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A comparison in osteological measurements of two populations from East Tennessee

Corrine Vitek

University of Tennessee at Chattanooga

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A Comparison in Osteological Measurements of Two Populations from East Tennessee

by
Corrine Vitek

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The University of Tennessee at Chattanooga
Department of Anthropology

Project Director: Thomas Bodkin
Examination Date: March 28, 2005
Thomas Bodkin
Dr. Nicholas Honerkamp
Dr. Zibin Guo
Dr. John Lynch

Examining Committee Signatures:

[redacted]
Project Director

[redacted]
Department Examiner

[redacted]
Department Examiner

[redacted]
Liaison, Departmental Honors Committee

[redacted]
Chairperson, University Departmental Honors Committee

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ABSTRACT

Forensic anthropology is the identification of skeletal remains in medicolegal death investigations. The foundation of forensic anthropology rests on "documented" skeletal collections, which provide a crucial repository of information from which experts can rely upon to make determinations about human skeletal remains. A "documented" skeletal collection is one in which the demographics (e.g., ancestry, sex, age, height) of each individual are supported by known facts about the decedent at the time of his/her death. A quantitative comparison between the Hamilton County Forensic Center's (HCFC) skeletal collection to the William M. Bass collection housed at the University of Tennessee at Knoxville (UTK) Department of Anthropology was conducted, using a statistical analysis of 17 skeletal measurements. The purpose of this study was to determine if the HCFC skeletal collection possessed an adequate representative sample population for future quantitative studies, whether used by itself or in conjunction with other skeletal collections.

INTRODUCTION

In the last century, the need to determine and assess the characteristics of the human skeleton brought about the rise of forensic anthropology. Applied forensic anthropology has long been involved with the research of human skeletal material identification techniques crucial in law enforcement investigations. Central to this research is the availability of documented skeletal series, or collections, of which age, race, gender, and stature of the individuals within are all known. Human skeletal variation is so wide that it can only be captured in large samples of known individuals of a population. This study is the comparison of two skeletal samples from East Tennessee that currently are used to establish forensic anthropology techniques: the Hamilton County Forensic Center Collection of Chattanooga, Tennessee and the William M. Bass Donated Skeletal Collection of the University of Tennessee at Knoxville. These large samples, or documented skeletal collections, are the primary source of skeletal biology research in Tennessee and the surrounding area. Due to the geographical proximity of these collections to each other, the hypothesis of this study is that there are no significant differences between the two samples. This will validate the HCFC sample as a viable source of skeletal material and an important research tool. If this hypothesis is accepted, then future forensic anthropology researchers can use both collections together or independently with greater confidence.

In order to understand the importance of forensic anthropology, it is necessary to first define it. Forensic anthropology is a specialty discipline combining biological anthropology and archaeology. Biological, or physical, anthropology is the study of human evolution and human variation with emphasis on skeletal biology. Archaeology is the study of past cultures based on their material remains. Both subfields are part of anthropology, which also includes the subfields of cultural anthropology and linguistics. While physical anthropology is the study of normal variation in the skeleton, forensic anthropology explores how external factors affect the skeleton, emphasizing the individual variation across populations (Işcan 1988). In forensic anthropology, archaeology and biological anthropology converge in the medicolegal setting. Archaeological techniques are used to recover human remains and other evidence from the field in a controlled manner, while the biological anthropologist's detailed knowledge of human skeleton variation leads to the identification of the remains. The primary goal of forensic anthropology is the identification of individuals who are no longer recognizable, for example from severe burning, decomposition, or skeletonization (Rhine 1998). Usually, these alterations are done with criminal intent to hide the person's identity or to destroy evidence. In recent years, especially since the O. J. Simpson trial, all the forensic sciences have come under scrutiny by the legal system, which demands that techniques introduced into court be grounded more in science than on the experience level of the expert witness (Nowicki and Bright 2004). This phenomenon has crossed over into other disciplines and goes by the phrase "evidence-based practice." Forensic anthropology is no different, but its techniques are only as good as the skeletal collections from which they are created. Forensic anthropologists must quantify their observations in the form of metric skeletal measurements that lend themselves to replication and tend to be independent of observer experience.

Historical Overview.

Tracing the history of forensic anthropology allows some insight into its importance in medicolegal investigations as well as the importance of skeletal collections to the field. Forensic anthropology is a recent addition to anthropology, and primarily an American endeavor with around 200 practitioners in 1994 (Işçan and Erksin 1994) and about 270 today (personal communication with Tom Bodkin, April 5, 2005). Tracing its development through the last century can be accomplished by categorizing development through three distinct phases: the Formative Period (pre-1939), the Consolidation Period (1939 - 1972), and the Modern Period (1972 - the present) (Thompson 1982).

The Formative Period actually began before the turn of the 20th century with a sparked interest in anatomical studies. Work by a nineteenth century anatomist, Thomas Dwight, marks the most distinct origins of the field. Holding the title of "The Father of Forensic Anthropology," Dwight was an anatomist interested not only in human skeletal biology but more specifically in human skeletal variation (Stewart 1978). Dwight, and those who followed after, concerned themselves with the documentation of variation between individuals, but not the identification of unknown individuals. It was this shift from basic anatomy to individualized study of variation, nevertheless, that gives the research a decidedly anthropological nature (Rhine 1998). In these earliest years, anatomy departments became the primary contributors and major training centers in skeletal biology as well as biological anthropology (Thompson 1982). Much of the data, methods, and skeletons used during this period are still considered valid today, attesting to the longstanding significance of this research. At the time, the two major centers of anatomy in the United States were Case Western Reserve University in Cleveland, Ohio and Washington University in St. Louis, Missouri. Both of these institutions would soon become the sites of significant skeletal documentation, amassing two distinctive skeletal series.

The publication of W.M. Krogman's 1939 article, "Guide to the Identification of Human Skeletal Material," in the *FBI Law Enforcement Bulletin* ushered in the Consolidation Period of forensic anthropology. Krogman's publication is the origin of many techniques determining age, sex, and race for skeletal material still used today (Rhine 1998). This was the turning point in forensic anthropology, as it marks the source of the field's anthropological association with medicolegal identification (Thompson 1982). During this period, the potential for human identification from skeletal remains became apparent, especially for the U.S. Military. At the end of the Second World War, the need to identify the growing number of war dead became glaringly apparent and Krogman's 1939 article soon became the working manual for the field. In 1947, Charles E. Snow was enlisted as chief physical anthropologist for the establishment of the U.S. Army's Central Identification Laboratory (CIL), in Honolulu, Hawaii (Snow 1948). A year later, Mildred Trotter, from the Department of Anatomy at Washington University, would take over for Snow. During her time at CIL, Trotter used long-bone measurements from the skeletons of the war dead to generate new regression equations for the estimation of stature (Trotter and Gleser 1952; Thompson 1982). In that same year, 1948, the annual meeting for the American Association of Physical Anthropology included a symposium for the application of physical anthropology that contained four major papers describing how anthropology could contribute to medicolegal investigations. Krogman expanded his 1939 article into a text published in 1962, *The Human Skeleton in Forensic Medicine*. A compilation of methods, techniques and case studies for the field, this book would become the first forensic anthropology textbook (Işcan and Erksin 1994).

