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Sex Estimation from the Clavicle: A Discriminant Function Analysis

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SEX ESTIMATION FROM THE CLAVICLE: A DISCRIMINANT
FUNCTION ANALYSIS

By

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Bachelor of Arts

University of California, Santa Cruz, 2009

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of
Master of Arts

Department of Anthropology in the Graduate School
Southern Illinois University, Carbondale
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THESIS APPROVAL

SEX ESTIMATION FROM THE HUMAN CLAVICLE

By

Megan K. Cleary

A Thesis Submitted in Partial
Fulfillment of the Requirements
for the Degree of
Masters of the Arts
in the field of Anthropology

Approved by:

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TITLE: SEX ESTIMATION FROM THE CLAVICLE: A DISCRIMINANT FUNCTION
ANALYSIS

MAJOR PROFESSOR: Dr. Gretchen R. Dabbs

The development of methods for sex estimation using postcranial remains other than the *os coxa* is imperative for physical anthropology to improve the reliability of biological profile estimates in cases of incomplete and/or fragmentary skeletal remains. As the last skeletal element to complete fusion, the clavicle has the longest period of time to develop sexually dimorphic features, making it an ideal skeletal element for use in sex estimation. Sexual dimorphism in the clavicle was assessed using 18 measurements of the left clavicle of 265 (129 females; 136 males) individuals from the Hamann-Todd Collection. Independent samples t-tests with Bonferroni correction show males and females differ at a statistically significant level for all 18 variables with a significance level of 0.0028. Discriminate function analyses using the stepwise method (0.05 to enter, 0.10 to exit) produced a four variable model with cross-validated accuracy of 89.8%. A holdout sample from the Hamann-Todd Collection (n=30) similar in demographic character to the calibration sample was tested using the four variable model. The accuracy of the four variable model on the holdout sample was 90.0%. Additionally, four single variable models developed to accommodate fragmentary remains also have high predictive power (75.1-82.3% cross-validated calibration sample; 60.0-86.7% hold-out sample).

DEDICATION

I would like to dedicate this thesis to my dad, Michael Cleary and my partner, Jason Moungey, without whose support I would never have made it this far. Thank you for giving me the confidence and the freedom to pursue my dreams.

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CHAPTER I

INTRODUCTION

Sex is one of the most important elements of the biological profile that can be estimated from skeletal remains. Whether an individual is part of the paleoanthropological, archaeological, or forensic record, significant cultural aspects can be inferred from the sex of skeletal remains. The pelvis and cranium are the most reliable for assessing sex in human skeletal remains but these elements are not always available for analysis (Williams and Rogers, 2006). Taphonomic processes including, but not limited to, decomposition, forensic dismemberment, scattering by animals, and cultural practices including looting can all compromise the amount of biological material left for an investigator (Haglund and Sorg, 1997). As a result, the quantity of skeletal remains available for analysis by the investigator varies a great deal. For this reason, it is vital to develop methods of estimating aspects of the biological profile from as many skeletal elements as possible.

This project examined the sexual dimorphism of the human clavicle to determine its potential for sex estimation. Eighteen measurements were collected in order to identify sexual dimorphism in clavicular size. The author developed fifteen of these measurements. These measurements were taken on the historical Hamann-Todd collection at the Cleveland Museum of Natural History. Recent studies (Jantz, 2001) have shown that historical collections are not sufficient for

use in forensic applications without testing due to secular change. Therefore, this method will need to be tested further to apply to other than 20th Century Midwestern Americans.

The clavicle was chosen because it is the last skeletal element to complete epiphyseal fusion, meaning it has an extended period to present sexually dimorphic features. It was also chosen because males are known for having wider shoulders, on average, than females (Hauspie et al., 2004). Wider shoulders in males suggest their clavicles should show a size difference from females to support their greater shoulder breadth.

CHAPTER II

BACKGROUND/REVIEW OF LITERATURE

Clavicle Anatomy

The clavicle is a short long bone that curves laterally and anteriorly for roughly half its length. It makes up part of both the shoulder and the pectoral girdle. The clavicle helps connect the upper limb to the trunk and is located above the first rib. The clavicle articulates with the sternum at the sternoclavicular joint and the acromion process of the scapula at the acromioclavicular joint. The clavicle supplies support for both the scapula and the upper limb. By keeping the upper limb lateral to the thorax, the clavicle supports maximum range of motion for the upper limb. Acting as a strut, the clavicle allows the scapula to move freely on the thoracic wall. The clavicle protects the neurovascular bundle that supplies the upper limb by covering the cervicoaxillary canal. The clavicle helps absorb impacts on the upper limb by dispersing them into the axial skeleton (Moore and Dalley, 1999).

Two ligaments stabilize the acromioclavicular joint by connecting the lateral end of the clavicle to the coracoid process of the scapula. The conoid tubercle is the attachment for the conoid ligament. The trapezoid line is the attachment of the trapezoid ligament. The subclavian sulcus is the attachment for the subclavian muscle, which acts as a stabilizer for the clavicle

(Aiello and Dean, 2002). The costal tuberosity is the attachment for the costoclavicular ligament. The trapezius, deltoid, and pectoralis major muscles also attach to the clavicle (White and Folkens, 1991). The deltoid muscle is the primary muscle involved in arm abduction along the frontal plane and is also involved in shoulder flexion and extension. The trapezius muscle is involved in rotation, retraction, elevation, and depression of the scapula. The subclavius muscle depresses the clavicle. The clavicular head of the pectoralis major muscle flexes the humerus, the sternocostal head extends the humerus, the pectoralis major muscle adducts and medially rotates the humerus, and it also draws the scapula anteriorly and inferiorly. The sternocleidomastoid muscle on its own tilts the head to its side and rotates the head so the face is turned facing the opposite side of the muscle. It is also involved in flexing the neck by raising the sternum and assisting in forced inspiration. The sternohyoid muscle depresses the hyoid (Moore and Dalley, 1999). Figure 1 depicts the general features of the clavicle below.

Evolutionary Significance of the Clavicle

Humans and apes have a much larger range of motion of the upper limb than monkeys and other quadrupedal mammals. This range of motion allows for locomotion via brachiation and other types of motion above the shoulder. During brachiation the arms are extended above the head to suspend and propel the animal through the trees. The similarities in morphology and mobility between humans and the great apes led to the assumption that humans descended from an ancestor that brachiated (Tuttle, 1975). Fleagle suggest that humans may not have descended from a brachiator, but instead from an ancestor with generalized climbing traits (1981). The

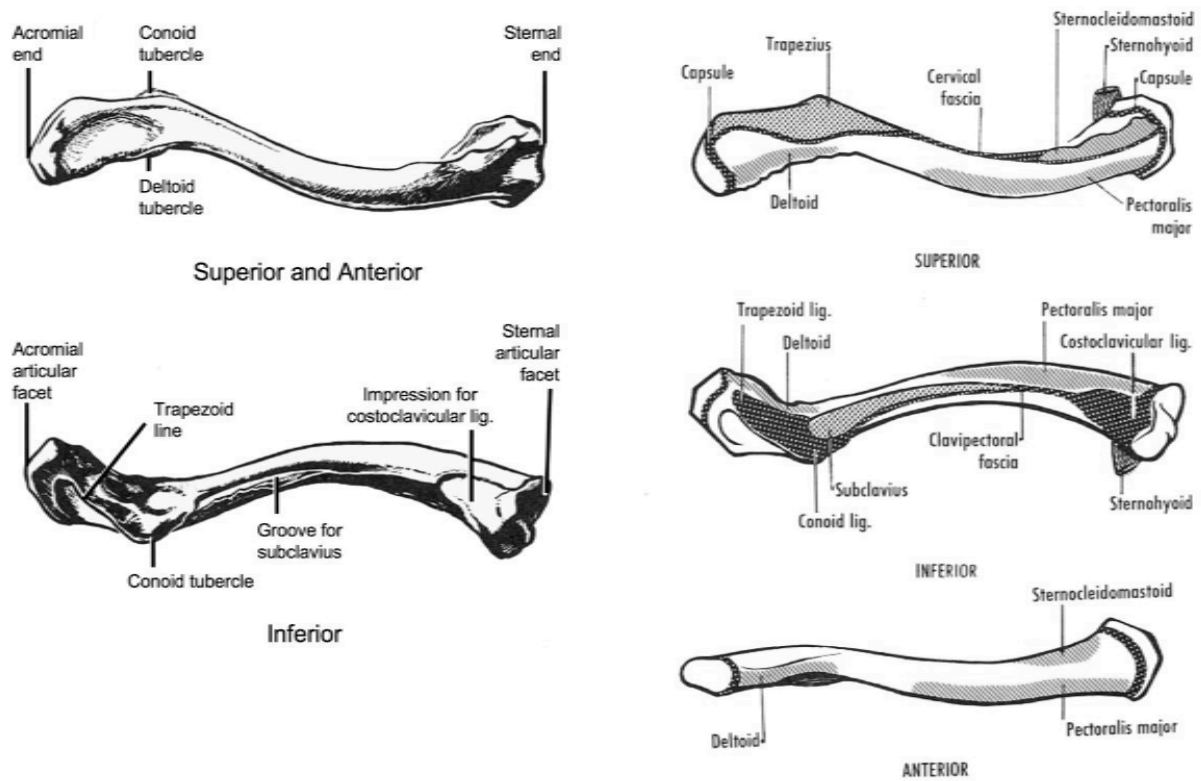


Figure 1. The images on the left show the structural features of the clavicle. The images on the right show muscle and ligament attachments (modified from O’Rahilly and Muller, 1982).

mobility in human upper limbs has been maintained through the selection for tool use and the manipulation of various materials.

The human upper limb is shorter than the upper limbs of any other ape relative to body size (Ashton and Oxnard, 1964). This shorter length is a result of shorter length in the radius and ulna rather than the humerus relative to body size (Ashton and Oxnard, 1964). The primary differences between the non-human ape and the human pectoral girdle and shoulder joint are found in the scapula and clavicle. These differences indicate that the human arm is adapted to use in a lowered position and is less powerful than a non-human ape's arm is in the raised position. The lack of pronounced cranial twist in human clavicles helps support this position (Ashton and Oxnard, 1964).

Clavicle curvature is very different in humans as compared to most other apes. Gibbon clavicles have a single anteriorly convex curve in their clavicles to support brachiation. Orangutan clavicles are mostly straight. Gorillas also have fairly straight clavicles except for the lateral acromial end, which is angled. Humans and chimpanzees share s-shaped curves in the clavicle (Schultz, 1930). These differences reflect different shoulder orientations and functions.

The pectoral girdle and shoulder joint are very poorly represented in the known skeletal remains of *Australopithecus* and early genus *Homo*. The known skeletal remains of *Ardipithecus kadabba* include a clavicle fragment but this fragment is very limited in its applicability because it is a fragment, *Ardipithecus kadabba* is thought to be chimpanzee like in size and bipedal. The postcranial material on *Ardipithecus kadabba* is very limited (Suwa, 1997)

The most discussed pectoral girdle fossils from the Plio-Pleistocene period are AL288-1 which is the scapular fragment belonging to the "Lucy" skeleton (*Australopithecus afarensis*) and Sts 7 the *Australopithecus africanus* scapular fragment from Sterkfontein. There are more

limited descriptions of the scapular fragment from KNM-ER 1500 and some proximal humeri from AL 288-1, Sts 7, KNM-ER 1473, and Omo 119-73-2718 that are robust with elements indicating a well-developed shoulder and brachial muscles. There are no clavicular remains identified from these species (McHenry, Temerin 1979; Johanson et al., 1982; Day 1988).

The material from the “archaic” hominin *Homo antecessor* shows a long, slender clavicle, which is most similar to Neanderthal clavicles (Lorenzo and Arguaga, 1999). Another clavicle attributed to *H. antecessor* was recovered in Sterkfontein’s Jacovec Cavern and is chimpanzee-like in that it has a pronounced conoid tubercle, which indicates a strong anterolateral angulation of the shaft at that point (van der Merwe et al., 2003).

In Neanderthals the pectoral girdle and shoulder joint is better understood due to the greater quantity of fossil material. The Western European Neanderthals had very broad shoulders in comparison to modern humans and other contemporary Neanderthals based on the claviculohumeral index (Trinkaus, 1983). Neanderthal clavicles are very gracile in comparison with the usually robust Neanderthal bones, which could be explained by their broad shoulders. Trinkaus showed that the midshaft circumference of the Neanderthal clavicles is within range of modern humans but their extreme length puts clavicular robusticity index towards the bottom of modern ranges. The other elements of the Neanderthal pectoral girdle reflect the robusticity and muscularity of the Neanderthal skeleton (Trinkaus, 1983).

Sexual Dimorphism

Primates

Many types of sexual dimorphism exist such as size and coloring. This work will focus only on size. In sexually dimorphic species the males are almost always larger (Kappeler and van Schaik, 2004). When males are larger, all other traits that are allometrically related to body size tend to differ accordingly. For example, males tend to have larger brains, but their brains are no larger relative to their body size. These size differences result from larger males having slower metabolic rates and taking longer to mature than females (Janson and van Schaik, 1993).

One argument for why sexual dimorphism developed is sexual selection. Sexual selection is a type of natural selection operating on only one sex, usually males. The selective force is usually male competition for mates or mate choice in females. Sexual selection increases the frequency of traits that favor greater success in mate acquisition. Sexual dimorphism is evident in many species. One of the best examples of sexual dimorphism in primates is the baboon. Males are not only almost twice as large as females, but they also have very large canines (Plavcan, 2001).

In primates, sexual selection plays the most significant role in species that are polygynous with a considerable competition between males for females. In these species, sexual selection produces sexual dimorphism especially in body size and many males have much larger canine teeth than females. These large canines serve to intimidate other males and are used in fights over females (Plavcan, 2001). Sexual dimorphism is typical of many terrestrial species and is especially prominent in baboons and patas monkeys. Male body weight can be twice that of females in these species. On the other hand, in species that live in pairs or where male

competition is reduced sexual dimorphism in body and canine size is greatly reduced or nonexistent, as seen in gibbons (Plavcan, 2001).

Phylogenetic constraints may affect the way sexual selection is expressed in primates. As a part of natural selection, sexual selection can only act on the variation present in a population. Sexual selection can only lead to high levels of sexual dimorphism if secondary sexual characteristics influence individual fitness and have a heritable component (Kappeler, 1997).

Ecological constraints can also affect the expression of sexual dimorphism. The mechanics associated with eating place limits on male canine size because if a male cannot successfully eat, it does not matter how intimidating or attractive he is. Larger males should have proportionately larger canines than females because of the scaling effects between tooth and body size (Rose, 1994). The ecological constraints on body size dimorphism are linked to the energy demands of diet and locomotion. Larger bodies require more food to sustain them but their metabolic requirements are lower per unit body weight than smaller bodies. This results in a predictable difference between the larger male diets than those of the smaller female (Rose, 1994). Females consume smaller quantities of high-energy foods and larger males consume larger quantities of lower-energy foods (Rose, 1994). It has been suggested that sexual dimorphism in body size reflects ecological selection pressures favoring the avoidance of feeding competition between the sexes (Demment, 1983).

The energetics of locomotion and the need for agility also affect sexual dimorphism in predictable ways. Larger arboreal males must maintain a balance between their size and their ability to maneuver efficiently in the canopy. The necessity of traveling long distances between food sources may offset the advantages to large body size. Consequently, sexual dimorphism is more pronounced in terrestrial species not facing such constraints than in arboreal species.

Secondary sexual characteristics such as striking colors or other physical attributes are also more prevalent in terrestrial species (Plavcan, 2001). Dimorphism is the result of both male and female traits. The secondary sex differences seen in most primates include body mass dimorphism, the canine/premolar complex, dental and skeletal dimorphism, pelage (coat of animal), and skin dimorphism (Leigh, 1994).

There are still other factors that affect canine sexual dimorphism. Canines are relatively larger in both males and females of species that have frequent antagonistic interactions. The canine is selected to be larger due to its use as a weapon in fights (Pavlov and Svenden, 2001). When hostile interactions are resolved between groups of individuals the selection pressures for enlarged canines are reduced even though antagonistic competition can still be aggressive. Female primates form groups to combat aggression much more frequently than males, which could, explain the reduced canine size in females (Pavlov and Svenden, 2001).

Human Evolution

The question of sexual dimorphism is complicated in early hominin species. Many scientists believe that some of the variation in size found in the paleoanthropological record can be attributed to sexual dimorphism, while others argue that the variation in size equates to different species (Suwa, 1997). It is important to remember that early hominins may,

vary between populations in a manner consistent with random genetic drift...and that excessive atomization of morphological features and their individual evaluations may then lead to erroneous phylogenetic and simplistic functional interpretations (Suwa, 1997:490).

Sexual dimorphism adds fuel to the ongoing debate between those that believe in very few ancient hominin species (the lumpers) and those that believe in many species (the splitters).

