AN EVALUATION OF THREE STERNAL RIB END AGING METHODS ON AN AMERICAN SAMPLE

By

Nicole Lynne Geske

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ABSTRACT

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The estimation of age is essential in the fields of physical and forensic anthropology; therefore the accuracy of these methods needs to be evaluated. Currently, there are multiple methods available for age estimation, including sternal rib end aging, which was specifically evaluated in this research.

Three sternal rib aging techniques, İşcan et al. (1984a; 1985), Hartnett-Fulginiti (2007; 2010), and Oettlé and Steyn (2000), were the focus of this study. The main objective was to determine the overall accuracy of each method, as well as examine differences in rates of accuracy between European-Americans and African-Americans. Data was collected from the Hamann-Todd and WM Bass collections. The sample consisted of male and female right fourth sternal rib ends from 411 individuals of both European and African ancestry, ranging in age from 16 to 97 years.

Results demonstrate that all three methods perform equally well, although the Hartnett-Fulginiti (2007; 2010) method is a slightly better predictor of age. Because the Oettlé and Steyn (2000) method was designed specifically on individuals of African ancestry from South Africa, it is not recommended for use within the United States. Additionally, due to similarities in accuracy for the Hartnett-Fulginiti (2007; 2010) and İşcan et al. (1984a; 1985) methods, both methods are a valuable age estimation technique in the field of physical anthropology and should be utilized based on level of experience and preference.

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INTRODUCTION

The estimation of age in the field of forensic anthropology is essential for the identification of human skeletal remains in medico-legal death investigations. This estimation is conducted through the use of a biological profile, consisting of the estimation of age, sex, ancestry, and living stature in order to reconstruct the identity of descendants (Byers, 2005). Currently, there are multiple techniques available to evaluate age-at-death, all of which vary significantly between adults and subadults. For instance, methods for subadult aging are based on growth and development, such as dental eruption and epiphyseal union. Comparatively, due to the maturation of the skeleton, adult aging methods are often more difficult, as they must instead evaluate more subtle changes, often the degeneration of elements (İşcan and Loth, 1989). Although the use of multiple techniques is ideal for aging an individual, problems of preservation or postmortem loss may inhibit this; thus the accuracy of these methods needs to be evaluated. Presently, there are four major elements primarily used for the morphoscopic determination of age in adults: the pubis, the auricular surface of the ilium, cranial sutures, and the fourth right sternal rib end. These four elements, as well as the aging techniques associated with them, will be discussed below in further detail.

Pubis

The pubic symphysis is generally thought to be the most accurate of these techniques due to the method's reliability and easily visible age-related changes (Meindl and Lovejoy, 1989). The first method for aging the pubic symphyses was developed by Todd (1920), who created a ten-stage phase system for European-American males based on changes in morphology that occur with age. Additional methods for European-American females and African-American males and females were developed the following year due to differences seen in the rates of aging (Todd, 1921). Generally it was found that the pubic symphyseal face contains ridges in young age, and as age increases, the ridges diminish with an overall degradation in bone quality (Todd, 1920).

Brooks (1955) later evaluated Todd's (1920; 1921) methods using Todd's original sample as well as an archaeological sample. The author found a tendency to over-age individuals, and therefore proposed modified age ranges in order to correct for these inaccuracies (Brooks, 1955). McKern and Stewart (1957) also tested Todd's (1920) methods and found that it did not take into account the range of variation that was observed. Therefore the authors developed a component analysis system based on a sample of males who had perished during the Korean War. Three features were used, consisting of the dorsal plateau, the ventral rampart, and the symphyseal rim. To apply the method, each feature is assigned a numerical score of 0 through 5 in order to obtain a composite score, corresponding to an overall age range (McKern and Stewart, 1957).

Because the McKern and Stewart (1957) method was developed only on males, the technique was also tested on females, in which it was found to significantly underestimate age for females over 40 years (Gilbert, 1973). Due to these variations, Gilbert and McKern (1973) developed an additional component analysis system for aging females using the same criteria defined by McKern and Stewart (1957). The authors found morphological developmental differences for females in that they generally appear older and may suffer from childbirth trauma, further complicating analysis (Gilbert and McKern, 1973).

Suchey (1979) later tested the Gilbert and McKern (1973) method on eleven females and found it to be generally unreliable, as a large amount of variation was found between the observer responses. Additionally, Katz and Suchey (1986) and Suchey et al. (1986) evaluated both the Todd (1920) and McKern and Stewart (1957) methods using a modern, autopsy sample. Results indicated that the Todd (1920) method overestimated age while the McKern and Stewart (1957) method was found to be less accurate for older individuals (Katz and Suchey, 1986; Suchey et al., 1986; Klepinger, 2006).

Based on these findings, Brooks and Suchey (1990) developed a revision of the Todd (1920; 1921) methods, which was based on a modern sample consisting of multiple ancestries and both sexes. This technique, commonly known as the Suchey-Brooks method, consists of six phases for each sex and is thought to be the most reliable of all aging methods (Brooks and Suchey, 1990; Klepinger, 2006).

Auricular Surface

The auricular surface of the ilium is less prone to postmortem damage than is the pubic symphysis and therefore may be utilized more frequently (Klepinger, 2006). And although the degenerative changes are more complex, several occur beyond the age of 50, unlike the pubic symphyses (Meindl and Lovejoy, 1989). The first method for aging from the auricular surface was developed by Lovejoy et al. (1985) and was based on correlations that were seen between age and degeneration in the features of the auricular surface, the apex, and the retroauricular surface of the ilium. The authors developed an eight-phase system, establishing standards that could be applied to both sexes (Lovejoy et al., 1985).

Buckberry and Chamberlain (2002) later revised the Lovejoy et al. (1985) method. These revisions made the method easier to apply and more accurate and reliable with increased age ranges and lowered rates of inter- and intra-observer error. The revised technique is based on a quantitative scoring system, in which multiple features are examined individually in order to obtain a composite score, corresponding to an overall age range. Tests of this revised method have shown that the method is equally applicable to males and females of both European and African ancestry (Mulhern and Jones, 2005). The revised method is also more accurate for younger individuals and easier to apply than the original method (Mulhern and Jones, 2005). Correlation values were also found to be higher than that of the Suchey-Brooks (1990) method, possibly indicating that the auricular surface may be more applicable, as its survival rate is also higher than that of other elements used for aging (Buckberry and Chamberlain, 2002).

Cranial Sutures

Although somewhat controversial, the cranium has also been used to estimate age by examining rates of ectocranial, endocranial, and maxillary suture closure (McKern and Stewart, 1957; Meindl and Lovejoy, 1985). The first modern study was conducted by Todd and Lyon (1924; 1925a;b;c), which examined rates of endocranial and ectocranial suture closure. In order to develop the method, crania were separated by sex and ancestry, and although differences were found, the authors believed that developing separate standards was not necessary (Todd and Lyon, 1925b).

Brooks (1955) later evaluated the technique, finding it to be generally unreliable, and therefore suggested that it should only be used to confirm other aging techniques. Due to these findings, Meindl and Lovejoy (1985) also conducted a test of the Todd and Lyon (1924; 1925a;b;c) method and developed a revision using a numerical scale of 0 (open) through 3 (obliterated) to evaluate suture closure at ten specific sites on the ectocranium (Meindl and Lovejoy, 1985). According to Garvin and Passalacqua (2012), this method is now the most commonly utilized for suture closure, although it still should be used with caution or in conjunction with other methods due to ancestral- and sex-based variations in the rate of closure which are not accounted for in the method (Meindl and Lovejoy, 1985).

Additionally, maxillary suture closure has also been studied. A method developed by Mann et al. (1987; 1991) evaluated rates of this closure the based on the obliteration of four palatal sutures. Although tests of this method have shown that maxillary sutures are a useful age estimator for older individuals (Ginter, 2005), the authors advise that it is only applicable for placing individuals into general age categories, separating commingled remains, or when the maxilla is the only element present (Mann et al., 1987; 1991; Gruspier and Mullen, 1991). Finally, an additional segmented approach for aging from the closure of maxillary sutures has also been developed by Beauthier et al. (2010), which also suffers from the same issues as the Mann et al. (1987; 1991) method, in that the age of young individuals was often overestimated and the age of older individuals was often underestimated.

Sternal Rib

The sternal end of the right fourth rib, which was evaluated in this research and is discussed later in detail, was developed by İşcan, Loth, and Wright (1984a;b; 1985), and is commonly known as the İşcan and Loth or the İşcan et al. method. In the development of this technique, the authors examined the morphological features of the sternal end of right fourth rib and determined that there were consistent, degenerative changes. Therefore, they were able to develop a phase system to document these changes, as well as link this degeneration with age based on changes "in the form, shape, texture, and overall quality of the sternal rib" (İşcan et al., 1984a:1096).

Research Objectives

The Scientific Working Group for Forensic Anthropology (SWGANTH) defines best practices for the field, including standards for age estimation. As detailed by SWGANTH (2010), the estimation of age should begin by first assessing the physiological age of the remains in order to associate it with a chronological, or actual, age. This is done through the examination of degenerative or developmental traits, which represent the biological or physiological age, as reflected in the skeleton. For adults, degenerative traits are used for this process, using methods that have been developed and tested on modern individuals (SWGANTH, 2010).

SWGANTH (2010) also states that when estimating the age of unknown individuals, standards that have been developed on individuals of similar sex and ancestry to the decedent should be utilized. Therefore, the objective of this research was to evaluate three sternal rib aging techniques, the İşcan et al. (1984a; 1985), Hartnett-Fulginiti (2007; 2010), and Oettlé and Steyn (2000) methods, for overall accuracy rates. Additionally, although the İşcan et al. (1984a; 1985) method has been previously tested, the Hartnett-Fulginiti (2007; 2010) and Oettlé and Steyn (2000) methods have not been previously evaluated and were therefore an important part of this research.

A second purpose of this study was to evaluate any possible differences in accuracy between European-Americans and African-Americans. Ancestral and population based differences have previously been demonstrated in the aging process. For example, İşcan et al. (1987) found differences in the rate and pattern of morphological age-related changes in African-Americans compared to European-Americans. Oettlé and Steyn (2000) found similar features in the degenerative changes in South Africans of African ancestry. Therefore it was important to examine if any differences in accuracy were evident between African-Americans and European-

Americans, for if significant differences are found, it may require the development of separate rib aging standards based on ancestry.

In addition to assessing the accuracy of African-Americans, all three methods were tested on European-Americans. Although the İşcan et al. (1984a; 1985) European-American methods are currently the most accepted technique for sternal rib aging, the Hartnett-Fulginiti (2007; 2010) method was developed as a revision of the technique. Both methods also utilized a mostly European-American population, therefore it was important to examine which method would be a better assessor of age for these individuals.

Research Questions

Using a sample of human remains from multiple collections, this research addressed the following questions:

1. Will the Hartnett-Fulginiti (2007; 2010) method more accurately assess age-at-death than the İşcan et al. (1984a; 1985) method and the Oettlé and Steyn (2000) method?
2. Will the Hartnett-Fulginiti (2007; 2010) method more accurately assess the age-at-death of European-Americans than the İşcan et al. (1984a; 1985) method and the Oettlé and Steyn (2000) method?
3. Will the Oettlé and Steyn (2000) method more accurately assess the age-at-death of African-Americans than the İşcan et al. (1984a; 1985) method and the Hartnett-Fulginiti (2007; 2010) method?
4. Will there be differences in accuracy based on ancestry for each method?
5. Will there be differences in accuracy based on sex for each method?
6. What are the rates of intra-observer error?

Research Hypotheses

This research had multiple hypotheses.

1. The Hartnett-Fulginiti (2007; 2010) method will more accurately assess age of all individuals within the sample than the İşcan et al. (1984a; 1985) method and the Oettlé and Steyn (2000) method.
2. The Hartnett-Fulginiti (2007; 2010) method will more accurately assess age of European-Americans than the İşcan et al. (1984a; 1985) method and the Oettlé and Steyn (2000) method.
3. The Oettlé and Steyn (2000) method will more accurately assess age of African-Americans than the Hartnett-Fulginiti (2007; 2010) method and the İşcan et al. (1984a; 1985) method.
4. There will be significant differences in accuracy between European-Americans and African-Americans.
5. There will be significant differences in accuracy between males and females.
6. The intra-observer error rates will be insignificant.

