, which would then suggest that the epicondyle would similarly correlate more with weight distribution than height.

Problems

Many different problems occurred throughout this study due to a lack of resources. Firstly, the limitations of the sample size, along with other factors like pathology, uneven number between sexes, unknown age, sex, and ethnicity.

The sample size was that of 20 individuals, but not all measurements could be taken from all the individuals meaning that some measurements had fewer than 20 samples. With this being said, 20 is not a large enough sample size to be an accurate representation of the overall population.

Along with the low number of individuals, almost all the bones showed some form of damage or pathology making measurements more difficult.

Additionally, the age, sex, and ethnicity of the individuals were unknown. Unknown age is not particularly important, unlike sex and ethnicity. Without knowing the correct sex of the individuals being studied, there is no baseline to determine which group they belong to. The femoral head is a good indicator of sex, but most people are right on the line; therefore, combined with human error it is very possible to assign the wrong sex. Since one cannot be sure of the number of males and females, this also makes it unclear whether the data being worked with is an accurate reflection of the population.

There has also been research debating the possibility that measurements vary with the ethnicity of the person. From the research located from previous studies done with sexing the femur, there were indications that the head measurements may vary by ethnicity, and without taking that into account, using the head measurements could easily misidentify solely due to ethnicity. This means that unknown ethnicity can possibly lead to inaccurate data if the baseline for the research is based on white individuals.

Because of these factors, in order for this research to be viable the study would need to increase the number of samples and have them be from known ethnicity and sex. A larger sample would also give an opportunity to look at more bones with fewer pathologies and would assist in getting a more accurate representation of differences in the femur. This does not mean this research was not valuable, but it does mean that further research must be done to have a larger impact on future sex identification methods.

Suggestions for future studies

Other factors to improve further research would be to consider the femoral angle, use 3D imaging, and include additional measurements.

Three-dimensional (3D) imaging of the bones may prove to be a more reliable way of sexing the femur according to a study done in 2016 by researchers. This paper discusses how sex estimation is used in forensic anthropology and how techniques can be improved. One thing discussed in the paper is that 3D imaging methods might have a vast advantage in the field of forensic anthropology because the imaging can show more patterns of sexual dimorphism than traditional methods. (Krishan,2016).

With the study done on total knee replacement they inspected the shape of the distal end of the femur. They concluded that the distal end of the female femur had more of a trapezoidal shape, compared to a rectangular shape in males (Conley,2007). Another study used x-rays of 200 individuals: half male and half female. The research used x-rays to measure the bicondylar width in patients in Nepal, which then determined if there were any differences in the femur between the sexes (Singh,2016).

Purkait writes about how other studies done on the femoral head did not account for the anatomical position of the bone, believing that the stress and strain is different for males and females and can affect the size and shape of the femoral head (Pukait, 2005).

There is substantial conflicting data on the femur: some studies show that there is a difference between sexes, while others show that there is not. There is just too much human variation and humans do not separate into nice, neat categories. It is possible that there are differences, but they are just too slight for humans to notice. This is where advances in technology could possibly benefit the field of forensic anthropology, to identify minor details that might not be so noticeable to the human eye. Sexing individuals takes years of practice, and can still be a subjective type of identification due to the slight variations between sexes and with human error this can easily lead to the individual being labeled as the wrong sex.

Conclusion

The original research question posed in this paper asked whether additional aspects of the femur are sexually dimorphic other than the femoral head.

When this study first began, before the bones had even been examined, there were concerns that the research would not yield quality results due to the limited resources and high pathology recorded on the bone specimens.

Many humans are not on either extreme of being hyper-male or hyper-female: when it comes to sex estimation, most of us fall in the middle of the range. That being said, the study results still indicated that there were multiple, significant sex differences in the head, head to greater trochanter, and also possibly the lateral-medial condyle. Additionally, the neck and head-to-greater trochanter measurements were highly and significantly correlated to the femoral head, which was used to determine sex.

Overall, the study noted that multiple traits of the femur are sexually dimorphic, and that specifically those of the proximal end show a greater differentiation between male and female.

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