How the Shape of the Cranium Affects Cranial Vault Thickness

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# TABLE OF CONTENTS

Abstract.............................................................................................................................3

Introduction......................................................................................................................4

Literature Review.............................................................................................................5
  Cranial Formation
  The Shape and Biomechanics of the Skull
  Functions of the Skull
  Theories on Cranial Vault Thickness
  Possible Factors of Cranial Vault Thickness Variability
  Cranial Vault Thickness through Evolution

Materials and Methods..................................................................................................23
  The Sample
  The Measurements
  Cranial Index
  Statistical Analysis

Results...............................................................................................................................28

Discussion.......................................................................................................................30

Conclusion.......................................................................................................................32

Acknowledgements.........................................................................................................35

Works Cited......................................................................................................................36

Appendix..........................................................................................................................40
Abstract

Cranial vault thickness is a variable measurement at all points along the cranium and among all individuals. There is, however, a pattern related to cranial thickness and the shape of the cranium. This study examines the relationship between cranial vault thickness and overall cranial shape. Measurements including cranial vault thickness (seven points along the cranium), maximum cranial length, and maximum cranial breadth were taken of sixteen cadavers from the District 8 Medical Examiner’s Office in Gainesville, Florida. A strong correlation of the cranial index and average cranial thickness was demonstrated. For those specimens with a higher cranial vault thickness (brachycrany or round headedness), the cranial vault thickness was thinner. Conversely, for the specimens with lower cranial vault thickness (dolichocrany or narrow headedness), the cranial vault thickness was thicker.
Introduction

Cranial vault thickness has never been an essential feature of physical anthropology until recently. Perhaps Todd says it best when he states, “I consider that Nature is not greatly concerned over the mere thickness of the cranium,” (1924:255). However, craniometric data, including cranial vault thickness, has been used in anthropology and bioarchaeology for decades (Hatipoglu et al. 2008).

Several extrinsic and intrinsic factors influence the thickness of the cranial vault. Extrinsic factors such as climate have been theorized to affect the thickness of the vault (Beals 1972). Intrinsic factors such as ancestry, sex, and body build have been popular factors to test for when considering vault thickness as well (Keen 1950, Rosset al 1998 Lynnerup 2000, Hatipoglu et al. 2008). Also, CVT has been utilized cladistically to aid in the classification of early hominids (Nawrocki 1991). This study, however, will focus on the cranial vault and its association with sphericity of the skull through cranial index.

This paper will determine to what extent cranial vault thickness affects the cranial index of the skull. My hypothesis states that the thickness of the cranial vault bones of the skull is directly related to the shape of the braincase and is an expression of the skull’s function of protecting the brain. The null hypothesis for this study is:

\( H_0: \) Cranial vault thickness does not vary with cranial index

In this study, the null hypothesis will be rejected and prove that cranial vault thickness does vary when considering cranial index and support the theory that if the skull is more spherical, it is better able to withstand external forces and can, therefore, be thinner in cross section. If the skull
is elongated and flatter along the top, then it is less able to withstand those forces and will compensate by developing a thicker cross-section. My research is based on the theory that skulls with a more spherical shape are stronger, and thus are not required to compensate with a thick cranial vault (Demes 1987, Nawrocki 1991, Lieberman 1996).
Literature Review

The first research concerning cranial thickness was pioneered by Anderson in 1882, and then by Todd in 1924. Since then, researchers have explored theories of cranial vault thickness and its role in human evolution, forensics, and biomechanics. The literature reviewed in this paper has aided in formulating the hypothesis that cranial vault thickness does in fact influence the shape of cranium. First, the process of cranial formation will be described along with an explanation of the shape of cranium and its biomechanical properties and functions. Next, literature assessing the relationship of cranial vault thickness and other various factors will be explained. Finally, a brief assessment of cranial vault thickness through the evolution of hominids will be discussed.

Cranial Development

First, to understand the thickness of the cranium, it is important to first understand its development. Early in the development of the cranial vault, osteoblasts in the membrane that surround the vault start to rapidly deposit vascularized woven bone to several ossification locations (Ohstuki 1977 and Rogers 1984). The cranial vault bones work to close the sutural margins by growing larger and thus, closer to one another (Moss and Young 1960). When the cranial vault begins to form, the vault bones grow out and then toward each other. As growth slows after birth, both the inner membrane (the endocranium) and the outer membrane (the pericranium) switch to depositing vascularized lamellar bone, which then forms the inner and outer tables of the cranium (Sperber 1989).

