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Use of the first rib in the age-at-death assessment of adult female skeletal remains

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Use of the First Rib in the Age-at-Death Assessment of Adult Female Skeletal Remains

By

Zachary A. Sullivan

Accepted in Partial Completion
Of the Requirements for the Degree
Master of Arts

Kathleen L. Kitto, Dean of the Graduate School

ADVISORY COMMITTEE

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MASTER'S THESIS

Zachary A. Sullivan

May 4th, 2012

Use of the First Rib in the Age-at-Death Assessment of Adult Female Skeletal Remains

A Thesis
Presented to
The Faculty of
Western Washington University

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ABSTRACT

The accurate assessment of age-at-death from skeletal remains is a key factor in both forensic anthropology and bioarchaeology. Several methods of determining age at death are currently employed that utilize the age specific changes of several anatomical regions of the skeleton. However, as skeletal remains are often incomplete, it is useful to develop new methods based on previously unevaluated anatomy. This makes it more likely that sets of incomplete skeletal remains may include some feature that can be used to determine age-at-death. DiGangi et al. (2009) proposed that three anatomical regions of the first rib demonstrate age-correlated changes that can be used in this manner. Their research incorporated 470 male individuals of Balkan ancestry recovered from a mass gravesite in Kosovo. The exclusion of female individuals thus raises the question of the reliability of their method when applied to both sexes.

This thesis attempted to validate DiGangi and colleagues' method by applying it to a set of female remains. The first ribs of 190 adult female skeletons from the William Bass Forensic Skeletal Collection at the University of Tennessee-Knoxville were evaluated and scored using the method proposed in the original publication.

The results of this research indicate that the Rib 1 aging method proposed by DiGangi and colleagues does not adequately assess age-at-death in female skeletal remains. There is a high degree of variation in the timing of morphological changes in the first rib with respect to age. The suggested reasons for this variation include a high degree of subjectivity within the method, as well as the existence of significant biological variation between both sexes, as well as between populations of different ancestry. Future research in these areas is

necessary to further our understanding of the methods of change in Rib 1 morphology, as well as to possibly remedy the sources of error in the utilization of the first rib in the assessment of age at death.

ACKNOWLEDGEMENTS

This research would not have been possible without the assistance of several individuals. I would like to first acknowledge the members of my thesis committee, Drs. Joan Stevenson, MJ Mosher, and Sarah Campbell for their constant guidance and support. Gratitude is extended to Dr. Benjamin Miner, Department of Biology and Dr. Victor Chan, Department of Mathematics for their assistance in the statistical analysis contained within this work.

I would also like to thank the managers of the William Bass Forensic Skeletal Collection at the University of Tennessee at Knoxville, Dr. Lee Meadows-Jantz and Ms. Rebecca Taylor, for their help in the collection of my data. Ms. Susan Larsen provided wonderful illustrations of the skeletal anatomy relevant to this research.

Last, but certainly not least, I would like to extend my utmost gratitude to the individuals and their families whose remains comprise the William Bass Forensic Skeletal Collection. Your selfless donations have allowed myself, and numerous other scholars to advance the field of physical anthropology.

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CHAPTER 1: Introduction

The accurate assessment of age-at-death of deceased individuals is one of many variables routinely inferred from physical remains of humans in physical anthropology (Dudar et al, 1993). Determination of age-at-death of unknown remains is used to narrow or eliminate potential missing persons for law enforcement personnel. Age-at-death is assessed for individuals at archaeological sites to interpret age-specific mortality and life expectancy of historical populations (Loth and Isçan, 1994). However, the assessment of age-at-death can be challenging (Dudar, 1993). Skeletal remains are often incomplete or severely degraded. Additionally, inter- and intraobserver error in method application can lead to misidentification of both necessary components and diagnostic morphological or anatomical features (Bedford et al 1993; Martrille et al, 2007). Aging methods are also limited in their ability to accurately assess age-at-death in individuals beyond the age of sixty, as morphological indicators become vague and uncorrelated (Martrille et al, 2007).

Because of the limitations of individual methods, multiple independent methods are used to assess age when a skeleton is relatively complete. Most popular are strategies that involve gross morphological changes that are easily discerned by the naked eye. Certain regions of the skeleton have received most of the attention. Typically examined in children and adolescents are: the lengths of limb bones (Stewart, 1979; Hoffman, 1979), the eruption sequence of teeth (Schour and Massler, 1941; Ubelaker, 1999) and the sequence of epiphyseal closure of the bones of the limbs and supporting pectoral and pelvic girdles (Ubelaker, 1994). The relevant changes that lead to inferences about age at death for adults affect other regions of the bony skeleton, and are not as accurate. The most commonly used are the sequence of endo- and/or ectocranial suture closure (Meindl and Lovejoy, 1985), morphological changes at the pubic symphyseal face (Todd, 1920 and 1921; McKern and Stewart, 1957; Suchey and Brooks, 1990) and auricular surface of the pelvis (Lovejoy, et al., 1985). Additional information can be determined from arthritic changes or from dental wear but these methods are population-specific. There are also histological methods that require special equipment and more training (Ubelaker, 1998).

A newer aging method evaluates morphological changes to the fourth rib (see, e.g. Iscan, et al., 1984a and b, 1985), and most recently, the first rib. Rib I is the most superior of the twelve ribs that comprise the human thorax (Gray, 1918). It articulates posteriorly with the pedicle and transverse process of the first thoracic vertebra and anteriorly with the manubrium of the sternum. Rib I is positioned inferior to the clavicle, and supports the subclavian artery and vein, as well as the lowest trunk of the brachial plexus as they pass from the thorax to the upper extremity. Additionally, Rib I helps to stabilize the articulation of the sternum and clavicle via costoclavicular ligaments, and also to transfer some of the weight of the upper extremity to the thorax (Pal and Routal, 1986). The muscles that attach to Rib I include the anterior, middle, and posterior scalene muscles. The scalenes facilitate in respiration by allowing the first rib to pivot at its vertebral articulation point. This raises the anterior portion of the rib cage, increasing thoracic volume (Dean and Aiello, 1990).

Using the first rib to determine age at death was first proposed by Kunos and colleagues (1999). The method evaluated age specific changes in the first rib for both subadults and adult remains. Kunos analyzed 74 individuals of known age, sex, and ancestry from the Hamann-Todd Osteologic Collection housed at the Cleveland Museum of Natural History. Two quantitative traits (the thickness of the costal face and the length of the rib) were recorded for the subadults and compared to known age. For adults three anatomical features of the first rib, the costal face, the rib head, and the tubercle facet were examined. Each feature was analyzed for five qualitative traits, including the appearance of the face and periarticular margins, as well as overall shape, topography, and texture. Kunos concluded that the morphological changes he observed in the first rib were highly correlated with age, and therefore could be utilized to predict the age-at-death of an unknown individual skeleton.

Utilization of the first rib is beneficial, as it possesses unique and easily identifiable morphological features, which tends to minimize intra-observer error (Dudar, 1993). DiGangi and colleagues (2009) modified the method published by Kunos and others (1999) to propose a new method of assessing age-at-death from mature skeletal remains. The analysis was performed using 470 male skeletal remains recovered from mass grave sites in Kosovo, Yugoslavia. This method uses the same distinctive features of the first rib that Kunos showed to have predictable morphological changes with age. DiGangi et al (2009) report that their method assesses age in individuals beyond the age of sixty years with a level of accuracy that exceeds the capabilities of other previously established methods. However, because it is a single study including only men of a similar ancestry, its general validity remains untested. First, as the DiGangi study did not evaluate female remains, it is unclear if their method will work equally well for both sexes. Second, all of the remains shared Balkan ancestry. This raises the question of whether or not the morphological changes of the rib are the same for multiple ancestries. The purpose of this research is to evaluate the validity of utilizing the first rib across multiple populations in general and its application to female remains in specific. Chapter 2 provides a brief history of common methods of age-at-death assessment, discussing both the application of single and multiple trait methods, as well as the limitations of each. Chapters 3 and 4 present the research design for this thesis and the results obtained, respectively. Discussions of the results are presented in Chapter 5, and this author’s conclusions and suggestions for future research possibilities are presented in Chapter 6.

CHAPTER 2: Brief Review of Assessment Methods and Their Limitations

The aging process of the human body leads to many changes in the bony skeleton, some of which exhibit patterns that can be used to infer age-at death of individuals from skeletal remains (Kemkes-Grottenthaler, 2002). Bones, including teeth, undergo morphological changes corresponding to the age of the individual. However, these changes are universal "[only] to the extent that [they] apply to both sexes and all populations (Kemkes-Grottenthaler, 2002:49)." Genetic differences, behavior, and interactions with the environment all affect the within-subject variability of age-associated morphological changes.

Additionally, there is a difference between *biological age* (i.e. the physiological state of an individual, as related to morphology) and *chronological* age (i.e. the time since the birth). The same person can age at different rates in different regions of the body. For example, athletes tend to experience more "wear and tear" on joints and other stressed areas than the average person, but may age slowly otherwise (less loss of calcium with age). Women who have many rather than few children and work physically hard all their lives may appear older in terms of gross aging changes in the pelvis and joints relative to their chronological age. This variability is inherent to most aging methods and affects the reliability of the prediction. There is presently no way to get an "average" reliability when using several methods because of the unique nature of this variation relative to each region of the body. Due to this region-specific variation, the correlation between chronological age and biological age has been extensively studied in several anatomical regions of the human skeleton, for the purpose of developing multiple reliable methods of age-at-death assessment.

Single Trait Methods

Early examinations of morphological indicators of age focused primarily on single traits. Most prominent among these were anatomical features of the os coxa (pelvis), cranial sutures, and dentition.

The Pubic Symphysis. T. Wingate Todd (1920, 1921) was among the first physical anthropologists to estimate age at death from human skeletal material, and he made a systematic study of the pubic symphysis. His analysis included 306 individuals from the Terry Collection of Caucasian, African, and what he termed "Hybrid" (i.e. mixed-race) individuals of known age-at death. Todd identified five regions of the pubic face: the surface, the dorsal and ventral borders, and the inferior and superior margins. Todd observed that each of these regions underwent patterned morphological changes that could be inferred from changes in the traits: billowing, ridges, and the ossific nodules. The sequence of changes was correlated with chronological age resulting in a ten-phase age-correlated transition of the pubic symphysis. Each phase was characterized by a unique configuration and expression of the traits in the five regions of the pubic symphysis.

McKern and Stewart (1957) re-evaluated Todd's method using skeletal samples from individuals who were killed in action during the Korean War. They were unable to account for significant variability in skeletal samples with regards to age. They reduced Todd's five regions to three: the dorsal plateau, the ventral rampart, and the symphyseal rim. Each of these regions was subdivided into six progressive stages, based on the observable morphology of each. Each of these stages were labeled on a scale from 0 to 5. McKern and Stewart also provided a chart that showed the sum of scores for all three regions in relation to chronological age.

Further refinements in the method were suggested by Suchey (1987; and Brooks, 1990) who illustrated the limitations of both the Todd and McKern-Stewart Methods as a method for inferring age at death of female skeletons. All prior work was based predominantly on male samples. Female pelves age faster than pelves of males because of the hormonal changes that lead to looser ligaments and joints. Remodeling occurs at the joints which leads to changes in the morphology of the symphyseal face and auricular surface of the pelvis. Suchey and Brooks (1990) adjusted the method for female samples. Pubic symphysis methods tend to over-estimate age for females but remain a critical element for inferring age at death for unknown remains.

The Auricular Surface. Another feature of the pelvis utilized in the assessment of age-at death is the auricular surface, which joins the left and right os coxa with the sacrum (Figure 1). Lovejoy and colleagues (1985) evaluated changes in the four regions of the auricular surface: the superior and inferior surface margins, the retroauricular area, and the apex. Their analysis was performed upon a subset (n=87) of remains excavated from a Bronze Age cemetery near the Dead Sea; these remains are currently housed at the University of Notre Dame. The distinguishable sequences of change in the morphology of traits were described for several morphological characteristics: surface granularity, porosity, local densifications, the presence or absence of transverse ridges (billowing and striation), and overall density of the surface. While more difficult to apply than methods using the pubic symphysis (due to the subjective nature of the scoring criteria), Lovejoy, et al. concluded that the utilization of the auricular surface method allowed for the adequate assessment of broader age categories.

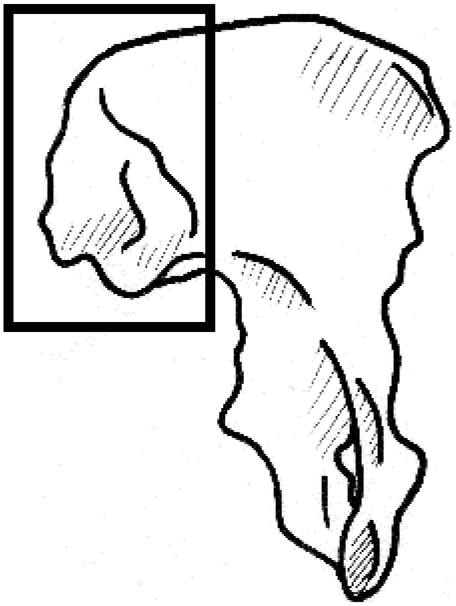


Figure 1 - The auricular surface (outlined) of the os coxa.

Cranial Sutures. Cranial suture closure has long been evaluated with respect to chronological age-at-death (Baker, 1987; Masset, 1989). Meindl and Lovejoy (1985) inspected the ten sutures that fuse the bones of the ectocranium (exterior skull – Figure 2). Each suture was evaluated by use of a simple scoring method, based on the level of closure at each site. Scores were assigned from 0 to 3, for open sutures, less that 50% fusion, greater than 50% fusion, and complete fusion, respectively. Scores for the six cranial vault sutures and the four lateral-anterior sutures were then summed and compared to associated age ranges (Figure 3).

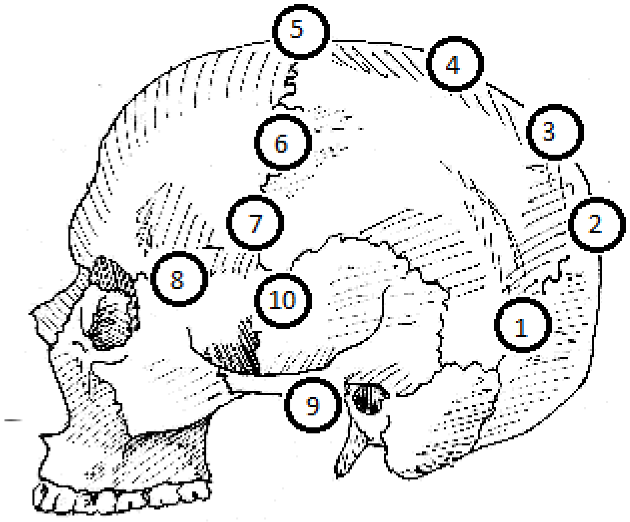


Figure 2 - Ectocranial sutures utilized by Meindl and Lovejoy (1985).