The association between forensic anthropology and the military would not end with WWII. In 1953, the end of the Korean War, the second major anthropological involvement in war dead identification began (Thompson 1982). The work of Ellis R. Kerley and Charles C. Warren was instrumental in the identification of the American soldiers lost in the conflict overseas, as they worked primarily in identification facilities in Japan. Concurrently, T. Dale Stewart was also enlisted by the Memorial Division of the Office of the Quartermaster General for consultation on the identification of the war dead (Ubelaker 2000). Later his work primarily became the investigation into age changes reflected in the skeleton, using American war dead as a primary source of material. What makes this study of historical interest is that Stewart's skeletal sample was composed of known individuals and represented a healthy, well-fed population, in contrast to past studies that primarily used samples of aged individuals with serious medical conditions (Thompson 1982). Stewart published his findings in a joint paper with Thomas W. McKern (1957), which set new standards in research for understanding skeleton maturation and human variation between individuals (Rhine 1998). The Vietnam Conflict of the late 1960's again provided the opportunity for anthropologists to lend their expertise to the identification of human remains. Realizing the potential of forensic anthropology and the need to maintain standardization of techniques, the military funded a symposium for practitioners in the field (Thompson 1982). Held in December of 1968 and organized by T.D. Stewart at the Smithsonian, this symposium brought together many experts of the field (e.g., McKern, Kerley, Trotter, Steele, Stewart) to discuss the developing techniques of the field, including the determinations of sex, age, stature, and race. The involvement of forensic anthropology with military affairs during the Consolidation Period created a relationship from which both parties benefited. In fact, the majority of development in forensic anthropology can be directly attributed to the support of the U.S. Army (Stewart 1979).

It is likely that the military involvement aided in lending legitimacy to the quickly growing field of forensic anthropology. This legitimacy was certified in 1972 with the establishment of the Physical Anthropology section as part of the American Academy of Forensics with 14 charter members (Işçan and Erksin 1994). It is with this sectional founding that the Modern Period of forensic anthropology began. Prior to this date, forensic anthropology had been shuffled into the Pathology-Biology section and, although it was already unofficially recognized as separate from this division, the founding of the section in 1972 presented a formal awareness of the field (Thompson 1982). In 1978, the American Board of Forensic Anthropology was established to add a formal certification to practitioners of the science. This move was intended to set up standards of practice in this relatively new field of science. Since that time, the role of the forensic anthropologist has shifted from merely advisory status to the authority in the identification of human skeletal remains (Işçan 1988).

In 1971, William M. Bass, previously from the University of Kansas and a student of Krogman, became chairman of the forensic anthropology program at the University of Tennessee at Knoxville (UTK). Bass made quick progress at the University, being among the leaders in the nation's forensic anthropology educational programs. He effectively created a "beehive of forensic activity in Tennessee" (Rhine 1998) with the advent of the Anthropology Research Facility, or "Body Farm" in 1981, which exists despite his retirement in the early 90's. In 1984, UTK became home to the Forensic Data Bank, a computerized database of skeletal measurements involved in forensic investigations to be used for research in the identification procedures for skeletal material (Jantz and Moore-Jansen 1988).

Forensic anthropology is beginning to become a global endeavor in this period as more nations form their own institutions to research their native populations. Turkey has begun assessing population specific standards for estimation techniques in age and sex (Işcan and Erikson 1994). Japan has begun assessing the variation in the effects of aging on skeletal material, focusing their endeavors in cross-population comparisons (Bass 1979). The Modern Period is also marked by branching out the field's areas of expertise. No longer are determining age, sex, race, and stature the limits. Today, forensic anthropologists engage in such tasks as bone trauma analysis, facial reconstructions from the skull, and even calculating elapsed time since death (Reichs 1992).

Forensic anthropologists are now utilized by law enforcement officers, coroners, and medical examiners (Reichs 1992). The context of the field has grown substantially from its roots in anatomical study of the 1800's. Forensic anthropology is more than just applied osteology, it is the "discovery, recovery, and analysis of human remains in a medicolegal context" (Rhine 1998). Skeletal material that possesses medicolegal significance presents the possibility that further legal implications regarding the remains may be present. Forensic anthropologists are frequently contacted by authorities for their expertise in identifying and analyzing the remains of the victims of violent crimes. Thus, forensic anthropologists are not only trained to be familiar with the hard tissues of the bone and the implications skeletal structures present in determining the identity of victims, but also have added responsibilities in aiding law enforcement officials, medical authorities, and legal representatives, such as preserving chain of custody from the field to the lab to the court room (Bass and Driscoll 1983). With the specialization of forensic anthropology, it is no surprise that the practitioners get a wide variety of interesting and unique cases that often fall outside the area of normal investigations. Therefore, it is imperative for methods of forensic anthropologists to possess an objective, scientific foundation for osteological knowledge relevant to the field.

Skeletal Collections.

The foundation of forensic anthropology rests on documented skeletal collections that provide a crucial bank of information from which experts can rely upon to make determinations about human skeletal remains. A *documented* skeletal collection is one in which the demographics (e.g., ancestry, sex, age, height) of each individual are supported by known facts about the decedent at the time of his/her death. The documentation of skeletal materials is arguably the most important part of forensic anthropology (Işcan 2005). It is through this documentation that forensic anthropologists can be definite in the knowledge of bones. Skeletal collections create a unique synthesis of general population and specific personal biology by combining the opportunity for statistical analysis with case studies. This is not to say that there can be nothing drawn from an unknown skeleton, especially when archaeologists base most of their knowledge of prehistoric cultures on skeletal remains that have no written documentation (Rhine 1998).

It is from these collections that a valuable research asset is gained. Data generated from studies of documented skeletal collections can prove vital in the production of techniques which are used in the estimation of age, sex, race, or stature of an unknown individual (Bass and Jefferson 2003). Skeletal collections are the best source of known osteological data for the human skeleton and human skeletal variation, as each individual in a collection can be considered a case study. Therefore, logic dictates that the larger and more demographically diverse the collection, the more variation.