Early hominins were much more sexually dimorphic than modern humans (Conroy, 2003). This possible sexual dimorphism raises questions about the social structure of these early hominins. As discussed previously, primates living in polygynous social groups tend to have a large degree of sexual dimorphism. This suggests that at some point in human history there was a strong competition between males for access to females (McHenry, 1992a;b).

Body weight estimates based on femoral head diameter in *Australopithecus robustus* point to males being around 40kg and females around 30kg. This amount of sexual dimorphism in body weight is larger than in modern humans, chimpanzees, or bonobos, but less than in gorillas and orangutans (Susman and de Ruiter, 2001). *Australopithecus afarensis* is thought to have been highly sexually dimorphic. Comparisons of material from Maka, Hadar, and Laetoli show that the male Maka humerus is much larger and more robust than the female humerus from Hadar, “Lucy” (White and Suwa, 2000). Many attribute all the Hadar australopiths to a single species, but the large sexual dimorphism makes some people skeptical (Falk et al., 1995). Size may not be static over time in *A. afarensis* thus secular trends especially in mandibular size combined with a large degree of sexual dimorphism may inflate size differences (Lockwood and Kimbel, 2000). Reno and Meindl. (2003) argue based on advances in statistical modeling and using body mass estimates from Al 288-1 (Lucy) and the Al 333 sample, that *A. afarensis* was only slightly sexually dimorphic, similar to *Homo* and chimpanzees.

Variations in both cranial and dental size of *Australopithecus boisei* suggest that *A. boisei* was highly sexually dimorphic with females averaging about 34 kg and males about 49 kg (Silverman and Richmond, 2001). Postcranial evidence from *Australopithecus africanus* suggests that *A. africanus* was gracile. The sexual dimorphism in this species has been suggested to be similar to *A. afarensis* based on a proximal femur from Makapansgat (Reed and Kitchling, 1993).

Reduction of sexual dimorphism, especially during the *Homo erectus* phase, is one of the defining characteristics that differentiate the genus *Homo*. The genus *Homo* includes modern humans, Neandertals, and *H. erectus*. The reduction of sexual dimorphism and the increase in mean body size are the two evident trends in the genus *Homo* over the last 2 million years (Conroy, 2003).

Sexual dimorphism in archaic *Homo sapiens* is pronounced in the population found in the cave deposits at Arago, France (320-470 kya) (Day, 1988). The mandibles show considerable variability in size and robustness, which is attributed to sexual dimorphism. In general, the levels of dental sexual dimorphism, especially the canines, exceed that of modern humans (de Castro et al., 2001).

Modern Humans

Adult male and female skeletons differ in both general shape and size within any modern population. Males can average up to 20% larger in some skeletal aspects than females and show almost no difference in others (White and Folkens, 1991). Every population possesses some gracile males and some robust females; consequently, the sexes often overlap significantly in terms of size (White and Folkens, 1991).

The *os coxae* present the most reliable sex indicators in the human skeleton because they are highly sexually dimorphic. Hormone driven growth changes during adolescence create distinctive differences in the male and female *os coxae*. Male growth patterns remain mostly the same while female *os coxae* expand relative to height. Males tend to have larger, more robust skulls but determining sex based on cranial features is less reliable than the *os coxae* (Spradley

and Jantz, 2011). Sex determination from post-cranial elements other than the *os coxae* is mostly based on size. Besides the skull, as mentioned above, the maximum diameter of the head of the femur and humerus are often used to estimate sex (White and Folkens, 1991).

Previous studies conducted to estimate sex from postcranial elements of the skeleton include the calcaneus (Introna et al., 1998; Murphy, 2002a; Bidmos, 2004), the clavicle (Frutos, 2003), the femur (Steyn and İşcan, 1997; Mall et al., 2000; Safont and Malgosa, 2000; Purkait and Chandra, 2002; Wrobel et al., 2002; Albanese, 2003; Purkait and Chandra, 2004; Sakaue, 2004), the humerus (İşcan et al., 1998; Safont et al., 2000; Wrobel et al., 2002; Sakaue, 2004), the metatarsals (Robling and Ubelaker, 1997), the patella (Introna et al., 1998; Bidmos, 2005), the radius (Safont et al., 2000; Wrobel et al., 2002; Sakaue, 2004), the ribs (Wiredu, 1999), the scapula (Dwight, 1894; Bainbridge and Tarazaga, 1956; vanDongen, 1963; Raju and Singh, 1978; Prescher and Klumpen, 1995; Murphy, 2002; Dabbs and Moore-Jansen, 2010; Frutos, 2003), the talus (Murphy, 2002c; Bidmos and Dayal, 2003; Özer et al., 2006), the tibia (Safont et al., 2000; Wrobel et al., 2002; Sakaue, 2004; İşcan and Miller-Shaivitz, 1984; İşcan et al., 1994; González-Reimers et al., 2000; Purkait, 2001), and the ulna (Safont et al., 2000; Purkait, 2001; Wrobel et al., 2002; Sakaue, 2004). Table 1 summarizes the studies mentioned above.

According to Humphrey, different functional systems grow at varying rates and attain adult size at different times during overall development (2008). The growth of each part of the skeleton is primarily a response to the requirements of the associated non-skeletal tissues, which allows skeletal material to be assessed in relation to the other functional components of the body. There are differences in male and female skeletal growth, which provide insight into the development of secondary sexual dimorphism in modern humans and can provide a basis for future interpretation of the evolutionary and functional significance of the sexual dimorphism.

TABLE 1- Previous Metric Sexual Dimorphism Studies of the post-cranium (excludes pelvis and *os coxae*)

Bone	Author (s)	Number of Measurements	Number of Individuals	Population	Accuracy/ Concordance
Calcaneus	Bidmos and Asala 2004	9	116	South African Blacks	79-86%
Calcaneus	Murphy 2002a	5	48	Prehistoric New Zealand Polynesian	88.4-93.5%
Clavicle and Scapula	Frutos 2002	4	97 clavicles, 103 scapula	Contemporary Guatemalan rural indigenous	85.6-94.8%
Humerus	İsçan et al. 1998	6	87 90 104	Chinese Japanese Thai	86.8-97.1%
Humerus, scapula, and clavicle	van Dongen 1963	?	?	Australian Aborigine	80%
Humerus, radius, ulna, femur, and tibia	Wrobel et al. 2002	Robusticity Measurements	82	Protohistoric Maya site of Tipu (Belize)	77.5-100%
Humerus, radius, ulna, femur, and tibia	Sakaue 2004	47	64	Modern Japanese	91-95%
Humerus, radius, ulna, femur, and tibia	Safont et al. 2000	At least 5	?	Late Roman site of Mas Rimbau/Mas Mallol (Spain)	80%-92.8%
Femur	Mall et al. 2000	6	170	Contemporary German	91.7%
Femur	Purkair and Chandra 2002	5	280	South Asian (Indian)	92% males, 96.3% females
Femur	Purkair and Chandra 2004	11	124	Central Indian	92.5% males, 95.5% females
Femur and Pelvis	Albanese 2003	?	324 232	Terry Collection Coimbra Collection	90.0-98.5%

TABLE 1- continued

Metatarsals	Robling and Ubelaker 1997	?	200	Terry Collection	83-100%
Patella	Introna et al. 1998	7	80	Italian	83.8%
Patella	Bidmos et al. 2005	6	120	South African Whites	83%
Ribs (sternal end)	Wiredu et al. 1999	2	346	Ghana	74-80%
Scapula (glenoid cavity)	Prescher and Klümpen 1995	1	214	German	60% male, 36% female
Scapula	Özer et al. 2006	4	93	Medieval Skeletons from East Anatolia	82.9-95.0%
Scapula	Dabbs and Moore Jansen 2010	6	804	Hamann-Todd Collection	95.7%
Talus	Murphey 2002c	5 (coupled with measurements of tibia)	51	Prehistoric Polynesian	85.1-93.3%
Talus	Bidmos and Dayal 2003	9	120	South African Whites	80-88%
Tibia	İsçan and Miller-Shaivitz 1984	4	159	Terry Collection (whites and blacks)	80-84%
Tibia	İsçan et al. 1994	?	84	Contemporary Japanese	80-89%
Tibia	González-Reimers et al. 2000	7	59	Canary Islands	65-94.7%
Ulna	Purkait 2001	3	160	Indian	90.6%

The foremost basis of sexual dimorphism in human stature and body weight is a result of the difference in both the rate and duration of growth in males and females. This is largely the result of the divergence of male and female growth patterns during adolescence. Sexual dimorphism does not develop in the same way throughout the skeleton (Humphrey, 2008).

Humphrey uses the curve fitting method, which allows objective comparisons of the growth of different parts of the skeleton. Her analysis demonstrates a range of growth patterns from the earliest growing parts of the cranium to the slowest growing long bone diameters. These growth patterns correlate with the growth of soft tissues. The level of sexual dimorphism in different parts of the modern human skeleton vary between areas where there is virtually no sexual dimorphism to areas where males average 20% larger than females. Early growing parts of the skeleton are generally less sexually dimorphic than later growing elements, likely due to the fact that both sexes would be expected to have similar growth trajectories until adolescence since their functional requirements are more similar prior to sexual maturation. Sexual dimorphism could be the result of the late divergence of male and female growth, so areas where growth is completed prior to adolescence would not show significant amounts of sexual dimorphism. If sexual dimorphism is instead caused by the difference in male and female growth rates, the development of sexual dimorphism may be limited to the time available for sexual differences to accumulate. Humphrey's study suggests that both reasons are present (2008).

The clavicle is the last skeletal element to complete growth and epiphyseal fusion, which based on Humphrey's work, would suggest that it may demonstrate extreme sexual dimorphism and be an excellent estimator of sex. The development of sexual dimorphism in the long bone lengths differs from the more general pattern observed in the post-cranial skeleton because males and females follow similar growth patterns prior to adolescence and the proportion of sexual

dimorphism resulting from differences in the duration of male and female growth is higher than in the other post-cranial dimensions. The development of sexual dimorphism in the long bone lengths follows the same pattern as body weight and stature. More than half of adult sexual dimorphism results from the separation of growth patterns that occurs at adolescence (Humphrey, 2008).

Bilateral Asymmetry

Measuring the left half of the body is the osteological standard as cited by editors Buikstra and Ubelaker's Standards for Data Collections from Human Skeletal Remains. After researching other discriminant function analysis for sex estimation on other bones, the majority of studies (Introna Jr. et al.(1998)- right patella, González-Reimers et al.(2000)- right tibia, Dabbs and Moore-Jansen (2010)- left scapula) have been found to focus on just the left or right bone. In many studies (Steyn and İşcan (1997) - femur and tibia, Mall et al.(2000)- femora, İşcan et al.(1997)-humerus, Murphy-talus(2002c), Murphy (2002a)-calcaneus) it is not clear whether both sides were measured or just one side. In the above mentioned articles it is not mentioned whether an average of both sides was taken or if just one side was measured. Some articles have debated a difference, especially in maximum length, on the clavicle (Mays et al., 1999; Danforth and Thompson, 2008). When both sides are measured, researchers are looking for bilateral asymmetry. When found bilateral asymmetry has not been found to affect studies of sexual dimorphism in the clavicle in a statistically significant way (Danforth and Thompson, 2008).

Even if bilateral asymmetry is present in the clavicles of the Hamann-Todd collection, the reason for the difference is unknown. The dominant hand in life was not recorded for these

individuals, and thus cannot be accounted for. Differences between the right and left clavicles could not be directly attributed to handedness in this population. Assuming Todd did not restrict the individuals based on their dominant hand, which there is no evidence he did, handedness was already taken into account by not restricting the calibration sample based on right or left handedness. Even if there is a correlation between clavicle size and dominant hand, the cause may be unrelated. Mays suggests asymmetry could be caused by the development of the brain and blood flow (Mays, 1999). No articles explicitly demonstrate a direct correlation between clavicle size and handedness. In both a forensic and a bioarchaeological context handedness will be unknown, similar to the calibration sample. This is an area where further research can be conducted, but it is outside the scope of this project.

Auerbach and Ruff studied bilateral asymmetry in the circumferences of limb bones of Holocene individuals. The maximum amount of bilateral asymmetry they found for the pooled Holocen sample was 3%. The smallest amount of sexual dimorphism found in a measurement in this study was 12% (this can be found in the summary statistics in Table 3). This measurement was maximum length. Since the sexual dimorphism of the clavicle is at minimum four times greater than the bilateral asymmetry, the degree of sexual dimorphism will outstrip bilateral asymmetry. Thus, bilateral asymmetry should not be a confounding factor, in other words there is little chance that a left handed female will be assessed as male due to their left asymmetry because males are minimally 12% (this can be found in the summary statistics in Table 5, p 39) larger and being left handed would only affect the measurement by 3%. Aurbach and Ruff also found that post-industrial individuals show less bilateral asymmetry than pre-industrial ones. This study was conducted on a post-industrial population so the bilateral asymmetry in this population is expected to be less than 3% (Auerbach and Ruff, 2006).

Previous Clavicle Studies

In his 1957 article Thieme uses clavicle length as one of eight measurements to estimate sex in African-American populations. He measured 98 males and 100 females. He found that clavicular length alone is not sufficient for accurate sex estimation, an exact accuracy rate was not given in the article. While this study could be helpful for African-American populations, it is reliant on the presence and completeness of multiple elements (Thieme, 1957).

In 1966 Jit and Singh used clavicle length, weight, and mid-clavicular circumference to predict sex in Indian populations with limited success. They found that mid-clavicular circumference was the best indicator of sex (Jit and Singh, 1966). The more limited success of Jit and Singh (1966), compared to this study may be attributed to the limited sexual dimorphism in Indian populations (Indriati, 2009). The circumference at the midshaft can discriminate 72% of cases as male. The use of the circumference at midshaft in female cases was less successful, only being 60-68% accurate (Jit and Singh, 1966).

Frutos (2003) uses the clavicle and scapula together to estimate sex in a contemporary Guatemalan rural indigenous population. The maximum length and circumference at midshaft of the clavicle and height and width of the glenoid fossa of the scapula were measured on 97 clavicles and 103 scapulae. This method produced classification success rates from 85.6-94.8% (Frutos, 2003). This method is a good basis when both the clavicle and the scapula are present, however this is not always the case. The method presented in this paper can be used when only the clavicle is present.

Unpublished prior to the beginning of this study is a dissertation conducted by Natalie Shirley on sex estimation and age estimation on the clavicle. In Shirley's study all analysis was performed on nine computer automated measurements from 1,414 clavicle models. Her cross-validated accuracy rates, "hovered around 92%" (Shirley, 2009). Shirley's study is not as applicable to field work because scanning equipment is difficult to bring into the field as well as expensive so access is not always an option. Scaling issues are possible with 3D scanning that could cause problems for this method. Shirley did not discuss scaling issues in her dissertation. Shirley scanned the William F. McCormick collection for her study. The McCormick collection is housed at the University of Tennessee in the Anthropology collection and consists of approximately 2,000 clavicle pairs from autopsies from 1986-1998 (Shirley, 2009).

CHAPTER III

MATERIALS AND METHODS

Data was collected, in the summer of 2011, on 295 individuals from the Hamann-Todd Collection. Thirty of these individuals, of similar demographic character to the calibration sample, were used as a hold out sample. The calibration consists of 265 individuals (129 females; 136 males). Individuals ranged in age from 18 to 93 years. All epiphyses were fully fused in the sample. There was a fairly equal proportion of black and white ancestry in both males and females. A Mitutoyo digital sliding caliper was used to take all measurements except the circumferences and maximum length. A fabric tape measure was used to take the circumferences. An osteometric board was used to measure maximum length.

The Hamann-Todd Osteological collection at the Cleveland Museum of Natural History consists of 3715 individuals collected during the early 20th Century and is largely representative of the indigent and working class populations of Cleveland during that time (Meindl et al., 1990). The inclusion criterion for this study requires accurate records of biological sex exist for the individual and that the complete, fully fused left clavicle was present for examination. The collection is predominately Caucasian individuals and individuals of African descent. The sample is biased towards sole representation of these groups.

Eighteen measurements of the clavicle were taken on the historical Hamann-Todd collection at the Cleveland Museum of Natural History. This collection has recorded biological sex for the individuals being measured. Fifteen measurements have been developed in addition to the three standard measurements of the clavicle, which are outlined in Table 2, p 23. Muscle attachments were avoided in the measurements due to the potential for morphological differences based on activity patterns during life.

Before the data was analyzed (using SPSS 17.0), histograms were created to draw attention to any potential issues. While outliers are present, they were not excluded from the calibration sample because they represent a portion of the range of modern human variation. Additionally, while sensitive to data abnormality, discriminate function analysis is robust enough to accommodate outliers on the tails of human variation.