Composite Score (Vault)	**Stage**	**Composite Score (lateral-anterior)**	**Stage**
1-2	S1	1	S1
3-6	S2	2	S2
7-11	S3	3-5	S3
12-15	S4	6	S4
16-18	S5	7-8	S5
19-20	S6	9-10	S6
		11-14	S7

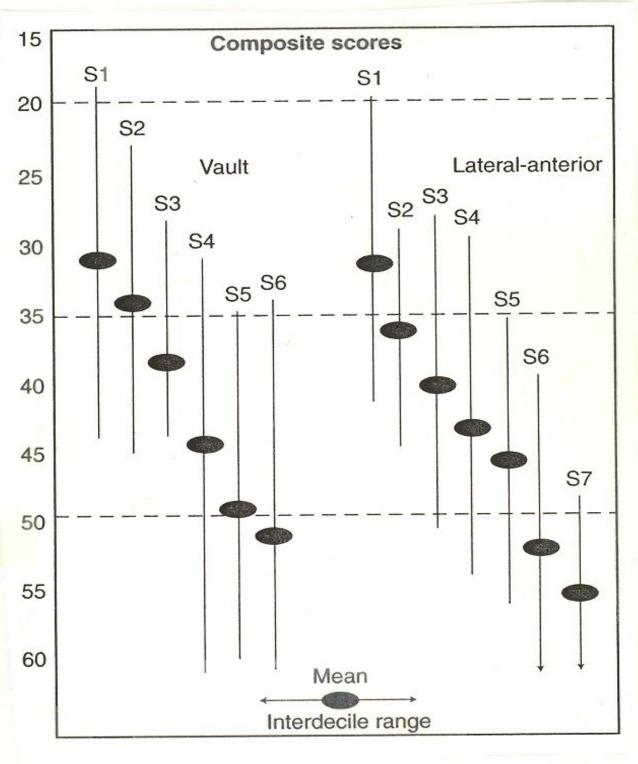


Figure 3 - Scoring method for the ectocranial sutures proposed by Meindl and Lovejoy (1985).

Dentition. The use of dental morphology to assess age-at-death of skeletal remains has an extensive history. Gustafson (1957) evaluated six dental criteria with respect to age: attrition, periodontosis (inflammation and infection of the jaw), secondary dentin (calcified external portion), cementum (calcified covering of the root), apposition, root resorption, and root transparency. In his method, characteristics of each criterion are scored, and the sum of the scores used to establish age. Bang and Ramm (1970) were also able to correlate age with root transparency. Charles et al (1986), Condon et al (1986), and Wittwer-Backofen and Buba (2002) demonstrated the ability to predict age-at-death based on annulations (formation of concentric rings) of cementum. Finally, Lamendin and others (1992) proposed a two-criteria method for aging single teeth, based on periodontosis and root transparency. This method has been subject to evaluation and modification using Bayesian analysis (Prince and Konigsberg, 2008; Prince, et al, 2008). However, the Lamendin method is the most often used currently, and has demonstrated high success in predicting age-at-death for middle adults (age 41-60 years) (Martrille, et al, 2007).

Other Methods

In addition to the single trait methods described above, others have been proposed that utilize alternative features of the human skeleton. These methods include regression analysis (Aykroyd, et al, 1997), evaluation of radiographic changes in the clavicle and proximal femur (Walker and Lovejoy, 1985), morphology of the acetabulum (hip socket, Rouge-Maillart, et al, 2009) and degree of fusion between the sacral vertebrae (Rios, et al, 2008), and histological and morphological traits of specific ribs (Dudar, et al, 1993; Stout and Paine 1992) .

Ribs. Essential to this thesis is the estimation of age-at-death using ribs. Methods of analysis include both histological and morphological features (Dudar, et al, 1993). Stout and Paine (1992) proposed a method based on examination of 40 individuals of known age-at death. Using cross-sectional samples from Rib VI, they quantified the relationship between cross-sectional area, intact osteon (bone tissue) density, and fragmentary osteon density. However, foremost among established rib aging methods are those using Rib IV.

MY Isçan (et al, 1984a, b, 1985, 1987; and Loth, 1986a-c) proposed nine phase method based on morphological changes of the sternal end of Rib IV. Each successive study applied their method to samples of males and females, as well as Caucasians and Blacks. The sternal rib end was evaluated based on three components of the pit formed at the costochondral junction (point of attachment between the rib and the sternum via connective cartilage). The three components include the formation of a pit at this junction, "its depth and shape, configuration of the walls and rim surrounding it, and the overall texture and quality of the bone (Isçan, et al, 1984a)." Pit shape was observed to progress from V-shaped to U-shaped with age, and depth from shallow to deep. The rim was observed to progress from rounded and regular to sharp and irregular. Last, the overall texture progressed from smooth and dense to thin and porous. Each of these characteristics was combined into nine phases (0-8), each with a corresponding age range. This method has been repeatedly tested using multiple populations, and its validity confirmed (Loth, 1995; Russell, et al, 1993; Yavuz, et al, 1998; Oettle and Steyn, 2000; Yoder, et al, 2001).

If any limitation may be ascribed to the Isçan method, it is that Rib IV is often difficult to distinguish from other ribs in disarticulated remains. As an alternative, Rib I, which has a distinctive morphology that helps reduce misidentification, has been evaluated for use in age-at-death assessment, (Dudar, 1993). Kunos, et al (1999) were the first to propose a method using Rib I, based on analysis of morphological changes of 74 juvenile and adult specimens from the Hamann-Todd Collection at the Cleveland Museum of Natural History. Juvenile first ribs were evaluated for two criteria: the overall length of the rib and the thickness of the costal face. Adult first ribs were evaluated for numerous morphological changes of three anatomical landmarks: the costal face, the rib head, and the tubercle facet (Figure 4). Each landmark was analyzed for changes in geometric shape, surface shape, surface topography and margins.

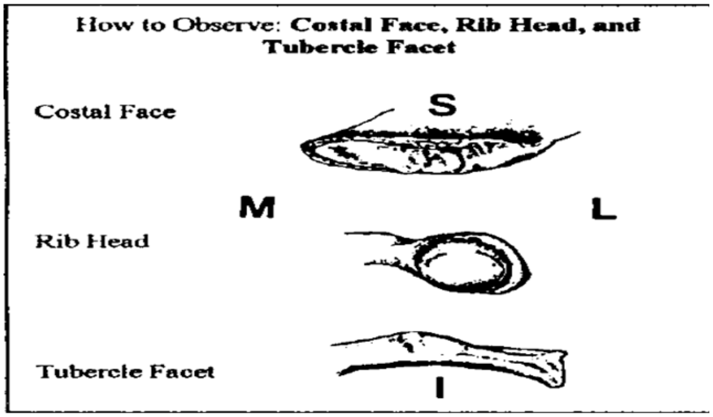


Figure 4 - Features of the first rib utilized by Kunos, et al. (1999).

Subsequently, each morphological category was further divided into several phases. The changes observed for all landmarks were then seriated by age, so that a target age of a specific individual could be determined through comparison.

Recent evaluations of Kunos' method, however, suggest that it is inaccurate and that it possesses a high degree of difficulty in its application. Schmitt and Murail (2004) tested Kunos' method on a Thai sample of skeletal remains. They concluded that Kunos' method is highly subjective and therefore difficult to apply with any confidence. Additionally, their observations showed that the age-specific morphological changes were more variable than expected among their test population. Finally, they stated that morphological characteristics of Rib 1 differed between their Thai sample and the North American sample utilized by Kunos.

Kurki (2005) applied Kunos' method to a sample of 29 skeletons from the J.C.B. Grant collection. Age-at-death was known for each individual within the sample. Kurki concluded that, while the Kunos method was "reasonably precise," it tended to over-age younger individuals and under-age older ones (Kurki, 2005:348). Kurki concluded that clarification of certain aspects of Kunos' method would facilitate its application. He also suggested that clearer descriptions (namely illustrations) of the morphological changes of the first rib were necessary. He also noticed that several of the observed morphological characteristics did not fit neatly into Kunos' descriptions, and therefore suggested that future research be aimed at modifying these descriptions.

DiGangi and others (2009) propose a modified version of Kunos' method, which aims to remedy these difficulties. The study analyzed 470 known-age males from mass graves in Kosovo, Yugoslavia. Their evaluation retained the number of landmarks evaluated, but reduced the number of morphological traits and inclusive phases. Descriptions of age-specific morphological changes were modified to reduce subjectivity. It also ignored assessment of juvenile individuals.

Multiple Trait Methods

The development of numerous single-trait methods for assessing age-at-death has led to the question of which method is most accurate. Brown (2009) asserted the need to develop new methods and use as many dental and skeletal indicators as possible. In addition, several methods utilize multiple traits simultaneously (Meindl and Russell, 1998). These include the complex method (Acsadi and Nemeskeri, 1970), multifactorial analysis

(Lovejoy, et al, 1985), and transition analysis (Boldsen, et al, 2002). All of these methods use statistical analysis to evaluate the combined conclusions of several criteria for aging human remains.

The complex method averages the age ranges determined through analysis of the femur, the humerus, ectocranial sutures and the pubis (Kemkes-Grottenthaler, 2002). The multifactorial method can utilize as many age indicators as are available, although the original publication used only the femur, the auricular surface, the pubic symphysis, dental wear, and the cranial sutures (Lovejoy, et al, 1985). The combination of observed traits is then subjected to principle component analysis to arrive at a specific age range. Tests of this method show that it is a more reliable indicator of age-at-death than any single-trait method (Bedford, et al, 1993). Finally, the transition method proposed by Boldsen and colleagues (2002) utilizes features of the pubic symphysis, the auricular surface, and the cranial sutures, each with several character states. The analysis assumes that the presence of each trait is independent, and then calculates the age at likelihood that each trait would appear at a given age.

Limitations of Current Aging Methods

It has been established that all of the current methods of assessing age-at-death in deceased individuals are subject to both inaccuracy and bias. Table 1 illustrates proposed sources of error for methods using ectocranial sutures (Masset, 1989), pubic symphysis (McKern and Stewart, 1957; Meindl, et al., 1985; Saunders, et al., 1992; Sinha and Gupta, 1995; Schmitt, 2004.), auricular surface (Murray and Murray, 1991; Saunders, et al., 1992) and fourth rib morphology (Isçan, et al., 1987).

Method	**Author**	**Sources of Error**
Ectocranial Sutures	Meindl and Lovejoy, 1985	- Timing of suture closure is sexually dimorphic. - Reference population was gender biased.
Pubic Symphysis	Todd, 1920	- Age results do not apply outside white/black populations.
Pubic Symphysis	McKern and Stewart, 1957	- Population is almost entirely male. - Limited age range of sample. - Based on single application.
Pubic Symphysis	Suchey and Brooks, 1990	- Tends to underage - Results in broad age ranges. - Asymmetry between left and right surfaces lead to different categorization. - Cannot be applied to Asian populations.
Auricular Surface	Lovejoy, et al., 1985	- Tends to overage younger individuals. - Difficulty to master, as reference samples are qualitative.
Fourth Rib	Isçan et al. 1984	- Overages Black populations.

Table 1 - Sources of error in several current methods of skeletal age assessment.

Limitations of Skeletal Reference Samples

In addition to sources of error inherent to specific methods, there also exists error in the skeletal samples from which these methods were derived (Usher, 2002). Usher evaluated three of the more commonly used skeletal reference collections in the United States are the Hamann-Todd Collection at the Cleveland Museum of Natural History, the Terry Collection at the Smithsonian Institution's National Museum of Natural History, and the William M. Bass Donated Collection at the University of Tennessee. All of these collections are extremely useful, yet none of them meet Usher's definition of an "ideal" skeletal sample. An ideal sample includes the following characteristics:

1. The individuals within the sample must be of true known age.
2. The sample must adequately represent the amount of racial, health, and socioeconomic variation present in the target population.
3. The sample must adequately represent both sexes and all age ranges.

According to Usher, reference samples do not often report true known ages. Instead, ages are self-reported by the individuals. This can lead to inaccuracy because individuals may not know their true age (in cases where birth dates where not recorded) or may chose for various reasons to alter their reported age. Additionally, population variation is often misrepresented in reference collections. This is usually the result of the collection methods employed by the institutions. For example, some collections are comprised primarily of individuals that donated their remains to science, while others are comprised of unclaimed forensic cases. Lastly, reference samples do not always equally represent all ages and/or both sexes. For example, the Korean war sample used by McKern and Stewart oversampled young men, due to the fact that the remains were from soldiers killed in action.

While Usher (2002) acknowledges that current reference samples are not ideal, she indicates that current samples are still useful in the development of age-at-death assessment methods. This is due to the presence within these methods of two underlying assumptions. The first is the assumption that reported ages are usually close to biological age, and therefore still represent valid data. The second is that the error in biological age is random or small relative to the age differences, and that the biological processes affecting skeletal morphological traits are uniform, in that age related changes are not affected by race, sex, or socioeconomic status.

CHAPTER 3: Methods

Sample Selection

The purpose of this thesis is to apply the Rib 1 age-at-death method of DiGangi et al. (2009) to a sample of known-age females to see if similar results could be obtained. DiGangi et al. (2009) described changes in morphological characteristics of the first rib and used statistical methods to determine whether the patterns observed correlated with the chronological ages of 470 known-age-males of Balkan ancestry recovered from mass grave sites in Kosovo. The sample size for females was too small to determine whether the techniques were effective for assessing age-at-death for females. Typically, new methods are formulated on a specific sample and may not be as effective on another human sample representing different population structure, diet, and activities within a local ecology. Thus, the goals here are to apply their method to a large sample of females to address the sex bias, and to draw it from a different population with different history and local ecology.