LITERATURE REVIEW

The impetus for the research conducted by İşcan, Loth, and Wright was Kerley's (1970) observation that there are morphological age-related changes in the sternal end of the rib, as well as from degenerative changes seen in other "radiographic, histological, and osteological studies" (İşcan et al., 1984b:147). Additionally, the thorax was favored as a location for age estimation, as there is limited stress applied to the region. This is in contrast to other aging methods, such as the pubic symphysis, which can suffer from weight bearing, locomotive, and childbirth stress (İşcan and Loth, 1986; İşcan, 1991; Hartnett, 2007). Therefore the sternal end of the rib was demonstrated to be an appropriate region to study age-related deterioration, as it is easily accessible, has consistent degenerative changes, and has minimal stress applied to the area.

Calcification of the Costal Cartilage

Although researchers have been unable to precisely determine the specific means and causes for the calcification of the costal cartilage, it is generally accepted that this process develops "in relation to the vascular canals … and increase[s] with age" (Sokoloff, 1983:110). It is the failure of this mechanism that alters the rate of calcification of the costal cartilage, affected by both mechanical and systemic factors (Horner, 1949; Garvin, 2010).

Mechanical factors affecting calcification of the costal cartilage include both biomechanical and physiological stresses (e.g. King, 1939; Sedlin et al., 1963; Semine and Damon, 1975), with differences in the rate and pattern of calcification based on sex and ancestry (e.g. Michelson, 1934; Elkeles, 1966; Saunders, 1966; Semine and Damon, 1975; McCormick, 1980; McCormick and Stewart, 1983; İşcan and Loth, 1986a;b; İşcan et al., 1987; Rao and Pai, 1988). For instance, King (1939) found that the calcification of the costal cartilage is a continuous process that occurs with age and is a consequence of the strain from intercostal muscle attachments. This can especially be seen in males, in which calcification begins at the superior and inferior margins, specifically where the intercostal muscles attach (Garvin, 2010).

Activity patterns may also affect the metamorphosis of the sternal rib ends (e.g. Rösing et al., 2007), as well as stress from normal respiration (e.g. Semine and Damon, 1975; İşcan and Loth, 1986c; McCormick and Stewart, 1988; Barchilon et al., 1996; Yoder et al., 2001). Specifically, it was determined that the upper ribs suffer from more stress due to their attachment to the sternum, therefore experiencing more torsional stress (Semine and Damon, 1975; Yoder et al., 2001). In addition, the first costal cartilage was found to have a different and more variable rate and pattern of calcification than that seen in the lower ribs (McCormick and Stewart, 1998). Barchilon et al. (1996) found similar results from the examination of the calcification patterns of the first rib, specifically that extreme physiological stress was one factor in early calcification of the first rib cartilage.

Additional systemic factors, such as abnormalities, pathologies, nutrition, and genetics, also affect age-related degenerative changes of the rib (e.g. Riebel, 1929; King, 1939; Vastine et al., 1948; Horner, 1949; Eichelberger and Roma, 1954; Sokoloff, 1983; Senac et al., 1985; Garvin, 2010; Webb et al., 2010; Ea et al., 2011). Webb et al. (2010) examined abnormal spinal curvature and found that it affected sternal rib aging by distorting the ribs, making the sternal ends appear more youthful or flattened. Therefore Webb et al. (2010) suggested that when aging individuals with scoliosis, shape criteria should not be a major factor. Instead, porosity and pitting should be examined in more detail (Webb et al., 2010).

In an additional study, Jordanoglou (1969) examined rib movement and found that individuals suffering from ankylosing spondylitis (the inflammation of joints in the spine, which leads to fusion) and kyphoscoliosis (abnormal spinal curvature) had rib movement that was reduced and limited to the rib-neck axis, possibly altering changes in the degeneration of the costal cartilage. Senac et al. (1985) also found an increased rate of costochondral calcification in adolescents with hyperthyroidism, linking the disease with increased bone maturation. Still, additional factors should be taken into account for individuals with hyperthyroidism, as they may also affect the rate of calcification, such as length of time the hormone level is elevated and nutritional stress, especially in regards to calcium (Semine and Damon, 1975; Senac et al., 1985).

The results of these studies demonstrated that although both mechanical and systemic factors affect both the rate and pattern of the degeneration of the sternal ends of the ribs, the area does not suffer from a large amount of stress, suggesting that the region may be an appropriate location for age estimation.

Costal Cartilage Aging

As a result of the studies mentioned above, which established that the calcification of the costal cartilage was a consequence of age, many researchers attempted to develop age estimation methods based on specific patterns seen in this degeneration process (e.g. Semine and Damon, 1975; McCormick, 1980; McCormick and Stewart, 1988; Barrès et al., 1989). For example, a study conducted by Semine and Damon (1975) examined the rate of costochondral calcification in five populations. The authors numerically scored the rate of calcification from 0 (none) to 4 (severe) from chest radiographs on the first rib and the lower ribs separately. The results indicated that calcification of the rib cartilage was correlated with age, and if further investigated, could prove to be an accurate age estimation technique. Additional sex and population differences were also noticed, demonstrating that standards should be separated based on these factors (Semine and Damon, 1975).

In another study, McCormick (1980) examined radiographs of 20 chest plates from an autopsy sample and confirmed that calcification of the costal cartilages was age-related. McCormick and Stewart (1983) later expanded on this research by examining 651 radiographs of chest plates from autopsy cases of known ancestry, sex, and age. Typical male and female patterns of age related changes were noted, with the calcification of costal cartilages increasing with age (McCormick and Stewart, 1983). Finally, McCormick and Stewart (1988) developed a method based on matching known patterns of calcification to those found in each individual. Additionally, a linear regression equation was developed, which was found to be reasonably predictive of age for younger individuals, but was less reliable for older ages (McCormick and Stewart, 1988).

Barrès et al. (1989) also developed a multiple linear regression equation based on the correlations seen between the calcification of the costal cartilage and age. A qualitative scoring system was used due to the multiple features seen in radiographs of chest plates. The method was later tested by Garvin (2010) on a modern sample and was found not to be reliable, although the author was able to revise the technique by applying a binomial scoring system. From this revised system, Garvin (2010) was able to obtain more accurate age estimations.

Sternal Rib End Aging

Previous studies concluded that the costal cartilage undergoes degenerative changes affecting the morphology of the sternal end of the rib. From these studies it was known that the rib end general starts out relatively blunt in young individuals and becomes sharper and more cup-shaped with age (Kerley, 1970; Ubelaker, 1978; McCormick and Stewart, 1988). Additionally, the positioning and function of the ribs were found not to be significantly affected by function or stress, with minimal respiration strain applied to the region, making the sternal end of the rib an appropriate location for age estimation (Semine and Damon, 1975; İşcan and Loth, 1986; Loth and İşcan, 1989; İşcan, 1991; Hartnett, 2007). Due to previous studies, such as these, the main objective of this area of research shifted from developing methods based on the calcification of the cartilage to the remodeling of the sternal end of the rib.

A method for age estimation based on the sternal end of the right fourth rib was first developed as a preliminary component analysis study (Loth et al., 1983), which was later tested and published by İşcan, Loth, and Wright (1984b). A total of 93 modern European-American males were used to develop this component analysis method, resembling that used by McKern and Stewart (1957). The technique was based on features that were noticed in the sternal ends of the ribs, consisting of the pit depth, pit shape, and rim and wall configurations (İşcan et al., 1984b). In order to apply the component analysis method, the pit depth was measured, while scoring of the pit shape consisted of morphological changes in the pit formation, such as taking on a V- and then a U-shape. Finally, the rim was scored based on edge morphology and texture. These three components were individually scored and placed into one of six stages, with the composite score of all three components corresponding to an overall age range (İşcan et al., 1984b).

This method was only found to be generally reliable for younger individuals as it became less accurate with age (İşcan et al., 1984b). Therefore, the technique was later replaced by a more accurate and simpler phase method, modeled after the Todd (1920) pubic symphysis method, which reduced the more complicated four steps into one step (Wright et al., 1984). This change may have improved accuracy, as it was found that the component methods often perform poorly due to “their failure to allow full integration of all age-related variables” (Meindl et al., 1990:349).

The İşcan, Loth, and Wright (1984a) study was conducted on a modern, autopsy sample of 118 European-American males, ranging in age from 17 to 85 years of known age, sex, and ancestry (Appendix A). Morphological age related changes were not seen in males younger than the age of 16, indicating that rib growth ends at this age; therefore individuals younger than this were excluded from the study. It was generally found that in males after the development of the rib is complete, the sternal end of the right fourth rib appears nearly flat with billowing (Phase 0). The degeneration of the rib begins with a pit on the medial articular surface (Phase 1), later taking on a V-shape as the pit deepens (Phases 2 and 3), which gradually widens into a U-shape (Phases 3 through 8). As age increases, the pit widens and deepens. Additionally, the rim boarder becomes irregular and the overall texture of the articular surface becomes brittle and more porous (İşcan et al., 1984a).

Tests of the method were conducted at the 1984 American Academy of Forensic Sciences meeting using 15 European-American male ribs from a medical examiner’s office, with judges consisting of students and professionals, as well as the authors (İşcan and Loth, 1986b). No descriptions of the phases were given; therefore phase classification was only determined based on the provided photographs. Results indicated that the changes in morphology were more clearly seen below Phase 4, as older phases become more difficult to age. Additionally, inter-observer error due to varying degree of experience was found to be minimal. Therefore the authors concluded that age estimation from the right fourth sternal rib end could be estimated to fit within the correct phase, and that the accuracy based on experience was not a large issue (İşcan and Loth, 1986b).

Sex Biases

Earlier studies showed sexual dimorphic differences in the calcification of costal cartilage (e.g. Fischer, 1955; Elkeles, 1966; Saunders, 1966; Navanti et al., 1970; Semine and Damon, 1975; Stewart and McCormick, 1983; Stewart and McCormick, 1984; McCormick et al., 1985; Rao and Pai, 1988; Torwalt and Hoppa, 2005; Rejtarová et al., 2009a; 2009b), as well as specifically in the sternal end of the rib (e.g. Cöloğlu et al., 1998; Wiredu et al., 1999; Koçak, 2003; Gavit, 2009). Fischer (1955) noticed specific sex-based patterns to the calcification of the costal cartilage, and Horner (1949) observed that menstrual disorders affect the rate and pattern of this calcification. Navani et al. (1970) also noted these patterns in a sample of 1000 chest radiographs and therefore proposed that these typologies could be used to predict sex by placing individuals into one of three categories, representing a specific pattern of calcification. From these typologies, Navani et al. (1970) determined that 95 percent of males and 93 percent of females could be correctly sexed.

Saunders (1966) and McCormick and Stewart (1983) also found similar male and female patterns of calcification of the costal cartilage. The authors found that males displayed linear or marginal calcification, which begins at the superior and inferior borders of the ribs. Females instead displayed calcification in the central area of the rib, often containing ossific nodules or areas of irregular calcification (Saunders, 1966; McCormick and Stewart, 1983). Additionally, Saunders (1966) found that when females displayed male patterns of calcification, most had undergone pelvic surgery, often hysterectomies. Therefore it was concluded that the rate and pattern of calcification of the costal cartilage is sex dependent and at least partially based on hormonal and genetic influences (Elkeles, 1966; Saunders, 1966; Semine and Damon, 1975; McCormick and Stewart, 1983; Rao and Pai, 1988).

Due to variations seen between males and females in the rate and pattern of degenerative changes, separate standards were developed for European-American females by İşcan, Loth, and Wright in 1985 in order to more accurately reflect the female aging process. The sample consisted of 86 European-American females ranging in age from 14 to 90 years that were collected from modern autopsies. Morphological age-related changes were not seen in samples of females younger than 14 years old, indicating that rib growth ends at this age; therefore individuals younger than this were excluded from the study. It was generally found that female development was slightly ahead of males, with the gap widening to ten years in later phases. Differences between the sexes were mostly found in the shape and depth of the pit on the medial articular surface and differences in the changes from the V- to U-shape of the pit (İşcan et al., 1985; İşcan, 1991).

The findings of this study resulted in the creation of a separate set of standards for European-American females (Appendix B). For females it was found that after development of the rib is complete, the sternal end of the right fourth rib appears nearly flat with billowing (Phase 0). The degeneration of the rib begins with a pit on the medial articular surface (Phase 1) that takes on a V-shape as the pit deepens (Phases 2 though 6), which gradually widen into a U-shape (Phases 3 through 8). As age increases, the pit does as well, becoming both wider and deeper. A scalloping pattern develops on the rim edges (Phases 2 through 4) and the rim border turns irregular (Phases 5 through 8), with the overall texture of the articular surface becoming brittle and porous with age (Phases 4 through 8). Additionally, females were found to have ribs that were thinner and less dense (İşcan and Loth, 1986c). Females also displayed a central arc of bone reaching from the anterior to the posterior walls and bony extensions within the pit (İşcan et al., 1985).