A bone from the cranial vault is comprised of three layers: the inner table, the outer table, and the middle layer or diploe (Rogers 1984). The inner and outer tables are comprised of dense cortical
tissue and a cancellous diploe between them, the middle table. The thickness of the three layers is not uniform through the vault and varies at different points in the cranium. The region of the cranium focused on for this study, the cranial vault, usually is composed of thicker inner and outer tables and a moderate diploe layer between them (Rogers 1984 and Nawrocki 1991). These tables are functionally independent of each other and grow independently as well (Dani et al. 1997). The inner table has the most effect on where the cranial bones will move, which is directly determined by brain shape; the outer table of the cranium is mostly influenced by outside forces such as muscles (Nawrocki 1991). Around age four, the vault starts resorbing and remodeling the woven bone (Lieberman 1996). When the brain stops growing, the rate of capsular expansion decreases as well. In turn, ossification in these bones decelerates and the sutures from adjacent bones become closer to each other. At this time bone growth changes so that osteoblasts use their energy to grow vertically rather than horizontally creating a thicker bone (Moss and Young 1960).

**Figure 1:** An illustration of cranial growth from Enlow (1990). (a) brain expansion, midsagittal plane; (b) basicranial growth sites; (c) brain expansion, coronal plain; (d) basicranial growth, posterior view.

White arrows show direction of neural expansion, black arrows show sutural growth direction; + shows pericranial and endocranial bone deposition; - shows pericranial and endocranial bone resorption.
The Shape and Biomechanics of the Skull

The cranial vault portion of the skull is best thought of as a three-dimensional structure. Spherical domes are the strongest of all shell structures, while cylindrical shells, those structures that are longer than adjacent sides, are weaker (Demes 1985 and 1987). Thus, a more globular skull is desired for maximum protection of the brain.

Weidenreich (1943) describes the main function of the frame of the vault to be a supporter of stress directed on the cranium. The cranial vault is also constantly put under stress from mastication and the necessity of supporting the cranium (Demes 1985 and Nawrocki 1991). Demes (1985) found that these strains are greater in crania that are long and low, resulting in a need for a thick cranial vault. Consequently, this increase in thickness is an adaptation to decrease the level of stress on the vault.

Figure 2: Illustration from Enlow (1990) of difference between dolichocephalic (top) and brachycephalic (bottom) skulls.
It is well known that bone tissue interacts dynamically with its mechanical environment. Basically, when force is applied to bone it generates strain which, if sufficient in magnitude, can damage its microstructure and mechanical integrity (Lieberman et al. 2000). To lessen the strain on the bone force must be lessened as well. The bone becomes adaptive and increases distribution in the plane of deformation to lessen strain, becoming more efficient (Demes 1985).

When the cranial vault dimensions increase, as illustrated through hominid evolution, the length of the force’s lever arms increase as well. This results in the bending of the wall, or parietal bones (Demes 1987). Then, all muscles and joints of the cranial vault are directed vertically toward the horizontal plane. Demes further explains that “the bending moments they create in the cranial walls are proportional to the horizontal distance between the point of load application and the wall” (1985:285). The curvature that results from a dimension increase reduces the bending stresses on the cranium, helping the cranium to become more efficient.

Central to Demes’ explanations of the biomechanical properties of the cranial vault, is the argument that a skull that exhibits curved bones (a more globular skull) is better able to handle stress than those skulls who exhibit flatter bones (a narrow skull). Because the curved bones can dissipate stress more effectively, they will be thinner and will require less thickness for protection. Nawrocki tested Demes’ hypothesis in his 1991 dissertation and found his data to significantly support her theory.
Functions of the Skull

The skull harbors several purposes in human life processes. The most important of these functions is protection against shock. Ultimately, the skull acts as a case that protects the brain from external blows to the head (Rogers 1984). The composition of bone creates an excellent shock absorber to combat these blows, with two hard tables on either side of a layer of cancellous tissue described earlier.

Rogers (1984) explains that the arch of the skull is a powerful shape that works to hold the skull together and resist heavy blows to the vault. However, if the impact of the blow is sufficiently high, the arch may give way, resulting in a fracture to the tables of the skull. Theories have been formulated on how this function affects cranial vault thickness and will be discussed later.

Additionally, the braincase functions to resist all pressures that could compromise the circulation of blood to the head (Rogers 1984). Blood to the brain is an essential feature in brain function and the brain requires an adequate, even flow of blood to work correctly (Enlow 1990). These pressures include, but are not limited to, gravity and muscle action from chewing.

Theories on Cranial Vault Thickness

There exist several interesting theories concerning cranial vault thickness and cranial shape. Researchers have been attempting to describe the decrease in cranial vault thickness of hominids for years. While some ideas seem sound, others are not as reasonable and do not have much data to support them.
Several theories exist concerning the relation of cranial morphology and violence through hominid evolution, a popular topic when considering cranial vault thickness and evolution. Carleton Coon (1962) postulates that the increased thickness of the cranial vault during the Middle Pleistocene is a result of a particular survival value. He supports Weidenreich’s (1939) theory that early humans had particularly violent tendencies and that most cranial vault remains, especially those of Homo erectus, show signs of healed or lethal trauma. Tappen (1969) suggests that hitting with clubs at close distances was the predominate method of combat in the early Pleistocene, which eventually resulted in the necessity of thicker cranial vaults. As weapons became more advanced, long-distance technologies, such as spears, eliminated the need for close combat, thus resulting in thinner skulls which are metabolically less expensive (Wolpoff 1980). While these theories are entertaining, they are not particularly sound. There are very few cases of early hominid violence and it is almost impossible to determine if the trauma suffered by the skulls were inflicted by another hominid (Nawrocki 1991).