These measurements were evaluated using univariate and multivariate statistics. Descriptive statistics were calculated to examine the range of values for each variable. Independent sample t-tests were computed to compare male and female means. These tests demonstrated sexual dimorphism. Stepwise discriminate functions (0.05 to enter; 0.10 to exit) were conducted to develop discriminant functions for assigning unknown individuals into male or female categories. The developed discriminant functions were tested on a hold out sample (n=30) similar in demographic makeup to the calibration sample from the Hamann-Todd collection to test the accuracy of the methods developed.

An intraobserver error test was run on the skeletal material housed at Southern Illinois University Carbondale. Twenty individuals were measured on two separate occasions, two weeks apart. This was conducted to determine if the differences in interpretation by the individual making

TABLE 2- Measurement Descriptions

Name of Measurement	Abbreviation	Description
Maximum Length*	MXL	“Maximum distance between the most extreme ends of the clavicle” (Buikstra and Ubelaker, 1994:79) osteometric board
Sagittal (Anterior-Posterior) Diameter at Midshaft*	SDM	“Distance from the anterior to the posterior surface at midshaft...Comment: determine the midpoint of the diaphysis on the osteometric board and mark it with a pencil” (Buikstra and Ubelaker, 1994:79) sliding caliper
Vertical (Superior-Inferior) Diameter at Midshaft*	VDM	“Distance from the superior to the inferior surface at midshaft” (Buikstra and Ubelaker, 1994:79) sliding caliper
Height of Acromial Curve	ACH	Place the anterior most part of the clavicle on the table and measure the height of the curve at its highest point (the apex)-sliding caliper (inside arms)
Length of Acromial End	AEL	Length from apex of the acromial curve to the most lateral point of the acromial end. The apex of the acromial curve is determined by finding the height of the acromial curve and using that point (apex) to measure to the most lateral point of the acromial end- sliding caliper
Height of Sternal Curve	SCH	Place the posterior most part of the clavicle on the table and measure the height of the curve at its highest point (the apex)-sliding caliper (inside arms)
Length of Sternal End	SEL	Length from apex of the sternal curve to the most medial point of the sternal end. The apex of the sternal curve is determined by finding the height of the sternal curve and using that point (apex) to measure to the most medial point of the acromial end-sliding caliper
Maximum Acromial End Width	AEW	Greatest posterior to anterior measurement of the acromial end-sliding caliper
Maximum Sternal End Width	SEW	Greatest posterior to anterior measurement of the sternal end-sliding caliper
Conoid tuberosity to acromial end	CTA	Conoid tuberosity to the most lateral end of the acromial end-sliding caliper
Height of Acromial End	HOA	Maximum superior to inferior measurement of the acromial end-sliding caliper
Height of Sternal End	SEH	Maximum superior to inferior measurement of the sternal end-sliding caliper

TABLE 2- Continued

Circumference of Midshaft	COM	Circumference at midshaft. Midshaft is determined by dividing the maximum length in half and measuring that distance from either end and taking the midshaft measurement at that mark-cloth tape
Circumference of Sternal End	COS	Circumference of the most medial end of the sternal end-cloth tape
Circumference at Conoid Tubercle	CCP	Circumference at the conoid tubercle including the conoid tubercle-cloth tape
Circumference of Acromial End	COA	The maximum circumference of the acromial end including the most posterior and anterior points of the acromial end-cloth tape
Height at Conoid Tubercle	LCP	Height (superior to inferior) at the conoid tubercle. The largest superior to inferior measurement including the conoid tubercle-sliding caliper
Length from Conoid Tubercle to Sternal End	CPS	Length from the conoid tubercle to the most medial sternal end-sliding caliper

*Standard measurements from Standards for Data Collection from Human Skeletal Remains edited by Jane E. Buikstra and Douglas H. Ubelaker

observations of the same measurement at different times were statistically significant. Paired t-tests were run using SPSS 17.0.

Statistics were run on age to ensure age did not present a statistically significant factor in the data. An independent sample t-test was conducted to identify differences in the mean age between males and females. Additionally, a chi-square analysis was also conducted to ensure the individuals were evenly distributed in four age groups (<25 years, 26-35 years, 36-50 years, and 50+ years).

CHAPTER IV

RESULTS

Below (Figure 2-19) are the histograms showing the normality of the data. Few outliers exist.

No measurements show statistically significant levels of intraobserver error after using Bonferroni correction. Before applying Bonferroni correction, none of the measurements that became a part of the models were statistically significant. Bonferroni correction was calculated with the equation $\beta = \alpha$ (or 0.05)/ n (or 18). This demonstrates the differences observed reported are true differences between males and females, and not just the result of measurement error.

Mean age was compared and determined not a statistically significant factor for the data collected. The overall mean for females was 46.60 years and for males was 47.74 years ($p=0.583$). Additionally, a chi-square test was conducted to examine the distribution of individuals in four age groups (≤ 25 , 26-35, 36-50, 50+ years). The results of this test show there is no statistically significant difference in the age distribution between males and females of the calibration sample ($p=0.8065$; $df=3$, $\chi^2=0.06$). Age was not a significant factor that could affect the data. Age statistics are listed in Table 4.

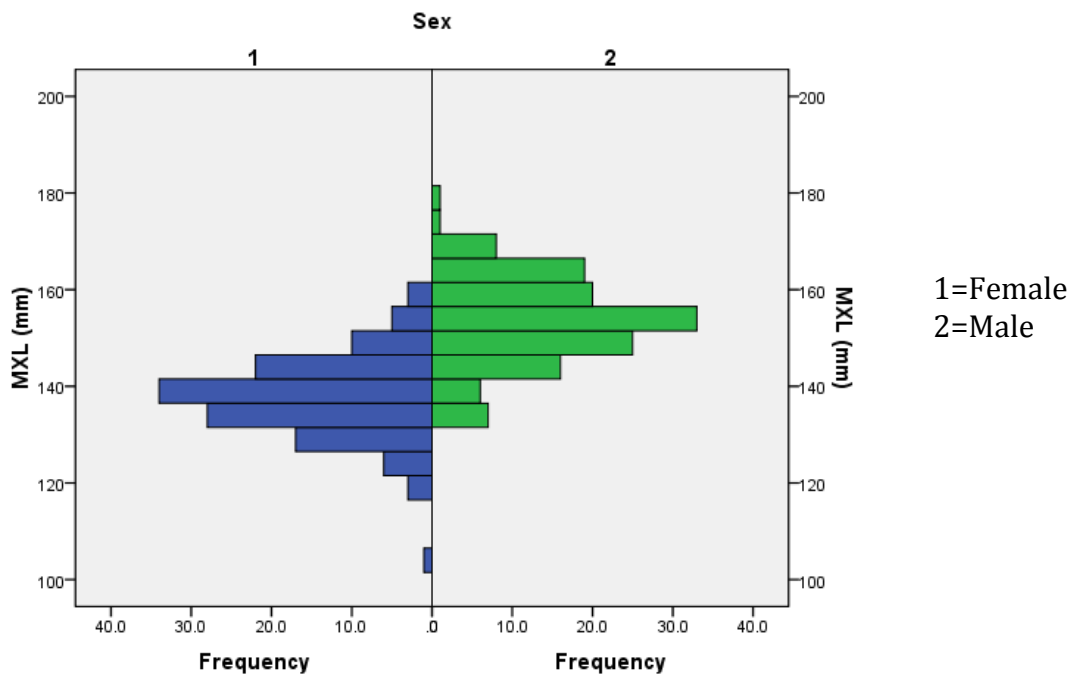


FIGURE 2. Histogram of maximum clavicle length showing the range of values present in the calibration sample.

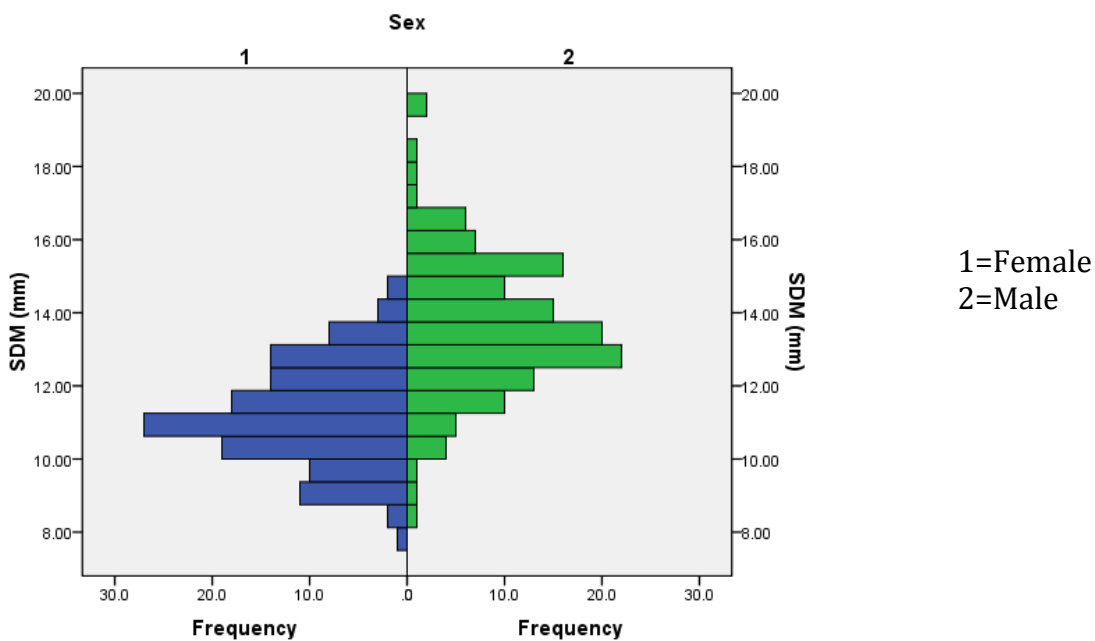


FIGURE 3. Histogram of sagittal diameter at midshaft showing the range of values present in the calibration sample.

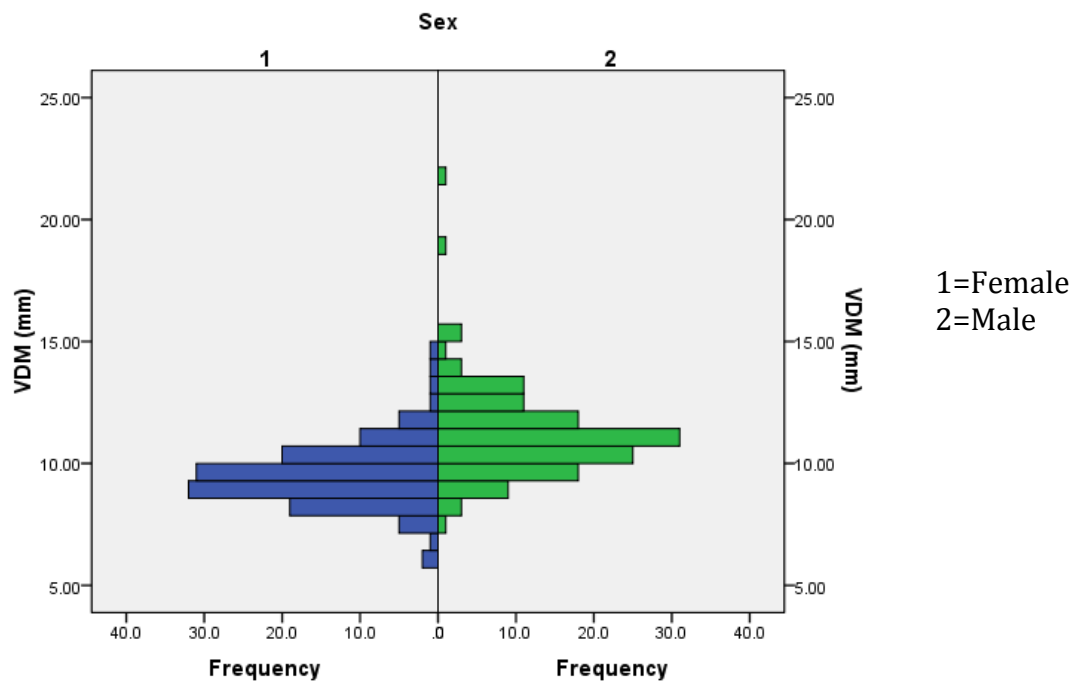


FIGURE 4. Histogram of vertical diameter at midshaft showing the range of values present in the calibration sample.

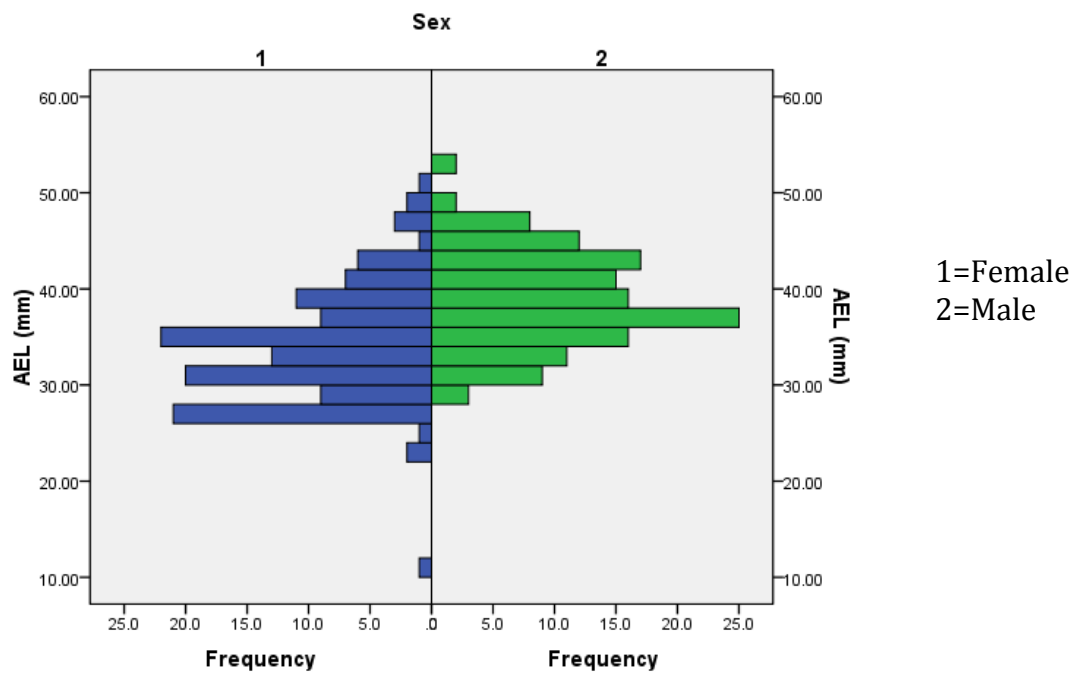


FIGURE 5. Histogram of length of acromial end showing the range of values present in the calibration sample.

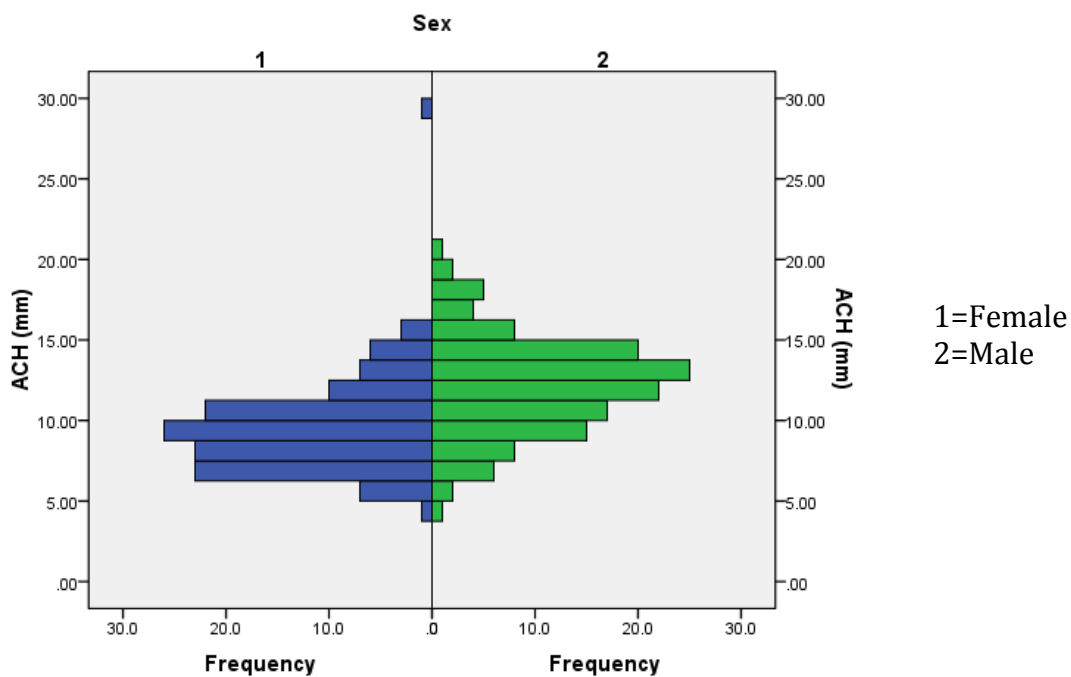


FIGURE 6. Histogram of height of acromial curve showing the range of values present in the calibration sample.