Tests of the method were conducted on a sample of ten European-American females from a medical examiner's office at the 1985 American Academy of Forensic Sciences meeting, with judges consisting of both students and professionals. Photographic standards for each phase were given to the observers, with the addition of two rib phase examples, in order to aid in the estimation of age. The tests indicated the need for written descriptions when applying the method, as sometimes one phase may resemble another if small nuances are not noticed (İşcan and Loth, 1986a).

Differences between European-American males and females were further tested by İşcan (1985). A modern, autopsy sample consisting of 144 European-American male and 86 European-American female fourth right sternal rib ends were used. Measurements were taken for the maximum superior-inferior height, the maximum anterior-posterior breadth, and the maximum pit depth. Significant differences were found between the sexes, indicating that sexual dimorphism can be reliably assessed metrically; therefore a discriminant function formula was developed in order to predict sex of the unknown rib (İşcan, 1985). Allen (1997) also tested sexual dimorphism on the ribs on a modern African-American sample, consisting of 110 males and 52 females. Discriminant function formulae were developed on ribs one through seven in order to determine sex, with a maximum accuracy of 83 percent for rib four, although these formulae are both population and rib specific (Allen, 1997).

Ancestral Biases

Although the estimation of ancestry is an important part of the biological profile, it is often the most controversial. Recently, the term “ancestry” has mostly replaced “race” within the field of forensic anthropology due to negative connotations of word. This has prompted some researchers to believe that the concept of race should be discarded completely in the field of anthropology, as it is purely a social construct (Armelagos and Goodman, 1998; Smay and Armelagos, 2000). Others, however, believe that although the concept is not valid, it may be necessary in forensic contexts (Sauer, 1992; Kennedy, 1995).

Race is often defined on the basis of phenotypic, or observable, variations, which are a result of adaptive responses to the environment. These variations can be seen in visible morphological features and in the skeleton, especially in the facial area. It is from these observable traits, such as skin color and facial features, that social categories of race have been developed. Therefore, anthropologists must often translate their estimation of ancestry into a racial category for identification purposes. This can be problematic, as racial and social identities may differ from biology. Still, the estimation of ancestry within the field is useful, especially when dealing with the identification of unknown decedents, as it allows for the estimation of an individual’s ancestral origins.

Previous studies determined that ancestral variation in the rate of aging was present in the costal cartilage and sternal end of the ribs (e.g. Michelson, 1934; Semine and Damon, 1975; İşcan et al., 1987; Loth, 1990; Russell et al., 1993; Yoder et al., 2001; Love, 2005). Michelson (1934) examined ancestral differences in the rate of first cartilage calcification found that it was more rapid in African-Americans than in European-Americans. Semine and Damon (1975) also noted population-based differences in the extent of the calcification of the costal cartilage.

Due to these known variations, the applicability of the sternal rib aging on African-Americans was evaluated as well (İşcan et al., 1987; Loth and İşcan, 1988). The İşcan et al. (1984a; 1985) methods for European-Americans were tested on a sample of 73 modern African-Americans, consisting of 49 males and 14 females of known age and sex. Results indicated differences in both the rate and the pattern of morphological changes indicative of aging between European-Americans and African-Americans, which were attributed to genetic influences (İşcan et al., 1987). Specifically, the authors found an earlier maturation rate for African-Americans. Degenerative changes occurred at a similar rate for both European-Americans and African-Americans until the late twenties, with nearly identical mean ages per phase. After the age of thirty, African-Americans were found to look older than European-Americans and were consistently over-aged by three to ten years due to the presence of "pointy rims and pronounced superior or inferior projections" (İşcan et al., 1987:455). Additionally, scalloping that was found in Phase 2 for European-Americans was found to be inconsistent and less pronounced in African-Americans. The anterior and posterior articular rim, which was usually rounded or flattened in European-Americans, was pointed, squared off, or flattened in African-Americans. These same projections appeared earlier and with greater frequency in African-Americans compared to European-Americans. These findings indicated that ancestral differences might affect the estimation of age. Therefore the authors proposed modifications of the phases to be applied to African-American males and females (İşcan et al., 1987; Loth and İşcan, 1989; İşcan, 1991), although according to Garvin and Passalacqua (2012), these standards are often not utilized.

Loth (1990) also examined differences between African-Americans and European-Americans using the İşcan et al. (1984a; 1985) European-American methods on third, fourth, and fifth ribs of 136 African-American individuals from the Terry Collection. Results indicated that the patterning of morphological changes seen in the African-Americans were similar to those seen in the İşcan et al. (1987) modern sample, with ribs of African-American individuals remaining more dense and solid with less deterioration than those of European-American individuals. Additionally, measurements of the ribs showed that African-Americans had smaller anterior-posterior and superior-inferior dimensions, indicating that there are morphological variations in the shape and degeneration of the sternal rib end between the two ancestral groups (Loth, 1990).

Russell et al. (1993) also examined both European-American and African-American males from the Hamann-Todd Osteological Collection. The İşcan et al. (1984a) method for European-American males was tested on two samples; the first consisted of 23 European-American males and the second consisted of 80 males: 41 European-Americans and 39 African-Americans with similar age distributions. A general non-significant tendency to under-age African-American males was found, which is contradictory to what İşcan et al. (1987) predicted. No statistically significant differences were found between the ancestries; therefore the authors concluded that the European-American male standards could be used to estimate age for both European-American and African-American males. Additionally, it was determined that although the method was a useful indicator, it should only be used in conjunction with other aging methods (Russell et al., 1993).

Finally, Love (2005) tested the İşcan et al. (1984a; 1985) European-American methods on a modern autopsy sample consisting 50 African-Americans and European-Americans of both sexes. The results found that 37 percent were assigned to the correct phase, with African-American males significantly over-aged. Due to the small sample size used for this research, Love (2005) also suggested that further research be conducted as to possible ancestral based differences in the rate and pattern of aging between European-Americans and African-Americans at the sternal end of the rib.

Intercostal Variation

In addition to the mentioned mechanical and systemic factors that may affect the reliability and repeatability of the method, another difficulty of the rib aging methods is that they were developed specifically on the fourth right sternal rib end. Although this rib was selected for its ease of acquisition during an autopsy (İşcan et al., 1984a; 1985), obtaining this specific rib may be difficult in both forensic and archaeological contexts due to poor preservation or postmortem loss. For these reasons, many researchers have addressed issues of intercostal variation by developing techniques that help to determine the side and rib number in order to better identify the fourth right rib. These techniques are based variation in the morphology of ribs had already been established, especially for the first rib and between the lower and upper ribs (e.g. Semine and Damon, 1975; İşcan and Loth, 1986c; McCormick and Stewart, 1988; Barchilon et al., 1996; Yoder et al., 2001). Additionally, tests of the İşcan et al. (1984a; 1985) methods were conducted on non-fourth ribs to determine the accuracy of the method when this rib is not available.

Mann (1993) described an approach to side and sequence ribs by using the features of the maximum rib length, size, and shape of the articular facets, the length between the facets and rib angle, and the height of the rib heads. Additionally, Dudar (1993) developed a method to identity the rib based on morphological changes seen in typical and atypical ribs, specifically changes seen in the angle in both the horizontal and vertical planes. The author then tested the İşcan et al. (1984a; 1985) European-American methods on ribs two through nine, and found no significant differences between non-fourth and fourth ribs. Therefore it was concluded that "the fourth rib standards can be cautiously applied to ribs two through nine when rib number cannot be identified, or when rib four is not preserved" (Dudar, 1993:796–797).

İşcan et al. (1989) tested ribs three, four, and five on a sample of 70 males and females in order to determine if they had similar accuracy rates. Results indicated that all three ribs were correctly phased in the majority of the cases and only minor differences between the ribs were observed. Additional tests of the third and fifth sternal rib ends were on African-Americans from the Terry Collection (Loth, 1990), the Spitalfields Collection (Loth, 2005), and a modern forensic sample (Loth et al., 1994). Specifically, Loth (1990) examined 136 African-Americans from the Terry Collection and compared those to modern a sample of 268 modern European-Americans and 89 African-Americans. Intercostal variation was examined using metric measurements of superior-inferior height and maximum anterior-posterior breadth. The results showed that most of ribs three and five were aged similarly to that of rib four, indicating that these ribs could be used as a proxy for when the fourth rib is not present (Loth, 1990).

Loth et al. (1994) also examined ribs three, four, and five of 135 European-American males and females in order to determine if rib aging standards could be used on adjacent ribs. Results showed that ribs three and five were typically phased correctly, with all three ribs placed in the same age range for 79 percent of the cases and 98 percent within one phase (Loth et al., 1994). From these studies it was demonstrated that ribs three and five could be used as a substitute in cases when the fourth rib was not present or damaged (Loth, 1990; Loth et al., 1994; Aykroyd et al., 1999; Loth, 2005).

Alsup (2007) additionally evaluated the İşcan et al. (1984a; 1985) European-American methods on second, fourth, and eighth ribs using a modern forensic sample of 156 individuals from the William M. Bass Donated Collection. The sample was divided into males and females, consisting of mostly European-Americans, but also a few African-Americans and Hispanics. Statistically significant differences were found on the right second and eighth ribs, with the second ribs overestimating and the eight ribs underestimating the age of the individuals (Alsup, 2007). Yoder et al. (2001) also evaluated the accuracy of the İşcan et al. (1984a; 1985) European-American methods on both left and right second through ninth ribs. The sample consisted of 231 European-American and African-American males and females from the Terry Collection, the Maxwell Museum Collection, and the William M. Bass Donated Collection. It was found that for ribs four through nine, the left side does not differ significantly from the right side, although statistically significant differences between ribs do appear when sex and ancestry are taken into account. Additionally, ribs two and three were found to have significant differences between the right and left sides, suggesting that the sides are not subjected to the same amount of stress. The authors also found that the right third and right fifth through ninth ribs do not significantly differ from the right fourth rib, suggesting these ribs could be substituted, although they should be used with caution. Finally, the authors recommend a composite scoring method of all ribs when possible due to variations in accuracy based on rib number and side (Yoder et al., 2001).

First Rib Aging

The first rib has also been examined, as it was found to ossify at a more advanced rate than the lower ribs (Semine and Damon, 1975; Barchilon et al., 1996). Kunos et al. (1999) developed an age estimation technique from the first rib using a sample from the Hamann-Todd Osteological Collection. This technique involves measurements of rib length and the costal face thickness, as well as morphological features seen in the costal face, rib head, and tubercle (Kunos et al. 1999).

Kurki's (2005) tests of the Kunos et al. (1999) method found it to be relatively accurate and precise, although Schmitt and Murail (2004) found it to be subjective, with only 55 percent of the sample correctly classified. Advantages of first rib aging methods are that the first rib is easily identifiable, less fragile, and subjected to limited mechanical stress. Additionally, these first rib aging methods take degenerative changes of the entire rib into account rather than just the sternal end (Kunos et al., 1999; Kurki, 2005). A modification of the Kunos et al. (1999) method has also been proposed by using the same criteria with additional categorical traits using a Bayesian analysis (DiGangi et al., 2009). It was found that two morphological traits were age-dependent: the geometric shape of the costal face and surface texture or the tubercle facet (DiGangi et al., 2009).

Accuracy of the Method

In order to achieve an accurate age estimate, multiple aging techniques should be utilized. Unfortunately, some elements may be missing or damaged and therefore the number of techniques available becomes limited. Due to these issues, the accuracy of all aging methods should be tested on multiple populations and contexts, as well as in comparison to other aging techniques.

Galera et al. (1995) tested multiple macroscopic aging methods, including the İşcan et al. (1984a; 1985) European-American methods on the Terry Collection on left and right fourth and seventh ribs. Results indicated that for all methods, there were no statistically significant differences among recorders, demonstrating low rates of inter-observer error, indicating that the methods are easy to apply and minimal experience is needed. Other tests by Loth and İşcan (1989) also found low rates of inter-observer error for the İşcan et al. (1984a; 1985) European-American methods. These results are in contrast to Dudar et al. (1993), who found high rates of inter-observer error within the method. Kimmerle et al. (2008) also tested inter-observer error of multiple methods, including the İşcan et al. (1984a; 1985) European-American methods, on a sample of individuals from Kosovo. Observers disagreed by one phase, with most discrepancies in Phases 3 through 7. This was determined to be a result of the variations seen within these phases, such as with the presence and amount of rim projections (Kimmerle et al., 2008).