In the Formative Period, as previously discussed, most work in skeletal biology was done by anatomists (Thompson 1982). As such, the first skeletal collection of merit in the United States was the work of anatomists. A joint effort between two of these anatomists, Carl August Hamann and T. Wingate Todd, the Hamann-Todd Collection was begun in 1893 with the work of Hamann in the anatomy department of Case Western Reserve University Medical School in Ohio. It was later continued by his successor, Todd. From 1893 to 1938, the collection grew to more than 3,000 human skeletons, most of which were medical school cadaver dissections with documentation (Jones-Kern and Latimer 2002). After the deaths of the two originators, the collection unfortunately fell into disrepair and was effectively lost on campus until the 1950's. It was rediscovered and is now housed at the Cleveland Museum of Natural History where it immediately became an important anatomical research tool. Since that time, it has become one of the most famous osteological collections and, even today, is one of the most studied skeletal collections in the world (Travis 2004).

At the cusp of the Consolidation Period in forensic anthropology, Robert Terry began amassing human skeletons from anatomy class cadavers at the Washington University Medical School with the intention of creating a base for research on the skeleton (Hunt 2004). This group of over 1,600 individual skeletons was collected in St. Louis, Missouri. Although he wasn't the first to begin such an endeavor, the Terry

Collection was the first to gain legitimacy as a research tool in osteology. Terry created a uniform system of collecting and cataloging the collection, lending legitimacy and credibility to his work. Although he began his work in the late 1920's, most of the skeletons in the collection date to just before the Second World War (Rhine 1998). The collection itself is now housed in the Smithsonian, where it is still used in research applications.

It is impossible to discount the significance of these two impressive collections but, as they are of the Formative and Consolidation Periods, they are of more historical importance than for modern forensic uses. These documented skeletal collections present the "opportunity to look into the window of the past" but can give researchers outdated information when used as a basis for statistical analysis (Rhine 1998). For example, the average adult human male is about two inches taller today compared to a century ago (Rhine 1998; Meadows and Jantz 1995). If researchers compare modern remains with out-of-date skeletal material, the possibility for error in estimation in stature and age drastically increases (Bass and Jefferson 2003). The need for an extensive modern documented skeletal collection was keenly felt by researchers of the late twentieth century (Bass 1979), as well as the need for samples representing populations outside of Cleveland, Ohio and St. Louis, Missouri.

In May of 1981, William Bass began work on what would soon be known colloquially as "The Body Farm" (Cornwell 1995), or more professionally as the Anthropology Research Facility at the University of Tennessee at Knoxville (UTK). The purpose of this facility was to research the decomposition rates of human tissue under a variety of postmortem circumstances (Mann, et al. 1990). Following the study of decay rates, each skeleton was cleaned and curated in perpetuity. This on-going research process has resulted in the extensive documented collection of modern skeletons Bass had been planning for years (Bass and Jefferson 2003). The purpose of this collection would be to fill the need for a Modern Period collection which would provide ample research material for professionals and students in the field.

Today, there are two osteological collections housed at UTK: the William M. Bass Forensic Skeletal Collection and the William M. Bass Donated Skeletal Collection. The Forensic Skeletal Collection is the precursor to the Donated Skeletal Collection, the former being comprised of over 300 cases, and is ideal for the study of ante- and perimortem trauma to the skeleton, including blunt force trauma and sharp force injury such as stabbings (Caswell 2004). Unfortunately, a relatively small number of these are complete or have been positively identified, leaving the majority of the individuals represented undocumented and therefore difficult to use in quantitative analysis. The Donated Skeletal Collection consists of more than 400 individuals (Caswell 2004), donated from various parts of the United States with the larger portion coming from the surrounding Tennessee area. The collection is composed primarily of Americans of European and African ancestry, with a smaller population of Hispanic descent. Individuals represented in the Donated Collection range in age from fetal to over one hundred years old (Caswell 2004).

One of the most important purposes these collections serve for UTK is that of education. Physical anthropology students, particularly those specializing in forensic studies, face enormous challenges in learning the variability of human skeletons. Human variation is the rule and not the exception; osteology education can only be accomplished by handling large numbers of skeletons (Bass and Jefferson 2003).

This is not to say that UTK houses the only Modern Period skeletal collection in the United States, as more educational institutions have begun forming their own collections. This accumulation of documented skeletons from different geographic regions has added to a balanced basis for comparison among populations, providing new opportunities for future research. The Maxwell Museum of Anthropology, part of the University of New Mexico, established its own skeletal collection in 1984. It has been used in recent years in association with the Office of the Medical Examiner and includes many cases of medicolegal interest. This collection includes approximately 235 known individuals and is the largest documented modern osteological collection in the western United States (Edgar 2004).

The Hamilton County Forensic Center (HCFC) in Chattanooga, Tennessee is another institution which in recent years has begun to compile a modest sample of skeletal material. Due largely in part to forensic anthropologist Tom Bodkin and his predecessor Craig Lahren, the HCFC has a growing collection of 67 identified skeletons since its beginnings in 1986, obtaining 5 donations in 2002 alone. The collection is made up of mostly complete donated skeletons with some forensic cases retained as evidence. The HCFC Donated Collection is both similar to and different from the UTK Bass Donated Collection. It is similar in that it represents a second East Tennessee sample, but different in that most of the individuals were given postmortem medical evaluations or autopsies prior to skeletonization. As such, extensive knowledge of the deceased is documented for all identified individuals, including medical history. Other data collected during postmortem examinations include both height (cadaver length) and weight at the time of death and a DNA sample of the individual. Like the UTK Collection, the HCFC Collection is also used in the education of human skeletal variation (and trauma) at the University of Tennessee at Chattanooga.

Although the HCFC skeletal collection is considered an excellent educational tool, it has yet to be quantified or compared to any larger skeletal series. Due to its modest size, a quantitative study has not been attempted until now. The purpose of the study is to quantitatively compare the Hamilton County Forensic Center's (HCFC) skeletal collection to the William M. Bass collection. As both the collections come mainly from populations in East Tennessee, it is logical to hypothesize that the HCFC collection is *not* statistically significantly different from the Bass UTK collection. This is not to say that the HCFC collection is lacking its own bias in some way (e.g., specific geographical region, period of time, or certain socioeconomic statuses), but instead that the two collections will share more similarities than differences. This lack of differences would suggest that there exists the possibility to use both collections in conjunction with one another for research purposes. The goal of this comparative study includes attaining a better understanding of the bias in the HCFC collection by comparing it against an already established documented collection. This understanding can then be used to develop caveats for future researchers utilizing the HCFC collection. The HCFC collection, because it is well "documented" and modern, could become a significant source of skeletal biological data in conjunction with the UTK collection or even independently.

METHODS

Materials.

