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Can we estimate stature from the scapula? A test considering sex and ancestry

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CAN WE ESTIMATE STATURE FROM THE SCAPULA? A TEST CONSIDERING SEX AND ANCESTRY

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The biological profile is one of the most important things that forensic anthropologists accomplish in their work. This includes the determination of age, race, sex, and stature. These four components of the biological profile aid in the identification of an individual in the forensic context. Since the beginning of the field of physical anthropology, osteologists and anatomists have studied human remains in order to provide new and more accurate ways of building the biological profile.

Two published studies have attempted to estimate stature from measurements of the scapula. One previous study found that certain measurements of the scapula were highly accurate in estimating the stature of males and females from an Italian population. However, another study concluded that other measurements of the skeleton were more useful in estimating stature than the maximum scapular breadth for a Chinese population.

The current research expands upon both of these previous studies using an American population collected from the Hamann-Todd Osteological Collection at the Cleveland Museum of Natural History. In so doing, this researcher hypothesized that there was a significant relationship between one or more measurements of the scapula and stature. Additionally, I performed a multiple regression analysis of the measurements in order to create regression formulae useful in estimating stature. After taking eleven measurements of the scapula, these variables were regressed against the stature measurements (N=223) provided in the Hamann-Todd Human Collection Database. The results show that several variables, including the length of the scapular spine, the maximum acromion-coracoid distance, the length of the axial border, the length of the coracoid, and the maximum scapular breadth each significantly contribute to stature. Additionally, race significantly contributes to stature. Regression formulae were calculated for populations when race is both known and unknown. After applying each of these formulae to a smaller test sample, results show that, contrary to the findings of previous research, stature could be predicted for all individuals with an accuracy of 27%, for blacks with an accuracy of 50%, and for whites with an accuracy of 36%.

CHAPTER ONE: INTRODUCTION

Recent trends in popular culture, including television shows and novels, have piqued American's interest in forensic science. This interest is good for forensic sciences because more people are interested in studying forensic sciences and building careers in the field. Importantly, these new forensic scientists will conduct research and train others in the forensic sciences. Encompassed within the forensic sciences is forensic anthropology, an applied form of anthropology. Specifically, forensic anthropology is the application of physical anthropology to the medico-legal field. Forensic anthropologists accomplish many important tasks. Lundy (1986) states the first goal of a forensic anthropologist is to determine whether or not recovered skeletal remains are human, and if the remains belong to one or more individuals. Additionally, Byers (2005) states that there are five other goals of the forensic anthropologist: establishing the decedent's biological profile, finding evidence of trauma, determining the length of the postmortem interval, recovering the decedent from the forensic site, and providing information to assist with a positive identification of the decedent.

The four components of the biological profile include age, sex, ancestry, and stature. These four factors are important to law enforcement officials as they aid in the ability to positively identify human skeletal remains. Some of the earliest research in forensic anthropology involved mechanisms to determine the biological profile. For example, Thomas Dwight devoted his work to the study of human skeletal anatomy, including techniques for establishing a biological profile and the postmortem interval (Byers 2005). In the early 20th century, a handful of physical anthropologists and doctors made several important contributions to the field of forensic anthropology. Physical anthropologists Aleš Hrdlička and Earnest

Hooton both devoted their careers to the study of the human skeleton. Additionally, the physicians T. Wingate Todd and Robert J. Terry amassed the Hamann-Todd and the Terry skeletal collections, respectively (Byers 2005).

The Hamann-Todd Osteological Collection was collected throughout the early 20th century in Cleveland, Ohio. The individuals in the collection were often patients of T. Wingate Todd or unclaimed morgue specimens. Despite the age of the Hamann-Todd Osteological Collection and the potential for bias in the collection due to secular changes affecting individuals since the collection was curated, it is still are used today to conduct important research within forensic anthropology. Included in this research are studies that have attempted to determine ways of estimating an individual's living height. Willey and Falsetti (1991:813) state that "the accurate determination of height is important in forensic investigation and identification," and Ousley (1995:768) believes that "driver's license stature is still valuable for the identification of human remains." However, the accuracy of stature estimates has been called into question by several researchers (Himes and Roche 1982; Ousley 1995; Willey and Falsetti 1991). One problem that forensic anthropologists find is that an individual's reported stature, whether self-reported on a driver's license or reported by a spouse or other family member, is often inaccurate. Although individuals do tend to report inaccurately their stature on driver's licenses, this is still one of the most common methods of determining an individual's forensic stature (Ousley 1995). Ousley (1995) argues that comparing measured stature to estimates of forensic stature taken from driver's licenses provides accurate results

Despite the fact that there is some inaccuracy and imprecision in predicting the living stature of an individual, this is still an important component of a decedent's biological profile. Forensic anthropologists commonly use long bones for estimating living stature. However, researching, testing, and developing new techniques for determining this component of the biological profile is still important. The scapula is potentially useful in estimating stature for several reasons. First, in the absence of other intact bones, measurements taken from the scapula might be useful for estimating stature. Second, Campobasso et al. (1998) state that scapular measurements that can be reliably employed in estimating height are standardized and easy to locate. Third, Murphy (1992) indicates that the scapula might be useful in discriminant function analysis because the measurements can be taken from incomplete bones.

This research attempts to answer several questions: Are measurements of the scapula useful in estimating living stature? Are certain measurements of the scapula more useful in estimating stature than others? Most importantly, can statistical formulae similar to those developed by Campobasso et al. (1998) be developed for American white and black males and females? In order to answer these questions, I spent two weeks measuring scapulae and femora from the Hamann-Todd Osteological Collection housed at the Cleveland Museum of Natural History. The scapulae lay between the second and seventh ribs, which articulate with the vertebrae, a primary component of stature. Due to this relationship, then, I hypothesize that there is a statistically significant relationship between at least one measurement of the scapula and the stature of an individual. This thesis reports the results of that research and adds to the current body of research on stature estimation in forensic investigations.

CHAPTER TWO: LITERATURE REVIEW

2.1 Stature Estimation in Forensic Investigations

Forensic anthropologists must be able to employ multiple techniques to build the biological profile for a couple of reasons. One important reason is that mass fatalities occur more frequently now than they have in the past. Disasters such as plane crashes, acts of terrorism, and natural disasters can take the lives of hundreds of thousands of victims. When such mass disasters occur, victims' remains may be fragmented, scattered, and mixed together, making it difficult to build complete biological profiles. Added to the frequency and extent of loss of human lives in modern times is the discovery that the anthropometric standards by which we estimate living height differ between populations. These standards and measurement techniques must be reevaluated constantly for precision and applicability (Mall et al. 2001).

Height is composed of the length, or height, of the cranium, vertebral column, pelvis, bones of the leg, and the ankle bones (calcaneous and talus) (Byers 2005). A considerable amount of research has been done on the estimation of living stature based on measurements of different bones. In early attempts to estimate height, researchers would simply rearticulate the skeleton and measure it. Though it seemed logical, this method for stature estimation was problematic. All of the bones must be present in order to rearticulate the skeleton, which is not always the case in the forensic context; also, this technique does not take into account cartilage and other soft tissue that might affect proper spacing (Byers 2005).

Long bones are used most commonly to estimate stature. Trotter and Gleser (1952) undertook one of the earliest, most comprehensive studies on estimating stature from long bones. They took measurements from a large sample of black and white male World War II military deceased and individuals in the Terry Anatomical Collections, which included a large sample of black and white males and females. Trotter and Gleser measured the maximum length of the humerus, femur, radius, ulna, tibia, and fibula, and the bicondylar length of the femur. Using the average length of the paired bones, Trotter and Gleser derived regression formulae for estimating stature from these long bones and concluded that a linear relationship existed between the maximum femur length and stature. They also found lower limb bones to be the better predictors of stature because the regression equations based on lower limb bones had smaller standard errors than those of the upper body (Trotter and Gleser 1952:512).