To do so, my goal was to evaluate as many applicable specimens (i.e. those with intact first ribs) as time permitted from the female individuals in the William Bass Forensic Skeletal Collection at the University of Tennessee at Knoxville. The Bass Collection contains over 870 individuals of both sexes, all with known age-at-death. The remains were acquired either via personal donation prior to death or via the medical examiner's office, and thus the collection is representative of the local population distributions with regards to age and ancestry (Taylor, 2011). The demographic profile of the collection is roughly 70% male and 30% female. Additionally, the individuals within the collection are predominantly (more than 75%) of European decent, with the remainder being of African, Native American, and

Hispanic in ancestry. Contact was made with both the primary and secondary authors (EA DiGangi and JD Bethard), as well as the curator of the collection, Dr. Lee Meadows-Jantz, and permission was obtained to proceed with this study. Review by an Internal Review Board was deemed unnecessary by Dr. Meadows-Jantz, because all remains lack personal identifiers.

Research Design – Data Collection

DiGangi and colleagues (2009) identified age related changes of three anatomical landmarks of the first rib: the costal face, the rib head, and the tubercle facet (Figure 5). Table 2 lists the three landmarks and identifies the aspects of each used in the rib aging method. Age specific variables in the morphology of the costal face of the first rib include the geometric shape, the surface topography and texture, and the margins of the face (Table 3).

Costal Face	***Rib Head***	***Tubercle Facet***
Geometric Shape (CF1)	Surface Shape (RH1)	Geometric Shape (TF1)
Surface Topography and Texture (CF2)	Surface Topography (RH2)	Surface Topography (TF2)
Margins of the Face (CF3)	Surface Texture (RH3)	Surface Texture (TF3)
	Edges of Margins (RH4)	Articular Margins (TF4)

Table 2 - Morphological Components of the First Rib

Age specific variables in the morphology of the rib head include surface shape, topography and texture, as well as the appearance of the edges of the margins (Table 4). Age specific variables in the morphology of the tubercle facet include geometric shape, surface topography and texture, and the appearance of the articular margins (Table 5). Each sample examined from the Bass Collection will be evaluated and scored for the following features.

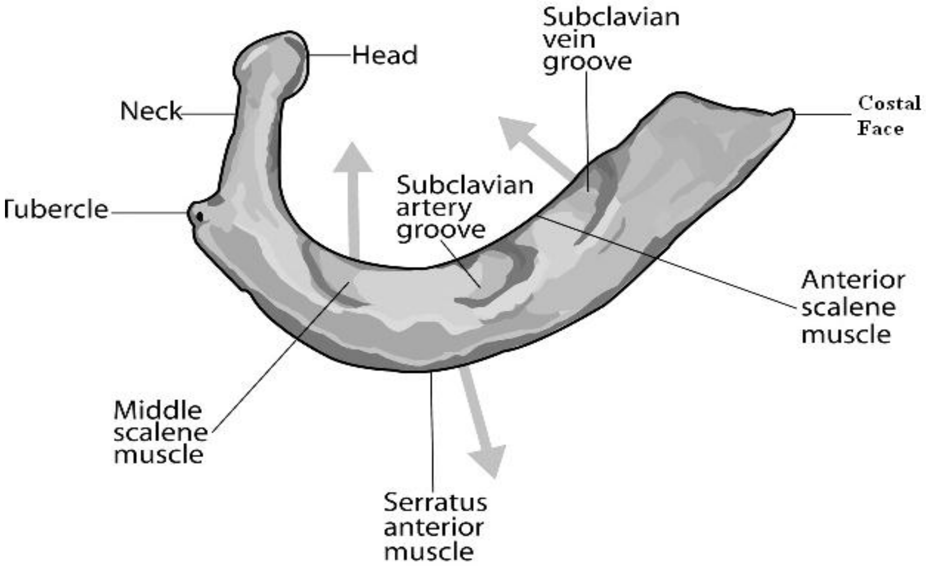


Figure 5 - Anatomy of the first rib (Left Rib 1, Superior View).

The costal face. When viewed from the medial direction, the geometric shape of the costal face (CF1) changes consistently and DiGangi et al. (2009) identify five stages representing different age categories. Initially the shape is oval, narrow and flat, as well as shallowly concave in appearance, and the lines of epiphyseal fusion are still evident. In the second stage the shape is narrow, oval and U-shaped, slightly concave in appearance, and lacks ridges upon the bottom surface. During stages three through five, the shape progresses from circular and concave to irregular and hollow to irregular and filled, respectively. The surface topography of the costal face (CF2) and texture also progresses through five stages. Stage one presents as irregular in texture, with knobby ridges and billows. During stage two the texture is smooth and lacks ridges. Stages three through five present respectively as microporous, concave, and macroporous in appearance. The margins of the costal face

(CF3) progress through four age-dependent changes. In stage one the margins are rounded and uneven, with projecting and scalloped edges. The margins become irregular and rugged in stage two. Stage three presents with the formation of large spicules along ¼ to ½ of the rim surface. Stage four shows ossification of these spicules, as well as osteoporotic thinning of the bone.

Trait and Score	***Description***
Geometric Shape (CF1)	
1	Narrow, oval, flat surface. Shallow with ridges. Lines of fusion evident.
2	Narrow, oval, and U-shaped. Slightly concave. Lacks ridges.
3	Circular and concave.
4	irregular, hollow shell.
5	irregular and filled in.
Surface Topography/Texture (CF2)	
1	Irregular with knobby ridges.
2	Smooth surface without ridges.
3	Microporosity evident.
4	Concave surface.
5	Macroporosity evident.
Margins of Face (CF3)	
1	Rounded and uneven with scalloped edges.
2	Irregular and rugged.
3	Large spicules present.
4	Thinning, osteoporotic bone. Ossification of spicules.

Table 3 - Scoring System for the Costal Face

The rib head. When viewed from the medial angle, the surface shape of the rib head (RH1) progresses in life through three observable stages. In stage one, the epiphysis is unfused, flat and circular. In stage two the shape is oval, and is irregular in stage three. The surface topography of the rib head (RH2) progresses through four distinct stages, from flat and convex; irregular; appearing with a medio-lateral groove; and secondarily smooth. The surface texture of the rib head (RH3) also progresses through four stages: dense and smooth, depressed and irregular, microporous, and arthritically lipped with evident macroporosity.

Trait and Score	***Description***
Surface Shape (RH1)	
1	Epiphysis unfused; flat and circular.
2	Oval.
3	Irregular.
Surface Topography (RH2)	
1	Flat or convex.
2	Irregular.
3	Medio-lateral groove present.
4	Secondarily smooth.
Surface Texture (RH3)	
1	Dense and smooth.
2	Depressed and Irregular.
3	Microporosity evident.
4	Lipping and macroporosity evident.
Edges of Margins (RH4)	
1	Rounded and smooth, with continuous dorsal margins.
2	Illdefined, irregular.
3	Well defined, irregular and sharp.
4	Lipping evident.

Table 4 - Scoring System for the Rib Head

The tubercle facet. The geometric shape (from the posterior view) of the tubercle facet (TF1) has four age-dependent stages. In stage one the epiphyseal line can be either unfused or fused, with a flat, oval shape. In stage two the shape is teardrop in appearance and has pointed medial margins. In stage three the shape is oval or crescent in appearance, and has a swollen superior edge. The final stage (four) presents as an irregular or circular shape. The surface topography of the tubercle (TF2) progresses through four stages: rounded, flat, concave, and irregular with evident macroporosity. The surface texture of the tubercle facet (TF3) also progresses through four stages: dense and smooth, depressed and irregular, microporous, and arthritically lipped with evident macroporosity. The articular margins of the tubercle facet (TF4) change from rounded and smooth to elevated, and then from rugged to depressed with evident osteophytes and arthritic lipping.

Trait and Score	***Description***
Geometric Shape (TF1)	
1	Unfused, or fused with oval shape. Defined ridges.
2	Teardrop shaped with pointed medial margins.
3	Oval, crescent shape with swollen superior edge.
4	Irregular and/or circular.
Surface Topography (TF2)	
1	Rounded.
2	Flat.
3	Concave.
4	Irregular with macroporosity evident.
Surface Texture (TF3)	
1	Dense and smooth.
2	Depressed and irregular.
3	Microporosity evident.
4	Lipping and macroporosity evident.
Articular Margins (TF4)	
1	Rounded and smooth.
2	Elevated rim.
3	Rugged.
4	Depressed superior margin, prominent osteophytes and lipping.

Table 5 - Scoring System for the Tubercle Facet

Research Design – Statistical Analysis

DiGangi et al. 2009 point out that the statistical analysis of these trait scores for ribs to produce an estimated age includes multiple levels of analysis (DiGangi, et al., 2009). Following their method, the first level of analysis is to determine the mean age at which an individual transitions from one morphological trait stage to the next; for example, the mean age at which an individual will move from Tubercle Facet – Surface Texture (TF3), Score 1 (dense and smooth) to Score 2 (depressed and irregular). The mean age of transition is then used to assemble a probability distribution of being in a particular trait stage, given a range of ages. The second level of analysis is to use this prior probability in a Bayesian model to determine the inverse, or the probability of being at a particular age, given a known trait score. It is this posterior probability that is used in assembling the model in which the age of an individual of unknown age is estimated.

DiGangi et al. 2009 also took their analysis to a last level of determining which two of the eleven scored traits were least correlated with one another, in order to reduce the number of traits an analyst would be required to assess in the field.

Calculating the mean age of transition is accomplished via what Boldsen (2002) refers to as “transition analysis”, also known as the proportional odds model. Transition analysis calculates the probability that the trait stage (Y_j) of a given individual is in the higher of two stages (1) versus the lower of two stages, given the age of the individual (a_j). This can be expressed mathematically by the equation

$$Pr\left(Y_j = 1 \middle| a_j\right) = \Lambda(\alpha + \beta a_j)$$

where alpha and beta are parameters estimated from the reference population, and Λ is the logit function $f(x) = \frac{e^x}{1- e^x}$. Additionally, the values for alpha and beta can be used to find the mean age of transition between stages, as well as the standard deviation. Specifically, the mean age at transition is equal to α/β, and the standard deviation is equal to $1/\beta$.

The transition analysis model works in the following manner. First, the probability of an individual at age a_j being in the higher of two sequential stages of a given trait is calculated by the quotient of the number of individuals at age a_j *and* at stage $Y = 1$ to the total number of individuals at age a_j. Performing this calculation for every occurrence of a_j within the data set, and then plotting a_j vs $Pr(Y_j = 1| a_j)$ yields a graph in which the best fit line is logarithmic, with the equation of

$$Pr(Y_j = 1|a_j) = \frac{e^{\alpha+\beta aj}}{1 - e^{\alpha+\beta aj}}$$

However, as the values for alpha and beta are needed to determine the mean age at transition between stages, the logit equation must be solved for x in terms of f(x). This is accomplished by using the natural log of the proportional odds of Y=1 occurring, as expressed by the equation

$$\ln\left(\frac{Pr(Y_j=1|a_j)}{1- Pr(Y_j=1|a_j)}\right) = \alpha + \beta a_j$$

Plotting the values of natural log of age versus proportional odds, along with a best fit line, now gives a linear equation where the intercept is α and the slope is β. This calculation is repeated for every sequential pair of stages for each trait assessed. The benefit of using the proportional odds model is that, although the mean ages of transition change between stages, the standard deviation does not (Boldsen, et al., 2002).

Once the mean ages of transition are determined, DiGangi and colleagues (2009) illustrate that these values can be used to determine probability of an individual being in a specific trait score, given any random age. This probability is equal to the area underneath a log normal distribution with means and standard deviations equal to those calculated via transition analysis.

> “The simplest example here is from the variable ‘‘Rib Head: Surface Shape,’’ as that variable has only three ordered stages. [DiGangi and colleagues’] results section shows that the common standard deviation for the two transitions (from Stage 1 to 2 and from Stage 2 to 3) is 0.5898 on a log scale for age. The two mean ages-to transition on the log scale are 3.0006 and 3.5314. From these parameters, one can find the probability that an individual who is, for example, age 34.34 years old is in the first stage as one (1) minus the lower tail area (up to 34.34) from a log normal distribution with a mean and standard deviation of 3.0006 and 0.5898. This probability is equal to 0.1819. The probability that such an individual would be in the second stage is the difference between the lower tail areas of log normal distributions with means of 3.0006 and 3.5314 and a common standard deviation of 0.5898. This probability is 0.3148. Finally, the probability that such an individual is in the third stage is the lower tail area from a log normal distribution with a mean of 3.5314 and a standard deviation of 0.5898. This final probability is 0.5033, and the sum of the probabilities (0.1819, 0.3148, and 0.5033) is equal to one (1) as someone who is 34.34 years old must be in one of the three defined stages.”
>
> -DiGangi, et al., 2009:167

Once the probability of being in a certain stage given a known age was established, DiGangi and colleagues (2009) then used Bayesian analysis to determine the probability of being at a specific age-at-death, given a known trait stage. This posterior probability is expressed mathematically as

$$f(a|i) = \frac{f(a|\theta)\Pr(i|a)}{\int f(a|\theta)\Pr(i|a)da}$$

where $f(a|i)$ is the probability of being at a specific age a, given a known stage i, $Pr(i|a)$ is the probability of someone at age a being in the observed stage i, and $f(a|\theta)$ is the prior probability of death at age a, which is determined by the parameters of a hazard model.

This posterior probability density is then plotted for each stage of the 11 rib traits.

Expectations and Implications

The prior work by DiGangi et al. (2009) suggests that the first rib may be effective at determining age-at-death in skeletal remains. It is my expectation that this method will work equally well when applied to a female sample as it did when applied to a male sample. The first rib is easily identified in human remains, yet it is prone to damage or erosion. Significant damage may obliterate any or all of the traits used in this method. I suggest that utilization of the first rib be limited to a forensic context rather than an archaeological one. Forensic cases normally include remains that are exposed to natural forces for significantly less time than archaeological cases, which would help limit the amount of damage or erosion to the first rib.

CHAPTER 4: Results

The William Bass Forensic Skeletal Collection contains over 870 individual skeletons, approximately 210 of which are female. Of these females, 190 were examined in this research. For the purpose of consistency, only the left rib of each specimen was evaluated. Those not examined were excluded for the following reasons: either 1) the rib was incomplete, 2) the rib was absent from the remains, or 3) pathology or other damage prevented assessment of all traits.

The recorded age-at-death for each individual was concealed from this author prior to trait scoring, to be revealed only after the scoring was complete. All observations were made by the author on location at the University of Tennessee – Knoxville between 07/25/2012 and 08/05/12. Approximately six hour per day were devoted to collecting data, with observations of each individual taking 5 to 10 minutes. Observations were recorded on a standardized form created by the author (See Appendix A). Photographs were taken of exemplar trait scores, with permission of the collection manager (See Appendix B).

Intra-observer error was minimized through the repeated scoring of two individuals. These two individuals were selected randomly by the author, and then scored in thirty minute intervals to check for consistency in scoring. The results of this initial scoring are displayed in Table 6.