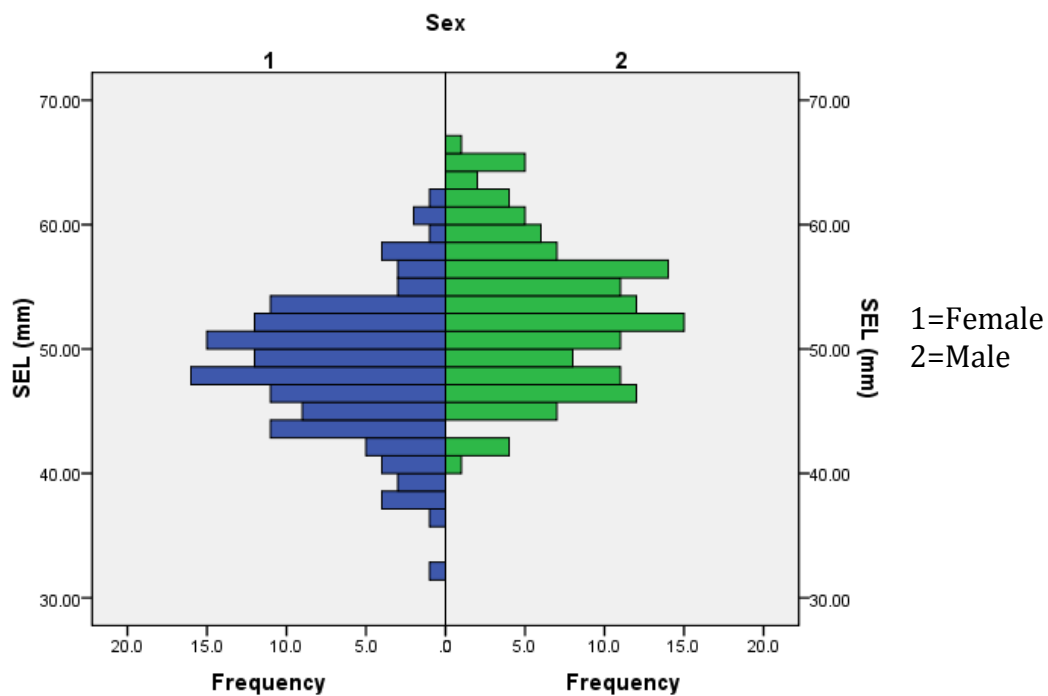


FIGURE 7. Histogram of length of sternal end showing the range of values present in the calibration sample.

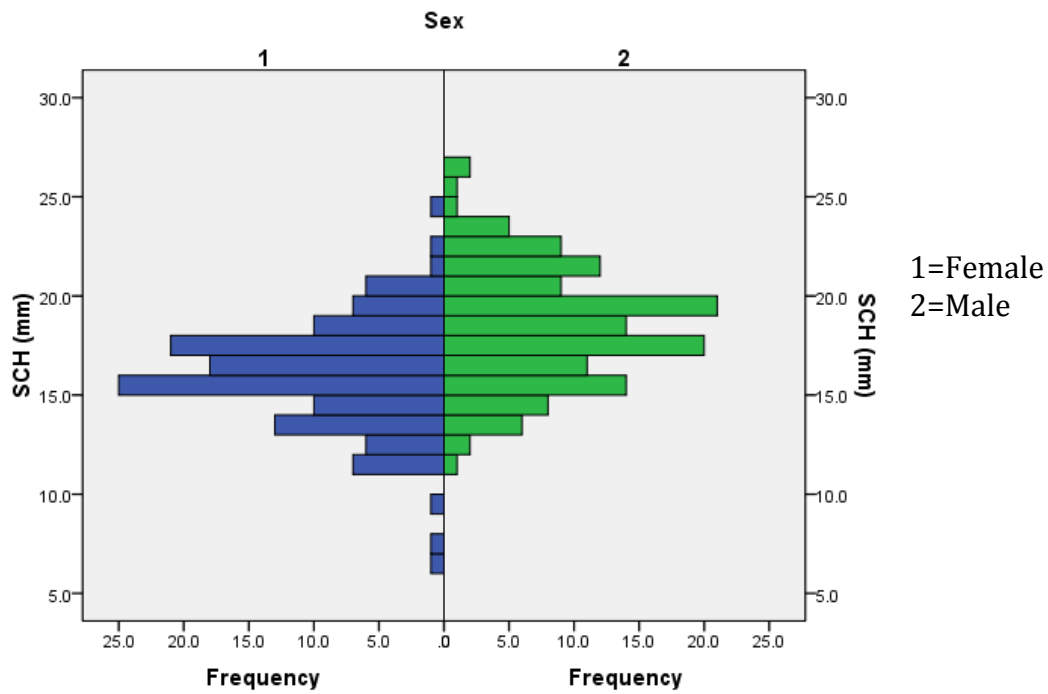


FIGURE 8. Histogram of height of sternal curve showing the range of values present in the calibration sample.

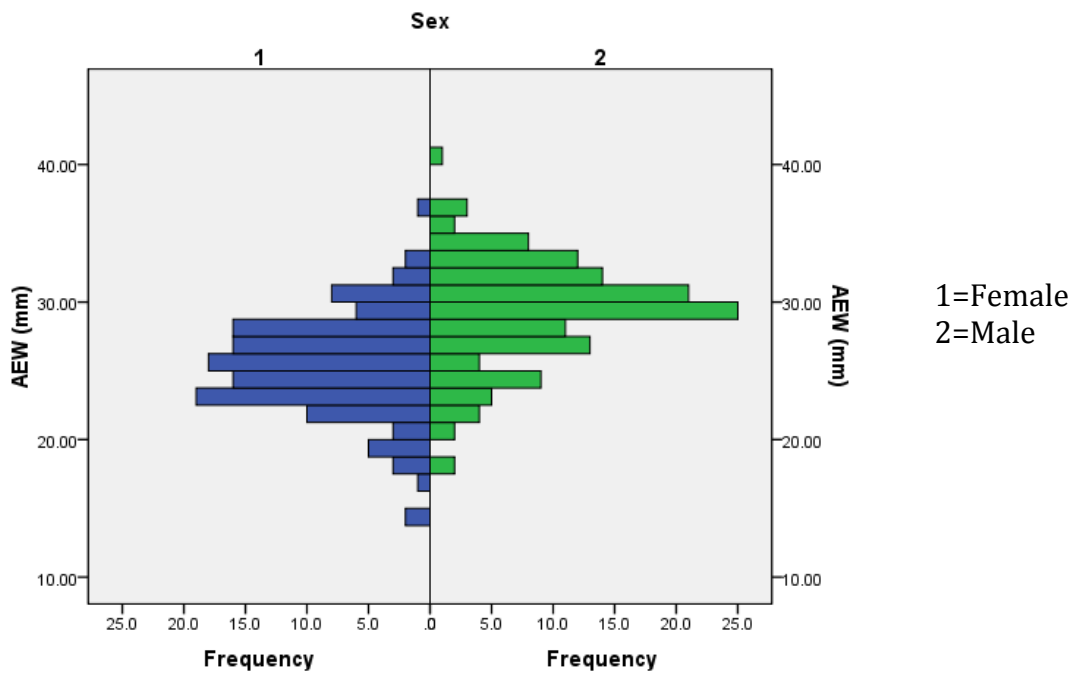


FIGURE 9. Histogram of maximum acromial end width showing the range of values present in the calibration sample.

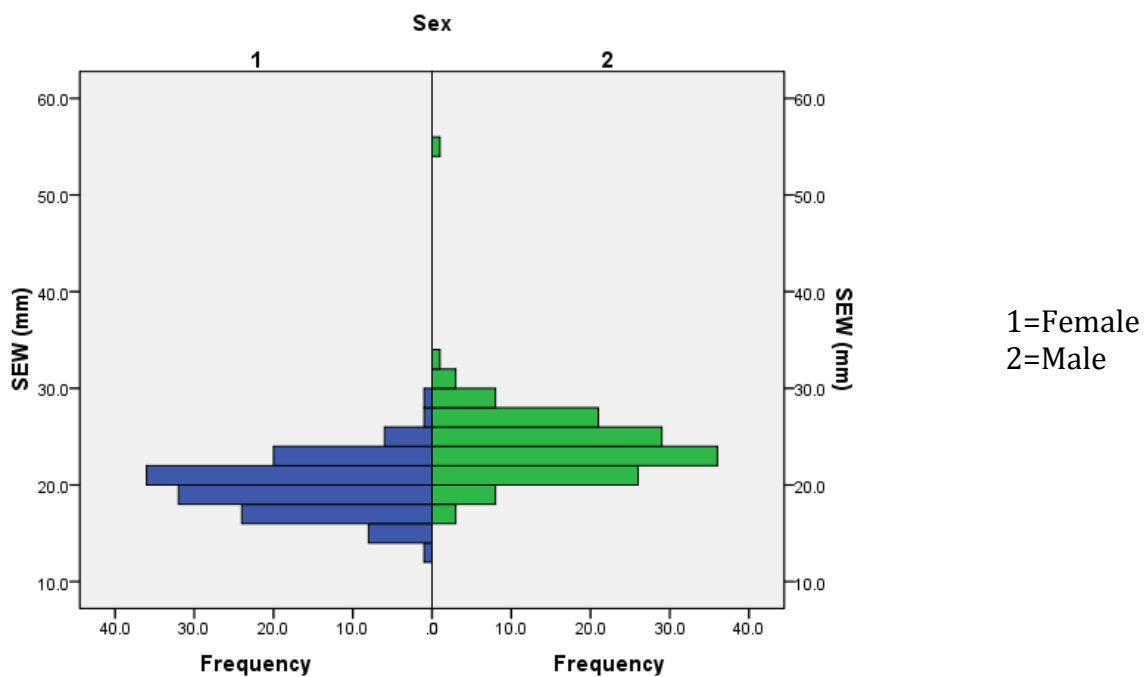


FIGURE 10. Histogram of maximum sternal end width showing the range of values present in the calibration sample.

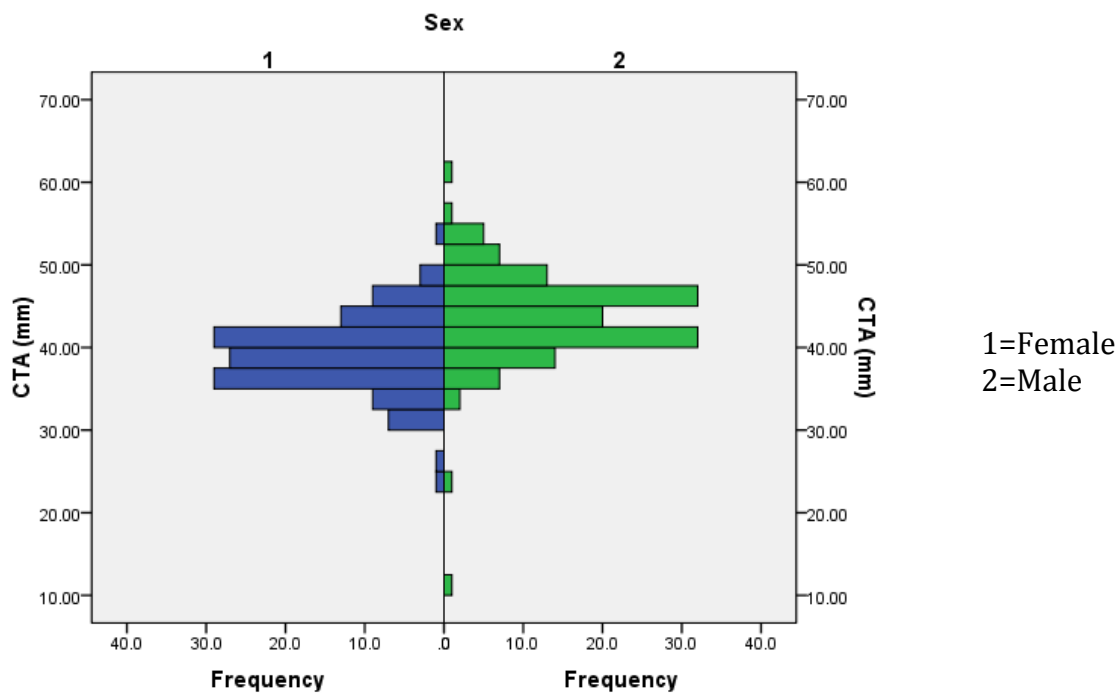


FIGURE 11. Histogram of conoid tuberosity to acromial end showing the range of values present in the calibration sample.

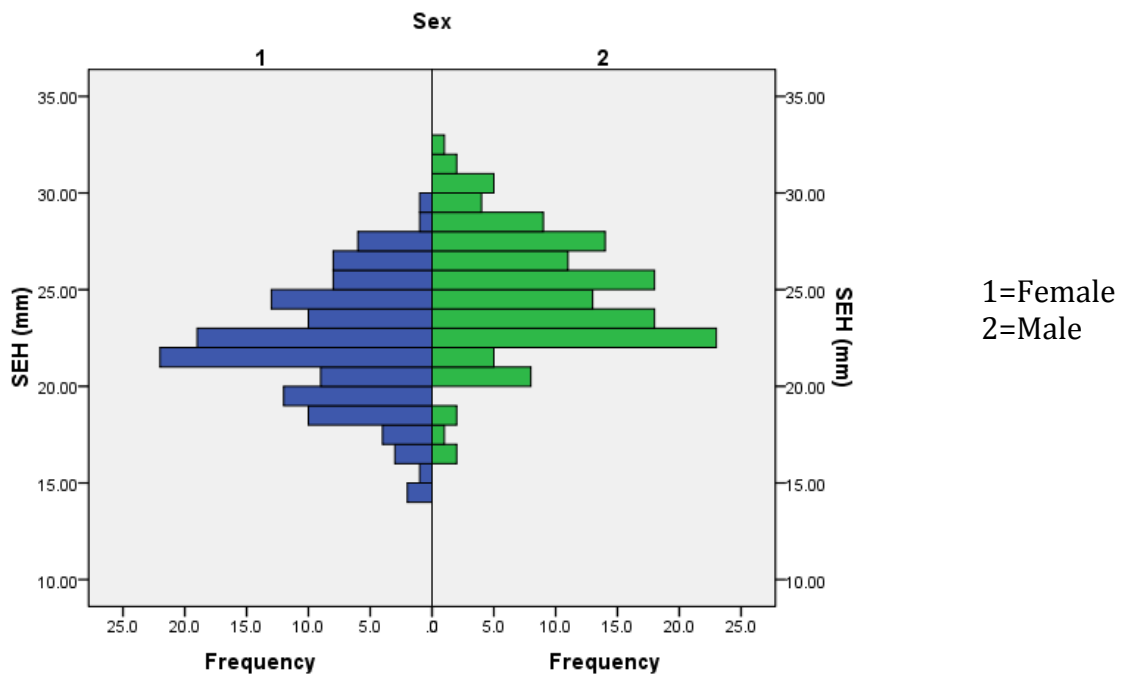


FIGURE 12. Histogram of height of sternal end showing the range of values present in the calibration sample.

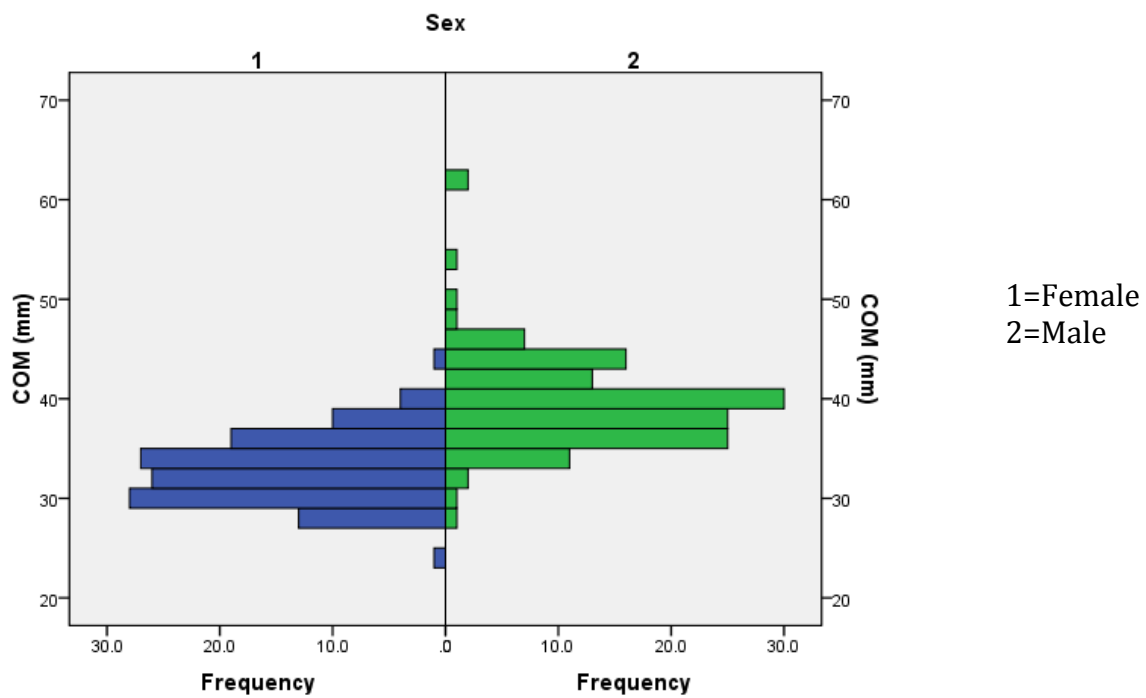


FIGURE 13. Histogram of circumference of midshaft showing the range of values present in the calibration sample.