Six years later, Trotter and Gleser (1958) conducted a similar study using Korean War deceased, all males of varying ancestry. The military had measured the height of these individuals upon their enrollment (Trotter and Gleser 1958). Trotter and Gleser took the same measurements from this sample population that they did in their previous study, this time considering each bone individually rather than pairing the bones from each side of the body. Again, Trotter and Gleser found that lower limb bones were the better predictors of living stature than the upper limb bones. These new measurements allowed them to re-evaluate the original regression formulae for both black and white males; however, according to Jantz (1992), there has been no comparable re-evaluation of black and white females since Trotter and Gleser's original 1952 study. Trotter (1970) later summarized the results of her 1952 and 1958 research, including the formulae with standard errors for estimating statures on intact long bones. Additionally, she concluded that to obtain an accurate measurement of cadaveric stature one should add 2.5 cm to the estimate of living stature derived from long bone measurements.

Jantz (1992) attempted to re-evaluate Trotter and Gleser's regression equations for females. Using a sample from the Forensic Anthropology Database (FADB) at the University of

Tennessee, Jantz compared the measurements from his sample to those of Trotter and Gleser. He found that, for both blacks and whites, all the measurements in the FADB were longer than those in the Terry Collection due to secular changes in bone growth. Jantz modified the female stature estimations for white females based on his research. He found that the changes in bone growth in black females was isometric, so those equations did not need to be adjusted.

Though widely criticized, the work of Trotter and Gleser is still thought by many to be the most reliable information that we have for estimating living height (Bass 1995; Byers 2005; Hauser et al. 2005). Byers' (2005) criticisms of Trotter and Gleser's work include the fact that Trotter's measuring techniques were unclear and that many of the formulae developed require prior knowledge of sex and ancestry, two factors that might not always be possible to determine in forensic contexts depending on what skeletal materials are recovered.

Researchers continue to derive formulae for estimating stature based on long bone lengths. These new studies take into account secular changes that have occurred in different populations over time in an attempt to provide more accurate linear regression formulae than the early work of Trotter and Gleser (1952; 1958). Duyar and Pelin (2003:23) hypothesized that "estimations of stature are more accurate if different regression formulae are used for specific stature group." A regression formula is the result of regression analysis, which allows researchers to predict the value of stature, in this case, from random variables. Duyar and Pelin (2003) grouped their sample of Turkish males into three stature groups: short (<1,652 mm), medium (1653-1840 mm), and tall (>1841 mm). Using measurements of the tibia, they found that they could generate different linear regression formulae for each height group. Their work indicates that, not only is there a need for different regression formulae between males, females, and different populations, but there is also a possible need for different formulae between stature groupings.

Using a Polish sample population, Hauser et al. (2005) determined that the longest measurement of the femur was the most useful for correlating with living height, at least in males. Similarly, de Mendonça (2000) found that the femur was the most useful for estimating stature in an adult Portuguese sample, and Genovés (1967) found the femur and tibia to be the best predictors of stature in a Mesoamerican sample population. Özaslan et al. (2003) used a Turkish population to determine that measurements of leg length correlate strongly with living stature. Petrovečki et al. (2007) used radiographic measurements of the long bones of a Croatian population, adding a correction factor of two mm and found that the humerus offered the best correlation for females; the tibia provided the strongest correlation in males.

Other studies have attempted to develop population-specific linear regression formulae for stature estimation based on forearm bone length, albeit with mixed results. Athawale (1963) used an Indian population to determine regression formulae for estimating stature from the forearm bones. Athawale's (1963) study indicates a more significant linear relationship between forearm length and stature than between either of the individual forearm bones and stature. Celbis and Agritmis (2006) found that the radius and ulna correlate strongly with stature in a modern Turkish population. Their study utilized recently deceased cadavers and concluded that linear regression formulae for males and females could be used to estimate living stature. Celbis and Agritmis' (2006) study is important because it shows that measurements taken from the bones of cadavers might be just as useful as measurements taken from dried bone to estimate stature. However, a German study by Mall et al. (2001) found a weak and otherwise insignificant correlation between the forearm bones and living stature.

Some studies have attempted to correlate measurements from the vertebral column with estimates of height. Using a South Indian population, Nagesh and Kumar (2006) measured the crown-heel length of cadavers to determine cadaveric height. They measured the entire length of the vertebral column as well as each of the three sections of vertebrae. Nagesh and Kumar concluded that the total length of the vertebral column provides the best estimates of stature than other segment or combination of segments. If forensic anthropologists are only able to use one segment of the vertebral column to estimate stature, Nagesh and Kumar found that the lumbar segment is the best option. Tibbetts (1981) conducted a study to estimate stature from the vertebral column of blacks from the Terry Anatomical Collection. Tibbetts (1981) showed that measurements of the vertebral column can be helpful in reconstructing living stature, but long bones are still the best option when available.

Many studies have attempted to correlate foot length, metacarpal and metatarsal length, and other foot bone length with stature. Robbins (1986) used both footprint and foot outlines to determine that footprint length is approximately 14% of stature and closer to 15% if using the foot's outline. Giles and Vallandigham (1991) found that the direct measurement of shoeprint length and linear regression formulae are also useful in estimating stature. Measurement of shoeprint length yielded 70% accuracy. Other measurements such as shoe size, for which there are no industry standards, are less useful. Gordon and Buikstra (1992) expanded the work of Giles and Vallandigham (1991), and found that when the sample population is broken into groups by race and sex, and linear regression formulae are created for each category, shoe size and shoeprint length may be even more useful in the forensic context. Krishan and Sharma (2007) and Agnihotri et al. (2007) both found that foot length provided a high degree of correlation with living stature in a North Indian and Mauritius population, respectively.

Musgrave and Harneja (1978) measured the metacarpals from a British population and found their technique to provide a rough estimate of stature, if researchers can accept that such estimates vary from estimates provided by long bone lengths by about 3%. Meadows and Jantz (1992) used both the Terry Anatomical Collection and a modern sample to derive regression formulae for estimating stature from metacarpal length. They found that the equations for white individuals are generally better than equations for black individuals. Meadows and Jantz (1992) also found that estimates for males perform best from metacarpals 2-5.

Byers et al. (1989) took measurements of the metatarsals in an attempt to estimate stature. Using black and white males and females, they found that all metatarsal lengths correlate strongly with stature, and when either metatarsals 2 or 4 are combined with metatarsal 1, these correlations with stature are even higher. A study of black South Africans found that the calcaneous provides the highest level of accuracy of stature estimation within two standard errors of the mean (Bidmos and Asala 2005). In the absence of long bones, Bidmos and Asala (2005) concluded that this was an acceptable method for estimating stature.

Oftentimes, bones are fragmented in modern forensic cases, which makes it difficult to estimate stature. Several studies have attempted to use bone fragments to estimate long bone length and, thus, the living stature of an individual. Steele and McKern (1969) used long bone fragments from prehistoric American populations in their study. They measured the maximum lengths of the femur, humus, and tibia, and applied regression formulae to bone segment lengths. Steele and McKern found that, utilizing specific segments of the humerus, femur, and tibia, they could estimate the corresponding long bone lengths and provide a reasonable estimate of living stature. Simmons et al. (1990) revised Steele and McKern's (1969) technique. Simmons et al. (1990) used standardized landmarks on the femur which are easy to both define and locate and found that their estimates test better than Steele and McKern's. Holland (1992) used the Hamann-Todd Osteological Collection to measure a sample of black and white males and females. He took five measurements of the tibial condyles based on the known linear relationship between "stature and dimensions of the proximal end of the tibia" (Holland 1992:1225). Holland found that every attempt should be made to estimate stature from fully intact long bones, but if this is not possible, then measurements from the proximal tibia may be reliable. Similarly, Chibba and Bidmos (2006) concluded that fragmentary tibie may be useful for estimating stature in the absence of long bones.