Forensic anthropology traditionally relies on a two-dimensional method of gathering data from the skeleton, chiefly metric measurements (Jantz and Moore-Jansen 1988). Standard osteological measurement equipment was used to measure skeletal material from the HCFC collection. The majority of these measurements were taken using four instruments (see Figure 1): a sliding caliper, spreading caliper, osteometric board, and metal measuring tape. The first is the external *spreading calipe*r, used primarily in craniofacial anthropometry, or the shape of the face and skull. Only two postcranial (non-cranial) measurements are taken with this instrument. The *sliding caliper* was used for both cranial and post cranial measurements.

As neither spreading nor sliding calipers are adequate in measuring capacity to determine the length of long bones, an osteometric board was required. *Osteometric boards* are measuring devices commonly employed to determine the physical length of long bones in the upper and lower appendages. They frequently induce less error than hand measurements (Adams and Byrd 2002). Finally, although used with less frequency, was a flexible metal measuring tape used to determine the diameter of long bones. All measurements were recorded to the nearest millimeter and collected using techniques outlined in the UTK publication Data Collection Procedures for Forensic Skeletal Material (Moore-Jansen et al. 1994).

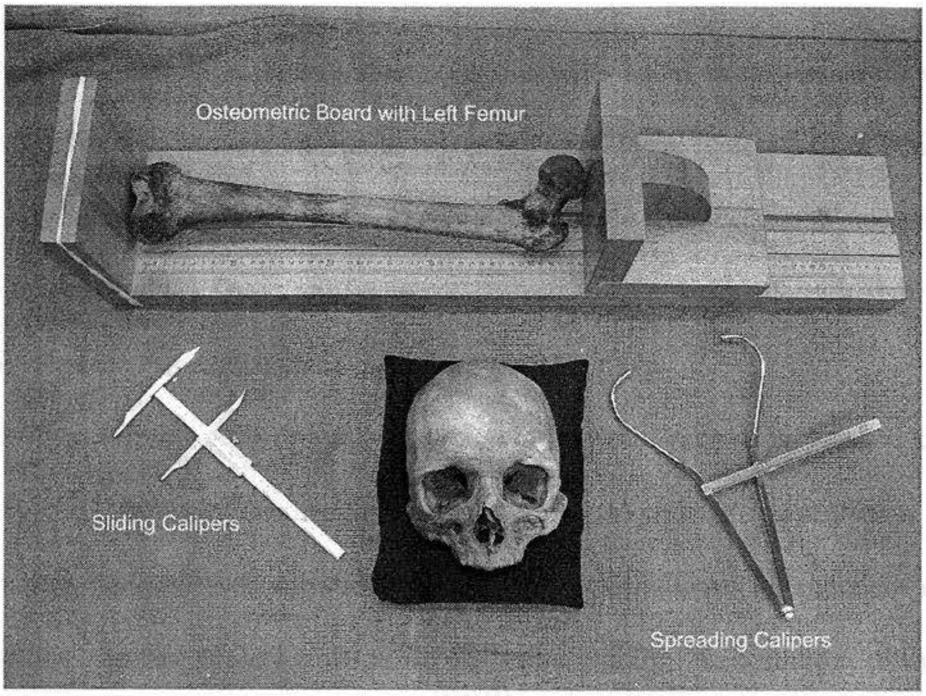

Figure 1. Osteological instruments used in this study. Not shown is the retractable metal measuring tape.

The Collections.

Two samples were used in the study, one from each of the two institutions. The sample from HCFC included 34 individuals while a total of 133 skeletons were sampled from the UTK collection. All the skeletons in this study were donated with the permission of next of kin or are unclaimed bodies for which no next of kin have been found after a diligent search. Unclaimed bodies donated by county medical examiners (to either UTK or HCFC) are covered under Tennessee state law [Tennessee Code Annotated 68-4-104(a)]. Both the written permission from next of kin and the provisions of Tennessee state law insure that the requirements for research on human subjects (albeit deceased) have been met. The bones in this study are shaded black in Appendix A.

Measurements.

Of the 78 individual and distinct measurements taken from each skeleton of the sample, a total of twelve were chosen to represent the skeletal material from which it was taken. Only skeletal material intact to yield all twelve measurements accurately was included in the study. These twelve were chosen on the basis of both their forensic biological relevance as well as their interobserver reliability.

Validity refers to the degree to which a variable measures what it claims to measure. In forensic anthropological studies regarding postmortem skeletal measurements, interobserver variation- the amount in which two independent observers vary from one another while reporting on the same material- is a seldom discussed but generally acknowledged phenomenon. This is a particularly relevant area of discussion for a comparative study done with two different populations, especially since no single researcher was responsible for collecting the measurements from the HCFC or UTK material. It was crucial to determine which measurements would present the least amount of interobserver variation in a worst-case scenario.

In a study done by Adams and Byrd (2002), the interobserver variation and reliability on 22 often problematic postcranial measurements was researched in order to determine which measurements held the greatest potential of interobserver error for the researcher. It was revealed that measurement errors fell in five distinct categories. However, it is only Type 5 errors that are not attributed to carelessness, but instead spring from a misunderstanding of the definition of skeletal landmarks (Adams and Byrd 2002). These errors are the most detrimental to the validity of a study, as they can cause significant errors in the study's results. This suggests that certain measurements can be problematic regardless of the level of experience the researcher possesses. One classic example of this occurrence is the mismeasure of the tibia in the 1952 Trotter and Gleser article. It was recently discovered that the measurement definition (for the maximum length of the tibia) and the data collected for the calculation of the stature estimation formulae possessed significant discrepancies and overestimation in stature (Jantz et al. 1995). Trotter trained technicians to collect the Korean War dead osteological data and did not take all the measurements herself, thereby introducing multiple observer complications. It is possible that some of her technicians introduced the mismeasurements that resulted in less than valid stature estimation formulae (Jantz et al. 1995).

To control for interobserver error, many possible measurements were omitted from this study and those with the least amount of interobserver error were used. Among those omitted was the ever problematic pubis length in the *innominate*, or the pelvis. This measurement depends on the location of a landmark in the acetabulum (socket joint in the hip), which is the point at which the 3 portions of the bone fused around 12-14 years old. This landmark is identified in the adult skeleton by a *possible* thickening seen by holding the bone up to a light, an irregularity, or a notch in the border of the articular surface of the bone. As anyone familiar with osteometrics is aware, this landmark is nearly impossible to see with back lighting, and the notched border of the acetabulum rim is naturally irregular in this area. Interobserver error for this measurement, stemming from disagreement of where the acetabulum landmark is located, is an example of one standard measurement excluded from this study.