In another study, İşcan et al. (1992) tested the İşcan et al. (1984a; 1985) European-American standards in comparison to the Angel's (1980) modification of Todd's (1920) pubic symphysis aging technique, as it is often thought to be of the most accurate and reliable aging methods. The right pubic bone and right fourth rib of an autopsy sample of 80 European-Americans of known ancestry, sex, and age were used for the sample. The results showed that the rib has less variation than the pubic symphyses. Additionally, the İşcan et al. method was able to estimate individuals within one phase 93 percent of the time, compared to 61 percent for the pubis, with females that were aged more accurately than males for both methods. The authors believe that the main reason for the difference is that the pelvis often suffers from weight bearing forces, which applies additional functional stress that may make the bone appear older (İşcan et al., 1992). Comparatively, these stresses are not applied to the ribs, or are less of a factor, and therefore morphological changes as seen in the rib have less variation and can give narrower age ranges (İşcan et al., 1992; Loth and İşcan, 1990; Aykroyd et al., 1999).

Baccino et al. (1999) examined four techniques to estimate the age of death in adult skeletal remains, including the İşcan et al. (1984a; 1985) European-American methods on a sample of 19 adults of known age and sex collected from autopsies in France. Tests indicated that the İşcan et al. (1984a; 1985) methods tended to overestimate age; therefore the authors suggested that multiple age estimators should be used in conjunction when possible, due to better rates of accuracy (Baccino et al., 1999). Martrille et al. (2007) also tested four aging methods, including the İşcan et al. (1984a; 1985) sternal rib end method on 218 individuals from the Terry collection, consisting of 98 European-Americans and 120 African-Americans. The results showed that all methods tested tend to over-age young individuals and under-age older individuals, although the İşcan et al. (1984a; 1985) method displayed the least amount of inaccuracy. It was also concluded that as many age estimators as possible should be used and the final evaluation should consider methods that have the highest accuracy (Martrille et al., 2007).

Finally, Brown (2009) tested multiple aging methods, including the İşcan et al. (1984a) European-American male method, to determine accuracy and reliability rates. For the İşcan et al. (1984a) method, an overall tendency to under-age males was found. When individuals were assigned into the closest two phases, accuracy increased to 100 percent, possibly indicating that the confidence intervals for this method are too small (Brown, 2009).

Applicability of the Method

Many studies demonstrated that the İşcan et al. (1984a; 1985) European-American methods were accurate in forensic contexts; therefore the applicability of the method to archaeological and historic contexts was also examined by additional researchers. Loth (2005) tested the İşcan et al. (1984a; 1985) methods on the archeological Spitalfields cemetery collection, consisting of 74 adult individuals: 36 males and 38 females. Results showed that this sample displayed the same age-related degenerative patterns to those of modern European-

Americans. An additional test of the method by Potter (2010) examined differences between historic (reference) and modern (recent) collections. Multiple methods were tested for this research, including the İşcan et al. (1984a; 1985) European-American methods. Results did not indicate differences in the rate of aging between the historic and modern collections, and the İşcan et al. (1984a; 1985) methods produced strong and highly significant correlations, indicating that the method is accurate and reliable.

In contrast, Saunders et al. (1992) applied multiple aging techniques, including the İşcan et al. (1984a; 1985) European-American methods, to a documented archaeological sample. Results showed that rates of intra- and inter-observer error were an issue for the İşcan et al. (1984a; 1985) methods, suggesting that the technique needs to be further revised. Additional issues, such as postmortem damage due to disinterment trauma or taphonomic processes were also determined to be a pitfall of this method (Saunders et al., 1992).

Finally, Ritz-Timme et al. (2000) gave recommendations for when it is appropriate to use specific age estimation techniques, including the İşcan et al. (1984a; 1985) European-American methods. The authors state that the method is appropriate for cadavers, human remains, and historic and archaeological remains. It is also most accurate for individuals younger than 40 years, as the method becomes less accurate with age. Additional factors of sex, ancestry, and socio-economic status should also be taken into account, as they may also influence the rate of these degenerative changes (Ritz-Timme et al., 2000).

Improvements of the Method

Based on results of the tests of the İşcan et al. (1984a; 1985) European-American methods, Hartnett (2007; 2010) developed a modification of the technique, known as the

Hartnett-Fulginiti method. The study was first conducted as a test of the method as a part of Hartnett's (2007) dissertation, which was later modified and published (Hartnett, 2010). The test was performed on a modern autopsy sample located at the Maricopa County Forensic Science Center, consisting of individuals of both sexes and of multiple ancestries. The results indicated moderately high correlation values, suggesting that the method does work, but could be improved. However, the cross-tabulation results were contradictory, as they resulted in poor agreement between the estimated and actual phase numbers, with less than half of the sample assigned to the correct phase, indicating that the method is reliable, but not accurate. Therefore in order to improve accuracy of the method, the Hartnett-Fulginiti method revised descriptions of phases and summary statistics and included a disclaimer that bone quality may affect phase classification (Harnett, 2007; 2010).

The Hartnett-Fulginiti (2007; 2010) method was developed on the same sample from the Maricopa County Forensic Science Center. Ribs were separated by sex and then seriated based on age-related morphological changes. Three features were considered to be the most important in age determination: the pit depth, the rim edges, and bone quality. The method consists of seven phases and an additional male variant phase, consisting of complete calcification of the costal cartilage that is sometimes seen in males (Appendices C and D). In general the new phase classification begins with morphological changes that start as a shallow and flat U-shaped pit (Phase 1). An indentation begins within the pit, which then takes on a V-shape with a well-defined rim (Phase 2), becoming slightly irregular (Phase 3). The pit then takes on a U-shape (Phases 3 through 7). As age further increases, porosities begin to form inside the pit (Phases 3 through 6), with the bone becoming course and brittle and bony growths present within the pit

(Phase 7). Although males and females have separate standards, the basic age changes remain the relatively the same (Hartnett, 2007; 2010).

Modifications of the Method

The İşcan et al. (1984a; 1985) European-American methods have also been applied and modified to reflect specific populations. One such study applied the İşcan et al. (1984a; 1985) methods to a Turkish sample of 150 males and 144 females of known age from a modern, forensic context in order to evaluate the accuracy. Results indicated that variability increased with age, especially after Phase 5, possibly due to small sample size of older individuals. Therefore the method was determined to be accurate for Turkish individuals (Yavuz et al., 1998).

A Balkan population was also used to evaluate the İşcan et al. (1984a; 1985) European-American methods (Đonić et al., 2005; Stuart and Konigsberg, 2004). These studies were in response to the İşcan et al. (1984a; 1985) aging standards being used for age estimation of Balkan war dead, although the accuracy of these methods had not yet been tested. Therefore Đonić et al. (2005) evaluated the İşcan et al. (1984a; 1985) methods on a Balkan sample and found significant differences between the actual and estimated phases, especially in older individuals.

Stuart and Konigsberg (2004) also tested the reliability of the İşcan et al. (1984a; 1985) methods using an American and Balkan sample. The American sample included a total of 188 individuals from the William B. Bass Donated Collection, Forensic Skeletal Collections, and the Forensic Data Bank, and the Balkan sample consisted of 529 males and 78 females. Cumulative probit and Bayesian approaches were proposed in order to improve accuracy. In addition, advantages of these more complex statistical models are that they are less subjective, give more realistic error estimates, and do not force truncated age estimates, such as 50 or older (Stuart and Konigsberg, 2004).

Fanton et al. (2010) examined the three variables used for the original component analysis method: pit depth, pit shape, and rim and wall configurations. A modern French sample was used, consisting of 59 males. Reproducibility for pit depth was found to be low, due to inaccuracies in measurement location. Pit shape and rim and wall configurations were found to have poor reproducibility, attributed to the descriptions. It was determined that the variables are good indicators of age, but that they need to analyzed with more detail and with additional variables, as well as the development of a multivariate statistical analysis (Fanton et al., 2010).

Verzeletti et al. (2010) developed a revision of the component analysis method on 49 Italian males. Three components were used: the articular surface, anterior-posterior walls, and superior-inferior edges. Each variable is scored and then input into a linear regression formula. Results indicated that for this formula, age was more accurately assessed for individuals younger than 50 (Verzeletti et al., 2010).

Finally, Oettlé and Steyn (2000) tested and applied the İşcan et al. (1984a) European-American methods on modern South Africans of African ancestry. A total of 339 rib ends were used: 265 males and 74 females, ranging in age between four and 94 years in males and eleven to 77 years in females, all of known age, sex, and ancestry. The sample consisted of right fourth ribs that were removed during postmortem examinations from the State Mortuary and from the cadaver collection at the Department of Anatomy, University of Pretoria.

The authors found that, generally, young males were often under-aged and older males were often over-aged, possibly indicating that in this population age related changes might take longer to appear in males. The method appeared less reliable for females, with no tendency to over- or under-age females. Features that were found only in African-Americans, such as more squared off and pointy scallops and an earlier development of bony projections and window formation were also found in the South African sample, although it was found that these degenerative features did not necessarily indicate older age. Additionally, plaque in the interior of the pit was also found more frequently in this population (Appendices E and F). These differences may have been the result of genetic influences, as well as disease, physical activity level, cultural variations, and socioeconomic and nutritional differences (Oettlé and Steyn, 2000).

Therefore, due to the unreliability of the İşcan et al. (1984a; 1985) methods on this population, new phases were developed by seriating the ribs according to age-related morphological changes. The new age ranges for each phase were developed within the 95 percent confidence level. For this method it was generally found that the fourth right sternal rib end begins as a billowy with a regular rim with an epiphyseal ring (Phase 0). Age related changes begin with an indication on the articular surface, starting as a round and regular pit (Phase 1), then deepening into a V-shape with scalloping edge that may be "pointed squared off, or flattened, or may be regular and receding" (Phase 2). The pit later takes on a U-shape with edges becoming more irregular (Phases 3 through 8). Age ranges for these phases were modified, as seen in timing of age related morphological changes (Oettlé and Steyn, 2000).

MATERIALS AND METHODS

Materials

This research evaluated the accuracy of the İşcan et al. (1984a; 1985), the Hartnett-Fulginiti (2007; 2010), and the Oettlé and Steyn (2000) sternal rib aging techniques. The sample included modern skeletal remains from the William M. Bass (WM Bass) Donated Skeletal Collection and historic skeletal remains from the Hamann-Todd Osteological Collection. Both collections were combined due to the limited amount of modern skeletal material available for research.

The entire sample consisted of right fourth ribs from 411 individuals, ranging in age from 24 to 97 years. The skeletal sample included a total of 209 African-Americans and 202 European-Americans. Of these, 143 were African-American males, 66 were African-American females, 149 were European-American males, and 53 were European-American females. The average age of the total sample was 42 years, with a median of 38 years and a mode of 40 years (Table 1).

Table 1: Distribution of total sample

Entire Sample	Count	% of Total	Mean Age	Median Age	Mode Age	Standard Deviation	Age Range
African-American Males	143	34.8%	37	35	35	15.12	18 – 84
African-American Females	66	16.1%	33	31	24	11.26	16 – 66
Total African-Americans	**209**	**50.9%**	**36**	**33**	**24**	**14.00**	**16 – 84**
European-American Males	149	36.3%	46	45	40	15.87	20 – 91
European-American Females	53	12.9%	53	54	38	19.08	16 – 97
Total European-Americans	**202**	**49.2%**	**48**	**46**	**40**	**16.98**	**16 – 97**
Total Males	292	71.0%	42	40	40	16.13	18 – 91
Total Females	119	29.0%	42	38	38	18.27	16 – 97
Total Sample	**411**	**100%**	**42**	**38**	**40**	**16.84**	**16 – 97**

For the purposes of this study, only European-Americans and African-Americans of known age, sex, and ancestry were included in order to determine any possible differences in accuracy between these two ancestral groups. Many individuals were excluded from sampling due to postmortem damage. This included individuals that had undergone autopsies, as ribs are cut near the sternal end in this process, which can prevent the identification of the right fourth rib in later analysis. Additional individuals suffering from other postmortem damage, such as fragmentation of the right fourth rib, were also excluded. Therefore all individuals of African and European ancestry that contained a usable right fourth rib were included in analysis. Biological profile information consisting of age, sex, and ancestry were recorded from the databases provided by each collection, with only sex and ancestry known to the author at the time of examination.