Based on measurements of maximum skull length of a Central Indian population, Patil and Mody (2005) determined that height could be estimated from the skull using separate regression formulae for males and females. They took measurements from lateral cephalograms and adjusted the cephalograms accordingly to account for the percent of magnification from the x-rays. This technique proved highly reliable for both males and females in the sample population.

Today, this type of research is still important to the forensic sciences. With 206 bones in the human body, there are still so many new ways that stature might be estimated. Any investigations that aim to build a better and more complete biological profile may be deemed useful in the forensic context because there is always the potential for identification of a missing person based on these studies. This research aims to add to the current body of knowledge on stature estimation.

2.2 Development and Morphology of the Scapula

2.2.1 Development of the Scapula

The scapula develops in many stages both as an embryo and as an adolescent or young adult. Early research by Gardner and Gray (1943) traces the prenatal development of the human shoulder. Using a total of 65 embryos and fetuses, Gardner and Gray studied the early growth of human embryos, ranging from developmental weeks six to fifteen, because "the most significant changes could be expected to take place during the early stage of development" (1943:223). Additionally, Gardner and Gray used one or more specimens to represent each two week term from developmental week fifteen to the end of term. A fetus at developmental week six is approximately 12 mm, and a fetus at term is approximately 370 mm (Gardner and Gray 1943).

At 12 mm, a fetal scapular body is shaped like an S, and both the acromion and the coracoid processes are large relative to the body of the scapula (Gardner and Gray 1943). As the fetus continues to grow, the acromion and the coracoid remain relatively large compared with the scapular body. At 20 mm, Gardner and Gray report that the scapular spine is visible for the first time, and that the articular surface of the glenoid fossa exhibits slight concavity. The scapula begins to look like a miniature version of its adult form when the fetus reaches 22 mm (Gardner and Gray 1943; Schwartz 2007).

During fetal development and the individual's lifespan, the scapula develops from several ossification centers. During the second fetal month, ossification centers begin to appear on the scapula (Gray 1977). Scapular ossification begins with the body. The ossification center at the body of the scapula appears and extends toward the scapular spine (Gardner and Gray 1943). Shortly thereafter, this ossification center extends toward the acromion as well (Gardner and Gray 1943). At approximately the same time, the spine begins to differentiate and another center of ossification appears at the base of the coracoid process. This new ossification center will give rise to the superior portion of the glenoid fossa (Schwartz 2007).

Centers of ossification continue to appear as the fetus grows. When the fetus is approximately 95 mm in length, the inferior angle and the vertebral border of the scapula are still mostly cartilaginous (Gardner and Gray 1943). At 106 and 107 mm length, Gardner and Gray (1943:230; see also Gray 1977) noted that the presence of cartilage of the scapula "was limited to the inferior angle, vertebral border, the greater part of the head, the greater part of the acromion, and all of the coracoid process."

At birth, the same structures of the scapula described by Gardner and Gray (1943) are still cartilaginous (Gray 1977). The acromion and the coracoid processes both develop from several ossification centers. At about 15 years of age, many of the scapular ossification centers begin to fuse. The coracoid process fuses with its base at this time (Gray 1977; Schwartz 2007). Coincident with the fusion of the coracoid base is the fusion of the glenoid fossa to the scapular body (Schwartz 2007). Additionally, the medial acromial ossification center fuses, as does the vertebral border (Schwartz 2007). A few years after this major stage of scapular ossification, other structures on the scapula begin to fuse. At approximately 17-19 years of age, the coracoid base fuses to the scapular body (Gray 1977; Schwartz 2007; Stevenson 1924). A couple of years after the fusion of the coracoid base with the scapular body occurs, the acromion and the coracoid fuse completely with the scapula; about a year later, the vertebral angle completely ossifies (Gray 1977; Schwartz 2007).

The processes of scapular development and ossification are highly variable between individuals. Individuals may experience differential rates of ossification, and some individuals will never experience full fusion of the acromial process to the scapula, a condition called *os acromiale*.

2.2.2 Morphology of the Scapula

The scapulae are a pair of triangularly shaped, large, flat bones (Figure 1). Situated dorsally on the rib cage, they lie between the second rib superiorly and the seventh rib inferiorly

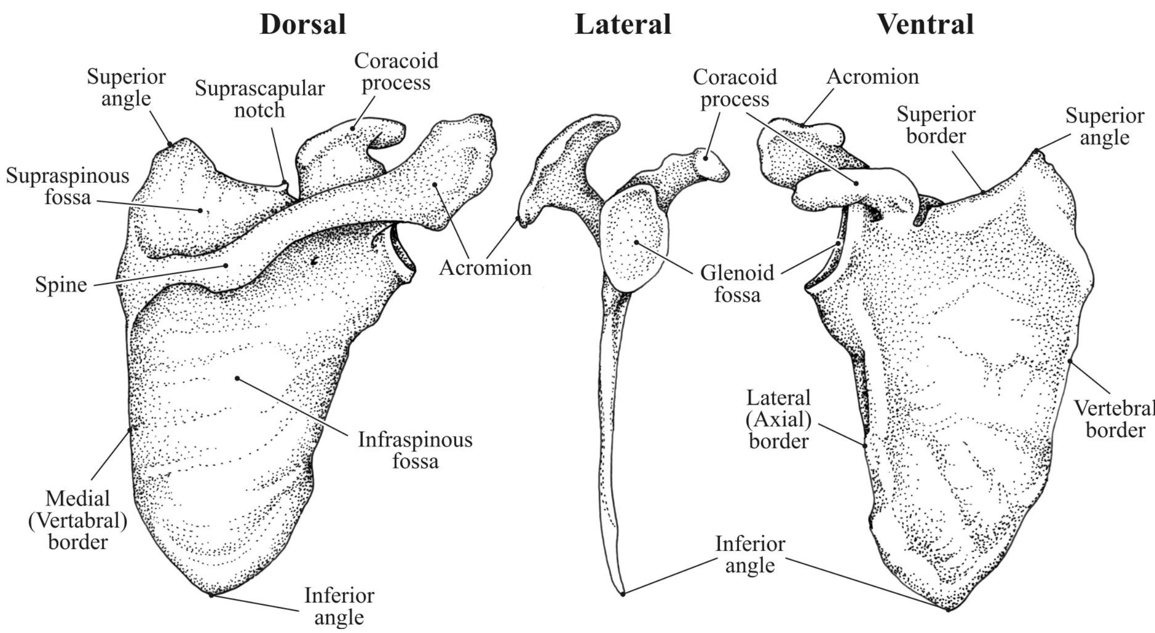

Figure 2-Dorsal, lateral, and ventral views of a right adult scapula, highlighting anatomical features. Illustration by Mary Lee Eggart, adapted from Schwartz 2007.

(Bass 1995; Marieb and Mallatt 2003). Three borders enclose the body of the scapula: the superior, medial, and lateral. The superior border is the shortest and the sharpest of the three borders and it ends at the scapular notch (Bass 1995; Marieb and Mallatt 2003). The medial border, also called the vertebral border, is the longest of the three borders, and it runs parallel to the vertebral column (Bass 1995; Marieb and Mallatt 2003). The medial border exhibits either a concave, convex, or straight pattern (Bass 1995; Dwight 1887; Graves 1921; Gray 1942; Hrdlička 1942a; Hrdlička 1942b; Hrdlička 1942c; Wolffson 1950). The lateral border is also referred to as the axillary border. The lateral border of the scapula terminates superiorly at the glenoid cavity, or fossa, and is the thickest of the three borders (Bass 1995; Marieb and Mallatt 2003).