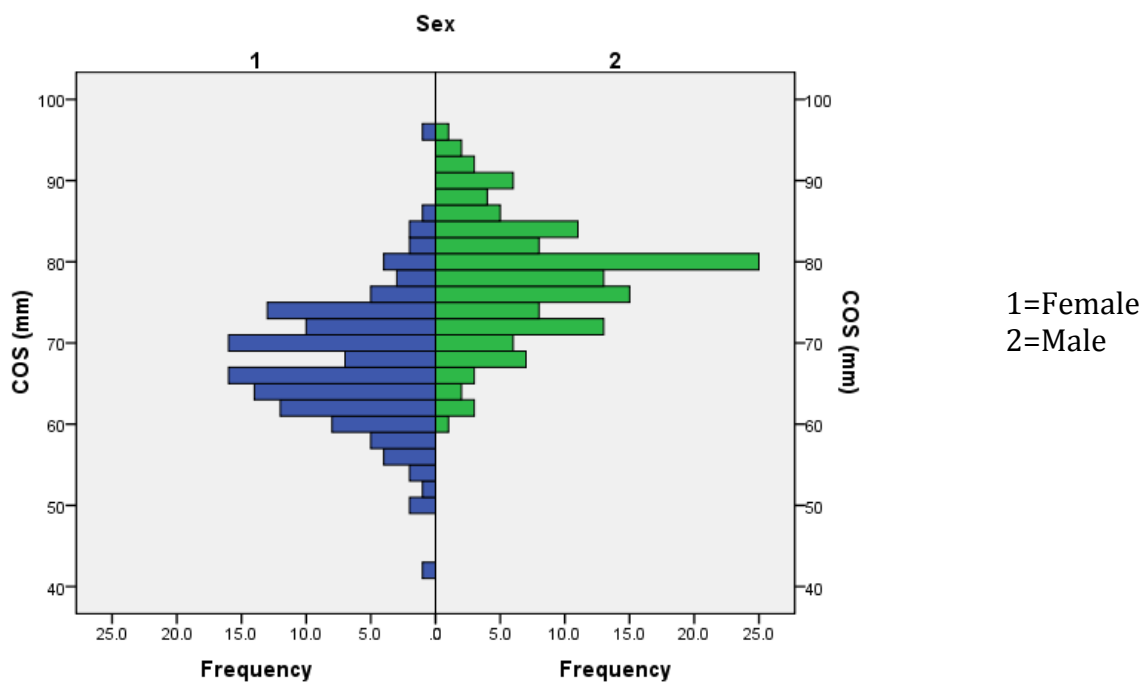


FIGURE 14. Histogram of circumference of sternal end showing the range of values present in the calibration sample.

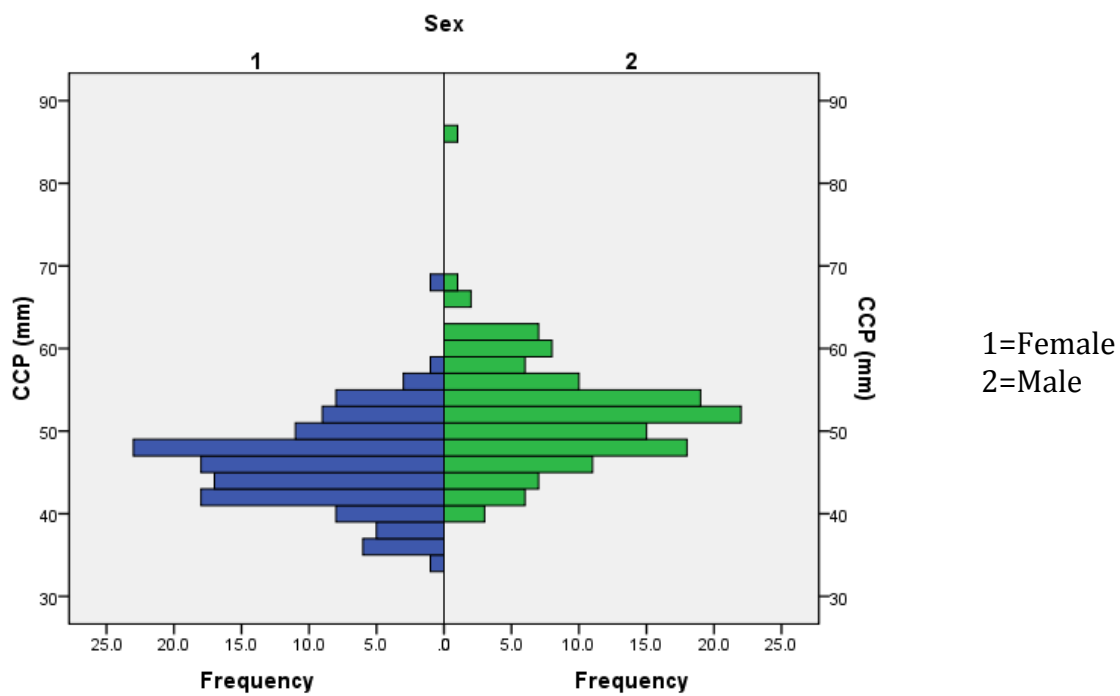


FIGURE 15. Histogram of circumference at conoid tubercle showing the range of values present in the calibration sample.

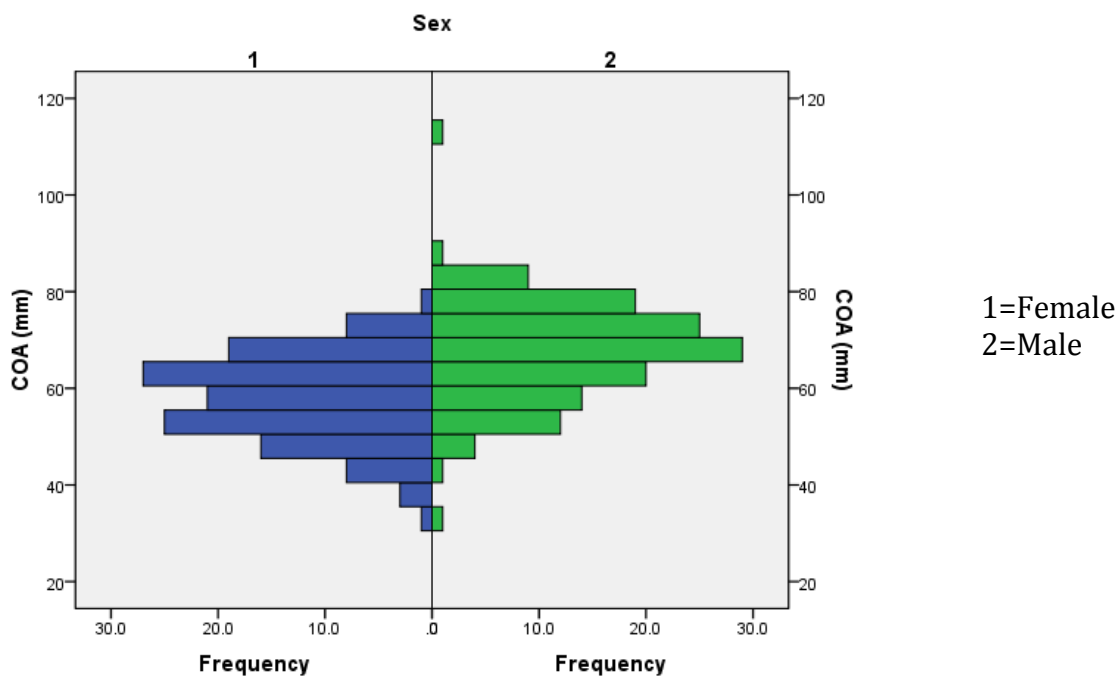


FIGURE 16. Histogram of circumference of acromial end showing the range of values present in the calibration sample.

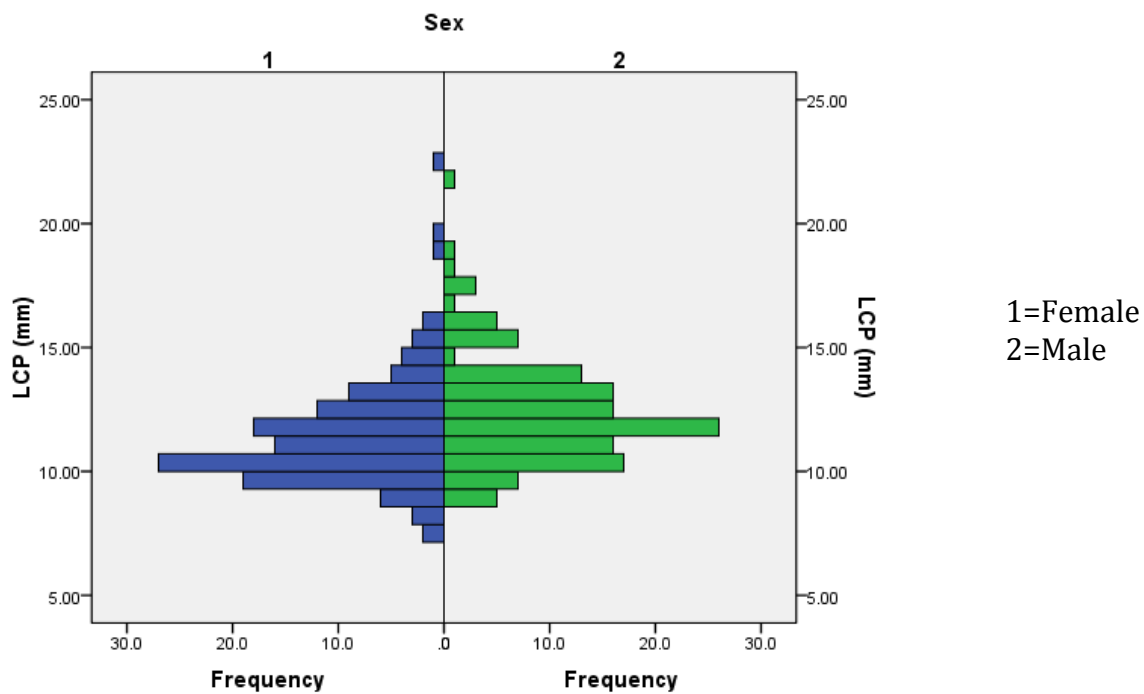


FIGURE 17. Histogram of height at conoid tubercle showing the range of values present in the calibration sample.

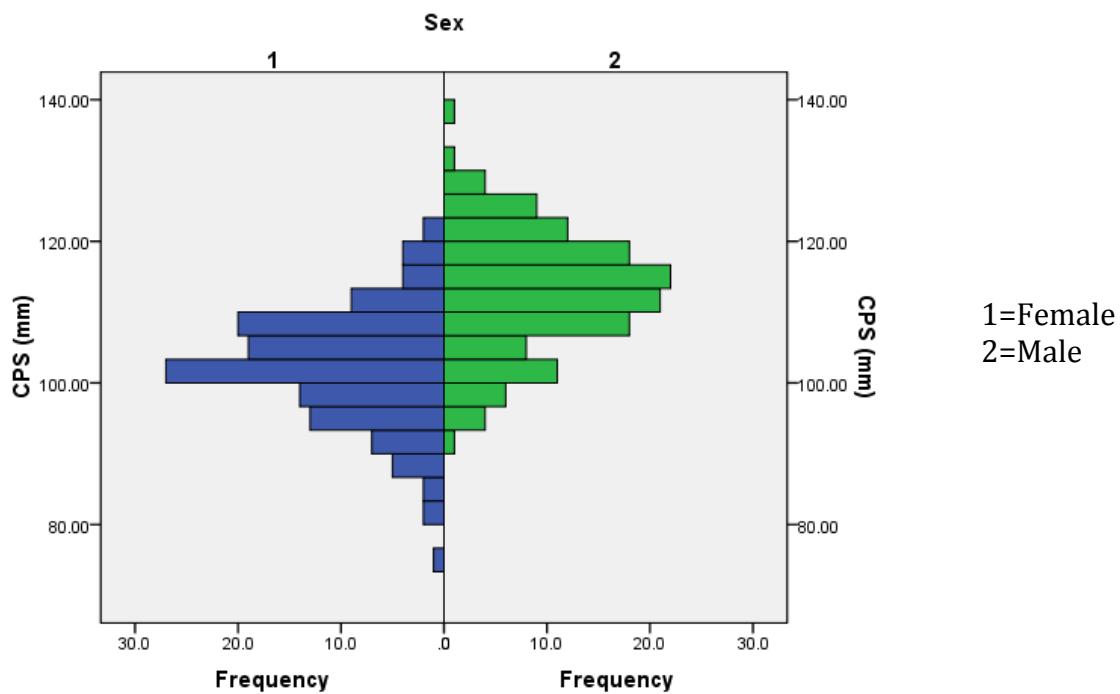


FIGURE 18. Histogram of length from conoid tubercle to sternal end showing the range of values present in the calibration sample.

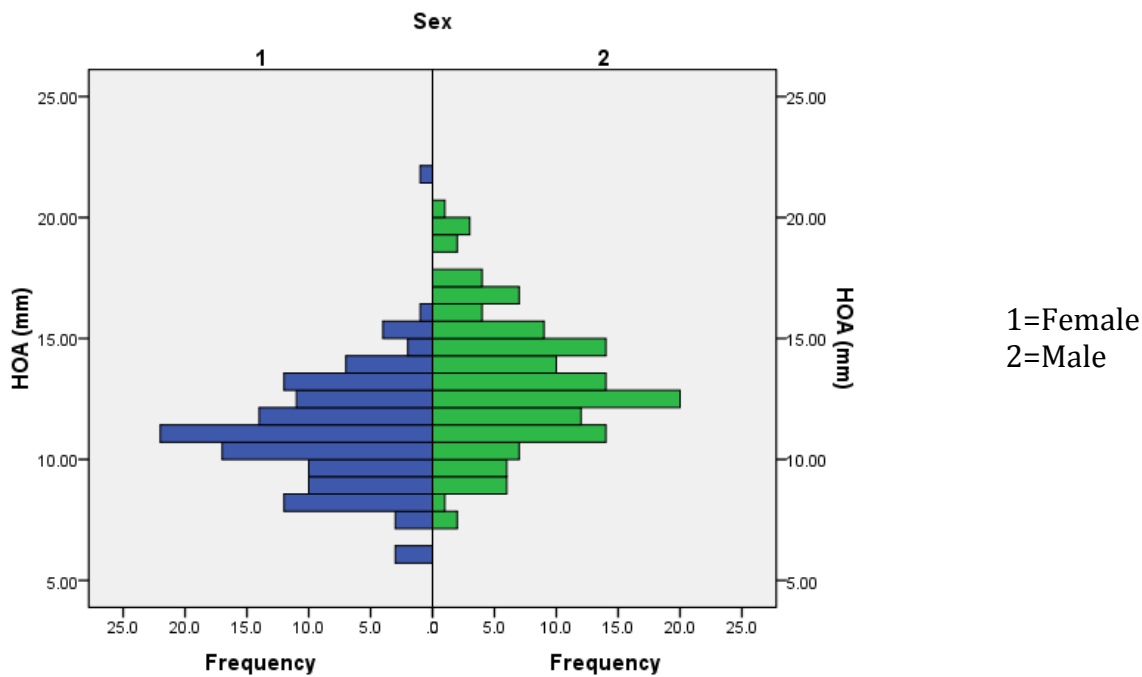


FIGURE 19. Histogram of height of acromial end showing the range of values present in the calibration sample.