Another interesting theory seeking to explain the variable thickness of cranial vaults in humans is a theory by Ivanhoe (1972) stating that the environmental effects of magnetism are to blame, and not the selective factors of genes. He finds a strong correlation between cranial vault thickness measurements of early humans and geomagnetic field intensities from the same time. Ivanhoe believes that bones increase osteon activity when in a weak magnetic field (1972). Nawrocki (1991), however, points out that it does not account for population variation in skeletal robusticity, a known occurrence in sub-recent humans.
A theory that is particularly fascinating is that of Kenneth Beals (1972). He argues that the distribution of cranial index is explained via climatic adaptation. Beals compares 339 populations across the world and discovers an inverse relationship between cephalic index and temperature: populations with high cephalic indices are characteristic of cold and dry climates, whereas populations with low cephalic indices are more likely to exist in hot climates. His theory stems from an observation made by Coon (1955) that a head with a larger superior surface area is easier to keep warm, and a head with a smaller superior surface area is easier to keep cool by absorbing less heat from the sun. Also, Allen (1887) and Bergmann’s (1847) ecological rules of area-to-volume ratio play a significant role in his analysis. It is a fact that the most efficient radiators of heat are those with a high surface area, and the least efficient are those with low surface area. Theoretically, if the skull follows this rule, then the most advantageous head shape to keep warm would be a round head and to keep cool would be a narrow head. This theory could also play a role in comparing skulls of differing ancestry. If Beals’ theory is correct, then populations in warm climates will have low, narrow vaults and, thus, will usually have darker skin. Additional correlations between ancestry and cranial shape will be discussed later.

Knusel theorizes in his dissertation (1991) that difference in cranial vault thickness through the evolution of hominids is a result from a change in dental loading to the anterior portion of the mouth. He conducted a photoelastic analysis to determine how different cranial shapes influence the transmission of forces. The results indicate that each specimen, with differing cranial vaults, experiences differential deformation from identical loads. Perhaps this conclusion can be supported by Jacobsen’s recent findings that individuals with skeletal deep bite have significantly thicker cranial vaults than those with neutral occlusion and normal vertical craniofacial morphology (Jacobson et al. 2008).
Nawrocki (1991) also assesses the affect of the mandible and teeth on the cranial vault in his dissertation. He concludes that the size of the face and mandible are strongly associated with vault thickness along with the thickness of the mandible body. However, it should be considered that the high correlation between the two may also be a result of the overall cortical bone development of the cranium.

Finally, all bone growth is mediated by hormones (Lieberman 1996). Thus, hormones play an important role in the formation and thickening of bones, including those of the cranial vault. A few studies (Kennedy 1985, Nawrocki 1991, Nelson and Gauld 1994) have ascertained that levels of certain hormones have an effect on cranial vault thickness. Particularly growth hormones have a substantial effect on bone thickness, including the cranial vault. Acromegals, individuals with high levels of growth hormone (GH), exhibit particularly thick cranial bones than those who suffer from hypopituitarism, or growth hormone deficiencies (Lieberman 1996). Along with GH, other hormones such as parathyroid hormone, calcitonin, and insulin have been found to display similar effects on bone thickness. Lieberman uses these findings to support his hypothesis of the effect of exercise on cranial vault thickness. He states that exercise elevates circulating GH levels, resulting in a thicker cranial vault.

Lieberman formulates the theory that cranial vault thickness increases more rapidly in juveniles with more exercise than those that led a more sedentary lifestyle. He believes that systemic cortical bone growth is induced by exercise. Lieberman evaluates the evolution of cranial thickness (a steady decrease that will be discussed later in this paper), and how those earlier
hominids have thicker crania because their lifestyle required more exercise than later hominids (1996).

In summary, all of these theories illustrate the point that cranial vault thickness is an occurrence that is affected by multiple variables. Several environmental and biological factors influence the thickness of the cranial vault and numerous theories have been constructed to assess the validity of these factors. These theories have been successful in exploring the various causes of a thick or thin cranial vault. However, some of these hypotheses do not offer sufficient results to substantiate these theories and may only offer an idea that should be explored further.

Possible Factors of Cranial Vault Thickness Variability

Several studies have attempted to determine a relationship between sex, age, and body build. These studies, however, have produced conflicting results. The incongruity of these studies is most likely a result of inconsistent landmarks and variables that could affect bone growth such as disease, or a combination of the two. These inconsistencies must be recognized and controlled in order for a reliable conclusion to be reached. Nevertheless, there has been agreement among some studies in recognizing patterns relating to humans and cranial vault thickness.