The scapula has three angles: the lateral, superior, and inferior. The glenoid cavity is oriented at the lateral angle (Marieb and Mallatt 2003). The superior and medial borders join to create the superior angle, and the medial and lateral borders form the inferior angle (Marieb and Mallatt 2003).

Two projecting processes and the glenoid cavity of the scapula articulate with other bones. The coracoid process projects anteriorly from the superior border of the scapula and is a site of muscle attachment for the biceps muscle (Bass 1995; Marieb and Mallatt 2003). The acromion is where the spine of the scapula terminates laterally, and it articulates with the clavicle (Bass 1995; Marieb and Mallatt 2003). The glenoid cavity is the site of articulation with the head of the humerus bone (Bass 1995; Marieb and Mallatt 2003).

The suprascapular notch is located on the superior border of the scapula. Its range of variation is wide; it may not be present at all or it may be a fully formed foramen (Bass 1995; Gray 1942; Hrdlička 1942a; Hrdlička 1942b; Hrdlička 1942c). Other anatomical features of the scapula include the supraspinous and the infraspinous fossae, located superiorly and inferiorly to the spine, respectively (Marieb and Mallatt 2003).

2.3 Early Descriptive Research on the Scapula

Early research on the scapula fell broadly into the fields of general physical anthropology and anatomy and sought to observe and describe traits and variations of the bone. Many of these physical anthropologists also made weak attempts to correlate the range of variation to racial types and sex. However, their investigations were still primarily descriptive and will be treated that way in this literature review.

Much of this research on the scapula focused on the medial, or vertebral, border. The vertebral border exhibits a wide range of variation. Graves (1921) sought to describe the range of variation of the vertebral border of the scapula. Based on information from over 1000 specimens, he characterized the form of the vertebral border into three categories: concave, convex, and straight. Graves believed that the convex type was the most common, and a vertebral border that ranged from slightly to markedly convex below the scapular spine characterized this type. A straight vertebral border was straighter or more slightly concave below the scapular spine than the convex type, and this was slightly less common than a convex border. The least common border type, according to Graves, was the concave border. Slight to marked concavity below the scapular spine characterized the concave vertebral border.

After carefully examining all of his samples, Graves (1921) attempted to correlate the variations of the vertebral border of the scapula with age. He observed that the shape of the vertebral border changed as the individual aged. Graves also concluded that the shape of the vertebral border of the scapula was inherited from one generation to the next. Additionally, he noted that the same range of variation of the scapula exists in all the races that were represented in his collection.

Following Grave's (1921) classification of the vertebral border, Hrdlička (1942c) added that a fourth border may be found in place of the inferior angle, and a fifth angle may be found if the vertebral border bends laterally above the spine. Hrdlička's (1942c) research primarily showed the variations that may occur in the body, the borders, and the suprascapular notch of the scapula.

According to Byers (2005), Thomas Dwight is considered to be the first forensic anthropologist in America. Dwight's work was devoted to the study of human skeletal anatomy, including techniques for establishing a biological profile and the postmortem interval (Byers 2005). Dwight (1887) wrote one of the first papers published in America describing variation within the scapula. Rather than focusing on just one area of the scapula i.e. the vertebral border, he looked at several scapular measurements and characteristics. From over 100 scapulae, Dwight (1887) calculated the breadth and the length of each scapula, the scapular index, and the infraspinous index. Dwight (1887) found that there was considerable variation within each of these four principal measurements of the scapula.

Early researchers such as Dwight (1887) recognized a relationship between the morphology of the scapula and its function. The human scapula is long and narrow to accommodate the human need for great range of motion in the arm joint (Dwight 1887). Hrdlička also noted the relationship between form and function in the scapula. Aleš Hrdlička (1942c:85) states that, "As the scapula is almost totally dependent on the muscles which are attached to it, it seems safe to conclude from the above indications that much of the ultimate form which the body of the bone achieves is of functional nature and due to muscular activity."

Wolffson (1950) tested the hypothesis that the surrounding musculature influences the shape of the scapula. Wolffson (1950) removed all muscles that attached to the scapula of laboratory rats at birth. The rats were subsequently killed at maturation, and the scapulae were removed, cleaned, and observed. Wolffson (1950) observed that there was markedly decreased development of many of the muscle attachment sites on the scapula, most notably the reduction, and in some cases complete absence, of the scapular spine. Based on this research experiment, Wolffson (1950) concluded that Hrdlička's (1942c) assumptions were correct, and the variation of the scapula was due mainly to stress from muscle attachment sites.

Gray (1942) added to the body of work on the variation of the human scapula. Gray studied cadavers as well as Native American skeletons from burial mounds. Among other features, Gray found foramina on the scapula, costal facets, suprascapular foramina in place of the suprascapular notch, and variation within the shape of the acromion and the glenoid fossa. Interestingly, in his conclusions, Gray attributed many of these variations in features and morphology to handedness.

Hrdlička recognized that there was a lack of information in the current literature on the juvenile scapula and published research and observations of those bones (Hrdlička 1942b, 1942a). Using fetal skeletons, Hrdlička (1942b) observed that the vertebral border appeared to change from convex toward concave through the duration of gestation. In juvenile skeletons, Hrdlička (1942b) observed similar variation among the same traits that he observed in the adults that he studied. He also noted (Hrdlička 1942b) that the morphology of the adult scapula is dictated by the juvenile morphology of the scapula.

In the last of three articles published in 1942, Hrdlička, upon increased observations from even more skeletal material, attempted to correlate many of his findings on the variations of the scapula to both sex and ancestry, or more accurately, ethnicity and handedness (Hrdlička 1942c). He concluded that the scapula undergoes many changes with age, often associated with the forces that muscles exert differentially on the parts of the scapula. Hrdlička (1942c) also concluded that the sex-related differences of the scapula begin at development, and that the female scapula exhibit more juvenile characteristics throughout the lifespan.

Robert van Dongen (1963) investigated the shoulder girdle of the Australian Aborigine. Based on morphological traits such as variation of the borders, suprascapular notch, and glenoid cavity, and metric traits, such as maximum length and breadth, and glenoid length, van Dongen found that the same variation occurred among Australian Aborigines as did in other populations to which he compared his findings. He did note, however, that the overall length of the scapula was shorter in Australian Aborigines than other groups.

2.4 Use of the Scapula in Forensic Investigations

One of the first articles published on the use of the scapula in "forensic" investigations was in 1879 by Flower and Garson. Flower and Garson (1879) measured 200 adult specimens from the Museum of the Royal College of Surgeons of England. They measured three dimensions of the scapula-the breadth, length, and infraspinous length-to determine whether or not any of these measurements correlated with the ancestry of an individual. Flower and Garson's sample population subdivided the three recognized ancestral groups, Caucasoid, Mongoloid, and Negroid, into geographical and ethnic types; in some cases, only two specimens were available. Flower and Garson's results were more descriptive of the measurements of the specimens that they used, rather than providing any practical information regarding the use of the scapula to determine ancestry.

2.4.1 Age Differences of the Scapula

Several studies have explored the use of the scapula to age an individual. In his second paper on the scapula, Graves (1922) explored the changes that occur in the scapula as a result of the aging process. Graves states that age-related changes in the scapula may be divided into two categories: changes that occur due to ossification processes and changes that occur due to atrophic processes. Changes that occur due to ossification processes include marginal lipping of the glenoid and granulation, or roughening, of the scapular surface at the base of the spine. Changes that occur due to atrophic processes include loss of vascularity of the scapular surface, localized areas of bone atrophy, and distortion or pleating of the thinning infrascapular fossa. In most cases of age-related changes due to both processes, an actual timeline outlining the sequence of changes is not presented.