TABLE 3- Intraobserver Error

Variable	n	Trial 1 Mean	Trial 2 Mean	Mean Difference	p-value
MXL*	20	148.90	149.00	0.10	0.163
SDM*	20	12.19	12.06	0.14	0.360
VDM	20	11.28	11.62	-0.34	0.083
AEL ⁺	20	39.31	37.76	1.55	0.006
ACH*	20	11.83	12.06	-0.23	0.074
SEL	20	53.58	55.07	-1.49	0.243
SCH	20	19.68	19.38	0.29	0.081
AEW	20	28.96	29.54	-0.59	0.020
SEW*	20	23.90	23.93	-0.03	0.824
CTA	20	42.96	43.02	-0.06	0.836
HOA ⁺	20	12.12	12.30	-0.17	0.028
SEH	20	24.45	24.14	0.31	0.456
COM*	20	3.68	3.68	0.00	1.000
COS*	20	7.54	7.52	0.02	0.104
CCP ⁺	20	5.07	5.04	0.03	0.021
COA	20	6.98	6.97	0.01	0.330
LCP ⁺	20	14.23	14.04	0.19	0.037
CPS	20	109.64	110.09	-0.44	0.239

*Variables used in developed models

+Needed Bonferroni correction (0.0028)

TABLE 4- Age Statistics

Group	Female	Male
<25 years	17	10
26-35 years	28	20
36-50 years	37	52
>50 years	47	54
Total	129	36

$\chi^2=0.06$, $p=0.8065$, $df=3$

The summary statistics (mean, maximum, minimum and standard deviation) are listed in Table 5. Independent sample t-tests using Bonferroni correction were then computed to identify sexual dimorphism between males and females. The t-tests show males and females differ at a statistically significant level for all 18 variables ($p < 0.0028$). The p -value either assumes unequal variances or equal variances depending on the significance found in Levene's test for that specific value.

Discriminate function analyses using the stepwise method (0.05 to enter, 0.10 to exit) produced four variables that were most predictive of sex. The circumference at midshaft (COM), maximum sternal end width (SEW), height of acromial curve (ACH), and maximum length (MXL) were the four variables with the highest discrimination power. This model has cross-validated (leave one out) accuracy of 89.8% on the calibration sample. A holdout sample ($n=30$) similar in demographic character from the Hamann-Todd collection was tested using the four variable model. The accuracy on the holdout sample was 90.0%.

A three variable, two variable, and multiple one variable models were also developed to accommodate fragmentary remains. The three variable model used all of the measurements used in the four variable models except maximum sternal end width (SEW). It also had a high predictive value of 88.3% (cross-validated) on the calibration sample and 93.3% on the hold out sample.

The two variable model uses the maximum length (MXL) and the circumference at midshaft (COM). The calibration sample had an accuracy of 87.5% (cross-validated) and the hold out sample had an accuracy of 86.7%. The discriminant function coefficients for the 4, 3, and 2 variable models are reported in Table 6, p 41.

TABLE 5- Summary Statistics

Variable	Measurement Name	Male (Mean) mm	Male (SD) mm	Female (Mean) mm	Female (SD) mm	p-value	Sexual Dimorph
MXL* ⁺⁻ _@	Maximum Length	153.54	9.20	137.84	8.57	<0.001	0.88
SDM _@	Sagittal (Anterior-Posterior) Diameter at Midshaft	13.63	1.93	11.23	1.39	<0.001	0.72
VDM	Vertical (Superior-Inferior) Diameter at Midshaft	11.20	1.86	9.50	1.30	<0.001	0.54
AEL	Length of Acromial End	39.09	5.05	33.88	6.20	<0.001	0.46
ACH* ⁺	Height of Acromial Curve	12.28	3.00	9.61	2.94	<0.001	0.45
SEL	Length of Sternal End	53.03	5.72	48.44	5.49	<0.001	0.41
SCH	Height of Sternal Curve	18.47	3.05	16.02	2.77	<0.001	0.42
AEW	Maximum Acromial End Width	29.26	3.91	25.34	3.80	<0.001	0.51
SEW*	Maximum Sternal End Width	24.18	4.02	20.01	2.72	<0.001	0.62
CTA	Conoid tuberosity to acromial end	43.78	5.66	39.11	4.48	<0.001	0.46
HOA	Height of Acromion	13.06	2.59	11.03	2.13	<0.001	0.43
SEH	Height of Sternal End	24.87	3.06	22.13	3.05	<0.001	0.45
COM* ⁺⁻ _@	Circumference of Midshaft	39.13	4.85	32.50	3.29	<0.001	0.81
COS _@	Circumference of Sternal End	77.57	7.37	67.13	7.93	<0.001	0.68
CCP	Circumference at Conoid Tubercle	51.64	6.43	45.58	5.39	<0.001	0.51
COA	Circumference of Acromial End	67.77	10.27	57.95	9.12	<0.001	0.51
LCP	Length at Conoid Tubercle	12.50	2.19	11.50	2.26	<0.001	0.22
CPS	Length from Conoid Tubercle to Sternal End	112.85	8.63	102.27	8.21	<0.001	0.63

*Used in four-variable model, +used in three-variable model, ~used in two-variable model, @ used in one-variable models. The equation used to determine sexual dimorphism is $(x_1 - x_2)/(s_1 + s_2)$, where x=mean, s= standard deviation, 1=male, and 2=female.

One variable models were also developed using maximum length (MXL) with an accuracy of 82.3% on the cross-validated calibration sample and 86.7% on the hold out sample. The one variable model for sagittal diameter at midshaft (SDM) had an accuracy of 75.8% on the cross-validated calibration sample and 80.0% on the hold out sample. The circumference of sternal end (COS) model an accuracy of 79.6% on the cross-validated calibration sample and 73.3% on the hold out sample. Finally, the circumference at midshaft (COM) with an accuracy of 79.6% on the cross validated calibration sample and 73.3% on the hold out sample. All of these equations are reported in Table 7, with their accuracies shown in Table 8. These four measurements were chosen for one variable models because they were capable of estimating sex with an accuracy of 75% or higher on their own. An example of a calculation to demonstrate the model is:

Individual 1562- Female
 MXL- 145mm
 COM- 26mm
 ACH- 7.16mm
 SEW- 18.56mm

$$0.161MXL+0.283COM+0.295ACH+0.205SEW-41.274$$

$$0.161*145+0.283*26+0.295*7.16+0.205*18.56-41.274=-4.654$$

The sectioning point is -0.065 and since $-4.654 < -0.065$ the individual is correctly classified as female.

TABLE 6- Multivariate Models

	4 Variable Model	3 Variable Model	2 Variable Model
MXL	0.161	0.169	0.171
COM	0.283	0.319	0.314
ACH	0.295	0.300	
SEW	0.205		
Constant	-41.274	-39.297	-36.178
Sectioning Point*	-0.065	-0.062	-0.058

*Males > sectioning point
 Females < sectioning point

TABLE 7-Single Variable Models

	MXL	SDM	COM	COS
MXL	0.198			
SDM		0.840		
COM			0.383	
COS				0.178
Constant	-28.902	-10.431	-13.706	-12.914
Sectioning Point*	-0.047	-0.037	-0.042	-0.036

*Males > sectioning point
 Females < sectioning point

TABLE 8- Test Accuracies

Variable(s)	Calibration Sample ^{*t}	Hold Out Sample [*]
Four Variable Model	89.8	90.0
Three Variable Model	88.3	93.3
Two Variable Model	87.5	86.7
MXL	82.3	86.7
SDM	75.8	80.0
COM	79.6	73.3
COS	75.1	60.0

^{*}Percent Correct

^tleave one out cross-validated

CHAPTER V

DISCUSSION

Sex is one of the most important elements of the biological profile. Correctly estimating sex can eliminate approximately 50% of the population from consideration as a possible missing person match in a forensic case. Sex is also one of the first things used to describe an individual. Sex estimation can be important in determining different mortuary practices and social status of individuals in the bioarchaeological context, potentially elucidating many complex and underlying social aspects not available to researchers when sex is unknown.

This study developing a method of sex estimation using metric analysis of the clavicle is important because many taphonomic processes can affect the quantity and quality of the skeletal remains present for analysis. Taphonomic processes include, but are not limited to, burial treatments, decomposition, forensic dismemberment, scattering by animals, and cultural practices like looting (Haglund and Sorg, 1997). Animal scavenging is less likely to affect the clavicle due to its location in the body, as well as its robusticity compared to other elements (Haglund et al., 1989). Scavengers tend to focus on the soft fleshy areas such as the neck and abdominal region, avoiding the clavicle. The clavicle is more robust and durable than preferred sex estimation elements such as the cranium and *os coxae* and is therefore more likely to be intact (Haglund et al., 1989), which is one of the reasons this element was chosen. Taphonomic

processes are unpredictable so the more resources that are available to the analyst, the more information he/she can gain from skeletal analysis. The one variable models could be used to estimate sex in fragmentary remains.

Sex estimation studies using the clavicle have been reported in the past, however at the onset of this study the author knew of no other study using only the clavicle, other than Jit and Singh (1966). It is important to be able to use just one skeletal element, because of the taphonomic processes listed above. Jit and Singh's article that uses clavicle length had lower accuracy rates than this study (Jit and Singh, 1966), which may be due to the limited sexual dimorphism present in Indian populations (Indriati, 2009).

Thieme also reported that clavicle length alone was not sufficient for estimating sex (1957). This is different than the results of this study, which found clavicle length to be one of the most accurate estimates of sex and was included in all of the multivariate models and a single variable model. The reason for this difference is unclear because Thieme does not report his accuracy rates with just the clavicle so there is no directly comparable information with this study. Thieme's article uses clavicular length in conjunction with other measurements. Since presence of multiple elements is unpredictable, being able to estimate sex from one element, as in this study is beneficial.

The Jit and Singh study used Indian populations, which do not have much sexual dimorphism and could explain some of the discrepancy in results. Thieme's population of African Americans was very similar to the Cleveland population used in this study, however his accuracy was not listed so it is difficult to compare Thieme's work with this study.

The study conducted on sex estimation from the clavicle by Natalie Shirley (2009) uses 3D scanning which is not available to all researchers and impossible in most field situations, thus is

not as applicable as this study. 3D scanning has accuracy and time constraints. 3D scanning can be problematic because pixel discrepancies can make it difficult for measurements to be exact. Shirley does not mention how long it takes to scan a clavicle. However taking the six measurements that are used in the models developed in this study takes about five minutes. So this method not only translates to field situations, but is also much more time efficient.

Metric analysis reduces the subjectivity of assessment of sex. Which is especially important because of the increasing emphasis on statistically verified methods of estimation of elements of the biological profile brought on by the Daubert vs. Merrell Dow Pharmaceuticals (1993) landmark case (Komar and Buikstra, 2008). This project has reported on a highly reliable model for estimation of sex based only on the clavicle, which is uncommon in the literature until now. Additionally, the one variable models can be used when the clavicle is present, but fragmentary or otherwise damaged by taphonomic processes.

Bilateral asymmetry presents a potential problem for this study. Activities during life do have an effect on the skeleton of the individual (Danforth and Thompson, 2008). Future research into this topic is necessary to assess the possible effects of bilateral asymmetry (Auerbach and Ruff, 2006). As discussed earlier, since sexual dimorphism of the clavicle is at least four times greater than the potential for bilateral asymmetry as discussed by Auerbach and Ruff, bilateral asymmetry should not be a confounding factor in this study. Further research in this area would be useful to completely eliminate this possibility.

This method may be applied to historic populations similar to the Cleveland population without correction. Once adjusted for secular change, this study may also be applied to other populations either pre- or post-dating the early 20th Century. This study demonstrates the presence of sexual dimorphism in the clavicle. With the increasing need for metric analysis in

sex estimation of skeletal remains and the unpredictability of taphonomic processes, this study has the potential to make a significant impact in the fields of forensic anthropology and bioarchaeology.

REFERENCES

- Aiello L, Dean C. 2002. An Introduction to Human Evolutionary Anatomy. Oxford:Elsevier Academic Press.
- Albanese J. 2003. A metric method for sex determination using the hipbone and the femur. *J Forensic Sci* 48:263-273.
- Ashton EH, Oxnard CE. 1964. Functional Adaptations in the Primate Shoulder Girdle. *Proceedings of the Zoological Society of London* 142:49-66.
- Aurbach BM, Ruff CB. 2006. Limb bone bilateral asymmetry: variability and commonality among modern humans. *J Hum Evol* 50:203-218.
- Bainbridge D, Tarazaga SG. 1956. A study of sex differences in the scapula. *J R Anthropolo Inst G* 86:109-34.
- Bidmos MA, Dayal MR. 2003. Sex determination from the talus of South African whites by discriminant function analysis. *Am J Forensic Med Path* 24:322-328.
- Bidmos MA, Asala SA. 2004. Sexual dimorphism of the calcaneus of South African Blacks. *J Forensic Sci* 49:446-50.
- Bidmos MA, Steinberg N, Kuykendall KL. 2005. Patella measurements of South African whites as sex assessors. *Homo* 56:69-74.

- Buikstra JE, Ubelaker DH (editors). 1994. Standards for data collections from human skeletal remains: proceedings of a seminar at the Field Museum of Natural History organized by Jonathan Haas. Fayetteville, AR: Arkansas Archaeological Survey Publications.
- Conroy G. 2003. The inverse relationship between species diversity and body mass: Do primates play by the “rule”? *J Hum Evol* 45:43-55.
- Dabbs GR, Moore-Jansen PH. 2010. A Method for Estimating Sex Using Metric Analysis of the Scapula. *J Forensic Sci* 55:149-152.
- Danforth ME, Thompson A. 2008. An evaluation of determination of handedness using standard osteological measurements. *J Forensic Sci* 53:777-781.
- Day M. 1988. Guide to fossil man. Chicago: University of Chicago Press.
- De Castro JM, Sarmiento S, Cunha E, Rosas A, Bastir M. 2001. Dental size variation in the Atapuerca-SH Middle Pleistocene hominids. *J Hum Evol* 41:195-209.
- Demment MW. 1983. Feeding ecology and the evolution of body size in baboons. *Afr J Ecol* 21:219-233.
- Dwight T. 1894. The range and significance of variation in the human skeleton. *Boston Med Surg J* 131:73-76.
- Falk D, Gage T, Olson TR. 1995. Did more than one species of hominid coexist before 3.0 ma? Evidence from blood and teeth. *J Hum Evol* 29:591-600.
- Fleagle JG. 1981. Climbing: a biomechanical link with brachiation and bipedalism. In: *Vertebrate Locomotion symposium of the Zoological Society of London* 48: 359-375.
- Frutos LR. 2003. Determination of sex from the clavicle and scapula in a Guatemalan contemporary rural indigenous population. *Am J of Forensic Med Path* 23:284-8.

González-Reimers E, Velasco-Vázquez J, Arnay-de-la-Rosa M, Santolaria-Fernández F. 2000.

Sex determination by discriminant function analysis of the right tibia in the prehispanic population of the Canary Islands. *Forensic Sci Int* 108:165-172.

Haglund WD, Reay DT, Swindler DT. 1989. Canid scavenging/disarticulation sequence of human remains in the pacific northwest. *J Forensic Sci* 34:587-606.

Haglund WD, Sorg MH. 1997. *Forensic Taphonomy: The Postmortem Fate of Human Remains*. New York:Taylor and Francis Group.

Hauspie RC, Cameron N, Molinari L. 2004. *Methods in Human Growth Research*. Columbia, SC:Columbia University Press.

Humphrey LT. 2008. Growth patterns in the modern human skeleton. *Am J Phys Anthropol* 105:57-72.

Indriati E. 2009. Historical Perspectives on Forensic Anthropology in Indonesia. In: Soren B, Ubelaker DB, editors. *Handbook of Forensic Anthropology and Archaeology*. . Walnut Creek, CA:Left Coast Press, Inc. p 32-64.

Introna Jr. F, DiVella G, Campobasso CP. 1998. Sex determination by discriminant analysis of patella measurements. *Forensic Sci Int* 95(1):39-45.

İsçan MY, Miller-Shaivitz P. 1984. Determination of sex from the tibia. *Am J Phys Anthropol* 64:53-57.

İsçan MY, Yoshino M, Kato S. 1994. Sex determination from the tibia: standards for contemporary Japan. *J Forensic Sci* 39:785-792.

İsçan MY, Loth SR, King CA, Shihai D, Yoshino M. 1998. Sexual dimorphism in the humerus: a comparative analysis of Chinese, Japanese and Thais. *Forensic Sci Int* 2:17-29.