Sex

The majority of cranial thickness studies have shown that males do not have a significantly greater overall cranial vault thickness than females, even though this is frequently assumed because of sexual dimorphism (Lynnerup et al. 2005, Nawrocki 1991, Roche 1953, Ross et al. 1998).
Nawrocki (1991), Lynnerup et al. (2005), Hatipoglu et al. (2008), and Todd (1924) find that vault thickness varies with sex, but only at different regions of the skull. Hatipoglu (2008) observes the only place to have a statistically significant difference in sex was the diploic thickness in the Glabella region. Lynnerup et al. (2005) determines that difference only occurred from diploe thickness at 1 cm anterior to Glabella. Nawrocki (1991) finds that cranial vault thickness (CVT) varies anteriorly versus posteriorly and that when CVT mean is computed, the results come to be approximately the same. Roche (1953) concludes that the anterior portion of most female crania is thicker than male crania, however the male crania are thicker posteriorly, supporting Nawrocki’s theory. The conflicting results in the literature throughout the years may be the result of varying sampling methods and sample points.

Also, when considering the cranial index or shape of the skull, one would expect the more *infantile* skull, the female skull, to tend toward brachycephaly. However, the difference of mean cranial indices between male and female are insignificant (Keen 1950).

The results from this sample show average cranial vault thickness of females ranging from 4.14 to 7.00 mm. The females in this study dominate the thinner range of average CVT of the entire sample, although this may be due to the limited number of individuals measured.

**Age**

One of the first studies of cranial thickness, from Todd (1924), found that skull thickness reaches its most stationary period between 30 and 50 years of age. After approximately 50 years of age, the thickness oscillates from sporadic thickening. Roche (1953) finds a rapid increase of cranial
thickness from 3 months to 21 years of age. Roche’s study also ascertains that the rate at which the increase occurs is the same in American white and blacks. Previous studies agree that there is a slight increase of cranial thickness in adults after the age of thirty until death (Todd 1924, Adeloye et al. 1976, Hartl and Burkhardt 1952).

As previously mentioned, the inner table is sensitive to cerebral morphology. Hurtl and Burkhardt (1952) believe that the inner table will also change to accommodate cerebral shrinkage from increased age by growing thicker. However, the slight increase of the inner table is not sufficient enough to produce a correlation between thickness and age derived from cranial vault bones (Schmitt and Saternus 1973). The lack of inner table thickening may be due to the osteoclastic resorption of the hill of the inner table, which would aid in “smoothing” out the inside of the cranium (Dani et al. 1997).

When an individual reaches middle age, the spongy bone of the cranium will start to diminish and will continue to diminish with age (Hurtl and Burkhardt 1952). However this diploic bone is replaced by fatty marrow (Schellinger et al. 2001). Because the diploe of the cranium is replaced by tissue at the same rate at which it diminishes, it may be speculated that cranial thickness does not change with age (Hatipoglu 2008).

Body Mass

The relationship between body mass and bone thickness is often associated with the postcranium portion of the skeleton. This relationship also exists in the cranium, though few studies have
been conducted to prove this. Even though an association between cranial thickness and body mass has been recognized, there has been little investigation into the subject.

Gauld (1996) conducted a study including both catarrhine and hominoid samples. He concludes that a strong covariance exists in both samples when comparing cranial thickness with body mass. However, Lynnerup (2000) analyzed the height and weight against the cranial thickness of a sample of 64 modern humans and determines that there was no correlation between the variables. I believe that a lack of correlation pattern may be due to the small sample size.

Ancestry
In Adeloye’s study (1976) of Americans with African ancestry versus those of European ancestry in male cranial thickness, she finds that the individuals of European descent have thicker frontal bones, while the parieto-occipital portion is thicker in those of African descent. She also explores the theory that the characteristic widening of the diploic space of individuals with African ancestry, is due to hemoglobinopathies, including sickle cell disease.

Kelso has compiled a list of average indices from varying populations around the world. These indices are found below:

<table>
<thead>
<tr>
<th>Region</th>
<th>Average Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>76.16</td>
</tr>
<tr>
<td>Asia</td>
<td>80.32</td>
</tr>
<tr>
<td>Europe</td>
<td>81.60</td>
</tr>
<tr>
<td>Oceania</td>
<td>78.76</td>
</tr>
<tr>
<td>New World</td>
<td>80.58</td>
</tr>
</tbody>
</table>

(Kelso 1970:241)
It is important to note that when examining this data, one may notice a confirmation of Beal’s (1972) theory mentioned previously in this paper. Higher indices (round crania) are characteristic of cold climates, such as Asia and Europe. Warm climates such as Africa and Oceania, however, have a lower average cephalic index, and thus a characteristically narrow cranium.