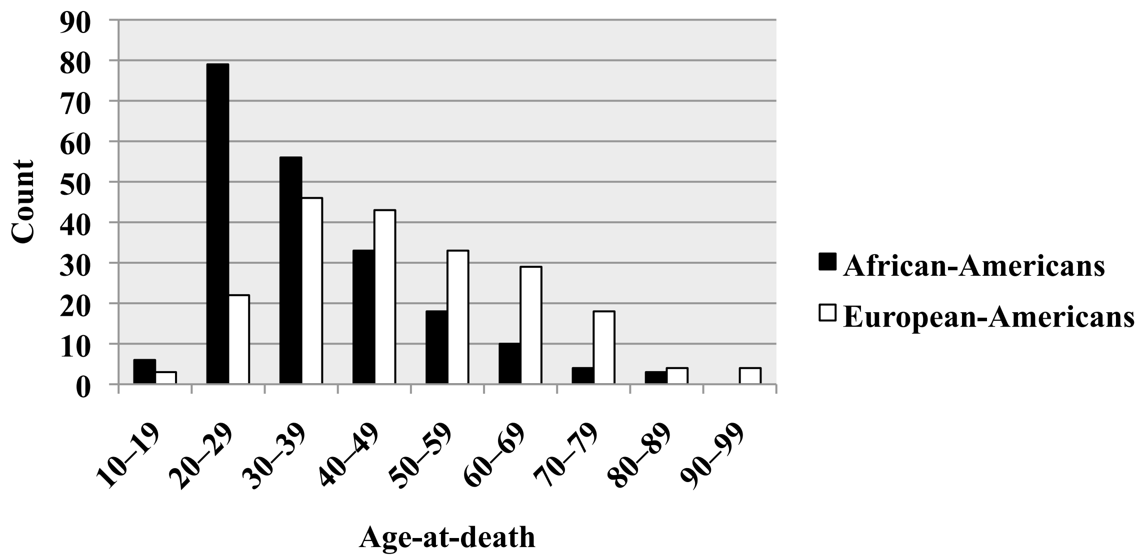
As demonstrated in Table 2, the distribution of ancestry of the total sample is relatively even, with 50.9 percent of the sample classified as African-Americans and 49.1 percent classified as European-Americans. Additionally, the WM Bass sample contained mostly European-Americans, while the Hamann-Todd sample contained slightly more African-Americans.

Table 2: Distribution of sample by ancestry and sex

	African-Americans	**European-Americans**	**Total**
WM Bass Males	11	37	48
WM Bass Females	4	29	32
Total WM Bass	**15**	**66**	**81**
Hamann-Todd Males	132	112	244
Hamann-Todd Females	62	24	66
Total Hamann-Todd	**194**	**136**	**330**
Total Males	143	149	292
Total Females	66	53	119
Total Sample	**209**	**202**	**411**

Age for the entire sample ranged from 16 to 97 years, with a majority of individuals classified as young to middle aged (Figure 1). African-Americans have a slightly younger distribution, with a mean age of 36 years and a standard deviation of 14 years, while European-Americans had a mean age of 48 years with a standard deviation of 16.98 years. Although African-Americans contained a skewed sample of younger individuals, the European-American sample approached a normal distribution.

Figure 1: Distribution of age by ancestry for the entire sample



The Hamann-Todd Subsample

A majority of the data was collected from historic individuals from the Hamann-Todd Osteological Collection curated at the Cleveland Museum of Natural History. This collection consists of over three thousand individuals of African and European ancestry born between the years of 1823 and 1934 (Potter, 2010). Carl August Hamann, an anatomy professor at the Western Reserve University in Cleveland, Ohio, began the collection in 1893 in order to develop an anatomical teaching museum. Many of these remains were first used for dissection at the university and then later cleaned and curated for the osteological collection (Cobb, 1981; Mensforth and Latimer, 1989; Wescott, 1996; Quigley, 2001). In 1912, Thomas Wingate Todd arrived at the university and expanded the collection by including unclaimed bodies from the nearby morgue and hospitals in addition to cadaveric bodies. The collection persisted until Todd's death in 1938, with the collection finally moved in 1951 from the university to its current location at the Cleveland Museum (Jones-Kern and Latimer, 1997; Quigley, 2001; Potter, 2010).

Documentation of individuals within the Hamann-Todd Osteological Collection includes age, ancestry, sex, date and place of birth, occupation, and date and cause of death (Cobb, 1959; Moore-Jansen, 1989). Within the collection, a majority of the individuals of European ancestry were born abroad, while most of the African-Americans migrated to the area from other regions within the United States (Cobb, 1952). This collection represents early twentieth century Industrial America before the introduction of modern medicine. Therefore, many of these individuals were of low socioeconomic status and may have been of poor health compared to the rest of the population at the time (Cobb, 1981; Mensforth and Latimer, 1989; Wescott, 1996; Kunos et al., 1999). Additionally, although this collection is very well documented for many individuals due to provided death certificates, others have estimated ages that were given by the family (Brooks and Suchey, 1990). This may be somewhat problematic, as ages for some individuals may not be exact.

Data collection at the Hamann-Todd Osteological Collection occurred from May 14, 2012 to May 23, 2012 and consisted of 330 individuals, ranging in age from 16 to 80 years (Table 3). The skeletal sample included 132 African-American males, 62 African-American females, 112 European-American males, and 24 European-American females. The average age of the Hamann-Todd sample was 38 years, with a median of 35 years and a mode of 40 years.

Table 3: Distribution of the Hamann-Todd subsample

Hamann-Todd Sample	Count	% of Total	Mean Age	Median Age	Mode Age	Standard Deviation	Age Range
African-American Males	132	40.0%	36	33	35	13.65	18 – 80
African-American Females	62	18.8%	32	31	24	10.67	16 – 65
Total African-Americans	**194**	**58.8%**	**35**	**32**	**24**	**12.84**	**16 – 80**
European-American Males	112	33.9%	43	40	40	14.52	20 – 80
European-American Females	24	7.3%	40	40	38	13.49	16 – 62
Total European-Americans	**136**	**41.2%**	**42**	**40**	**40**	**14.33**	**16 – 80**
Total Sample	**330**	**100%**	**38**	**35**	**40**	**13.99**	**16 – 80**

The William M. Bass Subsample

Additional data was collected from modern individuals at the William M. Bass (WM Bass) Donated Skeletal Collection located at the University of Tennessee, Knoxville. The collection resulted from a body donation program that began in 1981, in which many of the remains were used for decomposition studies at the Anthropology Research Facility and were then later cleaned and curated for the skeletal collection (Ubelaker and Hunt, 1995; Bassett et al., 2003; Tersigni-Tarrant and Shirley, 2012). It is now regarded as the largest collection of modern individuals in the United States, containing almost one thousand individuals born after 1982 (Tersigni-Tarrant and Shirley, 2012). Documentation of the remains consists of sex, age, ancestry, cause and date of death, date of birth, stature, weight, handedness, and education level (Potter, 2010). The collection contains mostly European-American males, but also individuals of other ancestries from a variety of socioeconomic backgrounds, with a majority of individuals originating from the Southeastern United States (Tersigni-Tarrant and Shirley, 2012).

Data collection at the WM Bass Donated Skeletal Collection was conducted from July 30, 2012 to August 2, 2012 and consisted of 81 individuals, ranging in age from 24 to 97 years (Table 4). The skeletal sample included eleven African-American males, four African-American females, 37 European-American males, and 29 European-American females. The average age of the WM Bass sample was 59.25 years, with a median of 59 years and a mode of 49 years. Higher standard deviations, mean ages, and age ranges reflect the older age of individuals within the donated WM Bass Collection.

Table 4: Distribution of the WM Bass subsample

WM Bass Sample	Count	% of Total	Mean Age	Median Age	Mode Age	Standard Deviation	Age Range
African-American Males	11	13.6%	58.55	55.0	49	16.51	25 – 84
African-American Females	4	4.9%	42.25	39.5	-	17.44	24 – 66
Total African-Americans	**15**	**18.5%**	**54.20**	**55.0**	**49**	**17.76**	**24 – 84**
European-American Males	37	45.7%	57.86	58.0	57	14.42	26 – 91
European-American Females	29	35.8%	63.62	61.0	73	16.51	36 – 97
Total European-Americans	**66**	**81.5%**	**60.39**	**60.0**	**38**	**15.52**	**26 – 97**
Total Sample	**81**	**100%**	**59.25**	**59.0**	**49**	**16.02**	**24 – 97**

Methods

The objective of this research was to evaluate accuracy of the İşcan et al. (1984a; 1985), Hartnett-Fulginiti (2007; 2010), and Oettlé and Steyn (2000) sternal rib aging methods. In addition, differences in accuracy between European-Americans and African-Americans were examined, due to indications of age-related variations based on ancestry, as seen in the literature. Specifically, the Oettlé and Steyn (2000) method was evaluated for these differences, as well as to determine if it is a viable method in the United States.

Although the literature has shown that the use of the left side or other ribs may give similar results (e.g. İşcan et al., 1989; Loth, 1990; Dudar, 1993; Loth et al., 1994; Yoder et al., 2001), only the right fourth sternal rib end was utilized for this research, as all three methods were developed specifically on the right fourth rib. Additionally, an attempt was made to include at least 15 individuals per phase for both African-American and European-American categories, although young individuals for both groups were limited. Finally, in order to prevent bias in the assignment of phase numbers, each method was performed separately on all individuals.

The İşcan et al. Method

The İşcan et al. (1984a; 1985) method is a phase system developed on an autopsy sample consisting of known individuals of European ancestry. To apply this method, the observer must first determine the sex of the decedent, as there are separate standards for males and females. Then the right fourth sternal rib is examined and matched to one of nine (0 through 8) phases. Each phase contains descriptions and photographs of the typical age-related changes seen with an associated age range. Due to the inclusion of a confidence interval, age ranges for each phase typically overlap. Rib casts are also available, which give a three-dimensional image of these age-related changes, as this method emphasizes morphological degenerative changes as the basis for age. The photographs, descriptions, and age ranges for the method may be found in Appendix A for males and Appendix B for females. Table 5 displays the distribution of individuals within each phase for the İşcan et al. (1984a; 1985) method.

Table 5: Number of individuals for the İşcan et al. method by phase

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
African-American Males	0	3	24	19	20	32	27	9	9
African-American Females	0	0	3	13	20	23	4	3	0
Total African-Americans	0	3	27	32	40	55	31	12	9
European-American Males	0	0	7	8	16	37	39	15	27
European-American Females	0	0	3	0	3	12	14	10	11
Total European-Americans	0	0	10	8	19	49	53	25	38
Total Sample	**0**	**3**	**37**	**40**	**59**	**104**	**84**	**37**	**47**

The Hartnett-Fulginiti Method

The Hartnett-Fulginiti (2007; 2010) method is also a phase system using the right fourth sternal rib end, and was developed on a modern autopsy sample of known individuals of multiple ancestries. Specifically, it was created as a revision to the İşcan et al. (1984a; 1985) method in order to improve accuracy of the technique. The estimation of age involves matching an unknown right fourth sternal rib end to one of eight phases (1 through 7), which give descriptions and photographs of the typical age-related changes seen, with standards that are separated on the basis of sex. Age ranges for each phase may overlap, due to the inclusion of a confidence interval. Rib casts are not available for this method, which may make it more difficult to visualize morphological features of each phase, although the emphasis for age determination is instead placed on the overall bone quality. The photographs, descriptions, and age ranges for the method may be found in Appendix C for males and Appendix D for females. Table 6 displays the distribution of individuals within each phase for the Hartnett-Fulginiti (2007; 2010) method. Additionally, individuals under the age of 18 were classified as a Phase 0, which is not a phase listed for the method.