Besides choosing measurements with low interobserver error, measurements were also chosen based on their biological relevancy in forensic contexts. Biologically relevant measurements refer to those measurements that have been proven useful in the analyses of osteological characteristics, specifically those used to estimate sex and stature (Jantz and Moore-Jansen 1988). The twelve measurements- two cranial and ten post-cranial- chosen for low interobserver error and biological relevance were as follows:

Cranial Measurements

Cranio-facial measurements are those most commonly used in determining the sex, race, and sometimes the age of an individual from skeletal material. Most cranial measurements are taken in relation to specific landmarks on the skull. All working definitions of these landmarks (and measurements pertaining to them) were taken from Data Collection Procedures for Forensic Skeletal Material for consistency in measurements.

1. Maximum Cranial Length. This is the distance from (g) *glabella* (most anterior projecting point of the frontal bone at the mid-sagittal plane) to (op) *opisthocranion* (most posterior point on the back of the skull at the occipital bone). These landmarks can be found on the skull depicted in Figure 2.

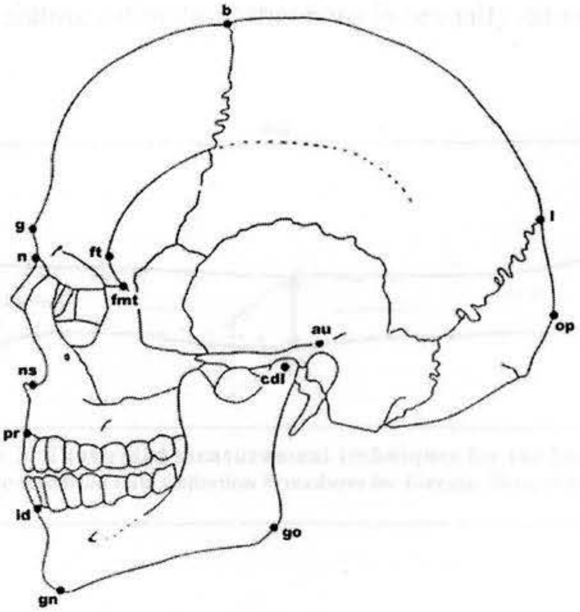

Figure 2. Lateral view of the skull with landmarks; note *g* and *op*. Reproduced from Data Collection Procedures for Forensic Skeletal Material.

2. Maximum Cranial Breadth. This measurement is taken at the maximum width of the cranium perpendicular to the midline. Like the maximum cranial length, this measurement is used in attribution of sex as well as race.

Post-Cranial Measurements

Measurements of the *appendicular* skeleton, especially those from the weight-bearing bones, are used in sex and age estimation. However, long bone measurements are the most helpful in stature determination (Burns 1999). For that reason, most post-cranial measurements selected for the study were the length of long bones. Interobserver variation has not historically been considered an issue when dealing with the maximum length of long bones, as the measurements regarding them are relatively simple and the use of an osteometric board has been shown to reduce the number of measurement errors (Adams and Byrd 2002). All measurements were collected using an osteometric board unless otherwise specified.

3. Maximum Length of the Clavicle. This measurement is produced by measuring the maximum distance between the most extreme ends of the clavicle. Although not particularly helpful in stature estimation, this bone is sexually dimorphic (Stewart 1978).

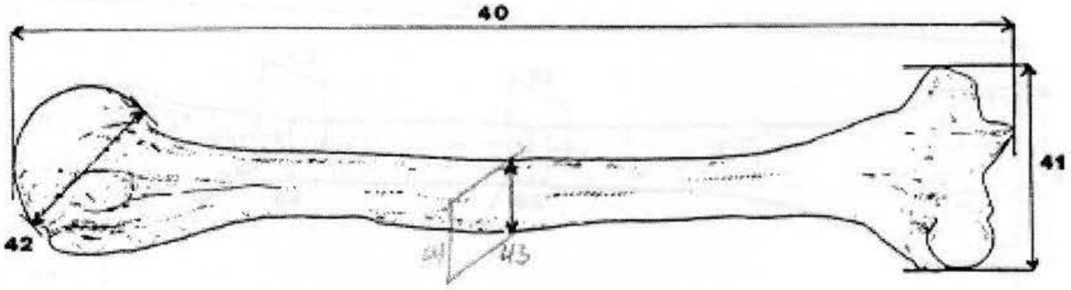

Figure 3. Illustrated measurement techniques for the humerus.
Reproduced from Data Collection Procedures for Forensic Skeletal Material.

4. Maximum Length of the Humerus. The distance from the more superior point on the head of the humerus to the most inferior point on the trochlea. Marked as measurement 40 on Figure 3.

5. Maximum Vertical Diameter of the Head of the Humerus. The distance between the most superior and inferior points on the border of the articular surface, determined with the use of a sliding caliper (See 42 marked on Figure 3). This measurement in an excellent source of data in relation to estimating the sex of an individual (Stewart 1978). Dwight (1905) determined this measurement possessed more validity in sex determination than the maximum length of the bone.

6. Maximum Length of the Radius. The distance from the most proximally positioned point on the head of the radius to the tip of the styloid process without regard to the long axis of the bone.

7. Maximum Length of the Ulna. The distance between the most superior point on the olecronon and the most inferior point on the styloid process.

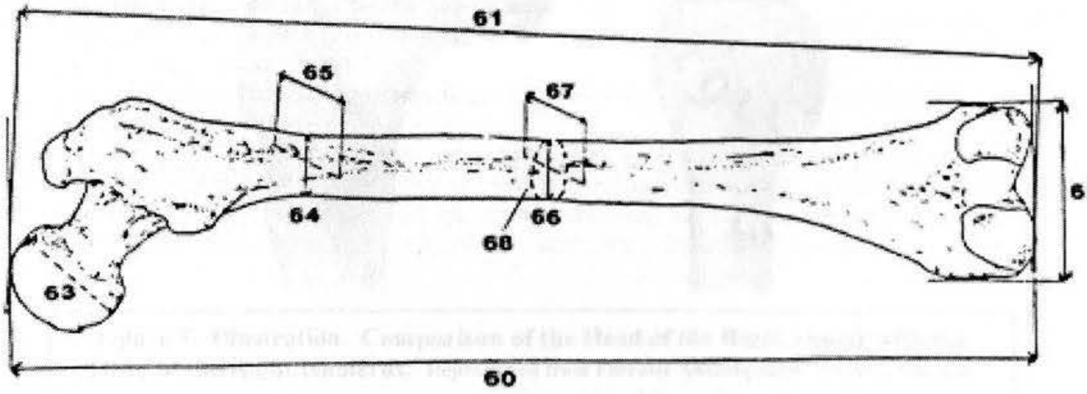

Figure 4. Illustrated techniques for femur measurement.
Reproduced from Data Collection Procedures for Forensic Skeletal Material.