Stevenson (1924) investigated the sequence of epiphyseal union in an attempt to age individuals. He found that the coracoid fuses with the body no later than age 15, the acromion fuses around age 19, and the epiphyses of the inferior angle and vertebral border fuse between the ages of 19 and 22.

2.4.2 Sex Differences of the Scapula

Several studies, including some very early research in the area, attempted to correlate measurements and morphological characteristics of the scapula with sex. Dwight (1887) alluded that measurements of the scapula, specifically the overall size and glenoid cavity measurements, might be useful in determining the sex of the individual. However, at the time, he believed that this was of little value. Seven years later, Dwight investigated his hypothesis. Dwight noted several morphological differences between the male and the female scapula. He noted that the glenoid cavity and socket are smaller and narrower in females than in males, the inferior angle sharper in females, and the coracoid more delicate. He believed that an expert should be able to determine the sex of an individual from the scapula at least 80% of the time (Dwight 1894).

Bainbridge and Tarazaga (1956) published a major study on the sex differences of the scapula. Using scapulae from several archaeological populations, they observed both morphological traits and analyzed metrical data to show if sex could be determined from the scapula. They found the axillary border to be one of the more useful morphological indicators of sex. In addition to Bainbridge and Tarazaga, other researchers found that the vertebral border was not particularly useful in sexing an individual due to the influence of muscle acting upon it (Bainbridge and Tarazaga 1956; Hrdlička 1942a; Wolffson 1950). After statistical analysis based on scapular measurements, Bainbridge and Tarazaga (1956) found that, using the scapular breadth, glenoid cavity breadth, scapular length, width of the axillary border, coracoid length, and length of axillary border, they were best able to determine the sex of the individuals in their sample population.

Di Vella et al. (1994) studied the scapulae of a modern southern Italian population in order to determine sex. This study used the measurements of the maximum length, maximum breadth, maximum distance between the acromion-coracoid processes, maximum length of the acromion and the coracoid, and length and breadth of the glenoid cavity. They determined that, using a multivariate discriminant analysis, the maximum distance between the acromion-coracoid processes, maximum length of the coracoid, and the length of the glenoid cavity, it was possible to sex a skeleton with 95% accuracy.

2.4.3 Racial Differences of the Scapula

Snow (2004) investigated the usefulness of geometric morphometry analysis of the scapula in determining both ancestry and sex. This method incorporated the three-dimensional aspect of shape in its analysis and was the first application of this technique to the study of the scapula. Snow obtained mixed results from several different methods of statistical analysis in determining sex and ancestry based on the geometric morphometry of the scapula, but found that obvious differences in shape do exist between males and females, and blacks and whites.

2.4.4 Use of the Scapula in Stature Estimation

In a Chinese study, Shulin and Fangwu (1983) studied the clavicle, skull, os coxa, and scapula of 70 skeletons from South China in an attempt to determine whether measurements from these three parts of the body were reliable for estimating stature. The only measurement that they used was the breadth of the scapula. The results of Shulin and Fangwu (1983) suggest that the breadth of the scapula is not as reliable an indicator of stature as are metric indicators found on the os coxa.

Campobasso et al. (1998) used the same seven measurements (maximum length, maximum breadth, maximum distance between the acromion-coracoid processes, maximum length of the acromion and the coracoid processes, length and breadth of the glenoid cavity) as Di Vella et al. (1994) in an attempt to use regression formulae to estimate stature. Using a sample of 80 modern southern Italian adults separated by sex, Campobasso et al. (1998) found that the best linear regression formulae for predicting living height from measurements of the scapula came from the maximum breadth and width of the glenoid cavity for males, and the maximum length of the coracoid and the width of the glenoid cavity for females. Their study is significant because it shows how fragments and incomplete bone may be used to estimate height in forensic investigations.

After a review of the literature, the studies by Shulin and Fangwu (1983) and Campobasso et al. (1998) were the only published reports that I found that attempted to estimate stature from scapular measurements. Based on the findings of Campobasso et al. (1998), the current research was undertaken on an American population to determine whether or not a statistically significant relationship exists between scapular measurements and stature. Most importantly, if a significant relationship between these variables does exist, the current research attempts to provide a regression formula for forensic anthropologists to determine stature from measurements of the scapula.

CHAPTER THREE: MATERIALS AND METHODS

This research follows the methodology for estimating stature based on measurements of the scapula as outlined by Campobasso et al. (1998). Using a sample of 80 scapulae (40 male and 40 female) with no known pathologies or fractures from a modern Southern Italian population, Campobasso et al. (1998) measured the maximum length, maximum breadth, maximum acromion-coracoid distance, maximum length of the acromion, maximum length of the coracoid, length of the glenoid cavity, and width of the glenoid cavity. They found that for males the association of the maximum breadth and the maximum length of the coracoid provided the best regression formulae, and for females the association of the maximum length of the coracoid and the width of the glenoid cavity provided the best regression formulae.

The current research was conducted using human skeletal material from the Hamann-Todd Osteological Collection at the Cleveland Museum of Natural History in Cleveland, Ohio. The recorded stature measurements for each individual in the Hamann-Todd Human Collection Database are cadaveric measurements. The cadavers were held upright with ice tongs in their ears, the Achilles tendons were cut, then the cadavers were positioned with their heels touching the floor and measured (Jellema, personal communication). Following Campobasso et al. (1998), I measured and analyzed the right scapulae of these individuals. In most individuals the scapula is not fully developed until the early to mid-20s (Gray 1977; Schwartz 2007; Stevenson 1924), therefore, this sample includes only individuals between the ages of 25-65 years of age. I chose 65 years of age as an arbitrary upper-end to my sample size to ensure that age-related changes, such as lipping or other distortions of the scapula, did not interfere with my measurements. Any pathological scapulae were excluded from the sample. This sample includes 103 white males, 45 black males, 35 white females, and 40 black females. Additionally, 10 black females, 10 white females, eight black males, and nine white males were taken from the larger sample population to test the statistical formulae for estimating height based on measurements of the scapula that I derived from my statistical analysis.

Using sliding calipers with an accuracy of 1.0 mm, I obtained the same seven measurements of each sample scapula as outlined by Campobasso et al. (1998), as well as four additional measurements, for a total of 11 measurements. I also took the maximum length of the right femur of each individual in the sample with an osteometric board to obtain another estimate of height in addition to the height recorded for each individual in the Hamann-Todd Human Collection Database. Trotter and Gleser (1952) found that bones from the left and right side of the body strongly correlate. Therefore, "it is irrelevant which bone (right or left) is used in any stature calculation" (Byers 2005:261). As I took measurements from the right scapula of each individual, I also chose to measure the right femur from each individual so that the measurements came from the same side of the body. The eleven scapular measurements (Fig. 2) and the guidelines for taking them are provided as follows:

1. Maximum length of scapula (Fig. 2, pt. A-B): maximum distance from the superior angle of the scapula to the inferior angle of the scapula (Bass 1995:122).
2. Maximum breadth of scapula (Fig. 2, pt. C-D): maximum distance between the middle of the dorsal border of the glenoid fossa to the end of the spinal axis at the vertebral border (Bass 1995:122).
3. Length of scapular spine (Fig. 2, pt. D-E): distance between the spinal axis at the vertebral border to the most distal point of the acromion process (Bass 1995:122).