Sample	Session	CF1	CF2	CF3	TF1	TF2	TF3	TF4	RH1	RH2	RH3	RH4
1	1	2	5	4	3	3	2	4	3	2	4	4
	2	2	5	4	4	4	2	4	3	2	4	4
	3	2	5	4	4	3	2	4	3	2	4	4
	4	2	5	4	3	3	2	4	3	2	4	4
2	1	2	4	3	3	3	2	4	2	1	2	3
	2	2	4	3	3	3	2	4	2	1	2	3
	3	2	4	3	3	3	3	4	2	1	2	3
	4	2	4	3	3	3	2	3	2	2	2	3

Table 6 – Results of random sample scoring as a check of observer consistency.

The original method provided photographic exemplars for only two of the eleven examined traits, the trait scores of the geometric shape of the costal face (CF1) and the surface texture of the tubercle facet (TF3). The remaining nine traits were described in text only. Therefore, it was often difficult to clearly assign an appropriate score, specifically with adjacent trait scores. For example, I frequently debated whether or not the score for the "Margins of the Rib Head" was most appropriately a score of 2 ("ill-defined and irregular") or a score of 3 ("well defined, irregular and sharp"). Distinctions between non-adjacent traits were somewhat easier to determine.

The sample of remains ranged from 22 years old to 99 years old at time of death, with a mean age at death of 63.18 years and a standard deviation of 14.02 years (Figure 6). The ancestry of the population included individuals of Caucasian, African, Hispanic, and Native American decent, as listed in Table 7.

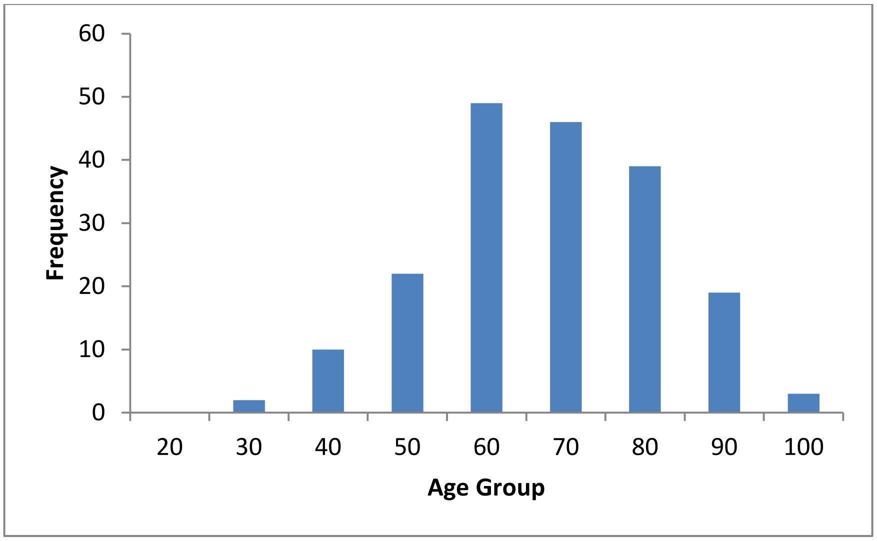


Figure 6 - Age Frequency Distribution of Skeletal Sample

ANCESTRY

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	White	179	94.2	94.2	94.2
	Black	9	4.7	4.7	98.9
	Hispanic	1	.5	.5	99.5
	Native American	1	.5	.5	100.0
	Total	190	100.0	100.0	

Table 7 – Ancestry frequency distribution for collected data.

When grouped in 10 year increments, there is an increase in the frequency of higher trait scores in older age groups. However, only a few of the traits exhibit a distinct shift in trait score frequencies with respect to age (See e.g. TF3, Figure 7). The frequency distributions for other trait scores are often bimodal in appearance. For example, for the surface topography of the rib head (RH2), scores 2 and 4 are the most frequent across several decades (Figure 8). Additionally, an increase in frequency of higher trait scores is not necessarily associated with a decrease in frequency of lower trait scores. In the case of the geometric shape of the costal face (CF1), scores 2 and 3 remain at high frequency up until the 7th decade, even though the frequency of higher score values is increasing (Figure 9).