Table 6: Number of individuals for the Hartnett-Fulginiti method by phase

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
African-American Males	0	11	37	33	24	24	7	7
African-American Females	2	8	16	24	9	4	2	1
Total African-Americans	2	19	53	57	33	28	9	8
European-American Males	0	2	13	28	37	31	26	12
European-American Females	1	2	1	10	7	12	10	10
Total European-Americans	1	4	14	38	44	43	36	22
Total Sample	**3**	**23**	**67**	**95**	**77**	**71**	**45**	**30**

The Oettlé and Steyn Method

Finally, the Oettlé and Steyn (2000) method is a phase system developed in South Africa based on an autopsy sample of known individuals of African ancestry. Age estimation is conducted by matching the unknown rib to one of nine phases (0 through 8 for males; 0 through 7 for females) based on descriptions and photographs of the typical age-related changes seen, with standards are separated on the basis of sex. The method is similar to the İşcan et al. (1984a; 1985) method, as it places more emphasis on morphological age-related characteristics. Rib casts are not available for this method, which may slightly inhibit the technique due to the emphasis on visual characteristics, as one or two photographs of each phase may not be sufficient to cover the variation within each phase. The photographs, descriptions, and age ranges for the method may be found in Appendix E for males and Appendix F for females. Table 7 displays the distribution of individuals within each phase for the Oettlé and Steyn (2000) method.

Table 7: Number of individuals of phases for the Oettlé and Steyn method by phase

	0	1	2	3	4	5	6	7	8
African-American Males	0	14	20	21	27	23	21	10	7
African-American Females	0	1	11	14	10	21	6	3	-
Total African-Americans	0	15	31	35	37	44	27	13	7
European-American Males	0	4	6	10	28	33	24	27	17
European-American Females	0	0	3	2	1	12	15	20	-
Total European-Americans	0	4	9	12	29	45	39	47	17
Total Sample	**0**	**19**	**40**	**47**	**66**	**89**	**66**	**60**	**24**

Intra-Observer Error

The author reexamined a total of 105 individuals in order to determine rates of intra-observer error (Table 8). Random samples of 15 individuals of each sex and ancestry, totaling 60 individuals, were re-tested from the Hamann-Todd collection, while only a total of 45 individuals from the WM Bass collection were re-tested due to the small sample size of African-Americans. The total sample consisted of 26 African-American males, 19 African-American females, 30 European-American males, and 30 European-American females. Each rib was reassessed individually for all three methods. Additionally, rates of inter-observer error could not be calculated due to the use of multiple collections.

Table 8: Sample used for intra-observer error

	Hamann-Todd	WM Bass	Total
African-American Males	15	11	26
African-American Females	15	4	19
Total African-Americans	30	15	45
European-American Males	15	15	30
European-American Females	15	15	30
Total European-Americans	30	30	60
Total Sample	**60**	**45**	**105**

Statistical Analysis

The objective of this research was to evaluate the accuracy rates of three sternal rib aging techniques: İşcan et al. (1984a; 1985), Hartnett-Fulginiti (2007; 2010), and Oettlé and Steyn (2000). The rates of accuracy for the three methods were compared for the entire sample, African-Americans, European-Americans, males, and females. Multiple statistical tests were performed, including descriptive statistics, correlation, cross-tabulation, inaccuracy, bias, and intra-observer error. All statistical analyses were conducted by hand or through the use of IMB SPSS statistical software, version 20 and a Microsoft Excel spreadsheet available for download from http://www.stat-help.com.

Descriptive Statistics

Summary statistics were collected for each method, and were presented earlier in this chapter. The counts; mean, median, and mode ages; standard deviations; and age ranges were calculated for African-Americans, European-Americans, and the entire sample, with these categories further divided by sex. Frequencies were also calculated and were separated on the basis of ancestry and sex.

Correlation

All three aging methods utilized for this research were phase systems, meaning a phase number, corresponding to an overall age range, was assigned to every individual. For the purposes of statistical analysis, the estimated phase number was then compared to the actual phase number, as determined by the individual's actual age-at-death. Although the data collected for this research was categorical, each phase was assigned a number, e.g. Phase 1 was assigned a 1, so that the data could be compared on an ordinal scale. Additionally, these categories were mutually exclusive, had a logical order, and were scaled, therefore a nonparametric correlation analysis was required for the analysis, as these types of tests do not require normal or homogeneous data (Hinkle et al., 1988; Drennan, 2004; Hartnett, 2010; Sokal and Rohlf, 2012). Finally, Pearson's r correlation was excluded from analysis, as it assumes a normal distribution. The Chi-squared test was also excluded, as the amount of zeros obtained would have violated the test.

Therefore, in order to find the level of association between the observed phase and the actual phase, a Spearman's coefficient of rank correlation was employed, as this test is highly robust, does not require normally distributed data, and does not rely on means or standard deviations or require other modifications (Drennan, 2004). Correlation coefficients produced by Spearman's rank describe the extent of the relationship between two sets of data (Hinkle et al., 1988). The values indicate the general linear pattern of the data between -1.0 and 1.0, with the sign indicating the direction of the relationship (Hinkle et al., 1988; Drennan, 2004). In order to determine the magnitude of the association, the absolute value of this number must be used, with 1.0 indicating a perfect correlation and 0 indicating no relationship between the variables (Hinkle et al., 1988).

Spearman's coefficient of rank correlation was calculated for comparisons between the estimated and actual phase numbers and between the estimated and actual ages. For each method a phase number was assigned to each individual based on the available casts and written descriptions from the original articles (İşcan and Loth, 1993; İşcan et al., 1984a; 1985; Hartnett, 2007; 2010; Oettlé and Steyn, 2000). This observed phase number was then compared to the actual phase number, as determined by the individual's actual age-at-death.

Comparisons were also made between the actual and estimated ages, which were conducted by converting the estimated phase number for each individual to the mean age for that specific phase. For example, for the Hartnett-Fulginiti (2007; 2010) method, if a female was estimated to be a Phase 1, that individual had an estimated age range of 18 to 22 years and therefore was approximately 19.57 years, which is the mean age for that phase. The estimated age and the individual's actual age-at-death were then compared through Spearman's coefficient of rank correlation.

In order to determine statistical significance in accuracy between the methods, the differences between the correlation coefficients must be evaluated, but since they are ordinal and not normally distributed, they cannot be directly compared (Hinkle et al., 1988). Therefore, in order to determine the statistical significance of the correlation coefficients obtained, Fisher's z and Steiger's z transformations were used, as these tests allow for the comparison of two correlation coefficients by converting the r-values to normally distributed z-scores (Cohen and Cohen, 1983). These tests determine how much the normal curve deviates in order to conclude if the correlation coefficients are equal, with values that are greater than |1.96| indicating statistical significance for the 2-tailed test (Cohen and Cohen, 1983).

More specifically, Fisher's z transformations require two independent correlation coefficients, in order to determine if the two samples are homogeneous in the population (Cohen and Cohen, 1983). Therefore these tests were only utilized for comparisons of categories within methods, e.g. African-Americans and European-Americans within the Oettlé and Steyn (2000) method, as these groups are independent of each other. However, comparisons between methods, e.g. overall accuracy for the İşcan et al. (1984a; 1985) method and the Hartnett-Fulginiti (2007; 2010) method, cannot be calculated with Fisher's z, as the coefficients are correlated due to the methods utilizing the same individuals. Thus, a Steiger's z transformation was used, as this test allows for comparisons between correlation coefficients from the same sample. Additionally, Steiger's z transformations were only used for comparisons between the actual and estimated ages, as comparisons between actual and estimated phases cannot be conducted due to differing actual phase values for each method. For example, a female may be 24 years, and would therefore have an actual phase of 2 for the Hartnett-Fulginiti (2007; 2010) method but an actual phase of 3 for the İşcan et al. (1984a; 1985) method. These differences would violate statistical analysis. Therefore only correlation coefficients of the estimated and actual ages could be used, as every individual had the same actual age-at-death for every method. The calculation of Fisher's z and Steiger's z transformations were conducted through a downloaded Microsoft

Excel spreadsheet from http://www.stat-help.com, which used Cohen et al.'s (2003) formula for the Fisher's z transformation and Steiger's (1980) formula for the Steiger's z transformation.

Sample Proportion

Finally, a binomial distribution was utilized to determine how well each method could predict age. This test is based on two mutually exclusive results, in which each observation was either estimated correctly, defined as a success, or incorrectly, defined as a failure. Specifically, a population proportion was used, because the results of the entire population are unknown, as only a proportion of the population was sampled. Due to these reasons and a large sample size, a binomial distribution was approximated by a normal distribution, known as the large sample approximation to the binomial distribution. This test states that even if the data is not normally distributed, the distribution of the sample approaches a normal distribution as sample size increases (Freund et al., 2010).

This test was conducted in order to determine the number of successes in the sample, which was then used to estimate the proportion of successes within a larger population. For each method, the proportion of successes, standard error, and confidence intervals were determined. The standard error was calculated, as it is an index of precision and indicates the amount of error, with a larger standard error indicating that the method is less precise (Peers, 1996). Confidence intervals were also calculated as they fall symmetrically around the sample proportion and therefore give a range of values and probable limits in which the parameter encompasses (Hinkle et al., 1988; Peers, 1996). Therefore, the method that displays the highest probability of successes indicates that it is a better predictor of age, with non-overlapping confidence intervals indicating significance.

Cross-tabulation

Cross-tabulation tables, adapted from Hartnett (2007), were also used to compare the estimated phase to the actual phase, giving a visual reference to the distribution of the data. Tables demonstrate the number of instances that each phase was estimated correctly, as well as the estimated phases in relation to the actual phases. Correct and incorrect phase classifications were calculated and percentages are given for correct phase, one-phase differences, and two-phase differences.

Inaccuracy and Bias

Inaccuracy and bias were also calculated for all groups and all methods between both the estimated and actual phase numbers and the actual and estimated ages. Rates of inaccuracy, also known as the absolute mean error, were calculated for all methods through the equation Σ |estimated phase - actual phase| / N, which represents the sums of the error from the actual phase number, divided by the number of individuals, without regard to whether the error is positive or negative (Russell et al., 1993; Martrille et al., 2007; Fleischman, 2011; Nawrocki, 2011). Inaccuracy was also calculated in terms of age through the equation of Σ |mean age - actual age| / N, which represents the sums of the absolute values of the difference between the mean ages of the estimated phases and the chronological, or actual, ages, divided by the number of individuals (Russell et al., 1993; Martrille et al., 2007). As mentioned earlier, due to the nature of the phase method, mean ages of each phase were used in substitute for an estimated age (Russell et al., 1993; Martrille et al., 2007; Fleischman, 2011; Nawrocki, 2011).

Bias is the tendency to either over- or under-age an individual and was calculated for both the estimated and actual phase numbers and the actual and estimated ages for each method.

Phase bias was calculated through the equation Σ (estimated phase - actual phase) / N, which is the sum of the estimated and actual phase numbers, divided by the number of individuals, while bias in terms of age was also calculated through the equation Σ (estimated age - actual age) / N, which is the sum of the estimated and actual ages, divided by the number of individuals. Again, due to the nature of the phase method, mean ages of each phase were used in substitute for an estimated age (Russell et al., 1993; Martrille et al., 2007; Nawrocki, 2011).

Intra-Observer Error

Finally, rates of intra-observer error were calculated for all three methods in order to measure the amount of precision, or the closeness of the repeated estimations. For this test, the author reevaluated a random selection of 105 individuals from the entire sample. Data was statistically analyzed for each method using Spearman's coefficient of rank correlation and Cohen's Kappa measure of agreement, as both tests describe the relationship between two sets of data, with 1.0 indicating a perfect correlation and 0 indicating no relationship between the variables (Hinkle et al., 1988). Additionally, Cohen's Kappa is a measure of association and is often used for determining rates of reliability and intra-observer error, as it specifically it measures agreement by examining the expected frequencies within contingency tables and also corrects for chance correlations (Sheskin, 2004).

RESULTS

In order to test the accuracy of the İşcan et al. (1984a; 1985), the Hartnett-Fulginiti (2007; 2010), and the Oettlé and Steyn (2000) sternal rib aging methods, each technique was performed separately in order to avoid bias in the assignment of phase numbers. The entire sample was first evaluated using the İşcan et al. (1984a; 1985) method, followed by the Hartnett-Fulginiti (2007; 2010) method, and finally the Oettlé and Steyn (2000) method. All evaluations were conducted through the use of the original published articles, which contained written descriptions and photographs of characteristic age-related features found within each phase, with the addition of rib casts for the İşcan et al. (1984a; 1985) method (İşcan and Loth, 1993).

Before statistical analysis was conducted, descriptive statistics were calculated; consisting of the counts; mean, median, and mode ages; standard deviations; and age ranges for African-Americans, European-Americans, and the total sample. Frequencies were also further divided into subsamples based on sex and ancestry.