8. Maximum Length of the Femur. The distance from the most superior point on the head of the femur to the most inferior point on the distal condyles. Designated as measurement 60 on Figure 4.

9. Bycondylar Length of the Femur. The distance from the most superior point on the head of the femur to a plane drawn along the inferior surfaces of the distal condyles. Designated as 61 on Figure 4. The maximum length measurement (#8) requires only the medial condyle to be in contact with the vertical end-board, and consequently this measurement is several millimeters shorter than the previous.

10. Maximum Diameter of the Femur Head. Taken with a sliding caliper, this measurement is measured on the border of the articular surface of the femoral head. Figure 5 depicts the differences in shape between the head of the humerus and the femur, both of which are used in sexual determination. In a study by Steyn and Isçan (2000), sex determination using the measurement of the maximum diameter of the femur head was accurately determined 86-91% of time.

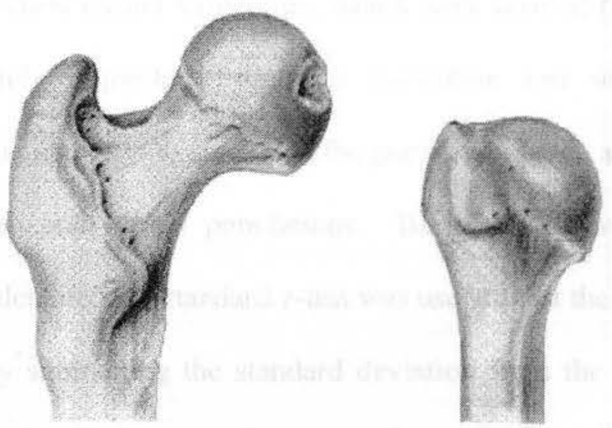

Figure 5. Illustration. Comparison of the Head of the Right Femur with the Head of the Right Humerus. Reproduced from Forensic Anthropology Training Manual.

11. Maximum Length of the Tibia. The distance from the superior articular surface of the lateral condyle of the tibia to the tip of the medial malleolus. This measurement is often used in a formula for stature analysis (Trotter and Gleser 1952; Jantz et al. 1995).

12. Maximum Length of the Fibula. The maximum distance between the most superior point on the fibular head and the most interior point on the lateral malleolus.

Each of the measurements used in the study was taken from the left side of the skeleton (except the two cranial measurements which are on the midline or bilateral), as is most commonly documented in skeletal material measurements submitted for the Forensic Data Bank (Jantz and Moore-Jansen 1988). Many skeletal biological studies are conducted with use of a single side of the skeleton for analysis. This was done with the assumption that there is little significant variation between the left and right side of an individual.

Procedure and Statistical Analysis

This author performed some of the skeletal measurements used in this study at the Hamilton County Forensic Center Collection, which were verified by Tom Bodkin. The UTK data was simply requested from that institution and sent electronically in spreadsheet form. The data was examined at the population level, and also examined by sex and race between and within populations. Basic descriptive statistics for each measurement were calculated. A standard z-test was used to test the null hypothesis. A z score is calculated by subtracting the standard deviation from the population mean (in millimeters) and dividing by the population standard deviation, which was computed during the descriptive statistics. It is assumed that these continuous variables in both populations are normally distributed (because no unusual standard deviations were observed). A z test is also referred to as "standardizing the data" to fit the normal distribution assumption whose mean is 0 and whose standard deviation is 1 (Madrigal 1998). The critical value for the z test was 1.96.

RESULTS

In order to test the primary research hypothesis that no significant differences were apparent between the HCFC and UTK collections, the measurements collected were used in a series of statistical analyses. These tests would determine the degree to which the mean scores of each measurement from both populations varied from one another. Table 1 represents the distribution of race and gender in the two samples used in the study. The total sample population size of the HCFC collection was 36, while the total sample population size for the UTK collection was 132.

TABLE 1 - Skeletal Material Sample Size Distribution.

	HCFC	**UTK**
Caucasian Males	16	88
African American Males	6	15
Caucasian Females	10	26
African American Females	2	3
Total (n) =	**36**	**132**

Once measurements were collected and compiled appropriately, a series of z score tests were completed, comparing distance in the standard deviation of the measurement means across populations to determine if any significant differences were present. After the z Scores were calculated, they were then compared across the sample populations. Tables 2 and 3 express the results of these analyses.

TABLE 2 - Comparison of z Scores of HCFC African American Sample to UTK African American Sample

Measurements	Difference Scores	
	Females	**Males**
Max. Cranial Length	0.71	0.27
Max. Cranial Breadth	0.46	0.31
Max. Clavicle Length	-1.47	-0.06
Max. Diameter of Humeral Head	0.60	-0.52
Max. Humerus Length	3.71*	0.12
Max. Radius Length	N/A	-0.02
Max. Ulna Length	N/A	0.11
Max. Femur Length	3.67*	-0.61
Bycondylar Femur Length	5.08*	0.63
Max. Diameter of Femur Head	-0.71	0.33
Max. Tibia Length	N/A	-0.92
Max. Fibula Length	N/A	-0.68

*** For all significant values, $p < 0.05$**

These results indicate no significant differences between African American Males in the HCFC collection and the UTK collection, yet this is not the case with African American Females. In the between population comparison, there are three significant differences recorded during the analysis. The maximum length of the humerus (3.71), the femur (3.67), and the bycondylar length of the femur (5.08) all vary significantly between the two population samples of African American Females. Scores marked with an N/A represent measurements which could not be tested, due to an inadequate measurement sample.

TABLE 3 - Comparison of Z Scores of HCFC Caucasian Sample to UTK Caucasian Sample

Measurement	Difference Score	
	Female	Male
Max. Cranial Length	0.43	-0.09
Max. Cranial Breadth	0.34	0.23
Max. Clavicle Length	-0.24	-0.58
Max. Diameter of Humeral Head	-0.29	0.08
Max. Humerus Length	0.13	0.00
Max. Radius Length	-0.15	0.05
Max. Ulna Length	-0.07	-0.07
Max. Femur Length	-0.31	0.11
Bycondylar Femur Length	-0.35	0.08
Max. Femur Head Diameter	0.22	-0.30
Max. Tibia Length	-0.29	0.09
Max. Fibula Length	-0.35	-0.10

Table 3 shows the results for the next set of analyses, which compare the z scores of Caucasians in the HCFC and UTK collections. As in Table 2, positive values indicate that HCFC measurement means had a higher value than UTK measurements. Negative values indicate UTK measurements had the higher mean. Most importantly, results show no significant differences between the two populations in both Caucasians males and females.