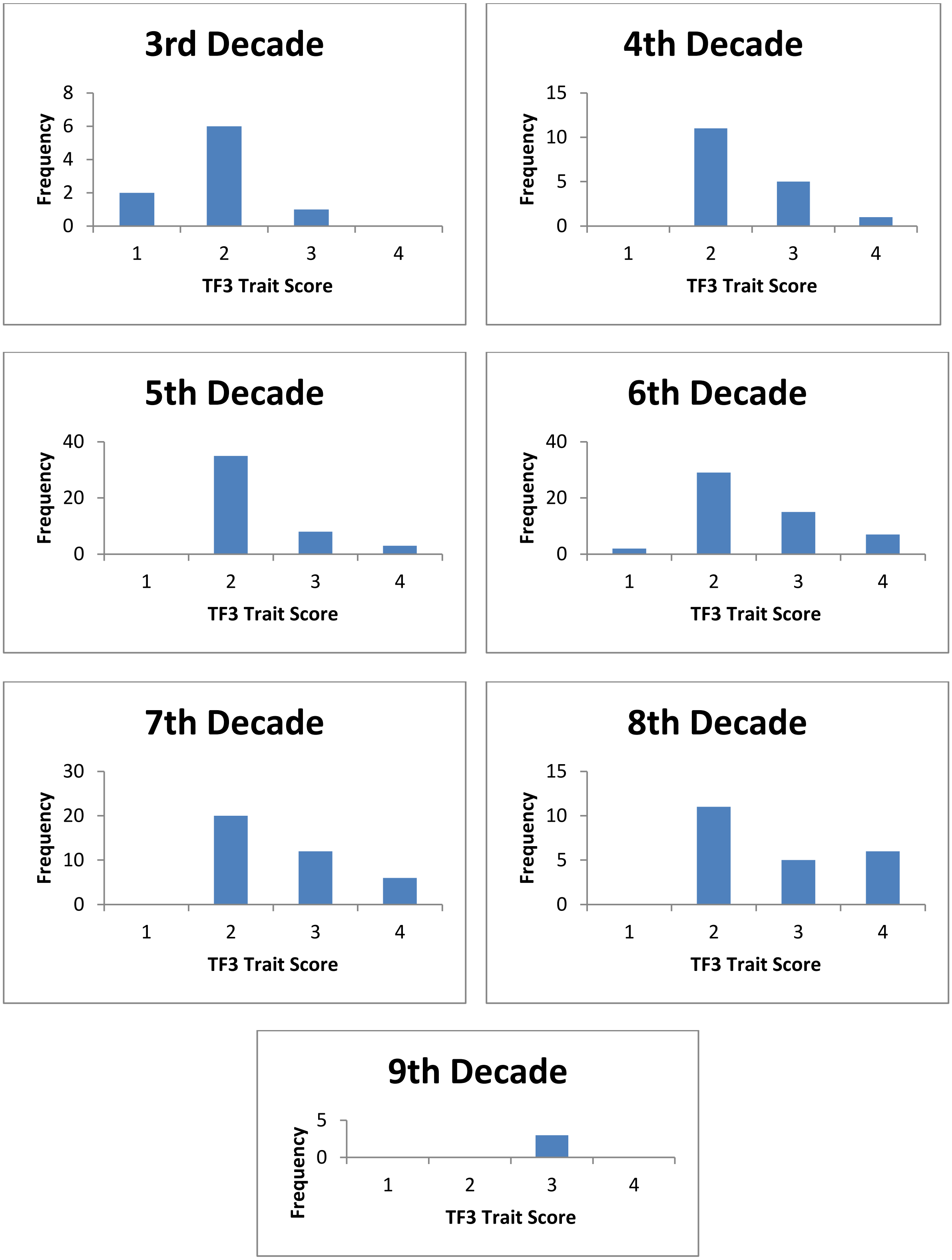


Figure 7 – Tubercle Facet 3 trait score frequencies by decade

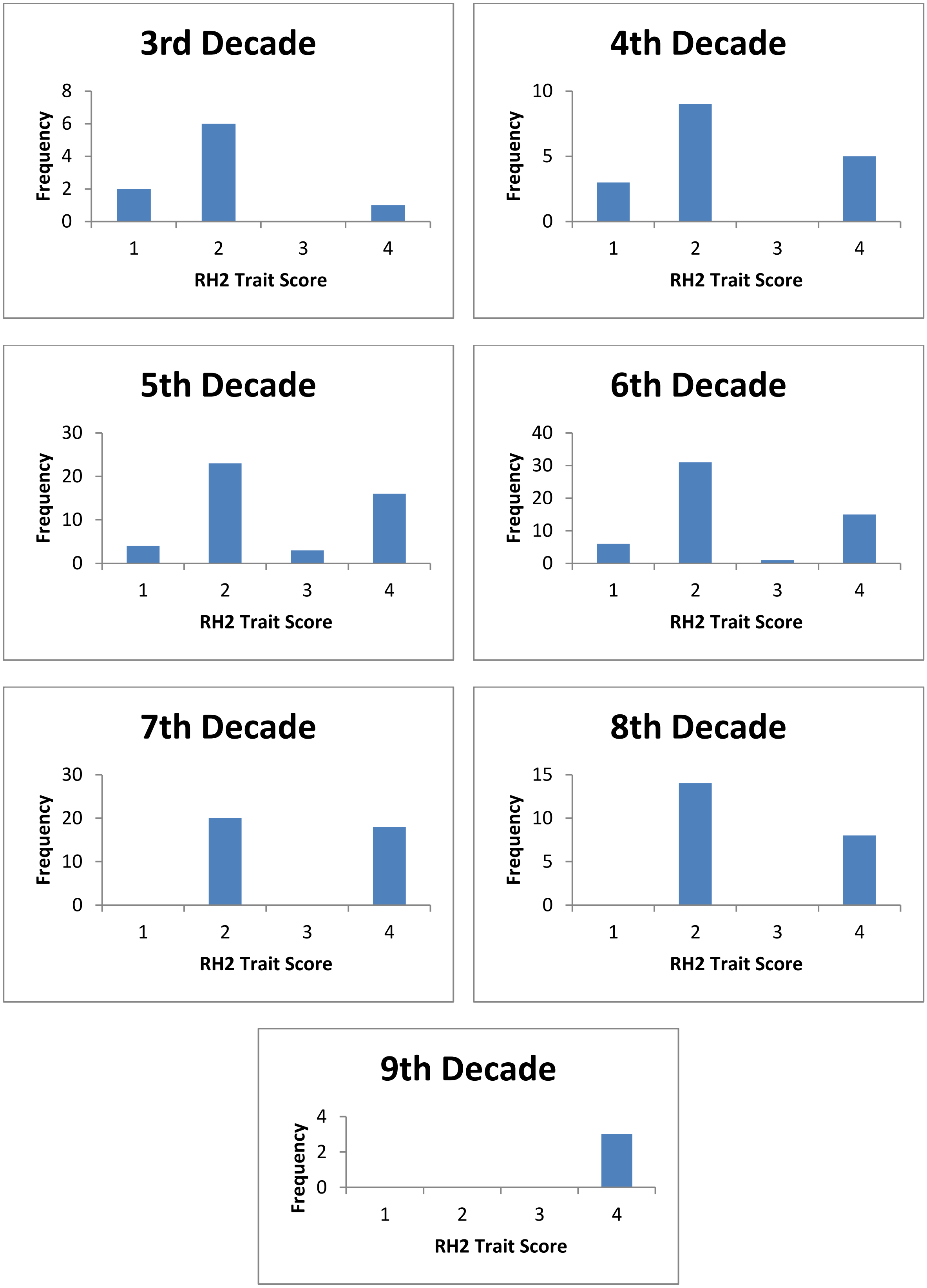


Figure 8 – Rib Head 2 trait score frequencies by decade

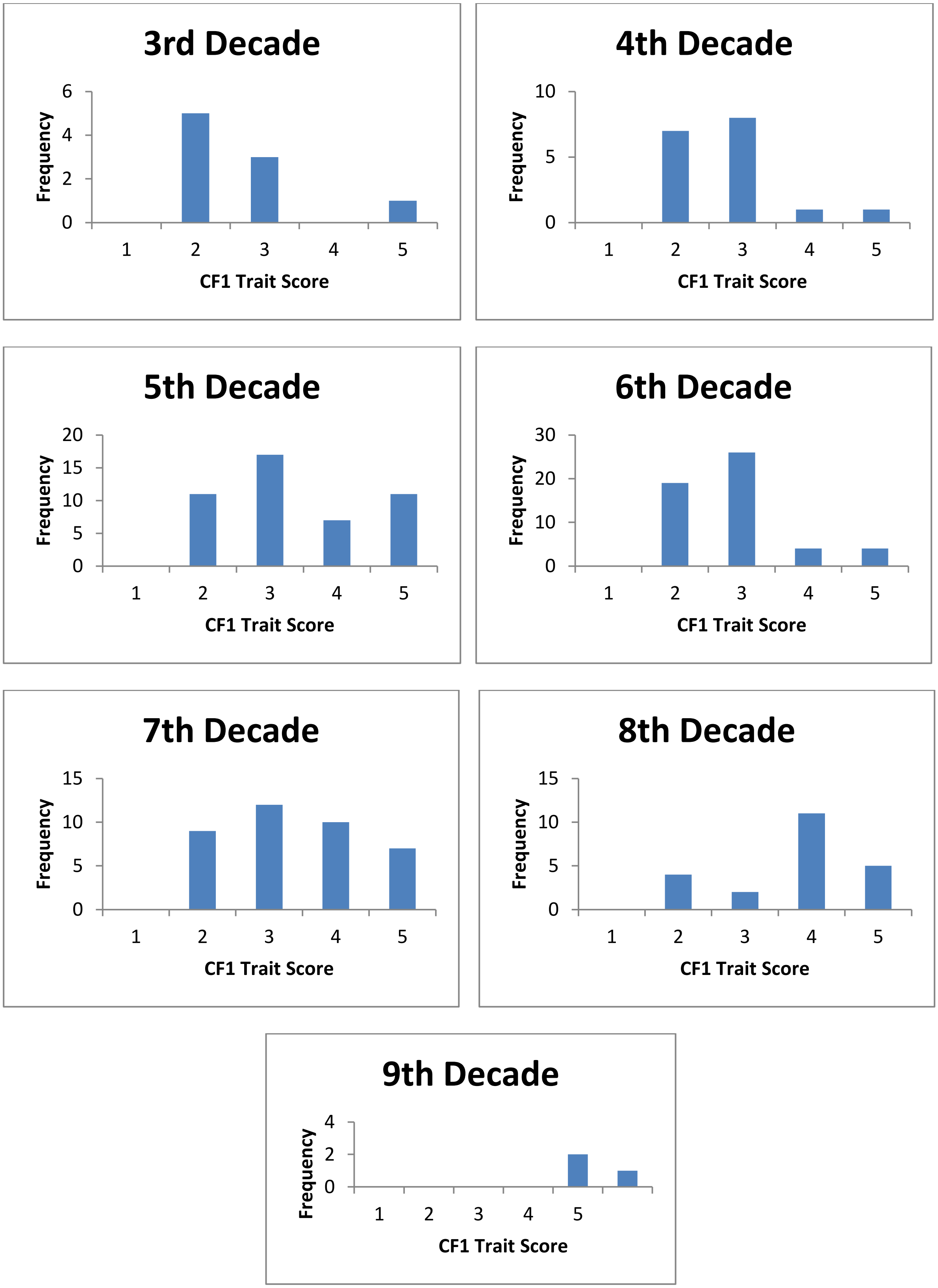


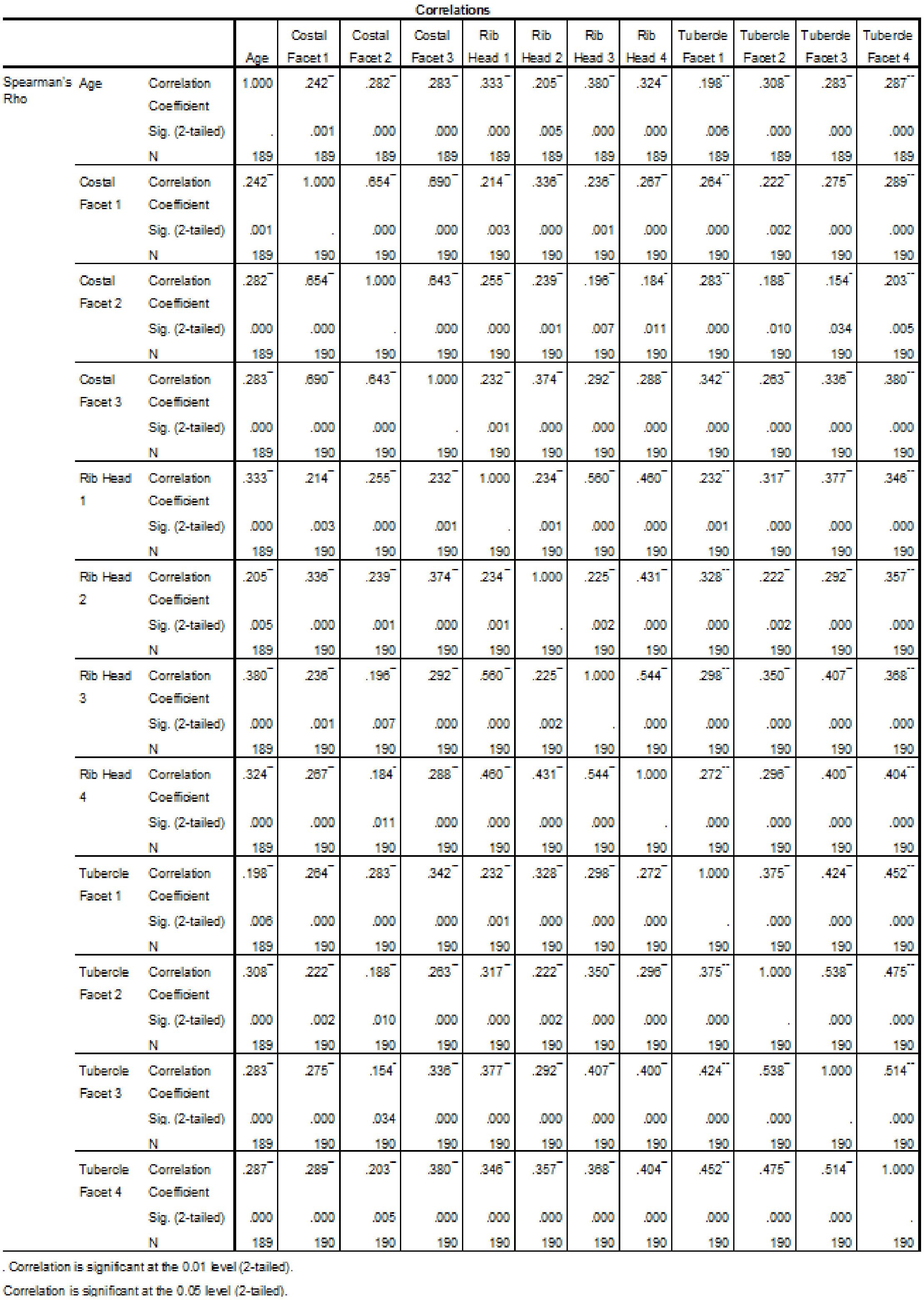
Figure 9 – Costal Face 1 trait score frequencies by decade

Some of the trait scores appear to increase in frequency, but then disappear entirely before reappearing in later decades. The best example of this is the surface topography of the rib head (RH2), in which score three is absent for the 3rd and 4th decade, present for the 5th and 6th, and then absent for the 7th, 8th, and 9th decades (Reference Figure 8). Moreover, the modal trait score for all traits tend to span several decades of life, although they do eventually increase (Table 8).

	CF1	CF2	CF3	TF1	TF2	TF3	TF4	RH1	RH2	RH3	RH4
30-39	2	3	2	2	3	2	3	2	2	2	2
40-49	3	3	2	3	3	2	3	2	2	2	2
50-59	3	5	4	3	3	2	3	2	2	2	2
60-69	3	3	2	3	3	2	4	2	2	3	4
70-79	3	5	4	3	3	2	4	3	2	4	4
80-89	4	4	4	3	3	2	4	3	2	3	4
90-99	4	5	4	4	3	3	4	3	4	4	4

Table 8 – Modal trait scores per age decade

The trait scores for all traits are also not highly correlated with age. As shown in Table 9, the highest degree of correlation between trait score and age was for the surface texture of the rib head (RH3), which has a coefficient of 0.380. The lowest coefficient (0.198) belonged to the geometry of the tubercle facet (TF1). This would suggest that changes in morphological characteristics of the first rib are not as distinctly associated with the aging process as previously stated.



Correlations

			Age	Costal Facet 1	Costal Facet 2	Costal Facet 3	Rib Head 1	Rib Head 2	Rib Head 3	Rib Head 4	Tuberde Facet 1	Tubercle Facet 2	Tuberde Facet 3	Tuberde Facet 4
Spearman's Rho	Age	Correlation Coefficient	1.000	.242**	.282**	.283**	.333**	.205**	.380**	.324**	.198**	.308**	.283**	.287**
		Sig. (2-tailed)	.	.001	.000	.000	.000	.005	.000	.000	.006	.000	.000	.000
		N	189	189	189	189	189	189	189	189	189	189	189	189
	Costal Facet 1	Correlation Coefficient	.242**	1.000	.654**	.690**	.214**	.336**	.236**	.267**	.264**	.222**	.275**	.289**
		Sig. (2-tailed)	.001	.	.000	.000	.003	.000	.001	.000	.000	.002	.000	.000
		N	189	190	190	190	190	190	190	190	190	190	190	190
	Costal Facet 2	Correlation Coefficient	.282**	.654**	1.000	.643**	.255**	.239**	.196**	.184*	.283**	.188**	.154*	.203**
		Sig. (2-tailed)	.000	.000	.	.000	.000	.001	.007	.011	.000	.010	.034	.005
		N	189	190	190	190	190	190	190	190	190	190	190	190
	Costal Facet 3	Correlation Coefficient	.283**	.690**	.643**	1.000	.232**	.374**	.292**	.288**	.342**	.263**	.336**	.380**
		Sig. (2-tailed)	.000	.000	.000	.	.001	.000	.000	.000	.000	.000	.000	.000
		N	189	190	190	190	190	190	190	190	190	190	190	190
	Rib Head 1	Correlation Coefficient	.333**	.214**	.255**	.232**	1.000	.234**	.560**	.460**	.232**	.317**	.377**	.346**
		Sig. (2-tailed)	.000	.003	.000	.001	.	.001	.000	.000	.001	.000	.000	.000
		N	189	190	190	190	190	190	190	190	190	190	190	190
	Rib Head 2	Correlation Coefficient	.205**	.336**	.239**	.374**	.234**	1.000	.225**	.431**	.328**	.222**	.292**	.357**
		Sig. (2-tailed)	.005	.000	.001	.000	.001	.	.002	.000	.000	.002	.000	.000
		N	189	190	190	190	190	190	190	190	190	190	190	190
	Rib Head 3	Correlation Coefficient	.380**	.236**	.196**	.292**	.560**	.225**	1.000	.544**	.298**	.350**	.407**	.368**
		Sig. (2-tailed)	.000	.001	.007	.000	.000	.002	.	.000	.000	.000	.000	.000
		N	189	190	190	190	190	190	190	190	190	190	190	190
	Rib Head 4	Correlation Coefficient	.324**	.267**	.184*	.288**	.460**	.431**	.544**	1.000	.272**	.296**	.400**	.404**
		Sig. (2-tailed)	.000	.000	.011	.000	.000	.000	.000	.	.000	.000	.000	.000
		N	189	190	190	190	190	190	190	190	190	190	190	190
	Tubercle Facet 1	Correlation Coefficient	.198**	.264**	.283**	.342**	.232**	.328**	.298**	.272**	1.000	.375**	.424**	.452**
		Sig. (2-tailed)	.006	.000	.000	.000	.001	.000	.000	.000	.	.000	.000	.000
		N	189	190	190	190	190	190	190	190	190	190	190	190
	Tubercle Facet 2	Correlation Coefficient	.308**	.222**	.188**	.263**	.317**	.222**	.350**	.296**	.375**	1.000	.538**	.475**
		Sig. (2-tailed)	.000	.002	.010	.000	.000	.002	.000	.000	.000	.	.000	.000
		N	189	190	190	190	190	190	190	190	190	190	190	190
	Tubercle Facet 3	Correlation Coefficient	.283**	.275**	.154*	.336**	.377**	.292**	.407**	.400**	.424**	.538**	1.000	.514**
		Sig. (2-tailed)	.000	.000	.034	.000	.000	.000	.000	.000	.000	.000	.	.000
		N	189	190	190	190	190	190	190	190	190	190	190	190
	Tubercle Facet 4	Correlation Coefficient	.287**	.289**	.203**	.380**	.346**	.357**	.368**	.404**	.452**	.475**	.514**	1.000
		Sig. (2-tailed)	.000	.000	.005	.000	.000	.000	.000	.000	.000	.000	.000	.
		N	189	190	190	190	190	190	190	190	190	190	190	190

. Correlation is significant at the 0.01 level (2-tailed).

Correlation is significant at the 0.05 level (2-tailed).

Table 9 – Correlation coefficients of trait scores versus age.

Transition analysis was performed upon the scored trait values for each of the individuals, following the protocol described by DiGangi, et al. (2009). The analysis was performed using the statistical package “R” (www.r-project.org), incorporating the programming code written by the authors (available online as an R workbook at https://netfiles.uiuc.edu/lylek/ www/ribs.RData). The complete scoring for each of the individuals is listed in Appendix A. The calculated mean ages-at-transition, along with their respective standard deviations, are displayed as log ages and year ages in Table 10 and Table 11, respectively.

It was apparent upon evaluation of the results of transition analysis that the mean ages-of-transition for several of the examined traits were unrealistic, often exceeding ages possible for a human life span. For example, the calculated mean age of transition between Tubercle Facet 3: Surface Texture, Score 3 – “Microporosity Evident” and Score 4 – “Lipping and Macroporosity Evident” was 154.94 years. After consulting with Dr. Joan C. Stevenson, it was decided that continuing to the next level of analysis would be superfluous, as the data collected during this research obviously does not support the predictive capabilities proposed by DiGangi and colleagues. Additionally, the trends observed in both trait score frequencies and modal trait scores suggest a high degree of variation in the timing of morphological changes within the sample population. Possible reasons for this outcome will be discussed in the following section of this thesis.

	Std. Dev	1|2	2|3	3|4	4|5
CF1	0.786	--	3.687	4.460	4.949
CF2	0.620	2.271	2.991	4.087	4.460
CF3	0.594	2.376	3.898	4.178	5.763
TF1	0.829	--	3.173	4.752	
TF2	0.622	2.986	3.507	4.785	
TF3	0.595	2.848	4.320	4.866	
TF4	0.605	2.834	3.415	4.199	
RH1	0.453	2.849	4.106		
RH2	0.758	3.043	4.390	4.433	
RH3	0.493	3.040	4.065	4.593	
RH4	0.673	2.725	3.827	4.183	

Table 10 – Mean ages-at-transition (in log years) for character states of the first rib.

	1|2	2|3	3|4	4|5
CF1	--	54.37	117.79	192.08
CF2	11.74	24.12	72.18	104.82
CF3	12.84	58.82	77.82	318.30
TF1	--	33.67	163.31	
TF2	24.03	40.47	145.25	
TF3	20.59	89.75	154.94	
TF4	20.43	36.53	80.00	
RH1	19.14	82.67		
RH2	27.95	107.48	112.20	
RH3	23.61	65.79	111.56	
RH4	19.13	57.60	82.23	

Table 11 – Mean ages-at-transition (in actual years) for character states of the first rib.

CHAPTER 5: Discussion

The results of this research indicate that the Rib 1 aging method proposed by DiGangi and colleagues does not adequately assess age-at-death in female skeletal remains. First, the mean ages-of-transition derived from the transition analysis are incompatible with the human life span. Additionally, the trait score frequency distributions, as well as the modal trait scores for each decade, suggest that there is significant variability in the timing of morphological changes in Rib 1 within the sample. Finally, the low degree of correlation between trait score and known age indicate that these morphological changes are not as associated with age as previously thought. There are three main possibilities for the disagreement between the results of this research and the results published by DiGangi and colleagues: 1) a high degree of subjectivity within the method, 2) errors in sampling, and 3) the existence of significant biological variation between both sexes, as well as between populations of different ancestry.