- Janson CH, van Schaik CP. 1993. Ecological risk aversion in juvenile primates: Slow and steady wins the race. In Pereira M E Fairbanks L A, editors, Juvenile Primates: Life History, Development, and Behavior. New York:Oxford University Press, p 57-74.
- Jantz RL. 2001. Cranial change in Americans: 1850-1975. J Forensic Sci 46:784-787.
- Jit I, Singh S. 1966. The sexing of the adult clavicles. Indian J Med Res 54:551-571.
- Johanson DC, Lovejoy CO, Kimbel WH, White TD, Ward, SC, Bush ME, Latimer BM, Coppens Y. 1982. Morphology of the Pliocene Partial hominid skeleton (AL 288-1) from the Hadar formation, Ethiopia. Am J Phys Anthropol 57:403-452.
- Kappeler PM. 1997. Determinants of primate social organization: Comparative evidence and new insights from Malagasy lemurs. Biological Reviews of the Cambridge Philisophical Society 72:111-151.
- Kappeler PM, van Schaik C (editors). 2004. Sexual Selection in Primates: New and Comparative Perspective. Cambridge: University Press Cambridge.
- Komar DA, Buikstra JE. 2008. Forensic Anthropology Contemporary Theory and Practice. New York:Oxford University Press. p 1-23.
- Leigh S. 1994. Growing up to be a primate. Evol Anthropol 3:106-108.
- Lockwood C, Kimbel W. 2000. Temporal trends and metric variation in the mandibles and dentition of *Australopithecus afarensis*. J Hum Evol 39:23-55.
- Lorenzo C, Arsuaga J. 1999. Hand and foot remains from the Gran Dolina Early Pleistocene site (Sierra de Atapuerca, Spain). J Hum Evol 37:501-522.
- Mall G, Graw M, Gehring KD, Hubig M. 2000. Determination of sex from femora. Forensic Sci Int 113:315-321.

- Mays S, Steele J, Ford M. 1999. Directional Asymmetry in the Human Clavicle. *Int J Osteoarchaeol* 9:18-28.
- McHenry HM. 1992a. Body size and proportions in early hominids. *Am J Phys Anthropol* 87:407-431.
- McHenry HM. 1992b. How big were early hominids? *Evol Anthropol* 1:15-20.
- McHenry HM, Temerin LA. 1979. The evolution of hominid bipedalism: evidence from the fossil record. *Yearb Phys Anthropol* 22:105-131.
- Meindl RS, Russell KF, Lovejoy CO. 1990. Reliability of age at death in the hamann-todd collection: Validity of subselection procedures used in blind tests of the summary age technique. *Am J Phys Anthropol* 83:349–357.
- Moore KL, Dalley AF. 1999. *Clinically Oriented Anatomy*. (4th edition). Philadelphia, PA:Lippincott Williams and Wilkins.
- Murphy AMC. 2002a. The calcaneus: sex assessment of prehistoric New Zealand Polynesian skeletal remains. *Forensic Sci Int* 129:205-208.
- Murphy AMC. 2002b. Articular surfaces of the pectoral girdle: sex assessment of prehistoric New Zealand Polynesian skeletal remains. *Forensic Sci Int* 125:134-136.
- Murphy AMC. 2002c. The talus: sex assessment of prehistoric New Zealand Polynesian skeletal remains. *Forensic Sci Int* 128:155-158.
- O’Rahilly R, Muller F. 1982. *Basic Human Anatomy: A Regional Study of Human Structure*. Philadelphia, PA:WB Saunders Co.
- Özer I, Katayama K, Sagir M, Gulec E. 2006. Sex determination using the scapula in medieval skeletons from East Anatolia. *Coll Anthropol* 30:415-419.

- Pavlov P, Svenden J. 2001. Human presence in the European Arctic nearly 40,000 years ago. *Nature* 413:64-67.
- Plavcan, JM. 2001. Sexual dimorphism in primate evolution. *Yearb Phys Anthropol* 44:25-53.
- Prescher A, Klumpen T. 1995. Does the area of the glenoid cavity of the scapula show sexual dimorphism?. *J Anat* 186:223-226.
- Purkait R. 2001. Measurements of ulna- a new method for determination of sex. *J Forensic Sci.* 46:924-927.
- Purkait R, Chandra H. 2002. Sexual dimorphism in femora: an Indian study. *Forensic Science Comm* 4:3.
- Purkait R, Chandra H. 2004. A study of sexual variation in Indian femur. *Forensic Sci Int* 146:25-33.
- Raju PB, Singh S. 1978. Sexual dimorphism in scapula. *J Indian Acad Forensic Sci* 17:23-34.
- Reed K, Kitching JW. 1993 Proximal femur of *Australopithecus africanus* from member 4, Makapansgat, South Africa. *Am J Phys Anthropol* 92:1-15.
- Reno PL, Meindl RS. 2003. Sexual dimorphism in *Australopithecus afarensis* was similar to that of modern humans. *P Natl Acad Sci USA* 100:9404-9409.
- Rightmire G, Deacon H. 2001. New human teeth from Middle Stone Age deposits at Klasies River, South Africa. *J Hum Evol* 41:535-544.
- Robling AG, Ubelaker DH. 1997. Sex estimation from the metatarsals. *J Forensic Sci* 42:1062-1069.
- Rose LM. 1994. Sex differences in diet and foraging behavior in white-faced capuchins (*Cebuscapucinus*). *Int J Primatol* 15:95-114.

- Safont S, Malgosa A, Subira ME. 2000. Sex assessment on the basis of long bone circumference. *Am J Phys Anthropol* 113:317-328.
- Sakaue K. 2004. Sexual determination of long bones in recent Japanese. *Anthropol Sci* 112:75-81.
- Schultz AH. 1930. The skeleton of the trunk and limbs of higher primates. *Human Biology* 2:303-438.
- Shirley NR. 2009. Age and Sex Estimation From the Human Clavicle: an Investigation of Traditional and Novel Methods. Dissertation received August 2009 at The University of Tennessee, Knoxville.
- Silverman N, Richmond B. 2001. Testing the taxonomic integrity of *Paranthropus boisei sensu stricto*. *Am J Phys Anthropol* 115:167-178.
- Spradley MK, Jantz RL. 2011. Sex Estimation in Forensic anthropology: Skull versus postcranial elements. *J Forensic Sci* 56:289-296.
- Steyn M, İşcan MY. 1997. Sex determination from the femur and tibia in South African whites. *Forensic Sci Int* 90:111-119.
- Susman R, de Ruiter. 2001. Recently identified postcranial remains of *Paranthropus* and early *Homo* from Swartkrans Cave, South Africa. *J Hum Evol* 41:607-629.
- Suwa G. 1997. The first skull of *Australopithecus boisei*. *Nature* 389:489-492.
- Thieme FP. 1957. Sex in Negro skeletons. *J Forensic Med* 4:72-81.
- Trinkaus E. 1983. *The Shanidar Neanderthals*. New York:Academic Press.
- Tuttle R. 1975. Parallelism, brachiation, and hominoid phylogeny. In: Luckett WP, Szalay FS, editors. *Phylogeny of the Primates, a Multidisciplinary Approach*. New York: Plenum Press. p 447-480.

- van der Merwe N, Thackeray F, Lee-Thorp JA, Luyt J. 2003. The carbon isotope ecology and diet of *Australopithecus africanus* at Sterkfontein, South Africa. *J Hum Evol* 44:581-597.
- vanDongen R. 1963. The shoulder girdle and humerus of the Australian aborigine. *Am J Phys Anthropol* 21:469-488.
- White T, Folkens P. 1991. Human osteology. San Francisco:Academic Press.
- White T, Suwa G. 2000. Jaws and teeth of *Australopithecus afarensis* from Maka, middle Awash, Ethiopia. *Am J Phys Anthropol* 111:45-68.
- Williams BA, Rodgers T. 2006. Evaluating the accuracy and precision of cranial morphological traits for sex determination. *J Forensic Sci* 51:729-735.
- Wiredu EK, Kumoji R, Seshadri R, Biritwum RB. 1999. Osteometric analysis of sexual dimorphism in the sternal end of the rib in a West African population. *J Forensic Sci* 44:921-925.
- Wrobel GD, Danforth ME, Armstrong C. 2002. Estimating sex of Maya skeletons by discriminant function analysis of long bone measurements from the protohistoric Maya site of Tipu, Belize. *Anc Mesoamerica* 13:255-263.

APPENDICES

Appendix A- Data Collection Sheet

Collection Name: _____

Specimen Number: _____

Sex: M / F

Ancestry: _____

Age: _____

Measurements:

MXL: _____

SDM: _____

VDM: _____

AEL: _____

ACH: _____

SEL: _____

SCH: _____

AEW: _____

SEW: _____

CTA: _____

HOA: _____

SEH: _____

COM: _____

COS: _____

CCP: _____

COA: _____

LCP: _____

CPS: _____

Appendix B- Pictures of Measurements

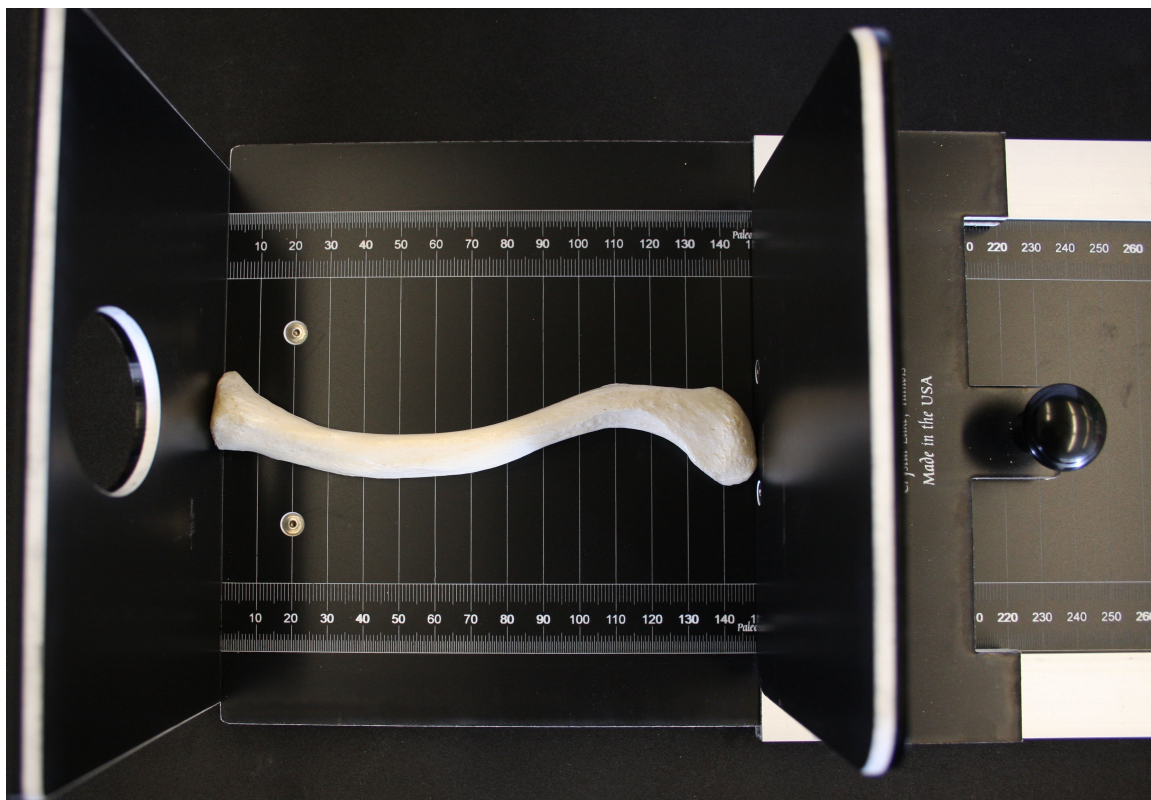


Figure 20. MXL- Maximum Length. "Maximum distance between the most extreme ends of the clavicle" (Buikstra and Ubelaker, 1994:79) osteometric board



Figure 21.SDM- Sagittal (Anterior-Posterior) Diameter at Midshaft“Distance from the anterior to the posterior surface at midshaft...Comment: determine the midpoint of the diaphysis on the osteometric board and mark it with a pencil” (Buikstra and Ubelaker, 1994:79) sliding caliper

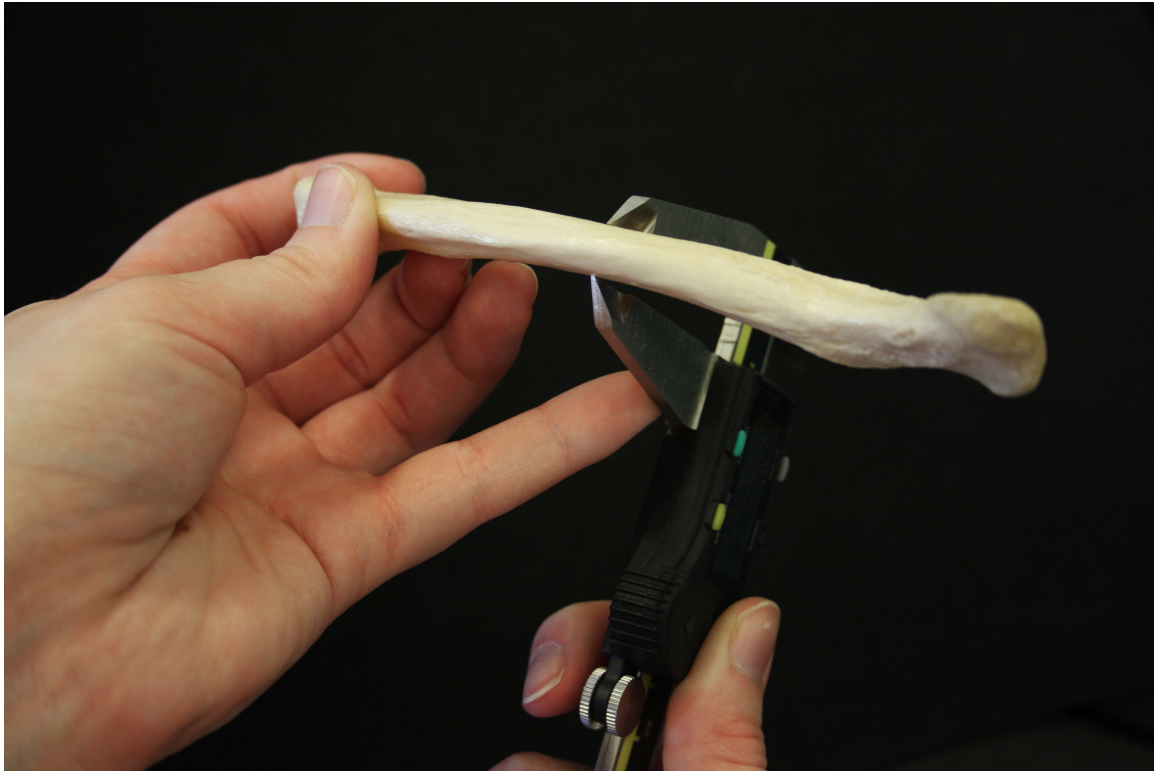


Figure 22. VDM-Vertical (Superior-Inferior) Diameter at Midshaft. “Distance from the superior to the inferior surface at midshaft” (Buikstra and Ubelaker, 1994:79) sliding caliper



Figure 23. ACH- Height of Acromial Curve. Place the anterior most part of the clavicle on the table and measure the height of the curve at its highest point (the apex)-sliding caliper (inside arms)



Figure 24. AEL- Length of Acromial End.Length from apex of the acromial curve to the most lateral point of the acromial end. The apex of the acromial curve is determined by finding the height of the acromial curve and using that point (apex) to measure to the most lateral point of the acromial end-sliding caliper



Figure 25. SCH- Height of Sternal Curve. Place the posterior most part of the clavicle on the table and measure the height of the curve at its highest point (the apex)-sliding caliper (inside arms).