Overall Accuracy

The first aim of this research was to evaluate the İşcan et al. (1984a; 1985), Hartnett-Fulginiti (2007; 2010), and Oettlé and Steyn (2000) methods for accuracy and how well each method could predict age-at-death. The entire sample was utilized in order to calculate rates of accuracy for all individuals of both European and African ancestry. It was hypothesized that the Hartnett-Fulginiti (2007; 2010) method would be a more accurate assessor of age for the entire sample, as the method was developed as a revision of the İşcan et al. (1984a; 1985) method in order to improve accuracy.

Correlation

In order to test the accuracy of the three sternal rib aging methods, Spearman's coefficient of rank correlation was utilized to make comparisons between the estimated and actual phase numbers and the estimated and actual ages for all individuals within the sample. In accordance with each method, a phase number corresponding to an age range was assigned to each individual based on the observed morphological features. This estimated phase number was then compared to the actual phase number, as determined by the individual's actual age-at-death. For the purposes of statistical analysis, additional comparisons between the estimated and actual age were also made. This was conducted by converting the estimated phase number to the mean age for that phase. For example, for the Hartnett-Fulginiti (2007; 2010) method, a Phase 1 for a female has an estimated age range of 18 to 22 years and would therefore have an estimated age of 19.57 years, which is the mean age for that phase.

The author examined a total of 411 right fourth sternal rib ends and scored them according to the available casts and written descriptions from the original articles (İşcan and Loth, 1993; İşcan et al., 1984a; 1985; Hartnett, 2007; 2010; Oettlé and Steyn, 2000). Table 9 displays the number of individuals, the correlation coefficients (r_S), and the significance for all three methods. When comparing the estimated and actual phase numbers the Hartnett-Fulginiti method had the strongest coefficient (r_S = 0.836), followed by İşcan et al. method (r_S = 0.785), and then Oettlé and Steyn method (r_S = 0.751). Similar correlation coefficients were also found when comparing the estimated and actual ages. The Hartnett-Fulginiti method displayed the strongest coefficient (r_S = 0.793), followed by İşcan et al. method (r_S = 0.745), and then the Oettlé and Steyn method (r_S = 0.741). Although the Hartnett-Fulginiti (2007; 2010) method had the strongest correlations, all three techniques had strong associations (r_S = 0.7–0.89) that were highly significant ($p < 0.0001$).

Table 9: Correlation for the total sample

Method	Count	Est vs. Actual Phase Spearman's r	Est vs. Actual Age Spearman's r	Significance
İşcan et al.	411	0.780	0.745	< 0.0001
Hartnett-Fulginiti	411	0.832	0.793	< 0.0001
Oettlé and Steyn	411	0.746	0.741	< 0.0001

Due to all three methods that displayed strong correlations, further analysis was required to determine if there were any statistically significant differences in accuracy between the methods. Statistical analysis of the correlation coefficients between the estimated and actual phases were not possible, as for some individuals the actual phase numbers differ depending on the method. Therefore comparisons could only made between the estimated and actual ages, as the actual ages for each individual remain the same for every method. This analysis was conducted through the use of a Steiger's z transformation. This test allows for comparisons between correlated samples by converting the r-scores to normally distributed z-scores, with a score greater than |1.96| indicating statistical significance.

Table 10 demonstrates the test performed; the correlation coefficients (r_S) of the first method, the second method, and between the estimated ages of the first and second methods; the z-scores; and the significance. When comparing the accuracy between the methods, two statistically significant differences were found. The first was between the Hartnett-Fulginiti (2007; 2010) method and the İşcan et al. (1984a; 1985) method ($p = 0.022$). The second was between the Hartnett-Fulginiti (2007; 2010) method and the Oettlé and Steyn (2000) method (p =

0.011). These results indicate that the Hartnett-Fulginiti (2007; 2010) method was the most accurate at assessing age for all individuals within the sample.

Table 10: Significance of the correlation coefficients for the total sample

Test			r(1)	r(2)	r(3)	z-score	Significance
İşcan et al.	**/**	**Hartnett-Fulginiti**	0.745	0.793	0.725	- 2.294	**0.022***
İşcan et al.	**/**	**Oettlé and Steyn**	0.745	0.741	0.738	0.182	0.855
Hartnett-Fulginiti	**/**	**Oettlé and Steyn**	0.741	0.793	0.743	- 2.539	**0.011***

*** p < 0.05; 2-tailed test, n = 411**

Additional tests of the methods were conducted using a binomial distribution, which determines how well each method can predict age. This is based on the amount of correct phase classifications, defined as successes, and the number of incorrect classifications, defined as failures. Due to the large sample size, a sample proportion was used, known as the normal approximation of the binomial distribution. Ninety-five percent confidence intervals were calculated and compared for each method, with non-overlapping confidence intervals indicating statistical significance.

Table 11 demonstrates the mean, the proportion of successes ($\hat{p}$), standard error, variance, and confidence interval of each method. The Harnett-Fulginiti (2007; 2010) method had the strongest $\hat{p}$-value ($\hat{p}$ = 0.4842) with a confidence interval between 0.4359–0.5325. Comparisons between the Hartnett-Fulginiti (2007; 2010) method and the İşcan et al. (1984a; 1985) method showed overlapping confidence intervals, indicating non-significance between the methods. In contrast, the Oettlé and Steyn (2000) method displayed a smaller and non-overlapping confidence interval (0.3160–0.4090) when compared to the Hartnett-Fulginiti method (0.4359–0.5325). This suggests that the Hartnett-Fulginiti (2007; 2010) method was more accurate at assessing age than the Oettlé and Steyn (2000) method. Additionally, the Harnett-Fulginiti

(2007; 2010) method had the strongest $\hat{p}$-value ($\hat{p}$ = 0.4842), suggesting that it was a better predictor of age in comparison to the other techniques.

Table 11: Binomial distribution for the total sample

Method	Mean	$\hat{p}$-value	Stand Error	Variance	Confidence Interval
İşcan et al.	168.02	0.4088	0.0242	0.000588	0.3613–0.4838
Hartnett-Fulginiti	199.01	0.4842	0.0261	0.000608	0.4359–0.5325
Oettlé and Steyn	148.99	0.3625	0.0237	0.000562	0.3160–0.4090

n = 411

Cross-tabulation

Cross-tabulation tables, modeled after Hartnett (2007), were also used to visually compare the estimated and actual phase numbers for each method. The darkest shaded diagonal region of the table designates when the actual and estimated phase numbers matched, while the lighter shaded regions indicates a difference of one phase either above or below the actual phase number.

Table 12 demonstrates the cross-tabulation table for the İşcan et al. (1984a; 1985) method, with 168 of 411 individuals (40.9%) that were assigned to the correct phase. An additional 179 (43.6%) were assigned within one phase from the actual phase number, meaning either one phase over (n = 69) or one phase under (n = 110). Finally, 52 individuals (12.7%) were assigned within two phases over (n = 18) or under (n = 34) the actual phase number.

Table 12: Cross-tabulation of estimated and actual İşcan et al. phases for the total sample

		Actual Phase								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Estimated Phase	**0**	0	0	0	0	0	0	0	0	0
	1	0	1	4	0	2	0	1	0	0
	2	0	1	21	9	0	1	0	0	0
	3	0	1	9	20	12	6	0	0	1
	4	0	0	3	8	22	32	13	0	1
	5	0	0	0	3	17	45	27	6	6
	6	0	0	0	0	6	16	33	9	9
	7	0	0	0	0	0	4	9	13	17
	8	0	0	0	0	0	0	1	9	13

Table 13 demonstrates the cross-tabulation table for the Hartnett-Fulginiti (2007; 2010) method, with 199 of 411 individuals (48.4%) that were assigned to the correct phase number. An additional 169 individuals (41.1%) were estimated within one phase over (n = 115) or one phase under (n = 54). Finally, 36 individuals (8.8%) were correctly assigned within two phases over (n = 26) or under (n = 10) the correct phase number.

Table 13: Cross-tabulation of estimated and actual Hartnett-Fulginiti phases for the total sample

		Actual Phase							
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Estimated Phase	**0**	0	0	0	0	0	0	0	0
	1	3	3	1	0	0	0	0	0
	2	0	13	36	9	0	0	0	0
	3	0	5	24	43	11	2	0	0
	4	0	1	4	30	35	9	3	0
	5	0	1	2	10	25	46	16	5
	6	0	0	0	3	6	13	19	8
	7	0	0	0	0	0	1	7	17

Table 14 demonstrates the cross-tabulation table for the Oettlé and Steyn (2000) method. The author assigned a total of 149 of 411 individuals (36.3%) to the correct phase, while 180 individuals (43.8%) were assigned within one phase over (n = 81) or under (n = 99) of the actual phase number. A total of 58 individuals (14.1%) were estimated within two phases over (n = 13) or under (n = 45) the correct phase number.

Table 14: Cross-tabulation of estimated and actual Oettlé and Steyn phases for the total sample

		Actual Phase								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Estimated Phase	**0**	0	0	0	0	0	0	0	0	0
	1	0	10	8	2	1	0	0	0	0
	2	0	3	10	1	1	2	0	0	0
	3	0	3	18	24	16	6	2	1	0
	4	0	2	1	16	28	24	15	3	1
	5	0	1	2	1	18	37	28	17	4
	6	0	0	1	3	2	14	12	16	4
	7	0	0	0	0	0	5	8	19	6
	8	0	0	0	0	0	1	1	4	9

The first hypothesis was accepted, as results showed that the Hartnett-Fulginiti (2007; 2010) method was the most accurate at assessing age for the entire sample. This technique was also a slightly better predictor of age ($\hat{p} = 0.4842$), had the strongest correlation coefficients (r_s = 0.832; 0.793), and displayed statistically significant differences in accuracy in comparison to the İşcan et al. (1984a; 1985) method and Oettlé and Steyn (2000) method.

Accuracy for European-Americans

The second research question addressed which method would more accurately predict and assess the age of European-Americans within the sample. The Hartnett-Fulginiti (2007;

2010) method was developed as a revision in order to improve accuracy rates for all individuals. Additionally, the technique is the most contemporary and was developed on a sample consisting of mostly Caucasian individuals. It was therefore hypothesized that the Hartnett-Fulginiti (2007; 2010) method would be more accurate for European-Americans compared to the İşcan et al. (1984a; 1985) method and Oettlé and Steyn (2000) method.

Correlation

To determine the accuracy of the İşcan et al. (1984a; 1985), Hartnett-Fulginiti (2007; 2010), and Oettlé and Steyn (2000) methods on European-Americans within the sample, comparisons of the actual and estimated phase numbers and actual and estimated ages were made through the use of Spearman's coefficient of rank correlation. Table 15 illustrates the number of individuals, the correlation coefficients (r_S), and the significance for all methods. For comparisons between the estimated and actual phase numbers, the Hartnett-Fulginiti method displayed the highest correlation coefficient ($r_S = 0.783$), followed by İşcan et al. method ($r_S = 0.731$), and then Oettlé and Steyn method ($r_S = 0.705$). Similar results were obtained with comparisons between the estimated and actual ages. The Hartnett-Fulginiti method displayed the strongest correlation coefficient ($r_S = 0.731$), followed by İşcan et al. method ($r_S = 0.716$), and then Oettlé and Steyn method ($r_S = 0.666$). Although the Hartnett-Fulginiti had the strongest correlations, all three techniques had strong associations ($r_S = 0.7$–0.89) that were highly significant ($p < 0.0001$).

Table 15: Correlation for European-Americans

	Count	Est vs. Actual Phase Spearman's r	Est vs. Actual Age Spearman's r	Significance
İşcan et al.	202	0.727	0.716	< 0.0001
Hartnett-Fulginiti	202	0.780	0.731	< 0.0001
Oettlé and Steyn	202	0.701	0.666	< 0.0001

Further analysis was required to determine if there were any significant differences in accuracy between the methods. This was conducted through the use of a Steiger's z transformation, as it allows for comparisons between related samples and includes an additional correlation coefficient between the estimated ages of the two methods compared. Table 16 demonstrates the test performed; the correlation coefficients (r_S) of the first method, the second method, and between the estimated ages of the first and second methods; the z-scores; and the significance for each test. There were no statistically significant values found between any of the methods, although two almost significant results were obtained. The first was between the Hartnett-Fulginiti (2007; 2010) method and İşcan et al. (1984a; 1985) method (p = 0.066). The second was between the Hartnett-Fulginiti (2007; 2010) method and Oettlé and Steyn (2000) method (p = 0.062). These results demonstrated that all three methods were able to assess age equally well on European-Americans within the sample.