Fortunately, because there is no significant correlation between age and sex, it allows researchers to combine individuals with different backgrounds when analyzing CVT. Regrettably, this does not allow researchers to utilize cranial vault thickness in a forensic context in the determination of human remains. Ancestry, sex, and body build cannot be determined from a single sample of the cranial vault when considering its thickness.

_Cranial Vault Thickness through Evolution_

The words of Spencer Rogers say it best concerning the skull through evolution:

“The human skull is a highly complex structure that embodies evidence of stages in the journey, during eons of time, from worm to man. The human skull, far from being thought of as a death’s head, should be considered a symbol of the ascendant life that began as a swimming worm and became a conscious, reflective, and sensitive mammal with the ability to observe his environment and to manipulate it in directions that a growing universe dictated.”

(Rogers 1984:35)

Cranial vault thickness is often utilized as a significant trait in cladistic analysis (Gauld 1996). When considering phylogenetic changes in cranial thickness, we know that a majority of hominids, archaic and modern, have thin skulls. Cortical robusticity in long bones is considered a major distinction between modern _Homo sapiens_ and earlier hominids (Wolpoff 1980 and Stringer and Andrews 1988). Cranial vault thickness also follows this trend through evolution. An analysis of cranial vault thickness shows a general decrease over time, but with no significant
difference between archaic and early anatomically modern humans from the Late Pleistocene (Lieberman 1996 and Nawrocki 1991).

*Homo habilis* began with a relatively thin vault during the early Pleistocene (Lieberman 1996). It was not until *Homo erectus* and *Homo heidelbergensis* that average vault thickness suddenly increases with the thickest cranial vault thickness values of the genus *Homo*. These values remain relatively unchanged through the Middle Pleistocene, making vault thickness an undistinguishable feature for hominids during that time period (Nawrocki 1991). Nawrocki (1991) finds that Neanderthals were the first of the hominids with substantial evidence of a decrease in vault thickness. This decrease of CVT continues with the *Homo sapiens* of the Pleistocene. These temporal changes of hominid CVT are illustrated in Figure 3 below. The cranial vault thickness reduction trend occurred in several geographical locations including Australia (Brown 1987), and Japan (Ishida and Dodo 1990) from the Upper Pleistocene to the early Holocene and remains consistent in modern humans (Nawrocki 1991).
The temporal trend for the decrease in cranial vault thickness appears to be a global phenomenon. Because the trend took place in several sites at relatively the same time, the cause of random genetic drift must be ruled out (Nawrocki 1991). Instead there must have been various selective pressures on the hominids to shed their thick skulls for thinner ones. Stringer and Andrews (1988) contend that the ultimate cranial shape of any animal depends more on physical constraints than on genetics. When one tries to understand the concept of evolution, it is important to recognize the relationship between form and function and not just genetics.

**Figure 3:** Temporal Change in Hominid Cranial Vault Thickness from Nawrocki (1991).

P = mean posterior upper vault thickness
T = mean upper vault thickness
A = mean anterior upper vault thickness
As stated earlier, the ultimate goal of the cranial vault is to protect the brain. When changes to
the skull occur over time, it is necessary for the bones of the cranial vault to adapt to maintain the
biomechanical integrity of the skull. Nawrocki theorizes that the thickening of the vaults in
hominids of the Middle Pleistocene may have aided in resisting the rise in deformation from
mastication (1991). He further explains that with the increase in cranial height of modern
humans, overall curvature of the cranial vault increases. When the curvature of the vault
increases, the bones adapt accordingly by becoming thinner. The bones become thinner as a
result from the decrease in bending stresses on the cranium (Demes 1985 and 1987).

As part of Nawocki’s dissertation (1991), he utilizes cranial vault thickness to determine if the
regional continuity theory or the replacement theory could be supported or rejected. He plots
cranial vault thickness against geological age from various Neanderthal sites and Homo sapiens
sites. He finds a significant correlation coefficient of .61, illustrating a decrease in CVT in
Europe and Africa during the end of the Pleistocene. Ultimately, Nawrocki’s analysis cannot
support or reject either theory, other than a trend towards decreasing vault thickness, with an
average reduction in CVT of .23 mm per ten-thousand years. Nevertheless it can be noted that
the reduction in vault thickness is a global occurrence and took place in both Europe and Africa.

Beal (1972) recognizes the increase of cranial index through evolution and into the modern
human population. In identifying that the majority of fossil hominids have long, low heads, he
theorizes that the long, low heads of current populations in warm climates is merely a
continuance of the ancestral condition. When hominids left Africa, their heads became rounder,
allowing them to live in cold climates. By adapting to the advantage of brachycephaly, hominids were better able to exploit the resources of the land and endure the cold weather (Beals 1972).