Subjectivity of the DiGangi Method

As mentioned in the preceding chapter, this author had significant difficulty in assigning the observed morphology of a given individual to the appropriate trait score. This was especially true when distinguishing between adjacent score values. This difficulty may be the result of the subjective nature of the trait score descriptions, as well as the lack of photographic exemplars. The research presented by DiGangi, et al., provided photographs for only two of the eleven evaluated traits. Interestingly, the issue of subjectivity mirrors critiques by several authors in previous evaluations of Kunos, et al.'s original method

(Schmitt and Murail, 2004; Kurki, 2005; DiGangi, et al., 2009). This problem was also something that DiGangi's work attempted to remedy.

These problems are consistent with what Brach and Dunn (2004) refer to as the two main types of error in skeletal analysis: Type A (random error) and Type B (systematic error). Random error affects reliability and precision, and is usually due to what Brown (2009:51) refers to as the "human factor." For example, random error may occur if an observer is unable to consistently place a given skeletal indicator in the correct stage. Random error may be reduced by careful technique during analysis. Systematic error is usually due to the morphological variation that exists between individuals (Brach and Dunn, 2004). Systematic error may occur when using cast moldings of age indicators (such as with the Isçan rib method), as these casting represent often represent the mean value of a given trait, rather than the total range of values. This error can be minimized through correlation analysis, which demonstrates how much variation exists between an observed variable and its mean (Levin and Fox, 2007).

Methodological Error

As with all research, adequate sampling plays an important role in data collection. The female skeletal remains from the Bass Collection vastly underrepresented individuals in the early decades of adulthood. This lack of representation may have resulted in unrealistic trait score distributions. This presents an error that Usher (2002) describes as age structure mimicry. Bouquet-Appel and Masset (1982) showed that the calculated mean of an age indicator often reflected the age structure of the reference sample being used. This means that the estimated age of an unknown sample would also reflect the age structure of the reference sample (Konigsberg and Frankenberg, 1992). This type of error is caused by biased skeletal samples, which may represent only a "select subset of individuals," rather than a widely varied population (Usher, 2002:31).

Biological Variation

Morphological differences in the bony skeleton between males and females have considerable impact on the development of age-at-death assessment methods. However, these differences are often not addressed when these methods are first developed. For example, the pubic symphyseal method proposed by Todd (1920, 1921) required further evaluation in order to adequately discuss the sexual dimorphism of the pubic symphysis. Suchey (1987; and Brooks,1990) documented that female pelves age faster than those of men due to the hormonal changes that occur during menopause. Additionally, Isçan (1985) noted sexually dimorphic differences in the superior-inferior height, width, and depth of the sternal end cavity of the fourth rib. These differences are significant enough to allow the determination of sex in an unknown sample.

To this author's knowledge, no literature exists discussing the sexual dimorphism of Rib I with regards to age-at-death assessment. However, the morphological differences of the thorax in general are well documented. As mentioned in the first chapter of this work, the first rib is involved in two main activities. First, Rib I helps to support the sternoclavicular joint, thereby transferring some of the weight and stress of the upper extremity to the thorax (Voisin, 2006). Second, the first rib facilitates in respiration by pivoting along its vertebral axis, which lifts the sternum superiorly, increasing the volume of the thoracic cavity. The constant activity of both passive and active respiration implies constant stress to the first rib (Cho and Stout, 2011). This stress in turn activates cortical remodeling and osteo-arthritic changes that may affect the morphological development of Rib I.

Sex Differences in Thorax Morphology. Aiello and Dean (1990) detailed the differences between males and females with regards to thorax morphology. Females possess a shorter sternum, which provides less of an area of attachment for the first rib. The female sternum is also positioned lower than the male sternum. In females, the top of the sternum is level with the third thoracic vertebra, while in males it is level with the second thoracic vertebrae. Females, on average also have a 10% reduction in overall thoracic volume when compared to males of similar size (Bellemare, et al., 2006). Sex differences studied in the costal cartilage of the thorax indicate that the costal cartilage of female ribs begins to calcify at an earlier rate than that observed in males (Elkeles, 1966; Saunders, 1966; Navani, et al., 1970; McCormick and Stewart, 1983).

Sex Differences in Physiological Processes. Guenette and colleagues (2009) evaluated work of breathing in both male and female athletes subjected to high intensity exercise. They concluded that women work harder to breath than men during intense exercise. This is most likely due to the smaller thoracic volume of females compared to males. Using a population sample excavated from the Imperial Roman necropolis of Isola Sacra, Cho and Stout (2011) demonstrated that females have a higher degree of bone loss and cortical remodeling for a given age than their male counterparts. Additionally, increased bone loss and a decrease in bone mineral density has been linked to the hormonal changes that occur in peri- and postmenopausal females (Kalu, 1991).

All of these differences indicate that the patterns and timing of morphological change are not contiguous between males and females. The differences in anatomical positioning of the upper thorax, the physical action of respiration, and the hormonal influences of menopause all create stress upon the first rib. These stresses, which are applied to both the anterior and posterior articulations of the first rib, result in increased activity of cortical remodeling, osteo-arthritic changes, and bone loss. This may help explain why the age-at-transition ranges determined from a female population are much higher than those determined for males. However, as the specific effects of sexual dimorphism of the first rib with respect to age have not been evaluated, further research is necessary to confirm these conclusions.

CHAPTER 6 – Conclusions and Suggestions for Future Research

In summation, it appears that morphology of the first rib does not accurately predict age-at-death when applied to a female population. The ultimate reasons for this failure are not immediately apparent. However, it would be a rash assumption to discard this method completely. Rather, future research could show promise in reevaluating the first rib and its application in skeletal assessment. This study could show more supportive results if repeated using a skeletal sample that adequately represents all age groups. Furthermore, as this thesis evaluated an entire population sample, it may also be necessary to stratify future samples by age in order to alleviate any underlying age bias.

Further evaluation of the method proposed by DiGangi, et al. should also include a comparison of males and females drawn from the same population. By incorporating both sexes, the conclusions reached by DiGangi could be evaluated while controlling for the effects of sex in the timing of morphological events. If significant differences between the sexes are still apparent, the scoring system previously devised may require alteration. This would allow for two separate sets of score descriptions, each appropriate for a specific sex.

REFERENCES CITED

Acsadi G and Nemeskeri J. 1970. History of human lifespan and mortality. Budapest: Akademiai Kiado.

Aiello LC and Dean C. 1990. An Introduction to Human Evolutionary Anatomy. London: Academic Press.

Aiello LC and Molleson T. 1993. Are microscopic aging techniques more accurate than macroscopic aging techniques? *J Archaeol Sci* 20:689-704.

Aykroyd RG, Lucy D, Pollard MA and Solheim T. 1997. Technical note: regression analysis in adult age estimation. *Am J Phys Anthropol* 104:259-265.

Baccino E, Ubelaker D, Hayek L and Zerilli A. 1999. Evaluation of seven methods of estimating age at death from mature human skeletal remains. *J Forensic Sci* 44:931-936.

Baker RK. 1987. The relationship of cranial suture closure and age analyzed in a modern multi-racial sample of males and females. Masters Thesis: California State University, Fullerton CA.

Bang G and Ramm E. 1970. Determination of age in humans from root dentin transparency. *Acta Odontologica Scandinavica* 28(1):3-8.

Bedford ME, Russel KF, Lovejoy CO, Meindl RS, Simpson SW and Stuart-Macadam PL. 1993. Test of the multifactorial aging method using skeletons with known ages-at-death from the Grant Collection. *Am J Phys Anthropol* 91:287-297.

Bocquet-Appel JP and Masset C. 1982. Farewell to paleodemography. *J Hum Evol* 11:321-333.

Boldsen J, Milner G, Konigsberg LW and Wood J. 2002. Transition analysis: a new method for estimating age from skeletons. In: Hoppa R and Vaupel J, ed. Paleodemography: age distributions from skeletal samples. Cambridge: Cambridge University Press. 73-106.

Brach RM and Dunn PF. 2004. Uncertainty Analysis in Forensic Science. Tucson, AZ: Lawyers and Judges Publishing Company, Inc.

Brooks S and Suchey JM. 1990. Skeletal age determination based on the os pubis: A comparison of the Acsadi-Nemeskeri and Suchey-Brooks methods. *J Hum Evol* 5(3):227-238.

Brown CA. 2009. Uncertainty in skeletal aging: a retrospective study and test of skeletal aging methods at the Joint POW/MIA Accounting Command Central Identification Laboratory. Masters Thesis, California State University-Chico.

Buikstra JE and Ubelaker DH. 1994. Standards for Data Collection from Human Skeletal Remains. Fayetteville, AR: Arkansas Archaeological Survey Research Series 44.

Charles DK, Condon K, Cheverud JM and Buikstra JE. 1986. Cementum annulations and age determination in *Homo sapiens.* I. Tooth variability and observer error. *Am J Phys Anthropol* 71(3):311-320.

Cho H and Stout SD. 2011. Age-associated bone loss and intraskeletal variability in the Imperial Romans. *J Anthropol Sci* 89:000

Condon K, Charles DK, Cheverud JM and Buikstra JE. 1986. Cementum annulations and age determination in *Homo sapiens.* II. Estimates and accuracy. *Am J Phys Anthropol* 71(3):321-330.

DiGangi EA, Bethard JD, Kimmerle EH and Konigsberg LW. 2009. A new method for estimating age-at-death from the first rib. *Am J Phys Anthropol* 138:164-176.

Dudar JC, Pfeiffer S and Saunders SR. 1993. Evaluation of morphological and histological age-at-death estimation techniques using ribs. *J Forensic Sci* 38(3):677-685.

Dudar JC. 1993. Identification of rib number and assessment of intercostal variation at the sternal rib end. *J Forensic Sci* 38(4): 788-797.

Elkeles A. 1966. Sex differences in the calcification of the costal cartilages. *Am Geriatrics J* 14:456-462

Gilbert BM and McKern TW. 1973. A method for aging the female os pubis. *Am J Phys Anthropol* 38:31-38.

Gray, Henry. 1918. Anatomy of the Human Body. Philadelphia: Lea & Febiger: 123.

Guenette JA, Querido JS, Eves ND, Chua R, and Sheel AW. 2009. Sex differences in the resistive and elastic work of breathing during exercise in endurance-trained athletes. *Am J Physiol Regul Integr Comp Physiol* 297:R166-R175.

Gustafson G. 1955. Age determinations in teeth. *J Am Dent Assoc* 41:45-54.

Hoffman JM. 1979. Age estimations from diaphyseal lengths: two months to twelve years. *J Forensic Sci* 24:461-469.

Iscan MY and Loth SR. 1986a. Determination of age from the costal rib in white males: a test of the phase method. *J Forensic Sci* 31:122-132.

Iscan MY and Loth SR. 1986b. Determination of age from the costal rib in white males: a test of the phase method. *J Forensic Sci* 31:122-132.

Iscan MY and Loth SR. 1986c. Determination of age from the costal rib in white females: a test of the phase method. *J Forensic Sci* 31:990-999.

Iscan MY, Loth SR and Wright RK. 1984a. Age estimation from the rib by phase analysis: white males. *J Forensic Sci* 29:1094-1104.

Iscan MY, Loth SR and Wright RK. 1984b. Metamorphosis at the costal rib end: a new method to estimate age at death in white males. *Am J Phys Anthropol* 65:147-156.

Iscan MY, Loth SR and Wright RK. 1985. Age estimation from the rib by phase analysis: white females. *J Forensic Sci* 30:853-863.

Iscan MY, Loth SR and Wright RK. 1987. Racial variation in the costal extremity of the rib and its effect on age estimation. *J Forensic Sci* 32:452-466.

Işçan MY. 1985. Osteometric analysis of sexual dimorphism in the sternal end of the rib. *J Forensic Sci* 30:1090-1099

Kalu DN. 1991. The ovariectomized rat model of post-menopausal bone loss. *Bone and Mineral* 15(3):175-191

Katz D and Suchey JM. 1986. Age determination of the male os pubis. *Am J Phys Anthropol* 69(4):427-435.

Kemkes-Grottenhaler A. 2002. Aging through the ages: historical perspectives on age indicator methods. In: Hoppa R and Vaupel J, ed. Paleodemography: age distributions from skeletal samples. Cambridge: Cambridge University Press. 48-72.

Konigsberg LW and Frankenberg SR. 1992. Estimation of age structure in anthropological demography. *Am J Phys Anthropol* 89:235-256.

Kunos CA, Simspon SW, Russell KF and Hershkovitz I. 1999. First rib metamorphosis: Its possible utility for human age-at-death estimation. *Am J Phys Anthropol* 110:303-323.

Kurki H. 2005. Use of the first rib for adult age estimation: a test of one method. *Int J Osteoarchaeol* 15:342-350.

Lamendin H, Baccino E, Humbert JF, Tavernier JC, Nossintchouk RM and Zerilli A. 1992. A simple technique for age estimation in adult corpses: the two criteria dental method. *J Forensic Scie* 37(5): 1373-1379.

Levin J and Fox JA. 2007. Elementary Statistics in Social Research: The Essentials, 2nd Edition. Boston: Pearson Education, Inc.

Loth SR and Iscan MY, 1994. Morphological indicators of skeletal aging: Implications for paleodemography and paleogerontology. In: Crews D and Garruto R, ed. Biological anthropology and aging: an emerging synthesis. New York: Oxford University Press. 394-425.

Loth SR. 1995. Age assessment of the Spitalfields cemetery population by rib phase analysis. *Am J Hum Biol* 7:465-471.

Lovejoy CO, Meindl RS, Mensforth RP and Barton TJ. 1985. Multifactorial determination of chronological age at death: Method and blind test of its accuracy. *Am J Phys Anthropol* 68(1):1-14.

Lovejoy CO, Meindl RS, Pryzbeck TR and Mensforth RP. 1985. Chronological metamorphosis of the auricular surface of the illium: a new method for the determination of skeletal age at death. *Am J Phys Anthropol* 68(1):15-28.

Martrille L, Ubelaker D, Cattaneo C, Seguret F, Tremblay M and Baccino E. 2007. Comparison of four skeletal methods for the estimation of age-at-death on white and black adults. *J Forensic Sci* 42: 302-307.

Masset C. 1989. Age estimation on the basis of cranial sutures. In: Age markers in the human skeleton. Işcan MY, ed. Springfield: Charles C. Thomas. Pp. 71-103.

McCormick WF and Stewart JH. 1983. Ossfication patterns of costal cartilage as an indicator of sex. *Arch Pathol Lab Med* 107:206-210

McKern TD and Stewart TD. 1957. Skeletal age changes in young American males. Analyzed from the skeletal standpoint of age identification. Technical Report EP-45: U.S. Army Quartermaster Research and Development Center.