Figure 26. SEL-Length of Sternal End. Length from apex of the sternal curve to the most medial point of the sternal end. The apex of the sternal curve is determined by finding the height of the sternal curve and using that point (apex) to measure to the most medial point of the sternal end-sliding caliper

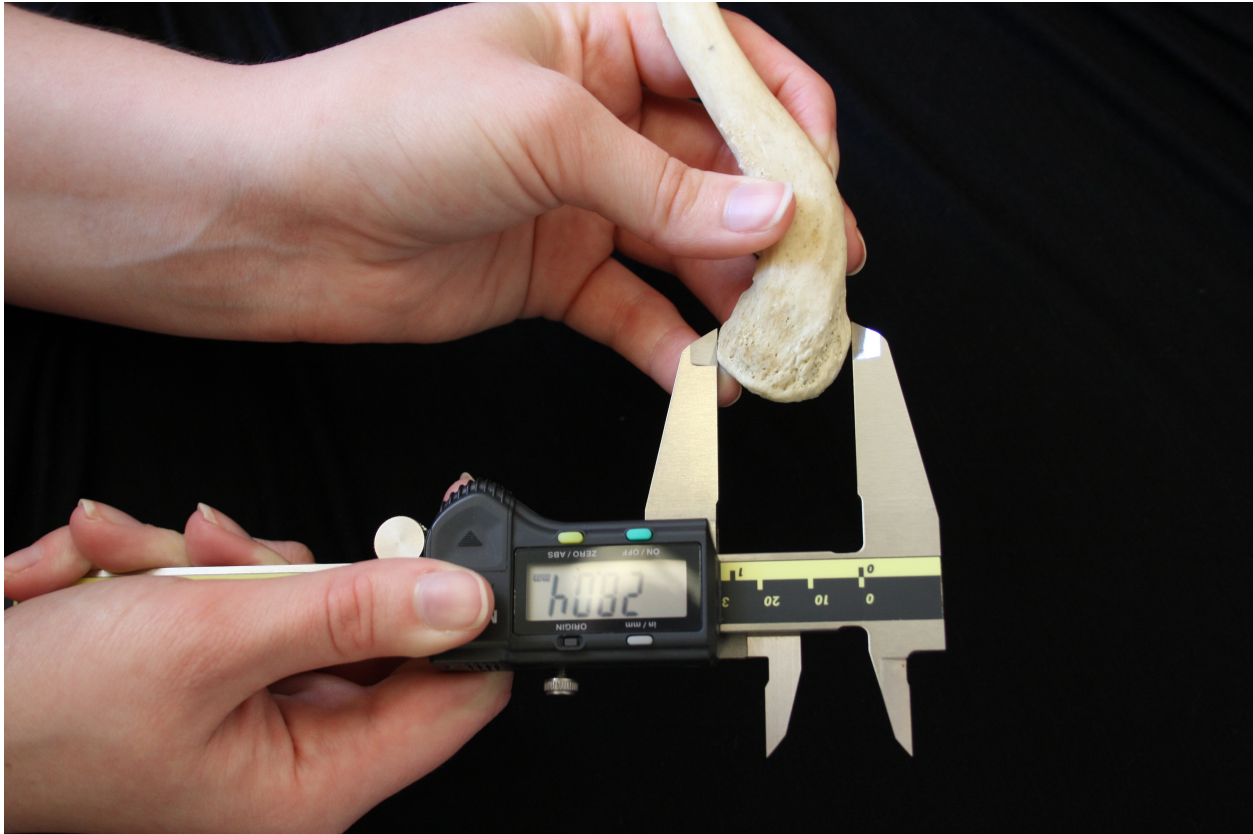


Figure 27. AEW- Maximum Acromial End Width. Greatest posterior to anterior measurement of the acromial end-sliding caliper

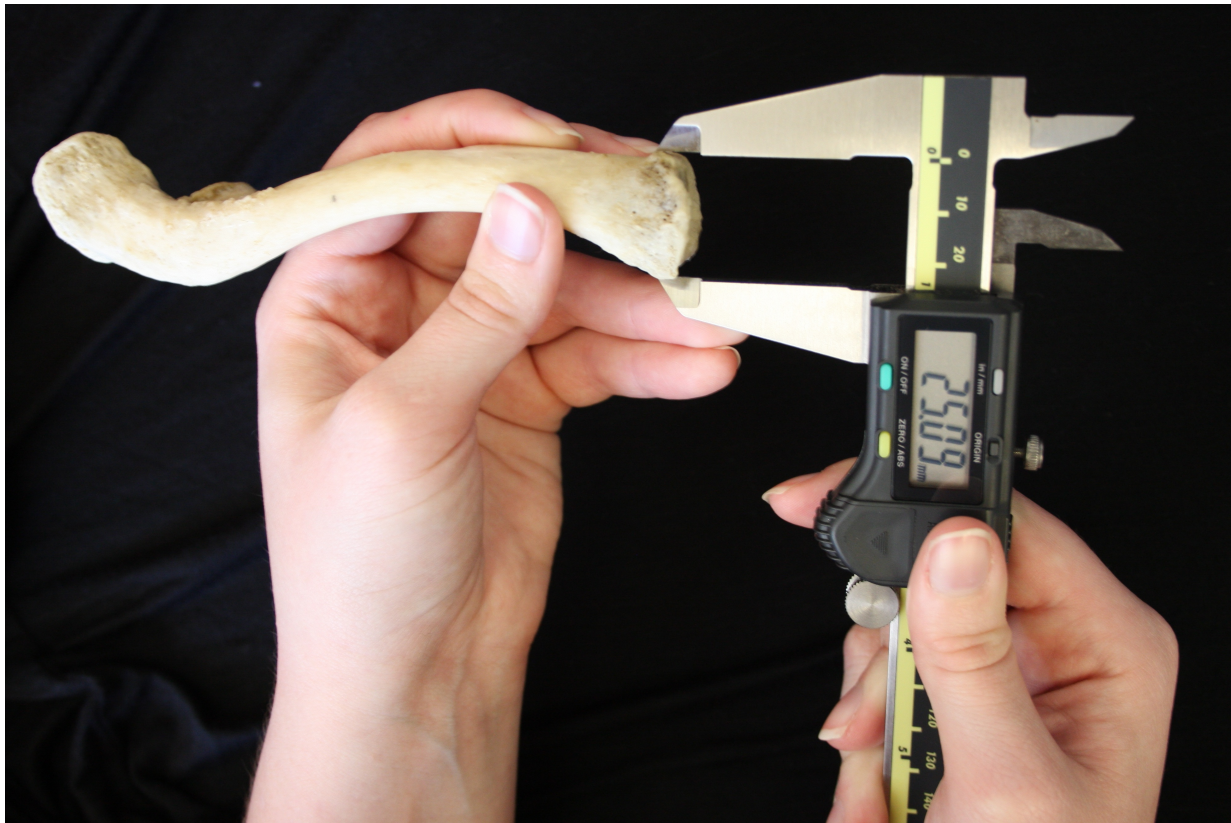


Figure 28. SEW- Maximum Sternal End Width. Greatest posterior to anterior measurement of the sternal end-sliding caliper



Figure 29. CTA- Conoid tuberosity to acromial end. Conoid tuberosity to the most lateral end of the acromial end-sliding caliper

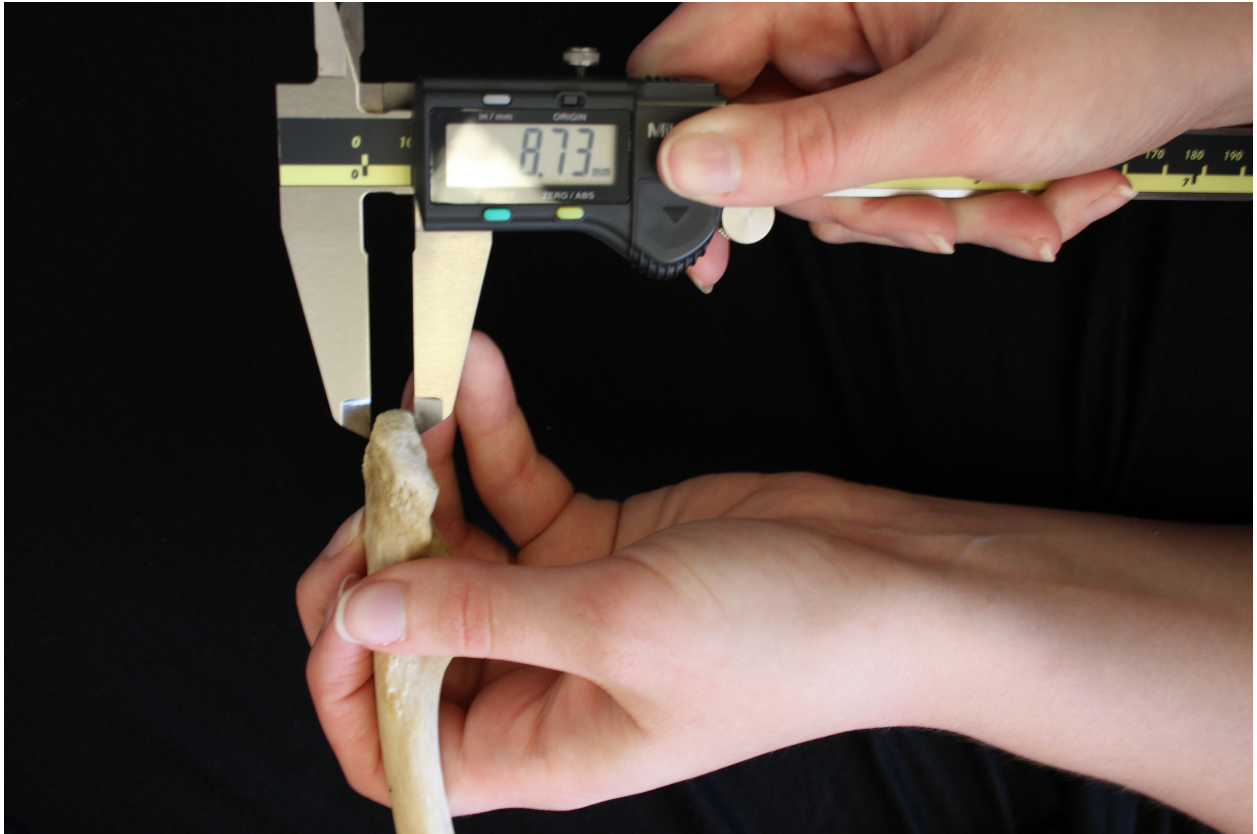


Figure 30. HOA- Height of Acromial End. Maximum superior to inferior measurement of the acromial end-sliding caliper

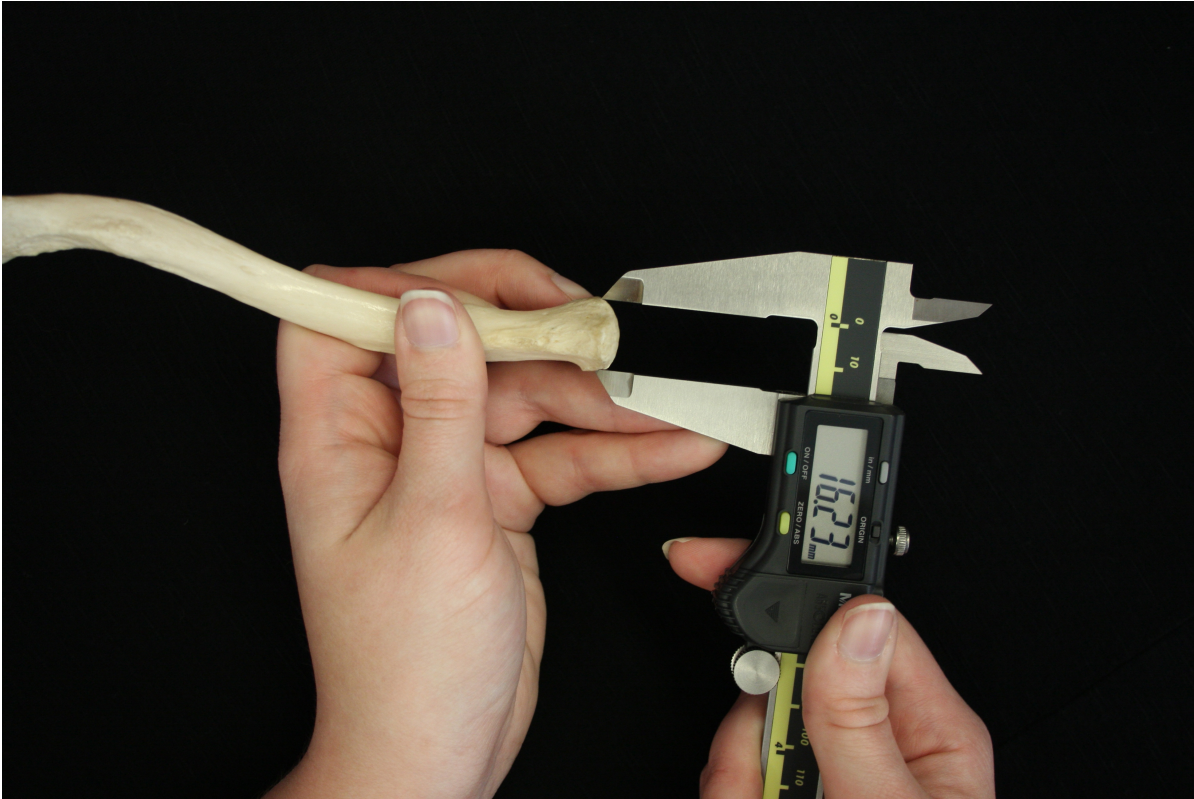


Figure 31. SEH- Height of Sternal End. Maximum superior to inferior measurement of the sternal end-sliding caliper



Figure 32. COM- Circumference of Midshaft. Circumference at midshaft. Midshaft is determined by dividing the maximum length in half and measuring that distance from either end and taking the midshaft measurement at that mark-cloth tape



Figure 33. COS- Circumference of Sternal End. Circumference of the most extreme end of the sternal end-cloth tape



Figure 34. CCP- Circumference at Conoid Tubercle. Circumference at the conoid tubercle including the conoid tubercle-cloth tape



Figure 35. COA- Circumference of Acromial End. The maximum circumference of the acromial end including the most posterior and anterior points of the acromial end-cloth tape



Figure 36. LCP- Height at Conoid Tubercle. Height (superior to inferior) at the conoid tubercle. The largest superior to inferior measurement including the conoid tubercle-sliding caliper

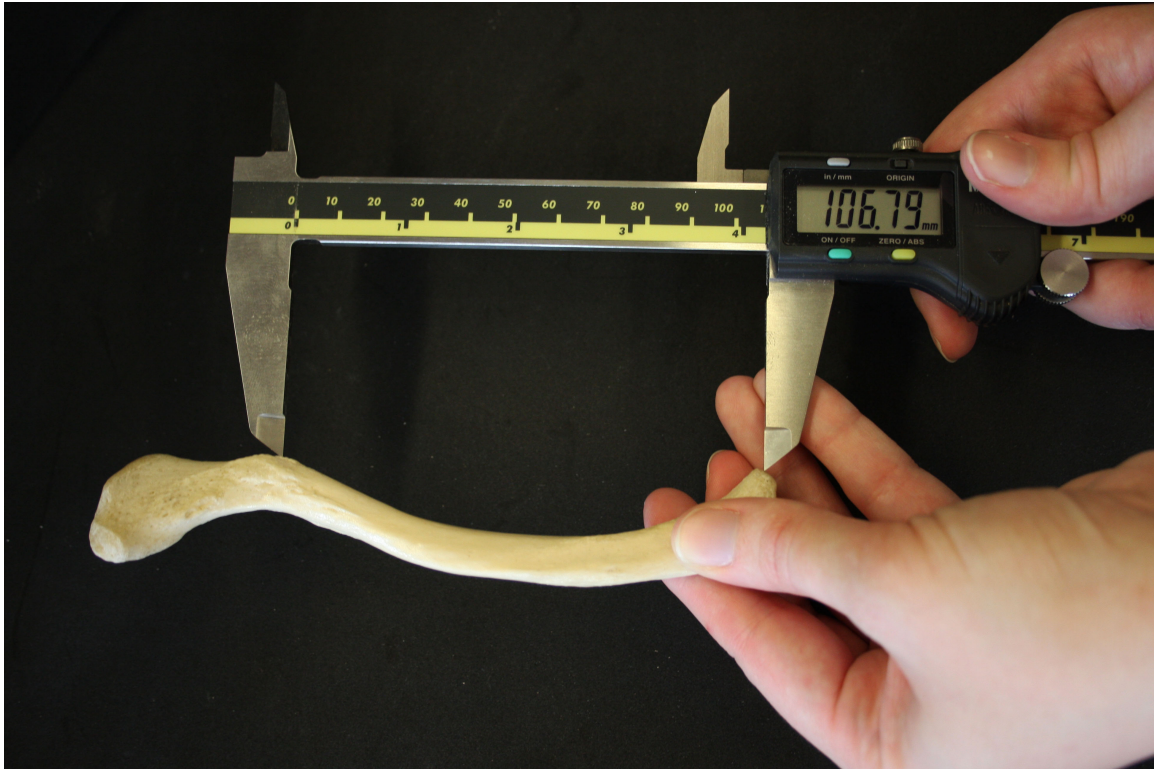



Figure 37. CPS- Length from Conoid Tubercle to Sternal End. Length from the conoid tubercle to the most extreme sternal end-sliding caliper

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to rand.s.swenson, Colleen.B.King

Dr. Swenson,

I would like permission to use a modified version of a clavicle picture from the online version of Basic Human Anatomy in my Masters thesis. I have attached the image below so you know which image I'm referring to.

Respectfully,

Megan Cleary
Graduate Student in the Department of Anthropology, SIUC
Research Assistant for Dr. Gretchen Dabbs



Rand Swenson rsswenson@gmail.com

Apr 3 (5 days ago) ★

You have permission to use this image in the manner you describe and with attribution to the on line resource (in the manner recommended by your institution).

Regards,

Rand

...

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Major Professor: Gretchen R. Dabbs

Cleary MK, Dabbs, GR. 2011. "Sex Estimation from the Clavicle: A Discriminant Function Analysis." Presentation at Bioarchaeology and Forensic Anthropology Annual Meetings October 2011, Bloomington, IL.

Cleary MK, Martin DC, Dabbs DR. 2012. "The Unique Biodiversity of Avian and Mammalian Carrion Scavengers in Southern Illinois and Their Effect on Decomposition Rate and Pattern," Poster presentation at the American Academy of Forensic Sciences meeting, February 2012, Atlanta, GA.