In summary, cranial vault thickness began its sudden decrease one to two hundred thousand years ago (Nawrocki 1991 and Lieberman et al. 2000). It is no coincidence that this change takes place at the same time as the rapid expansion of the brain. These changes created increasingly spherical cranial vaults that became more biomechanically efficient than the hominid skulls before them (Lieberman 1996). Along with the expansion of the brain, other factors have affected the trend toward greater sphericity of the cranium including advances in technology and eating practices. Large prognathic faces no longer became necessary in the cooking and processing of food, resulting in a decrease of stress on the vault (Nawrocki 1991). A combination of these factors has produced a more efficient, globular cranium for modern humans.
Materials and Methods

The Sample

The materials studied consisted of sixteen normal cadavers from the District 8 Medical Examiner’s Office in Gainesville, Florida, between November 2, 2009 and December 22, 2009, on crania between 22 to 88 years of age at death. The cadavers comprised of seven females and nine males. Only patients without trauma to the cranium were accepted. All measurements were taken with spreading calipers and flexible ruler. These measurements were obtained by the author during autopsy. Measurements for cranial length and width were taken before the calotte was removed and measurements for cranial vault thickness were taken after removal of the calotte.

The Measurements

Measurements were chosen to adequately describe the overall thickness of the cranial vault and can be easily determined by using landmarks such as Lambda and Bregma. The chosen points are less likely to be altered by existing muscle attachments which could compromise the external surfaces of the bone. Also, regions that tend to be thicker or thinner were excluded to ensure that the average of cranial vault thickness is truly comparable, rather than varied when they are averaged together to find the mean CVT. The following points were chosen and measured to determine cranial vault thickness (see Fig. 4):

1: 3cm anterior to Bregma
2: Bregma
   The intersection of the coronal and sagittal sutures, in the midline
3: 3 cm posterior to Bregma
4: 3 cm right of 3cm posterior to Bregma
5: 3 cm left of 3 cm posterior to Bregma
6: Lambda
The intersection of the sagittal and lambdoidal sutures in the midline

7: 3 cm anterior lambda

8: Maximum cranial breadth (Euryon to Euryon or XCB)
   Determined instrumentally as both ends of the spreading caliper are
   moved back and forth on the sides of the skull above the supramastoid
   crest until the maximum width is located (Bass 1995)

9: Maximum cranial length (Glabella to Opisthocranion or GOL)
   Determined by placing one end of the spreading caliper on Glabella and
   with the other end, locate the most posterior point on the midline,
   Opisthocranion, and record the length (Bass 1995)

Figure 4: Illustration of cranial measurements listed above

The measurement sites were taken with a ruler from known reference points such as Bregma
and Lambda and then spreading calipers to determine thickness. Also, measurements of cranial
length (Glabella to Opisthocranion) and cranial width (Euryon to Euryon) were taken with
spreading calipers to determine cranial index. Measurements for each individual can be found
in Table 1 in the appendix of this paper.
When measuring the points of thickness on the calotte with spreading calipers, one hand holds the angle of the calipers with the medial part of the palm. Next, stabilize the first arm on the ectocranial aspect of the reference point and use the index finger to direct the other arm to the endocranial aspect of the same reference point without placing pressure on either of the caliper arms. Vault thickness was then calibrated to the nearest millimeter. The seven measurements made along the cranial vault were averaged to calculate a mean cranial vault thickness of each specimen to compare with its cranial index.

Because measurements were taken during autopsy, the periosteum and galea apourneurotica must be taken into account for all measurements. These two layers, however, are negligible when measuring to the nearest millimeter and because all the measurements were taken with these layers intact, the results were not hindered. All dura mater was removed prior to the measurement of cranial thickness.

It should be mentioned that medical records were not considered when sampling the individual. This may have resulted in an inconsistency in the results. A history of bone disease may have hindered the measurements of an individual or individuals. Also, a history of drug or alcohol abuse may have indirectly affected the measurements. Chronic drug or alcohol abuse may disturb bone metabolism, which could result in a reduction of bone mass (Preedy et al. 1991). However, Lynnerup (2000) considered these factors in his analysis of a Danish sample when measuring cranial vault thickness and concluded that no statistically significant differences were found when data from those individuals with a history of drug or alcohol abuse was compared to the individuals without such a history.
Cranial Index

Throughout all of the studies of the cranium it has been of particular interest to compare individuals and groups to identify similarities and possible relationships or patterns. To help accomplish this, indices were created as a technique of measurement that provides an analysis of the shape and structure that is independent of the size of the individual (Rogers 1984).

Cranial index is a “numerical device for expressing the ratio of the breadth of the skull to the length in percent” (Bass 1995:70). Cranial index is determined from the following formula:

\[ \text{Cranial Index} = \frac{\text{Cranial Breadth}}{\text{Cranial Length}} \times 100 \]

The higher the index, the farther the skull is from perfect sphericity. For example, a skull whose breadth is the same as its length, a perfect sphere, would have a cranial index of 100.00.