Meindl RS and Lovejoy CO. 1985. Ectocranial suture closure: A revised method for the determination of chronological age at death based on the lateral-anterior sutures. *Am J Phys Anthropol* 68(1):57-67.

Meindl RS and Russell KF. 1998. Recent advances in method and theory in paleodemography. *Annu Rev Anthropol* 27:375-399.

Meindl RS, Lovejoy CO, Mensforth RP and Walker RA. 1985. A revised method of age determination using the os pubis, with a review and test of accuracy of other current methods of pubic symphyseal aging. *Am J Phys Anthropol* 68(1):29-46.

Navani S, Shah JR, and Levy PS. 1970. Determination of sex by costal cartilage calcification. *Am J Roentgen* 108:771-774

Oettle AC and Steyn M. 2000. Age estimation from sternal ends of ribs by phase analysis in South African blacks. *J Forensic Sci* 45:1071-1079.

Pal GP and Routal RV. 1986. A study of weight transmission through the cervical and upper thoracic regions of the vertebral column in man. *J Anatomy* 148:245-261.

Prince DA and Konigsberg LW. 2008. New formulae for estimating age at death in the Balkans utilizing Lamendin's dental technique and Bayesian analysis. *J Forensic Sci* 53:578-587.

Prince DA, Kimmerle EH and Konigsberg LW. 2008. A Bayesian approach to estimate skeletal age at death using dental wear. *J Forensic Sci* 53:588-593.

Rios L, Weisensee K and Rissech C. 2008. Sacral fusion as an aid in age estimation. *Forensic Sci Int* 180: 111E1-111E7

Rouge-Maillart C, Vielle B, Jousset N, Chappard D, Telmon N and Cunha E. 2009. Development of a method to estimate skeletal age at death in adults using the acetabulum and auricular surface on a Portuguese population. *Forensic Sci Int* 188:91-95.

Russell KF, Simpson SW, Genovese J, Kinkel MD, Meindel RS and Lovejoy CO. 1993. Independent test of the fourth rib aging technique. *Am J Phys Anthropol* 92:53-62.

Saunders CF. 1966 Sexing by costal cartilage calcification. *Br J Radiol* 39:233

Saunders SR , Fitzgerald C, Rogers T, Dudar C, and McKillop H. 1992. A test of several methods of skeletal age estimation using a documented archaeological sample. *Canadian Soc of Forensic Sci J* 25(2):97-118.

Schmitt A and Murail P. 2004. Is the first rib a reliable indicator of age-at-death assessment? Test of the method developed by Kunos et al. 1999. *Homo* 54:207-214.

Schmitt A. 2004. Age-at-Death Assessment Using the Os Pubis and the Auricular Surface of the Ilium: a Test on an Identified Asian Sample. *Int J Osteoarchaeol* 14:1-6.

Schour I and Massler M. 1941. The development of the human dentition. *J Am Dent Assoc* 28:1153

Sinha, A and Gupta V. 1995. A study on estimation of age from pubic symphysis. *Forensic Sci Int* 75:73-78.

Stewart TD. 1979. Essentials of Forensic Anthropology. Springfield, IL: Charles C. Thomas.

Stout SD and Paine RR. 1992. Histological age estimation using the rib and clavicle. *Am J Phys Anthropol* 87:111-115.

Suchey JM. 1987. Use of the Suchey-Brooks system for aging the male os pubis. *Am J Phys Anthropol* 72(2):259.

Taylor, R. 2009. Collection Manager of the William Bass Forensic Skeletal Collection, University of Tennessee-Knoxville. Personal Communication.

Todd TW. 1920. Age changes in the pubic bones. I. The male white pubis. *Am J Phys Anthropol* 3:285-334.

Todd TW. 1921. Age changes in the pubic bone. II. The pubis of the male Negro-white hybrid. III. The pubis of the white female. IV. The pubis of the female Negro-white hybrid. *Am J Phys Anthropol* 4:4-70.

Ubelaker DH. 1998. The evolving roll of the microscope in forensic anthropology. In: Reichs KJ, ed. Forensic Osteology Advances in the Identification of Human Remains, 2nd ed. Springfield, IL: Charles C. Thomas.

Ubelaker DH. 1999. Human Skeletal Remains, 3rd ed. Washington, DC: Taraxacum Press.

Usher BM. 2002. Reference samples: the first step in linking biology and age in the human skeleton. In: Hoppa R and Vaupel J, ed. Paleodemography: age distributions from skeletal samples. Cambridge: Cambridge University Press. 29-47.

Voisin JL. 2006. Clavicle, a neglected bone: morphology and relation to arm movements and shoulder architecture in primates. *The Anatomical Record Part A* 288A:944-953.

Walker RA and Lovejoy CO. 1985. Radiographic changes in the clavicle and proximal femur and their use in determination of skeletal age at death. *Am J Phys Anthropol* 68(1):67-78.

Wittwer-Backofen U and Buba H. 2002. Age estimation by tooth cementum annulations: perspectives of a new validation study. In: Hoppa RD and Vaupel J, ed. Paleodemography: age distributions from skeletal samples. Cambridge: Cambridge University Press. 119-129.

Yavuz MF, Iscan MY and Cologlu AS. 1998. Age assessment by rib phase analysis in Turks. *Forensic Sci Int* 98:47-58.

Yoder C, Ubelaker DH and Powell JF. 2001. Examination of variation in sternal rib end morphology relevant to age assessment. *J Forensic Sci* 46:223-227.

APPENDIX A – Raw Data of Trait Scores

SAMPLE NUMBER	AGE	ANCESTRY	CF1	CF2	CF3	TF1	TF2	TF3	TF4	RH1	RH2	RH3	RH4
WMB0104D	74	White	4	5	4	4	2	3	4	2	4	2	4
WMB0183D	79	White	2	5	4	3	3	2	4	3	2	4	4
WMB0185D	22	White	2	1	1	2	2	1	1	1	1	1	1
WMB0188D	71	White	2	4	3	3	3	2	3	2	2	2	3
WMB0193D	53	White	2	3	2	3	1	3	3	3	2	4	4
WMB0196D	66	Black	2	3	2	3	2	3	3	3	2	3	4
WMB0205D	76	White	2	3	2	3	3	2	3	3	4	2	2
WMB0208D	65	White	3	3	3	3	3	3	3	2	4	2	3
WMB0286D	39	Black	2	4	3	2	2	1	3	2	1	1	2
WMB0292D	62	White	3	4	2	4	3	2	4	3	2	4	4
WMB0295D	80	White	4	5	4	4	3	3	4	3	4	3	4
WMB0298D	53	White	5	5	4	3	3	2	3	2	2	2	2
WMB0301D	62	White	3	3	4	3	4	4	4	3	4	4	4
WMB0306D	52	White	2	3	2	3	2	2	3	2	2	2	2
WMB0307D	61	White	2	3	2	3	2	1	1	2	1	3	3
WMB0308D	61	White	3	4	4	3	3	3	4	2	4	3	3
WMB0396D	55	White	3	4	4	4	4	3	4	3	2	3	4
WMB0399D	66	White	2	3	2	4	4	4	4	3	4	3	2
WMB0402D	60	White	2	3	2	2	2	2	3	3	2	2	3
WMB0406D	58	White	4	4	4	4	4	4	4	2	4	2	3
WMB0481D	35	White	5	5	4	3	1	1	1	1	2	3	2
WMB0501D	59	Black	3	3	2	2	2	3	3	2	1	2	3
WMB0507D	72	White	2	4	2	2	3	2	3	3	4	4	4
WMB0587D	53	White	5	5	4	3	1	2	3	3	1	2	2
WMB0592D	62	White	2	5	4	4	4	4	4	3	2	2	4
WMB0689D	40	Black	4	5	4	3	3	2	4	3	4	3	4
WMB0692D	62	White	3	4	2	4	2	2	4	3	2	2	4
WMB0693D	80	White	4	5	4	3	4	4	4	3	2	4	4
WMB0707D	67	White	2	3	2	3	2	2	3	2	2	2	3
WMB0792D	64	White	4	5	4	3	4	4	4	3	2	4	4
WMB0795D	71	White	3	4	3	3	3	2	3	3	2	2	2
WMB0802D	79	White	5	5	4	3	3	3	3	3	4	3	4
WMB0807D	57	White	2	3	2	3	3	2	3	2	2	2	2
WMB0900D	43	White	3	3	2	3	4	4	4	2	1	2	3
WMB0995D	65	White	2	4	3	3	3	2	4	2	1	3	2
WMB0999D	54	White	3	2	4	3	2	3	3	3	4	3	4
WMB1001D	75	White	4	5	4	3	3	3	4	3	4	3	4
WMB1007D	50	White	3	3	3	3	3	2	4	2	4	3	2

WMB10106D	60	White	3	3	3	2	3	2	4	2	2	3	2
WMB10107D	89	White	4	4	4	4	4	4	4	3	2	4	4
WMB10507D	68	White	3	5	4	4	3	4	4	3	2	4	4
WMB10607D	70	White	4	4	4	3	3	3	4	2	4	2	4
WMB10706D	54	White	3	4	4	3	2	2	3	2	1	2	2
WMB10807D	69	White	3	3	3	3	3	2	2	2	2	3	2
WMB10907D	48	White	3	3	4	3	4	3	4	3	2	3	2
WMB1098D	69	White	2	5	2	3	3	2	2	2	1	3	2
WMB1101D	88	White	4	5	4	3	3	2	3	3	2	3	2
WMB1103D	47	White	2	3	2	3	3	2	3	3	2	2	4
WMB1104D	54	White	5	5	4	3	3	2	4	3	4	2	4
WMB1105D	76	White	4	5	4	4	4	3	4	3	2	4	4
WMB1106D	60	White	3	2	2	2	2	2	3	2	2	2	3
WMB1108D	79	White	2	3	4	3	3	3	3	3	4	3	4
WMB11107D	50	White	2	3	2	2	3	2	2	3	2	2	2
WMB11207D	64	White	3	3	2	3	3	2	3	2	2	2	2
WMB11307D	75	White	4	5	4	3	3	2	3	3	2	2	2
WMB11507D	57	White	5	5	4	3	3	2	3	3	4	4	4
WMB1190D	68	White	3	4	4	2	1	1	2	2	1	1	1
WMB1202D	49	White	3	3	2	3	1	2	3	2	4	2	4
WMB1204D	60	White	3	4	4	3	3	3	3	2	4	2	3
WMB1299D	72	White	3	3	4	3	4	4	4	3	2	4	4
WMB1302D	69	White	5	5	3	4	3	3	4	3	2	3	2
WMB1305D	74	White	3	5	3	3	4	2	4	3	2	4	4
WMB1308D	75	White	3	3	3	4	4	4	4	3	2	3	4
WMB1397D	71	White	5	5	4	4	4	4	4	3	2	4	4
WMB1401D	78	White	2	3	4	4	3	4	4	3	4	4	4
WMB1407D	79	White	4	5	4	4	3	4	4	3	4	4	4
WMB1501D	61	White	3	3	3	3	3	2	3	2	2	2	2
WMB1506D	59	White	4	5	4	4	3	2	4	3	4	3	4
WMB1507D	69	White	3	3	3	4	3	3	4	2	2	3	3
WMB1597D	35	Black	2	5	3	3	3	2	3	2	2	2	4
WMB1598D	81	White	4	5	4	4	3	2	4	3	4	2	2
WMB1699D	82	White	2	3	2	3	3	2	3	3	2	3	2
WMB1702D	50	White	3	3	2	2	3	2	3	3	2	2	2
WMB1703D	58	White	5	5	4	4	4	4	4	3	4	4	4
WMB1704D	91	White	5	5	4	3	3	3	3	3	4	3	4
WMB1705D	58	White	3	4	4	3	3	2	4	2	2	2	3
WMB1706D	50	White	3	3	4	3	3	2	2	2	2	2	3
WMB1797D	84	White	5	4	3	3	3	2	2	2	2	3	4
WMB1803D	47	White	2	3	2	3	3	2	3	2	2	3	3

WMB1804D	44	White	5	4	4	4	3	3	4	3	4	3	4
WMB1805D	99	Black	4	5	4	4	3	3	4	3	4	4	4
WMB1894D	83	White	5	4	4	3	3	3	3	3	4	3	4
WMB1902D	85	White	4	3	4	4	3	2	4	3	4	3	4
WMB1904D	60	White	5	5	4	3	3	2	3	3	2	4	4
WMB2006D	71	White	2	3	2	3	3	2	4	2	2	2	2
WMB2008D	62	White	3	3	3	4	3	3	4	2	2	3	3
WMB2091D	76	White	4	5	4	3	2	2	4	3	2	3	4
WMB2098D	63	White	2	3	4	4	4	2	4	3	4	4	4
WMB2102D	85	White	4	5	4	4	4	4	4	3	2	4	4
WMB2108D	65	White	2	3	3	3	3	2	3	3	2	3	4
WMB2193D	82	White	3	3	2	4	4	2	3	3	4	4	4
WMB2208D	50	White	2	2	2	2	1	2	2	2	2	2	2
WMB2300D	81	White	5	4	4	3	3	4	4	2	4	4	4
WMB2302D	62	White	4	4	4	3	3	2	4	2	4	2	4
WMB2307D	64	White	2	3	2	3	3	2	3	2	2	3	2
WMB2388D	59	White	2	3	2	3	2	2	2	3	2	3	4
WMB2400D	73	White	3	4	2	2	3	2	3	3	2	4	4
WMB2505D	51	White	4	4	4	3	3	3	4	2	4	4	4
WMB2506D	44	White	2	5	3	4	3	3	3	3	4	3	2
WMB2507D	77	White	5	5	4	3	3	2	3	3	4	4	4
WMB2599D	67	White	4	5	4	3	3	3	4	3	2	3	2
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WMB2693D	62	White	4	5	4	3	3	2	3	3	2	3	4
WMB2699D	74	White	5	5	4	3	3	3	2	3	4	3	4
WMB2701D	73	White	3	3	4	4	4	4	4	3	2	4	4
WMB2702D	63	White	2	3	2	2	3	2	2	2	1	1	1
WMB2705D	59	White	5	5	4	4	3	2	3	2	3	2	2
WMB2707D	45	White	3	4	2	3	2	2	3	2	2	2	2
WMB2791D	38	White	3	3	2	4	4	3	3	3	2	2	2
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WMB3206D	39	White	2	3	2	2	1	2	3	2	2	2	3
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WMB3307D	70	White	3	5	4	3	2	2	2	3	2	3	2
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WMB8306D	76	White	3	3	4	3	3	3	4	2	2	3	3
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WMB9707D	66	White	3	3	3	3	3	2	4	2	2	3	4
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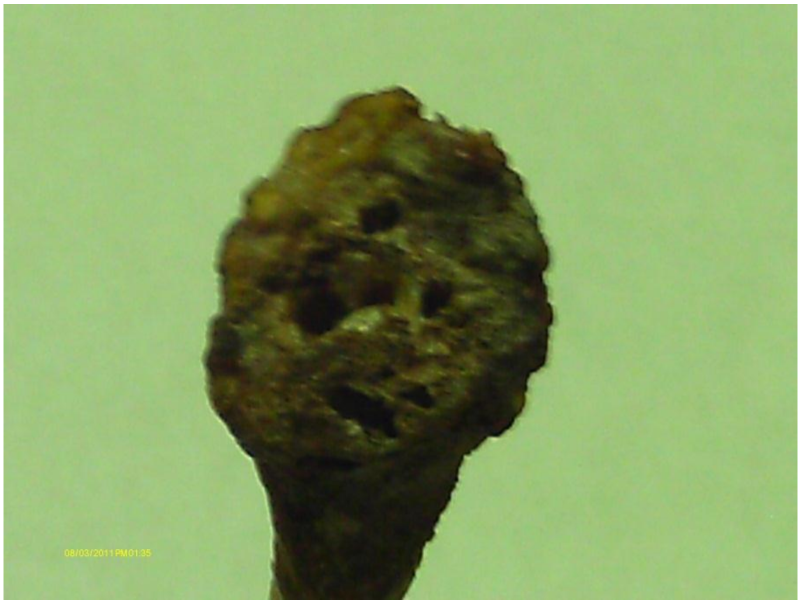
APPENDIX B – Photographic Exemplars of Trait Scores

COSTAL FACE 1 – SCORE 2 (Narrow, oval, and U-shaped. Slightly concave. Lacks ridges).