TABLE 4 - Within-Population Comparison of z Scores: HCFC

Measurement	Caucasian Males to Females	African American Males to Females
Max. Cranial Length	1.15	1.16
Max. Cranial Breadth	0.42	0.46
Max. Clavicle Length	2.75*	3.13*
Max. Diameter of Humeral Head	2.52*	1.16
Max. Humerus Length	2.78*	2.69*
Max. Radius Length	3.06*	1.34
Max. Ulna Length	3.18*	15.34*
Max. Femur Length	2.97*	0.57
Bycondylar Femur Length	3.06*	0.67
Max. Femur Head Diameter	2.48*	3.15*
Max. Tibia Length	3.33*	-0.72
Max. Fibula Length	3.23*	-0.51

*** For all significant values, $p < 0.05$**

Once the z scores were calculated for between population measurements, the technique was then applied to within population measurements. Z scores for a gender based analysis within the two sample populations were then conducted. Table 4 illustrates the results of such an analysis for the HCFC sample. Positive values indicate the mean measurement value was higher among males. Negative values indicate it was higher among females. Caucasian males were compared to Caucasian females, resulting in some very significant differences in the standard distribution of means. Maximum clavicle length (2.75), maximum diameter of the head of the humerus (2.52), and bycondylar length of the femur (3.06) as well as maximum length of the humerus (2.78), the femur (2.97), and the tibia (3.33) were all included among the results found to be significantly different from one another.

The same can be said for the comparison between African American males and females in the HCFC Collection, although there were fewer significant differences in the scores. Table 4 also shows that the maximum length of the clavicle (3.13), the humerus (2.69), the ulna (15.34), and the maximum diameter of the femur head (3.35) were all found to be significantly different in a gender comparison among African Americans. The ulna seemed to bear the more drastic difference in scores with a z score of 15.34.

DISCUSSION

This study was a comparison of the skeletal material housed at the Hamilton County Forensic Center with the William M. Bass Donated Skeletal Collection located at the University of Tennessee at Knoxville. It was hypothesized that there would be no significant differences between the populations represented in the samples, as both sample populations were taken primarily from individuals who lived in and around East Tennessee. This hypothesis would support the allowance of the HCFC collection to be used in conjunction with the UTK collection to obtain a larger, more expansive analysis of skeletal morphology or variation for use in studies. In addition, it was also hoped that such a comparative study would result in the validation of the HCFC skeletal material as an independent source of research material for future studies in the field.

As anticipated, there were no significant differences found between the two collections. This allows for the rejection of the null hypothesis which stated that such differences would exist. These findings suggest that the population represented in the HCFC Collection varies little from the population represented in the collection at UTK.

Despite the rejection of the null hypothesis, the results conveyed in Table 2 regarding the cross-population comparison between African American females in the HCFC collection and those in the UTK collection bear discussion. As seen in the table, there are three measurements bearing significant differences between the two samples: maximum length of the humerus, maximum length of the femur, and bycondylar length of the femur. These are the only instances in which significant differences between collections were recorded. While it might be considered indicative of important population differences between the two samples, it is unlikely that this is the case. With the demographic information presented in Table 1 in mind, the number of African American females represented by the two samples is hardy enough to encompass the true amount of variation within that group. This inadequacy in sample size can lend itself heavily to skewed results, as any measurement could potentially be outside the normal distribution of means and lead to such results as presented in Table 2. There is no way of knowing whether or not this was the case unless a larger sample from both populations could be secured for analysis. Therefore, at this time it is suspected that these significant results are fictitious ones, due primarily to the small sample size and missing values in the analysis. Given the non-significant results for each of the other cross-population comparisons, there is no reason to theorize that if the population sample for African American females were larger, the outcome would be dissimilar. Future research should include a more in-depth look at these findings once a greater sample of African American female skeletal material becomes available.

Sexual Dimorphism

Another significant finding of the study relates to the within population comparison results. When the Caucasian and African American male measurement means were compared to the racially corresponding female measurement means, significant differences were found between the two. The implication of this is that males in the HCFC Collection vary significantly from the females. The skeletal structures of males and females do differ in substantial ways. Typically, the long bones in males are seen as larger and more robust than those in females (Burns 1999). This rule of typicality seems to be clearly illustrated in the HCFC Collection when the measurements taken from males were compared to those same measurements taken from females.

Although human beings are not always easy to divide into typical males or typical females based only on skeletal traits (after all, human variation is the rule), the Z score analysis detected these differences among the mean values of the measurements. It is also interesting to note that in Table 4, the cranial metric measurements were not significantly different between the sexes, a finding that has been supported in other research of sexual morphology. This indicates that the HCFC collection contains at least a minimum number of skeletons needed to observe sexually dimorphic metric traits in the mean scores. It also suggests that the collection is large enough to differentiate non-significant measurements from significant ones.

Limitations and Biases

This study must be regarded as a preliminary work in the quantification of the Hamilton County Forensic Center Skeletal Collection. As such, it is host to numerous limitations. The most obvious limitation in this study is the amount of skeletal material presented in the HCFC Collection. The total number of skeletons in the sample for this study numbered at 36, which is a contrast to the 132 present in the UTK sample. Although it is important to bear in mind the time required to amass a sizable collection of skeletal material. Such an endeavor is not one accomplished easily or quickly.

As it stands, the HCFC Collection is composed of 67 individuals, 36 of which were used in the analysis for this study. Of those not included, nine skeletons are fetal and have not been measured. Some are forensic cases often lacking the measurements needed for this study due to bone trauma or other extenuating circumstances. Still others have not been measured in accordance to the Jantz and Moore-Jansen guidelines because they are in various stages of the preparation process for curation. The Hamilton County Forensic Center is not as well known an institution as the Anthropological Research Facility at UTK and does not have privy to as many donations which are available to larger, more affiliated centers.

Despite this, the size of the collection is not cause to dismiss its reliability. As addressed earlier, the size of the sample did not impede its ability to be used comparatively to show sexual dimorphism among the individuals. Nevertheless, future donations to the collection will increase the degree of human variation present in the collection, as well as the number of skeletons available for research study.

The number of individuals in a collection directly and indirectly contributes to other limitations in the study. Primarily, there is the question of different racial groups represented in the collection. Looking at the data in Table 1, it is obvious that the number of Caucasian individuals in the HCFC collection vastly outnumbers those of African Americans. This is mirrored in the UTK sample, especially in the case of African American females. Much fewer African American skeletons are present in skeletal collections in comparison to the number of Caucasians. In addition, there is also a distinct lack of Hispanic, Native American, and Asian individuals in the HCFC Collection. This phenomenon of racial bias in skeletal collections is not unknown and the cause is not a racial bias among researchers, but instead more related to the cultural perceptions behind scientific donation.