Nawrocki (1991) evaluated the cranial index formula to determine if vault size affects the outcome. He establishes that the formula is not completely unaffected by cranial size, but the difference is not significant enough to hinder any results when comparing cranial shape. Rogers (1984) asserts that there is a constant relationship between the dimensions of the skull regardless of size. Thus, cranial index is a reliable formula to judge the shape of the skull even when cranial size varies.
Statistical Analysis

Three tests of significance were conducted using SPSS Version 17® to assess the relationship between cranial index and average cranial vault thickness. A coefficient of determination coefficient ($R^2$) was determined by means of Simple Linear regression, and an analysis of covariance (ANOVA) calculated the level of significance between the two variables of interests. Using the following model:

$$CVT = CI + ERROR$$

The dependent variable for this model is CVT, which is the average cranial vault thickness of each individual. The main effect is CI (cranial index) and error is the continuous covariate. A Pearson Correlation coefficient ($r$) was used to determine measure of correlation, linear dependence, between the two variables. A standard alpha level of $p \leq 0.05$ was used for the confidence interval.
Results

The results show cranial indices ranging from 71.73 (dolichocrany) to 85.23 (hyerbrachycrany), with a moderate distribution, including a cranial index mean and standard deviation of 77.81 ± 1.367. Average cranial vault thickness was also parametrically distributed from 4.14 to 8.14 mm, with a mean value of 6.14 ± 3.94 mm.

Table 2: Summary of statistics for CVT (mm) and CI

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>St Dev</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVT</td>
<td>6.14</td>
<td>1.367</td>
<td>16</td>
</tr>
<tr>
<td>CI</td>
<td>77.81</td>
<td>3.94</td>
<td>16</td>
</tr>
</tbody>
</table>

Figure 5: Graph plotting the average cranial vault thickness and cranial index for each individual with a regression analysis

\[
y = -0.3389x + 32.514 \\
R^2 = 0.9527
\]
The relationship between the average cranial vault thickness and cranial index indicate a strong negative Pearson Correlation coefficient ($r = -0.976$).

**Table 3: Model Summary**

<table>
<thead>
<tr>
<th>R</th>
<th>$r^2$</th>
<th>Adjusted $r^2$</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.976</td>
<td>0.953</td>
<td>0.95</td>
<td>0.30699</td>
</tr>
</tbody>
</table>

The goodness-of-fit calculated from the linear regression model found no significant deviations from the linear model. The relationship between cranial index and average cranial vault thickness was highly significant ($p \leq 0.001$).

**Table 2: ANOVA Results for the Sample with CVT as the dependent variable**

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Sq.</th>
<th>df</th>
<th>F</th>
<th>Sig</th>
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<td>283.63</td>
<td>0.000</td>
</tr>
<tr>
<td>Residual</td>
<td>1.31</td>
<td>14</td>
<td>0.094</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>28.05</td>
<td>15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$r^2 = .953$
Discussion

The hypothesis that a thin cranial vault is a result of a globular skull is supported by the data collected. An analysis of the data produces a strong relationship between cranial index and average cranial vault thickness. Cranial index and average cranial vault thickness prove to be highly correlated with each other. The high correlation coefficient \((r)\) indicates that average cranial vault thickness is extremely dependent on the shape of the cranium. The level of correlation suggests that confounding variables do not influence this relationship, and therefore results from this study could be applied across multiple categories. The results clearly show that with an increase in cranial index (a rounder, more spherical cranial shape), a decrease in cranial vault thickness follows. Therefore, those individuals who depart from a perfect sphericity of the skull (i.e. long-headed individuals) will have a greater average cranial vault thickness.

Within the sixteen individuals measured, no outliers were present, and there were no significant deviations from the regression line. Due to the strength of the model, the regression formula might be applied for further consideration in forensic, bioarchaeological, and biomechanical studies.

Additionally, one aspect of the study that should be noted is that one of the individuals from the study exhibited Down’s syndrome. This individual was BW-04, showing a cranial index of 85.23 and average cranial vault thickness of 4.14 mm. The individual showed the highest cranial index and lowest average cranial vault thickness of the sample, which fit into the hyperbrachycrany category of cranial sphericity, or a highly rounded cranium. Lestrel and Roche (1979) explored this topic further and sampled 80 trisomics for cranial vault thickness to determine if the thinner
cranial vault thickness was due to the fact that trisomics have significantly smaller skulls. They compared the sample of trisomics with an equal number of controls and found the cranial thickness for those with Down’s syndrome to be “absolutely thinner than that of the normal controls and reflects the accumulating effect to the abnormal growth process in Down’s syndrome” (Lestrel and Roche 1979:110).
Conclusion

It is beyond the capacity of this thesis to address the abundance of factors that influence cranial vault thickness and cranial shape. There exist several factors that have not yet been explored or proven that could increase our understanding of the cranial vault and its function, formation, and evolution through time. Additionally, there is a lack of cranial vault values of fossil crania.

From the data that does exist, much is not eligible for comparison because of variation in measurements or an insufficient number of measurements from each specimen.