COSTAL FACE 1 – SCORE 3 (Circular and concave).

COSTAL FACE 1 – SCORE 4 (Irregular, hollow shell).



COSTAL FACE 1 – SCORE 5 (Irregular and filled in).

08/03/2011 AM 11:48

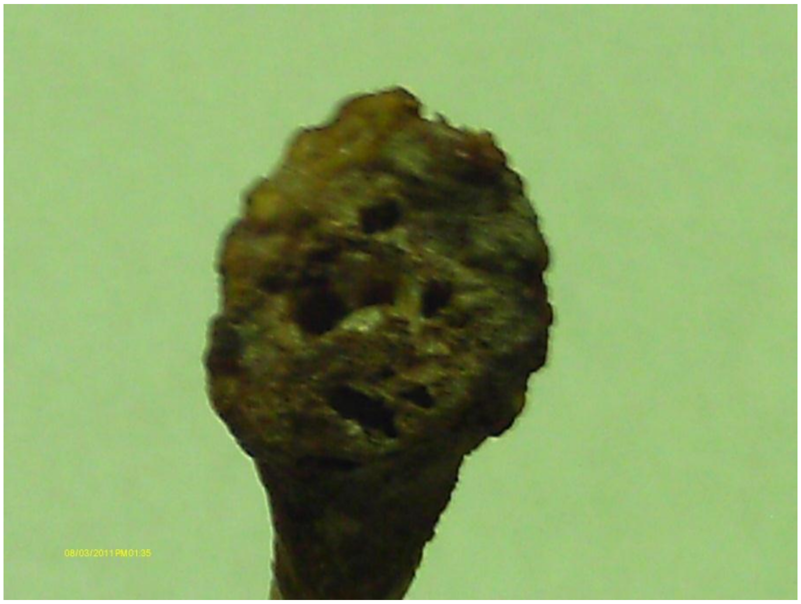
COSTAL FACE 2 – SCORE 1 (Irregular with knobby ridges).

08/03/2011 PM 12:32

COSTAL FACE 2 – SCORE 2 (Smooth surface without ridges).

COSTAL FACE 2 – SCORE 3 (Microporosity evident).

COSTAL FACE 2 – SCORE 4 (Concave surface).

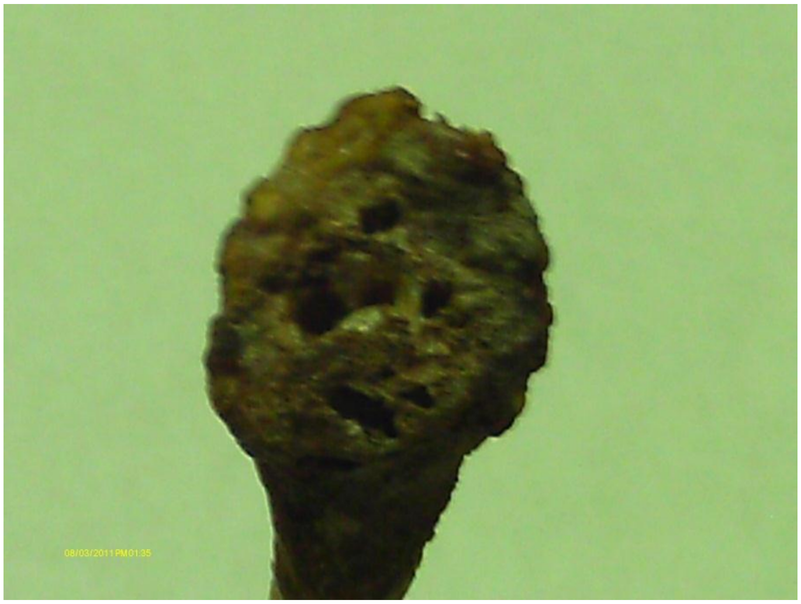


COSTAL FACE 2 – SCORE 5 (Macroporosity evident).

COSTAL FACE 3 – SCORE 1 (Rounded and uneven with scalloped edges).

COSTAL FACE 3 – SCORE 2 (Irregular and rugged).

COSTAL FACE 3 – SCORE 3 (Large spicules present).



COSTAL FACE 3 – SCORE 4 (Thinning, osteoporotic bone, ossification of spicules).

RIB HEAD 1 – SCORE 1 (Epiphysis unfused, flat and circular).

RIB HEAD 1 – SCORE 2 (Oval).

RIB HEAD 1 – SCORE 3 (Irregular).

RIB HEAD 2 – SCORE 1 (Flat or convex).

RIB HEAD 2 – SCORE 2 (Irregular).

RIB HEAD 2 – SCORE 3 (Medio-lateral groove present).

RIB HEAD 2 – SCORE 4 (Secondarily smooth).

RIB HEAD 3 – SCORE 1 (Dense and smooth).

RIB HEAD 3 – SCORE 2 (Depressed and irregular).

RIB HEAD 3 – SCORE 3 (Microporosity evident).

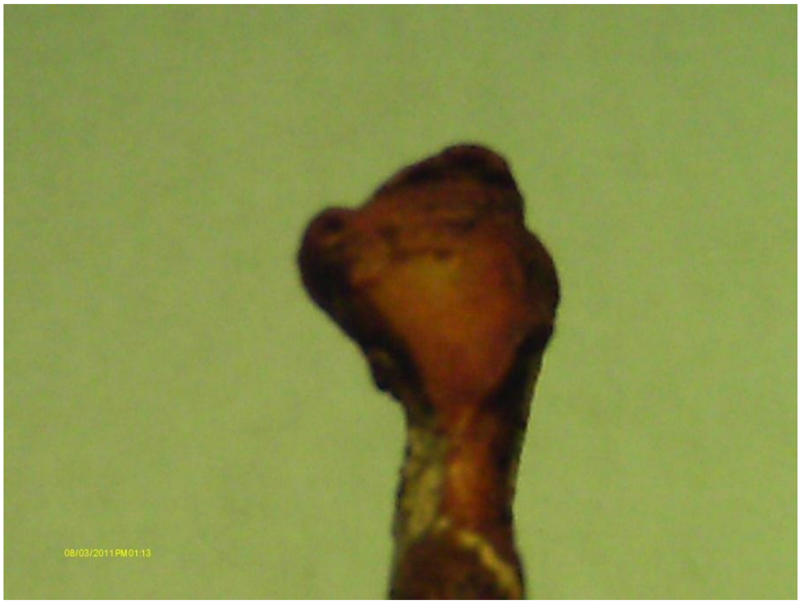
RIB HEAD 3 – SCORE 4 (Lipping and macroporosity evident).

RIB HEAD 4 – SCORE 1 (Rounded and smooth with continuous dorsal margins).

RIB HEAD 4 – SCORE 2 (Illdefined, irregular).

RIB HEAD 4 – SCORE 3 (Well defined, irregular and sharp).

RIB HEAD 4 – SCORE 4 (Lipping evident).



TUBERCLE FACET 1 – SCORE 2 (Teardrop shaped with pointed medial margins).

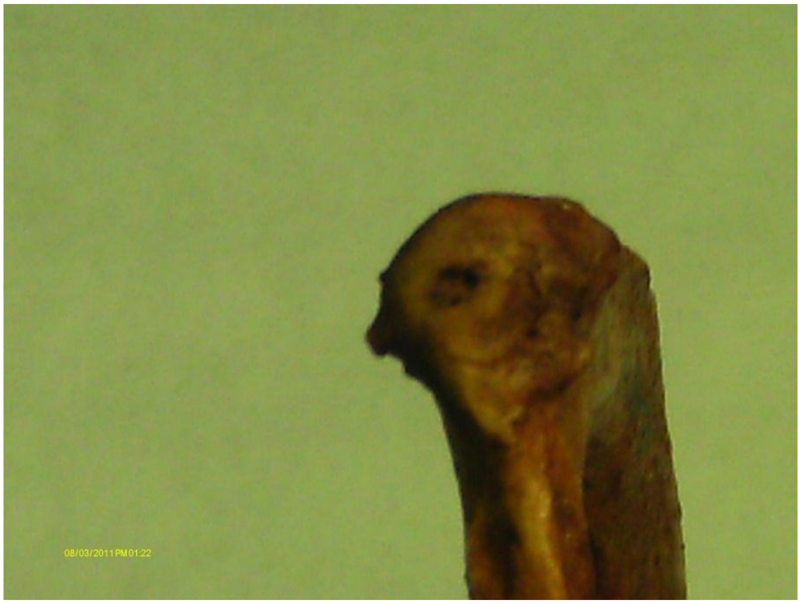
TUBERCLE FACET 1 – SCORE 3 (Cresent shaped with swollen superior edge).

TUBERCLE FACET 1 – SCORE 4 (Irregular or circular).

TUBERCLE FACET 2 – SCORE 1 (Rounded).

TUBERCLE FACET 2 – SCORE 2 (Flat).

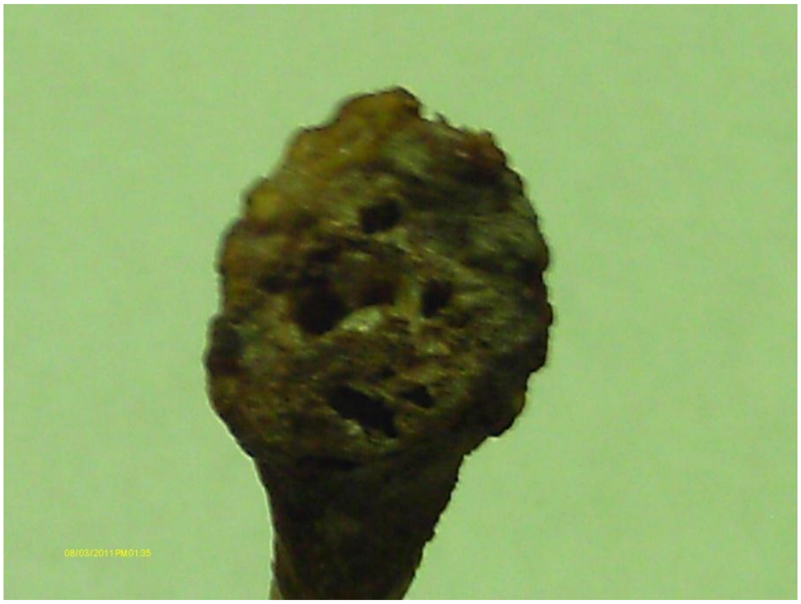
TUBERCLE FACET 2 – SCORE 3 (Concave).



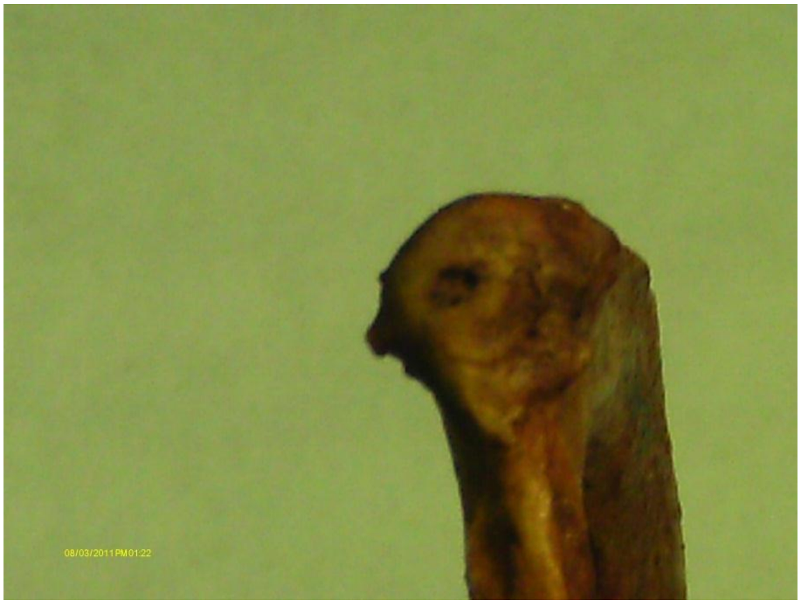
TUBERCLE FACET 2 – SCORE 4 (Irregular with macroporosity evident).

TUBERCLE FACET 3 – SCORE 1 (Dense and smooth).

TUBERCLE FACET 3 – SCORE 2 (Depressed and irregular).



TUBERCLE FACET 3 – SCORE 3 (Microporosity evident).



TUBERCLE FACET 3 – SCORE 4 (Lipping and macroporosity evident).

TUBERCLE FACET 4 – SCORE 1 (Rounded and smooth).

TUBERCLE FACET 4 – SCORE 2 (Elevated rim).

TUBERCLE FACET 4 – SCORE 3 (Rugged).

TUBERCLE FACET 4 – SCORE 4 (Depressed superior margins, prominent osteophytes and lipping).