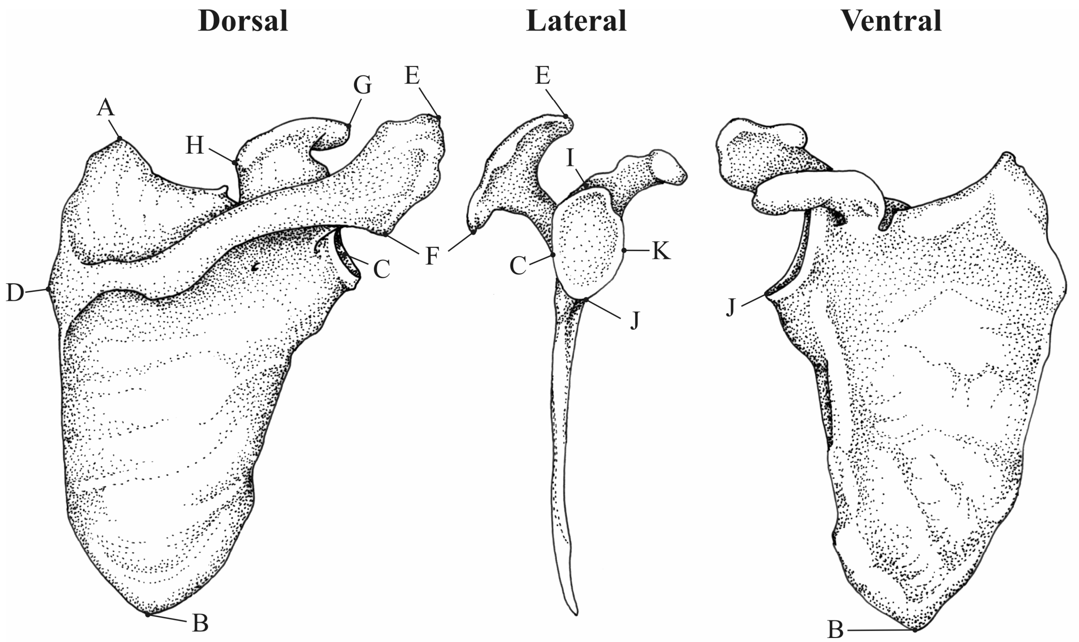

Figure 3-Dorsal, lateral, and ventral views of a right adult scapula with landmarks for measurements. Illustration by Mary Lee Eggart.

4. Length of supraspinous line (Fig. 2, pt. A-D): distance between the top of the anterior angle and the spinal axis on the vertebral border (Bass 1995:122).
5. Length of infraspinous line (Fig. 2, pt. B-D): distance between the bottom of the inferior angle and the spinal axis on the vertebral border (Bass 1995:122).
6. Maximum distance between acromion and coracoid processes (Fig. 2, pt. F-G): distance between the most dorsal point on the acromion and the most latero-ventral point on the coracoid (Campobasso et al. 1998:76).
7. Maximum length of acromion process (Fig. 2, pt. E-F): distance between the most superior point and the most inferior point on the acromion (Campobasso et al. 1998:76).
8. Maximum length of coracoid process (Fig. 2, pt. G-H): distance between the most latero-ventral point of the coracoid and the base of the most medial point of the coracoid, often just above the scapular notch (Campobasso et al. 1998:76)

9. Maximum length of glenoid fossa (Fig. 2, pt. I-J): maximum distance between the superior border and the inferior border of the glenoid fossa (Campobasso et al. 1998:76).

10. Maximum breadth of glenoid fossa (Fig. 2, pt. C-K): maximum distance between the ventral border and the dorsal border of the glenoid, usually around the midpoint of the glenoid fossa (Campobasso et al. 1998:76).

11. Length of axial border (Fig. 2, pt. B-J): distance between the most inferior point of the glenoid fossa and the bottom of the inferior angle (Bainbridge and Tarazaga 1956).

Each measurement was recorded in an Excel spreadsheet and submitted for regression analysis using SPSS (Statistical Package for the Social Sciences 15). Each of the 11 variables was considered in stepwise multiple regression analysis against both the stature measurement provided in the Hamann-Todd Human Collection Database and the mean stature estimate taken from the femur. The stature measurements in the Hamann-Todd Human Collection Database were taken by measuring the full-body length of the cadavers in the collection (İşcan 1990). This statistical analysis helped me determine relationships between measurements of the scapula and living stature and whether or not an appropriate statistical formula might be used to estimate living stature based on any scapular measurements. I compared also the stature estimates that I obtained from the scapular measurements with the stature estimates from the femur. Because several researchers have shown sex and race differences of the scapula (Bainbridge and Tarazaga 1956; Di Vella et al. 1994; Dwight 1887, 1894; Snow 2004), these differences were also considered in this research.

CHAPTER FOUR: RESULTS

4.1 Results of Multiple Regression Analysis

The goal of the current research is to provide forensic anthropologists with another means of estimating stature through linear regression formulae. This research takes into account eleven measurements (variables) from the scapula regressed against the actual recorded cadaveric stature, the dependent variable for each analysis, from the Hamann-Todd Human Collection Database (HTHCD). Table 1 shows the Pearson's Correlation coefficients for each variable with the HTHCD stature measurements. The results presented indicate a statistically significant correlation between each variable and the HTHCD stature measurement. The descriptive statistics for each variable are shown in Table 2.

Table 1. Pearson's Correlation between each Scapular Measurement and the Stature Measurement from the HTHCD

	Pearson's Correlation	P-value
Maximum Scapular Length	0.567	<0.001*
Maximum Scapular Breadth	0.581	<0.001*
Length of Scapular Spine	0.610	<0.001*
Length of Supraspinous Line	0.425	<0.001*
Length of Infraspinous Line	0.551	<0.001*
Maximum Acromion-Coracoid Distance	0.646	<0.001*
Length of Acromion	0.542	<0.001*
Length of Coracoid	0.530	<0.001*
Length of Glenoid Fossa	0.587	<0.001*
Breadth of Glenoid Fossa	0.493	<0.001*
Length of Axial Border	0.604	<0.001*

* Correlation is significant at the 0.01 level (two-tailed).

Table 2. Descriptive Statistics for Total Sample Population and All Variables[a]

Variable	N[b]	Minimum	Maximum	Mean	Std. Deviation
Stature from Hamann-Todd Database	223	137.10	190.20	168.2112	8.93790
Maximum Scapular Length	223	10.00	18.5	15.5448	1.36799
Maximum Scapular Breadth	223	8.50	12.50	10.2426	0.77780
Length of Scapular Spine	223	10.70	16.30	13.6803	1.04186
Length of Supraspinous Line	223	3.80	7.0	5.3206	0.65211
Length of Infraspinous Line	223	8.80	14.20	11.5803	1.12877
Maximum Acromion-Coracoid Distance	223	5.50	9.90	7.4928	0.73585
Length of Acromion	223	3.30	7.20	4.7888	0.61124
Length of Coracoid	223	3.10	5.80	4.4650	0.46415
Length of Glenoid Fossa	223	3.20	4.8	3.9565	0.35316
Breadth of Glenoid Fossa	223	2.10	4.60	2.8112	0.31880
Length of Axial Border	223	11.00	15.80	13.4937	1.06613

a. Measurements shown in cm.
b. Sample includes a total of 75 females and 148 males and a total of 85 blacks and 138 whites.

Stepwise multiple regression analysis was performed first for all specimens (N=223) in the test sample. This analysis included each of the 11 variables regressed against the cadaveric stature measurement from the HTHCD. The results of this analysis are presented in Tables 3-6.