In this study, if it were possible to measure cranial height (Basion to Bregma or BBH), the ectocranial skull sphericity index could be determined and would have given a better calculation of the shape of the cranial vault. During autopsy, however, it is impossible to get to Basion without separating the cranium from the body. This problem could be solved by using collections that allowed access to the base of the cranium, instead of intact cadavers. In studies that were able to measure height (Nawrocki 1991) greater height values contributed to a decrease in cranial index values which, in turn, corresponded to a thicker cranial vault thickness. This is to be expected with the results shown in this study, when considering how cranial height influences the spherical shape of the cranium. Thus, narrow skulls will decrease the cranial index values and will cause more strain on the skull, resulting in a thicker cranium. A comparison of the accuracy of measurements with and without cranial height could be measured to assess the necessity of cranial height for future studies measuring cranial index.

In future studies, sex and ancestry should be considered. The statistical analysis would have been more accurate and statistically sound had sex and ancestry been considered as variables.
during calculations. It is with regret that ancestry was not observed during data collecting process. A comparison of ancestry could have shed light on a relationship between ancestry and cranial vault thickness.

Unfortunately, as mentioned earlier, cranial vault thickness cannot be utilized to determine an individual’s general body build or stature. Large individuals may actually exhibit thin skulls whereas a small individual may have a thick skull. Also, as mentioned earlier, cranial vault thickness is not a reliable indicator of age and sex when looking to determine identification from human remains. However, further research of the cranial vault in time may shed light on new methods that may confirm a relationship between the cranial vault and other factors, aiding in the determination of human identification.

From an additional forensic view, an improved understanding of cranial vault thickness may facilitate in the analysis of trauma to the head. It has been suggested that the degree of cranial vault fracturing from external force has a relationship to cranial vault thickness (Gurdjian 1950). This is an interesting aspect to expand upon when used in a forensic pathological situation.

On a separate note, it is necessary to conduct research that could contribute to the understanding of cranial vault thickness variation through evolution. More importantly, it is imperative that further research is conducted on the hominid skeletal robusticity phenomenon as well. To determine the degree at which robusticity affects the cranial vault could aid in the processing of hominid fossils and how place them cladistically.
Finally, the evidence from this study that a strong relationship exists between cranial vault thickness and the sphericity of the skull is only a small factor in understanding cranial vault thickness and cranial shape. Further research from future studies will undoubtedly uncover additional relationships between cranial vault thickness and other aspects of the body along with a better understanding of the cranial vault through evolution. I plan to address several of these factors during my graduate education and hope to contribute to a more extensive understanding of the cranial vault and its function through time. Most importantly, I hope to discover a relationship between the cranial vault and other parts of the skeleton which could contribute to the identification of human remains.
Acknowledgments

An undergraduate honors seems like only a small accomplishment to some. However, to collect my own data and construct a thesis on that data, to me, is a great accomplishment. This thesis is not only a test concerning the cranium; it is a test to determine if I can handle my future in anthropology.

I would like to thank those who contributed to this small study. First, Dr. Michael Warren, my mentor, who enabled me to collect data at the District 8 Medical Examiner’s Office and instructed me on how to conduct my data collection and process my results. No one could ask for a better mentor in and outside the field of anthropology. Next, to everyone at the C. A. Pound Lab who helped in the thesis writing process, especially Carlos Zambrano who edited my thesis and is probably the only other person in the world as interested in the cranial vault as me. Next, a big thank you to everyone at the District 8 Medical Examiner’s Office who allowed me to slow down the autopsy process to collect my measurements. Also, to Dr. Krigbaum who served as a fantastic advisor and managed to keep me optimistic when the semester became rough. I would also like to thank a fellow undergraduate Michael Grantatosky who managed to dumb down statistics and help me turn my data into results. Last but far from least, a thank you to my patient and understanding fiancé Michael Stewart who shared me with this thesis for the past year.
Works Cited


Appendix

Table 1: Table of raw data for each individual, also with calculated cranial index and average cranial vault thickness (measurements are in mm except cranial index):

<table>
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<th>##</th>
<th>Sex</th>
<th>Age</th>
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<th>8</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Cranial Index</th>
<th>Average CVT</th>
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Summary of statistical run in SPSS Version 17® including model regression analysis, ANOVA, and Pearson correlation:

### Descriptive Statistics

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### Correlations

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### Variables Entered/Removed

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<th>Variables Removed</th>
<th>Method</th>
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</table>

a. All requested variables entered.
b. Dependent Variable: CVT

### Model Summary

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<th>Std. Error of the Estimate</th>
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<td>.953</td>
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<td>.30699</td>
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</table>

a. Predictors: (Constant), Cranial_Index

### ANOVA

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<td>Residual</td>
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<td>28.050</td>
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a. Predictors: (Constant), Cranial_Index
b. Dependent Variable: CVT