All skeletal collections contain a bias; it is unavoidable. The Terry and Hamann-Todd collections are both examples of collections with a time bias, as both of the collections were compiled in the earliest part of the 20th century. An important aspect of this study was to determine the biases of the HCFC Collection in order to make future research more efficient. The ethnic variability bias shown in the collection can be addressed by determining which ethnic groups most frequently make cadaver donations. African Americans donate their skeletons with far less frequency than Caucasians. The cause of this has traditionally been placed on cultural differences between ethnic populations. Furthermore, the donation of female skeletons is much less prevalent as well. The combination of the two could be the possible connection to the findings of the Z score analysis represented by Table 2 - the differences found between the African American female samples. The best represented population in the HCFC Collection is the Caucasian male population, which remains consistent with the UTK Donated Collection, as these individuals are most likely to be donated or unclaimed by next of kin. This bias is one that can be overcome, however, by using the UTK Donated Collection in conjunction with the HCFC Collection to provide a larger sample size of individuals from which to conduct skeletal biology research.

Future Research

Once again, it is imperative to view the study conducted here as a preliminary one. Much work is yet to be accomplished in regards to the HCFC Collection. One of the most immediate goals to be considered is the proper cataloging and measuring of the remaining skeletal material housed at the Hamilton County Forensic Center. This additional material would prove an asset to the collection in expanding the degree of human variation represented within it. None of the fetal skeletons were included in this study, which may also be an avenue for future research for comparison with the corresponding UTK data. There is also the process of continuing the collection, which is an ongoing practice at the HCFC. By adding more skeletal material to the collection, it will continue to increase in size and more importantly, in ethnic variability. That may be the most important focus for future additions to the collection. By building a substantially diverse skeletal collection, it will be possible to open more areas of research into human skeletal variability

Expanding the collection is an enterprise that is slowly being accomplished. Skeletal collections take years, or even decades to develop into extensive research tools. A variety of factors come into play during the process. The assembling of a collection is based on the availability of resources, which depends exclusively on the number of donations acquired. From there, the time-consuming process of excising, cleaning, and measuring the skeleton can take weeks or even months, depending on the methods used. At this point, it is possible to do some further research into the sexual variation that the HCFC Collection offers. Since sexual dimorphism is evident in the study results, the possibility of applying a discriminant function analysis to determine which measurements are the best predictors of sex within the HCFC Collection is viable and recommended.

It might be suggested to compare the HCFC Collection to older, more established collections such as the Terry or Hamann-Todd Collection in order to determine if any significant differences exist between them. Both of those historical collections represent populations of another time and area of the United States. By comparing the HCFC material to such collections may help in further establishing the changes in skeletal morphology through time. Also, it might prove useful to compare the collection to other Modern Period collections, such as the one located at the University of New Mexico. The effect of environmental factors, such as regional variation, may play a larger part in skeletal morphology.

Comparison of two skeletal collections from East Tennessee, the William A. Bass Donated Collection and the Hamilton County Forensic Center Collection, yielded that there were no significant differences existing between the collections that could not be explained by the small sample size. With the validation of the HCFC Collection as a viable research tool, many new avenues have been opened for investigation. In the coming years, it will be possible to conduct a wide range of studies with the skeletal material housed at the Hamilton County Forensic Center, many of which would not be otherwise possible without the substantiation process accomplished by this study.

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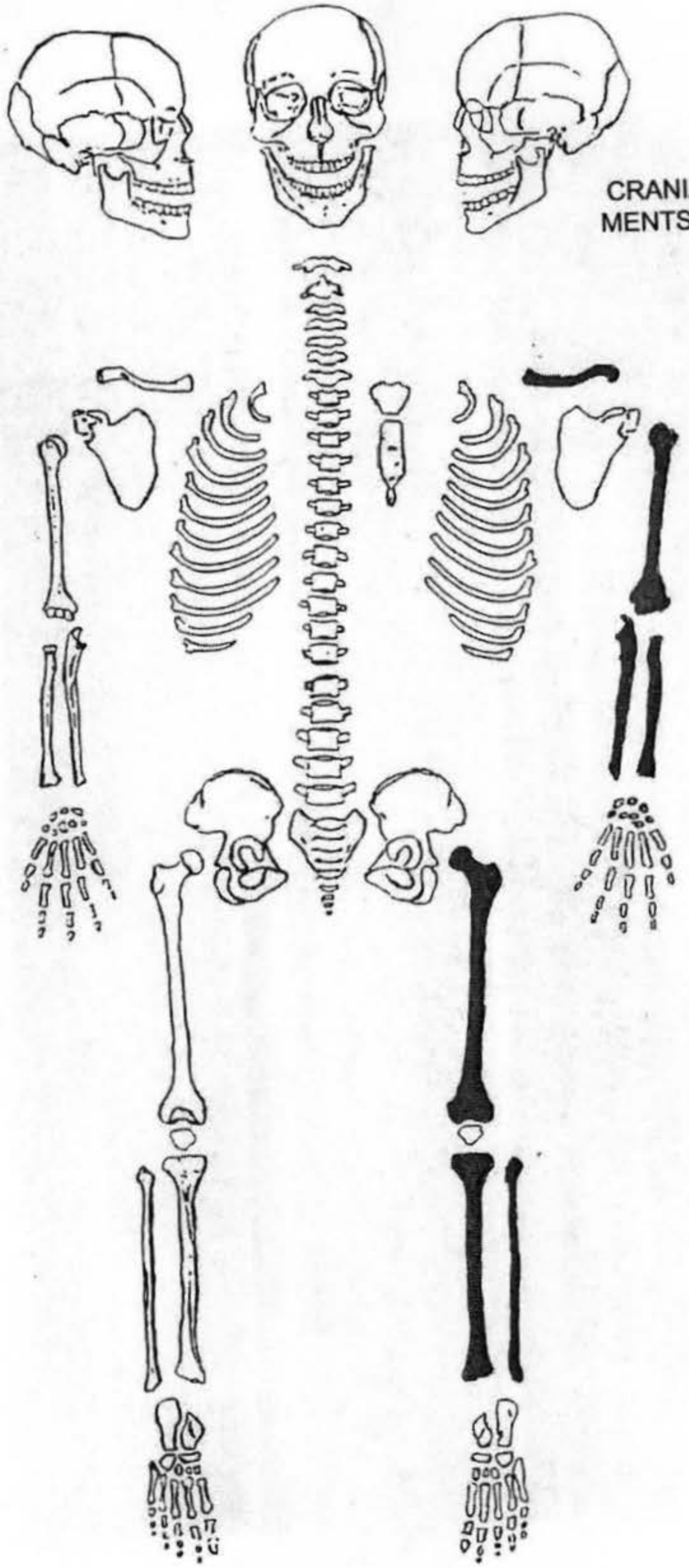
APPENDIX A



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