Table 3 shows each of the variables entered and removed through three models. No variables were removed, and the variables entered in each of the three models were the maximum acromion-coracoid distance, the length of the scapular spine, and the length of the axial border. Table 4 confirms that these three variables combined contribute significantly to stature (R=0.690) and the ANOVA table presented in Table 5 also shows that at least one of these variables contributes to stature at a level of significance α=0.05. Table 6 provides both the unstandardized and standardized coefficients for these variables. No standardized coefficient is given for the constant. The standardized coefficients, show the relative contribution of each variable, with the maximum acromion-coracoid distance contributing the most to stature (β=0.371), followed by the length of the scapular spine (β=0.224) and the length of the axial border (β=0.166). Unstandardized coefficients are standardized by the z score, which provides a normal distribution curve with a mean of zero and a standard deviation of one. Based on Table 6, the resulting regression formula is equation 1:

Stature = 89.36 + 4.51(maximum acromion-coracoid distance) + 1.92(length of scapular spine) + 1.39(length of axial border).

Table 3. Multiple Regression for All Specimens and All Variables[a] Without Sex or Race

Model	Variables Entered	Variables Removed	Method
1	Maximum Acromion-Coracoid Distance	--	Stepwise*
2	Length of Scapular Spine	--	Stepwise*
3	Length of Axial Border	--	Stepwise*

a. Dependent Variable: Stature Measurement from HTHCD
* probability of F to enter ≤0.05, probability of F to remove ≥0.10

Table 4. Model 3 Summary of Multiple Regression for All Specimens Without Sex or Race

R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
.690[a]	.477	.470	6.50946	.009	3.941	1	219	.048

a. Predictors: (Constant), Maximum Acromion-Coracoid Distance, Length of Scapular Spine, Length of Axial Border

Table 5. Model 3 ANOVA Table of Multiple Regression for All Specimens Without Sex or Race

	Sum of Squares	df	Mean Square	F	Sig.
Regression	8455.032	3	2818.344	66.513	<0.001[b]
Residual	9579.690	219	42.373		
Total	17734.722	222			

a. Predictors: (Constant), Maximum Acromion-Coracoid Distance, Length of Scapular Spine, Length of Axial Border

Table 6. Model 3 Coefficients of Multiple Regression for All Specimens Without Sex or Race

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% C.I. for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
Constant	89.361	6.011	--	14.865	.000	77.513	101.208
Maximum Acromion-Coracoid Distance	4.510	.899	.371	5.018	.000	2.739	6.282
Length of Scapular Spine	1.925	.695	.224	2.770	.006	.555	3.294
Length of Axial Border	1.387	.699	.166	1.985	.048	.010	2.765

Stepwise multiple regression analysis was also performed for all specimens in the sample (N=223) with each of the 11 variables as well as sex and race as dummy variables. Sex and race were included in this second analysis in order to determine what effect, if any, they had on the estimation of stature. Tables 7-10 show the results of this regression analysis. Table 7 shows that the maximum acromion-coracoid distance, the length of the scapular spine, race, and the length of the infraspinous line significantly contribute to stature. Because race provides a significant contribution to stature, additional regression analyses were performed for both black and white subsets and regression formulae were calculated based on the results. Table 8 provides the summary for Model 4, showing the level of significance (R=0.700) that the four variables contribute to stature. The Analysis of Variance (ANOVA) table for Model 4 is presented in Table 9 and shows that one or more of these variables is a significant ($\alpha<0.05$) predictor of stature in this analysis. Table 10 reflects that the maximum distance between the acromion and coracoid has the most influence on stature ($\beta=0.338$), followed by the length of the scapular spine ($\beta=0.258$), the length of the infraspinous line ($\beta=0.198$), and race ($\beta=0.154$), each with a level of significance $\alpha<0.05$. Race was coded as 0 for whites and 1 for blacks in the regression analysis.

Table 7. Multiple Regression for All Specimens and All Variables Including Sex and Race

Model	Variables Entered	Variables Removed	Method
1	Maximum Acromion-Coracoid Distance	--	Stepwise*
2	Length of Scapular Spine	--	Stepwise*
3	Race	--	Stepwise*
4	Length of Infraspinous Line	--	Stepwise*

* probability of F to enter ≤ 0.05, probability of F to remove ≥ 0.10

Table 8. Model 4 Summary of Multiple Regression for All Specimens[a] Including Sex and Race

				Change Statistics				
R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
.700[b]	.490	.480	6.45613	.017	7.261	1	219	.008

a. Dependent Variable: Stature Measurement from HTHCD
b. Predictors: (Constant), Maximum Acromion-Coracoid Distance, Length of Scapular Spine, Race, Length of Infraspinous Line

Table 9. Model 4 ANOVA Table of Multiple Regression for All Specimens Including Sex and Race

	Sum of Squares	df	Mean Square	F	Sig.
Regression	8754.347	4	2188.587	52.507	<0.001[a]
Residual	9128.278	219	41.682		
Total	17882.625	223			

a. Predictors: (Constant), Maximum Acromion-Coracoid Distance, Length of Scapular Spine, Race, Length of Infraspinous Line

Table 10. Model 4 Coefficients of Multiple Regression for All Specimens Including Sex and Race

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% C.I. for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
Constant	87.626	5.942	--	14.748	.000	75.916	99.337
Maximum Acromion-Coracoid Distance	4.116	.966	.338	4.260	.000	2.212	6.021
Length of Scapular Spine	2.226	.595	.258	3.740	.000	1.053	3.399
Race	2.828	.937	.154	3.019	.003	.982	4.675
Length of Infraspinous Line	1.577	.585	.198	2.695	.008	.423	2.730

The results of regression analysis including all 11 variables for all black individuals in the sample population (N=85) are provided in Tables 11-14. Tables 11 and 12 show that two variables, the length of the axial border and the length of the coracoid, significantly contribute to stature (R=0.691). The ANOVA table presented in Table 13 confirms that in this combination of variables, at least one variable significantly ($\alpha<0.05$) contributes to the stature estimate. Table 14 shows that the length of the axial border has the most influence on predicting stature in black individuals (β=0.429), and the length of the coracoid slightly less (β=0.326). The regression formula from this analysis is equation 2:

Stature = 92.55 + 3.58(length of axial border) + 6.67(length of coracoid).

Table 11. Multiple Regression for Blacks and All Variables

Model	Variables Entered	Variables Removed	Method
1	Length of Axial Border	--	Stepwise*
2	Length of Coracoid	--	Stepwise*

* probability of F to enter ≤ 0.05, probability of F to remove ≥ 0.10

Table 12. Model 2 Summary of Multiple Regression for Blacks

				Change Statistics				
R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
.691[a]	.477	.465	6.809356	.058	9.140	1	82	.003

a. Predictors: (Constant), Length of Axial Border, Length of Coracoid

Table 13. Model 2 ANOVA Table of Multiple Regression for Blacks

	Sum of Squares	df	Mean Square	F	Sig.
Regression	3472.283	2	1736.142	37.443	<0.001[a]
Residual	3802.121	82	46.367	--	--
Total	7274.404	84	--	--	--

a. Predictors: (Constant), Length of Axial Border, Length of Coracoid

Table 14. Model 2 Coefficients of Multiple Regression for Blacks

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% C.I. for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
Constant	92.551	9.004	--	10.279	.000	74.639	110.464
Length of Axial Border	3.585	.900	.429	3.982	.000	1.794	5.376
Length of Coracoid	6.674	2.208	.326	3.023	.003	2.282	11.066

Tables 15-18 show the results of regression analysis that include all variables in predicting stature for whites (N=138). The maximum acromion-coracoid distance and the maximum scapular breadth are the two variables that contribute the most when predicting the stature of white individuals (R=0.724) (Tables 15 and 16). Table 17 provides the ANOVA table for this regression, which confirms the results of Tables 15 and 16, showing that these variables significantly ($\alpha<0.05$) contribute to stature. The maximum acromion-coracoid distance contributes the most to stature (β=0.493), and the maximum scapular breadth contributes less (β=0.297) at a level of significance α<0.05 (Table 18). The regression formula derived from this analysis (Table 18) of whites is equation 3:

Stature = 88.50 + 5.76(maximum acromion-coracoid distance) + 3.50(maximum scapular breadth).

Table 15. Multiple Regression for Whites and All Variables

Model	Variables Entered	Variables Removed	Method
1	Maximum Acromion-Coracoid Distance	--	Stepwise*
2	Maximum Scapular Breadth	--	Stepwise*

* probability of F to enter ≤ 0.05, probability of F to remove ≥ 0.10

Table 16. Model 2 Summary of Multiple Regression for Whites[a]

				Change Statistics				
R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
.724[b]	.524	.517	6.065638	.050	14.215	1	135	<0.001

a. Dependent Variable: Stature Measurement from HTHCD
b. Predictors: (Constant), Maximum Acromion-Coracoid Distance, Maximum Scapular Breadth

Table 17. Model 2 ANOVA Table of Multiple Regression for Whites[a]

	Sum of Squares	df	Mean Square	F	Sig.
Regression	5464.716	2	2732.356	74.265	<0.001 [b]
Residual	4966.915	135	36.792	--	--
Total	10431.628	137	--	--	--

a. Dependent Variable: Stature Measurement from HTHCD
b. Predictors: (Constant), Maximum Acromion-Coracoid Distance, Maximum Scapular Breadth

Table 18. Model 2 Coefficients of Multiple Regression for Whites

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% C.I. for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
Constant	88.502	7.223	--	12.23	.000	74.218	102.789
Maximum Acromion-Coracoid Distance	5.761	.919	.493	6.267	.000	3.943	7.579
Maximum Scapular Breadth	3.502	.929	.297	3.770	.000	1.665	5.340

4.2 Application of Regression Formulae to the Estimation of Stature

Regression formulae resulting from multiple regression analysis were applied to a test sample (N=37) in order to determine their accuracy in predicting stature. In a forensic investigation, the stature estimate is provided as a range. Byers (2005) states that an estimate interval for stature based on the confidence interval is more accurate than an interval based on the standard error, a more unreliable method often used in regression formulae (see also Ousley 1995). For these reasons, a prediction interval for estimating stature from measurements of the scapula was calculated using the corresponding confidence interval.

Table 19 shows the results of the regression formula (Equation 1) based on all 11 variables for all specimens when applied to the test sample. The actual stature measurement provided in the HTHCD fell into the prediction interval 27% of the time, and 73% of the time the prediction interval did not include the stature measurement. Of this 73% of inaccuracy, 33% of the time the prediction interval overestimated stature, and 66% of the time the interval underestimated stature. Table 20 presents the results of the regression formulae (Equations 2 & 3) applied to the test sample when separated by race. Though race might be undeterminable in the forensic context, in the event that an individual's race is determined, the accuracy of stature estimation increases. For blacks, the regression formula based on the length of the axial border

Table 19. Accuracy of Regression Formula (Equation 1) (not Including Sex or Race) Applied to Test Sample[a]

Percent of cases outside the prediction interval	73%
Percent of cases inside the prediction interval	27%
Percent of time the prediction interval overestimated measurement	33%
Percent of time the prediction interval underestimated measurement	66%

a. N=37

Table 20. Accuracy of Regression Formula Applied to Black and White Test Sample

	Black Test Sample[a] N=18	White Test Sample[b] N=19
Percent of cases outside the prediction interval	50%	64%
Percent of cases inside the prediction interval	50%	36%
Percent of time the prediction interval overestimated measurement	66%	25%
Percent of tie the prediction interval underestimated measurement	34%	75%

a. variables: length of axial border and length of coracoid
b. variables: maximum acromion-coracoid distance and maximum scapular breadth

and the length of the coracoid provides a prediction interval with an accuracy of 50%. When inaccurate, the formula overestimates stature 66% of the time and underestimates stature 34% of the time. The regression formula for whites based on the maximum acromion-coracoid distance and the maximum scapular breadth are accurate 36% of the time. When the formula is inaccurate, stature is underestimated 75% of the time.

Table 21 presents the accuracy of the stature estimate derived from the maximum length of the femur when compared with the cadaveric measurement provided in the HTHCD. Using the regression formulae for black and white males and females provided by Trotter and Gleser (1970), I obtained the estimate of living stature from the maximum length of the femur.

Table 21. Accuracy of Stature Estimate from the Femur

	Black Test Sample[a]	White Test Sample[b]
Percent of cases outside the prediction interval	71%	42%
Percent of cases inside the prediction interval	39%	58%
Percent of time the prediction interval overestimated measurement	0%	0%
Percent of tie the prediction interval underestimated measurement	100%	100%

a. N=18
b. N=19

Additionally, I calculated the prediction range using the standard errors as provided by Trotter and Gleser. I used the standard errors to create the prediction range rather than the confidence interval because Trotter and Gleser's method is most often used in forensic anthropology. The results shown in Table 21 indicate that the traditional method of estimating stature from the femur is about as reliable as the scapula for blacks and whites

CHAPTER FIVE: DISCUSSION AND CONCLUSIONS

This researcher hypothesized that a statistically significant relationship exists between one or more variables of the scapula and living stature. The current research shows that several variables are important for estimating stature from the scapula. These variables include the length of the scapular spine, the maximum acromion-coracoid distance, the length of the axial border, the length of the coracoid, and the maximum scapular breadth. Additionally, when sex and race are included as dummy variables in regression analysis, race becomes a significant influence on stature, but sex does not. Several studies have shown that sex differences of the scapula do exist (Bainbridge and Tarazaga 1956; Di Vella et al. 1994; Dwight 1887, 1894; Snow 2004). Therefore, the fact that sex did not significantly influence stature was surprising. However, most of these studies used non-metric traits of the scapula, whereas the present research solely relied on metric traits.

Of the 11 scapular measurements considered, this research found that six measurements provided no significant contribution to stature. These findings are somewhat contrary to those of Campobasso et al. (1998). Their research found that measurements of the maximum scapular breadth and the length of the coracoid provided the best regression formulae for males, and the length of the coracoid and the breadth of the glenoid fossa were the most useful for predicting the stature of females. Both studies found the length of the coracoid and the maximum scapular breadth significant in predicting stature, but the present research did not find the breadth of the glenoid fossa to contribute meaningfully to stature. This research used an American sample, and populational differences in features of the scapula might help to explain why Campobasso et al. (1998) found different scapular measurements more useful in estimating stature than the present research. Researchers have found a strong relationship between the form and function of the scapula (Dwight 1887; Hrdlička 1942c; Wolffson 1950). Therefore, individual variation in the surrounding musculature and muscle attachments likely influences differentially the anatomical features of the scapula. These individual variations might explain why the scapula is only reliable for predicting stature a relatively small percent of the time.

Campobasso et al. (1998:80) state that the scapula "can be reliably employed for the estimation of stature in forensic practice," but their study does not quantify this level of accuracy. In an attempt to determine to what level measurements of the scapula may be reliably employed to estimate stature, the current research found that when race and sex are unknown the stature estimate intervals accurately predicted stature 27% of the time. When race, a significant variable in estimating stature, was known, stature estimates for blacks could be reliably employed 50% of the time and, for whites, 36% of the time.

This study failed to determine any highly accurate regression formulae for estimating stature based on scapular measurements. Despite this low level of accuracy, however, this study also showed that stature estimates based on scapular measurements were nearly as reliable as stature estimates from the femur. This type of research is still important within forensic anthropology. In the absence of intact long bones, which are most commonly used for estimating stature, and the fact that mass disasters often leave only bone fragments and commingled remains, new methods for estimating stature must continue to be developed and tested. To this end, the current research is the only known study of its kind undertaken on an American population. Further research in this area, particularly on different populations throughout the world, will continue to provide valuable information for forensic anthropologists to aid in constructing the biological profile.

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VITA

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