Table 16: Significance of the correlation coefficients for European-Americans

Test	r(1)	r(2)	r(3)	z-score	Significance
İşcan et al. / Hartnett-Fulginiti	0.716	0.731	0.709	- 0.438	0.066
İşcan et al. / Oettlé and Steyn	0.716	0.666	0.705	1.369	0.171
Hartnett-Fulginiti / Oettlé and Steyn	0.731	0.666	0.727	1.868	0.062

2-tailed test, n = 202

Additional tests of accuracy of the methods for European-Americans were compared using a binomial distribution. Ninety-five percent confidence intervals were calculated for each method and were then compared to determine if any overlapping confidence intervals were present, with non-overlapping intervals indicating significance. Table 17 demonstrates the mean, the proportion of successes ($\hat{p}$), standard error, variance, and confidence interval of each method. As can be seen from the table, all confidence intervals overlapped, demonstrating no statistical significance in accuracy between the methods, although the Hartnett-Fulginiti (2007; 2010) method proved to be a slightly better predictor of age for European-Americans as it had the highest $\hat{p}$-value ($\hat{p}$ = 0.4901).

Table 17: Binomial distribution for European-Americans

Method	Mean	$\hat{p}$-value	Stand Error	Variance	Confidence Interval
İşcan et al.	83.00	0.4109	0.0346	0.0012	0.3430–0.4788
Hartnett-Fulginiti	48.52	0.4901	0.0346	0.0012	0.4222–0.5580
Oettlé and Steyn	71.99	0.3564	0.0332	0.0011	0.2904–0.4224

n = 202

Cross-tabulation

Cross-tabulation tables were also used in order to visually compare the estimated and actual phase numbers. Table 18 demonstrates the cross-tabulation table for European-Americans for the İşcan et al. (1984a; 1985) method, with 83 of 202 individuals (41.1%) assigned to the correct phase. An additional 91 individuals (45.1%) were assigned within one phase from the actual phase number, either one phase over (n = 34) or one phase under (n = 57). Finally, 21 individuals (10.4%) were assigned two phases over (n = 2) or under (n = 19) the actual phase number.

Table 18: Cross-tabulation of estimated and actual İşcan et al. phases for European-Americans

		Actual Phase							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Estimated Phase	**1**	0	1	0	0	0	1	0	0
	2	0	6	2	1	0	0	0	0
	3	0	3	5	4	1	0	0	1
	4	0	0	1	6	13	6	0	1
	5	0	0	0	9	25	18	4	5
	6	0	0	0	0	9	22	5	7
	7	0	0	0	0	1	5	9	14
	8	0	0	0	0	0	1	7	10

Table 19 demonstrates the cross-tabulation table for European-Americans for the Hartnett-Fulginiti (2007; 2010) method. A total of 99 of 202 individuals (49.0%) were assigned to the correct phase number, with another 79 individuals (39.1%) estimated either one phase over (n = 52) or one phase under (n = 27) the correct phase. Finally, an additional 22 individuals (10.9%) were assigned within two phases over (n = 15) or under (n = 7) the correct phase number.

Table 19: Cross-tabulation of estimated and actual Hartnett-Fulginiti phases for European-Americans

		Actual Phase							
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Estimated Phase	**0**	0	0	0	0	0	0	0	0
	1	1	3	0	0	0	0	0	0
	2	0	1	6	2	0	0	0	0
	3	0	0	7	14	6	0	0	0
	4	0	0	1	13	20	5	3	0
	5	0	0	0	7	12	26	9	4
	6	0	0	0	2	6	11	17	5
	7	0	0	0	0	0	1	7	13

Table 20 demonstrates the cross-tabulation table for European-Americans for the Oettlé and Steyn (2000) method. The author assigned 72 of 202 individuals (35.7%) to the correct phase, while 90 individuals (44.6%) were assigned either one phase over (n = 35) or under (n = 55) of the actual phase. Finally, 30 individuals (14.9%) were estimated either two phases over (n = 7) or under (n = 23) the correct phase number.

Table 20: Cross-tabulation of estimated and actual Oettlé and Steyn phases for European-Americans

		Actual Phase								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Estimated Phase	**0**	0	0	0	0	0	0	0	0	0
	1	0	2	1	1	0	0	0	0	0
	2	0	1	4	0	0	1	0	0	0
	3	0	1	4	6	5	1	1	0	0
	4	0	0	0	4	12	15	7	1	1
	5	0	0	0	0	11	18	16	12	4
	6	0	0	0	1	1	5	8	13	2
	7	0	0	0	0	0	4	6	17	5
	8	0	0	0	0	0	1	1	4	5

Although the Hartnett-Fulginiti (2007; 2010) method had the highest correlation coefficients (r_s = 0.780; 0.731) of all three methods, no statistically significant differences in accuracy were found between the three techniques. Therefore, results rejected the second hypothesis, which predicted that the Hartnett-Fulginiti (2007; 2010) method would more accurately assess age of European-Americans than the İşcan et al. (1984a; 1985) method and the Oettlé and Steyn (2000) method. Instead it was found that all three methods performed equally well at assessing age for this population, although the Hartnett-Fulginiti (2007; 2010) method proved to be a slightly better predictor of age for European-Americans ($\hat{p}$ = 0.4901).

Accuracy for African-Americans

The third research question addressed if the Oettlé and Steyn (2000) method would more accurately assess and predict the age of African-Americans in the sample. Although this technique was developed on South Africans, it was hypothesized that this technique would be more accurate for African-Americans than European-Americans, as it was developed on a population of individuals of African ancestry. Testing the accuracy of the Oettlé and Steyn (2000) method on an American population was also a main concern of this research, as if this method proved to be reliable and accurate, it could possibly become a viable method within the United States.

Correlation

In order to test the accuracy of the İşcan et al. (1984a; 1985), Hartnett-Fulginiti (2007; 2010), and Oettlé and Steyn (2000) methods for African-Americans, comparisons of the actual and estimated phase numbers and estimated and actual ages were made using Spearman's coefficient of rank correlation. Table 21 illustrates the number of individuals, the correlation coefficients (r_S), and the significance for all methods. For comparisons between the actual and estimated phase numbers, the Hartnett-Fulginiti method had the highest correlation coefficient (r_S = 0.790), followed by İşcan et al. method (r_S = 0.769) and then Oettlé and Steyn method (r_S = 0.704). Similar results were obtained when the estimated and actual ages were compared. The Harnett-Fulginiti method displayed the strongest correlation coefficient (r_S = 0.739), followed by İşcan et al. method (r_S = 0.704) and then Oettlé and Steyn method (r_S = 0.692). For African-Americans within the sample, the Hartnett-Fulginiti (2007; 2010) method had the strongest correlation coefficients, although all three techniques had strong ($r_S = 0.7–0.89$) and highly significant associations ($p < 0.0001$).

Table 21: Correlation for African-Americans

	Count	Est vs. Actual Phase Spearman's r	Est vs. Actual Age Spearman's r	Significance
İşcan et al.	209	0.762	0.704	< 0.0001
Hartnett-Fulginiti	209	0.784	0.739	< 0.0001
Oettlé and Steyn	209	0.696	0.692	< 0.0001

Further analysis was required to determine if the differences in accuracy between the methods were significant. Therefore correlation coefficients between the actual and estimated ages were compared through the use of a Steiger's z transformation. Table 22 demonstrates the test performed; the correlation coefficients of the first method, the second method, and between the estimated ages of the first and second methods; the z-scores; and the significance. No statistically significant results were found, indicating that all three methods were able to assess age equally well for African-Americans within the sample.

Table 22: Significance of the correlation coefficients for African-Americans

Test	r(1)	r(2)	r(3)	z-score	Significance
İşcan et al. / Hartnett-Fulginiti	0.704	0.739	0.662	- 0.978	0.328
İşcan et al. / Oettlé and Steyn	0.704	0.692	0.697	0.334	0.738
Hartnett-Fulginiti / Oettlé and Steyn	0.739	0.692	0.641	1.268	0.205

2-tailed test, n = 209

Additional tests of accuracy of the methods for African-Americans were compared using a binomial distribution. Ninety-five percent confidence intervals were calculated for each method and were then compared to determine if any overlapping confidence intervals were present, with non-overlapping intervals indicating significance. Table 23 demonstrates the mean, the proportion of successes (ṕ), standard error, variance, and confidence interval of each method. As can be seen from the table, all confidence intervals overlap, demonstrating no statistical significance in accuracy between the methods, although the Hartnett-Fulginiti (2007; 2010) method proved to be a slightly better predictor of age for European-Americans as it had the strongest ṕ-value (ṕ = 0.4737).

Table 23: Binomial distribution for European-Americans

Method	Mean	ṕ-value	Stand Error	Variance	Confidence Interval
İşcan et al.	85.00	0.4067	0.0340	0.0012	0.3727–0.4407
Hartnett-Fulginiti	99.00	0.4737	0.0344	0.0012	0.4390–0.5078
Oettlé and Steyn	77.00	0.3684	0.0332	0.0011	0.3352–0.4016

n = 209

Cross-tabulation

Cross-tabulation tables were also used in order to visually compare the estimated and actual phase numbers. Table 24 demonstrates the cross-tabulation table for African-Americans for the İşcan et al. (1984a; 1985) method. This table shows that 85 of 209 individuals (40.7%) were assigned to the correct phase, with an additional 88 individuals (42.1%) assigned within one phase from the actual phase number, meaning either one phase over (n = 35) or one phase under (n = 53). Finally, 32 individuals (15.3%) were assigned within two phases over (n = 16) or under (n = 16) the correct phase number.

Table 24: Cross-tabulation of estimated and actual İşcan et al. phases for African-Americans

		Actual Phase								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Estimated Phase	**0**	0	0	0	0	0	0	0	0	0
	1	0	1	3	0	2	0	0	0	0
	2	0	1	15	7	0	1	0	0	0
	3	0	1	6	15	8	5	0	0	0
	4	0	0	3	7	16	19	7	0	0
	5	0	0	0	3	8	20	9	2	1
	6	0	0	0	0	6	7	11	4	2
	7	0	0	0	0	0	3	4	4	3
	8	0	0	0	0	0	0	0	2	3

Table 25 demonstrates the cross-tabulation table for African-Americans for the Hartnett-Fulginiti (2007; 2010) method, with 99 of 209 individuals (47.4%) that were assigned to the correct phase number. Another 91 individuals (43.5%) were assigned either one phase over (n = 63) or one phase under (n = 28) the correct phase. Finally, 14 individuals (6.7%) were correctly assigned either two phases over (n = 11) or under (n = 3) the actual phase number.

Table 25: Cross-tabulation of estimated and actual Hartnett-Fulginiti phases for African-Americans

		Actual Phase							
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Estimated Phase	**0**	0	0	0	0	0	0	0	0
	1	2	0	1	0	0	0	0	0
	2	0	12	30	7	0	0	0	0
	3	0	5	17	29	5	2	0	0
	4	0	1	3	17	14	5	0	0
	5	0	1	2	3	13	20	7	1
	6	0	0	0	1	0	2	2	3
	7	0	0	0	0	0	0	0	4

Table 26 demonstrates the cross-tabulation table for African-Americans for the Oettlé and Steyn (2000) method. A total of 77 of 209 individuals (36.8%) were assigned to the correct phase, while another 90 individuals (43.1%) were assigned within one phase over (n = 46) or under (n = 44) the correct phase. Finally, 28 individuals (13.4%), age was assigned estimated two phases over (n = 6) or under (n = 22) the actual phase number.

Table 26: Cross-tabulation of estimated and actual Oettlé and Steyn phases for African-Americans

		Actual Phase								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Estimated Phase	**0**	0	0	0	0	0	0	0	0	0
	1	0	8	7	1	1	0	0	0	0
	2	0	2	6	1	1	1	0	0	0
	3	0	2	14	18	11	5	1	1	0
	4	0	2	1	12	16	9	8	2	0
	5	0	1	2	1	7	19	12	5	0
	6	0	0	1	2	1	9	4	3	2
	7	0	0	0	0	0	1	2	2	1
	8	0	0	0	0	0	0	0	0	4

Results rejected the third hypothesis, which predicted that the Oettlé and Steyn (2000) method would more accurately assess age of African-Americans than the Hartnett-Fulginiti (2007; 2010) method and the İşcan et al. (1984a; 1985) method. Instead it was found that all three methods were able to assess age equally well for African-Americans within the sample. Although the Hartnett-Fulginiti (2007; 2010) method displayed the highest correlation coefficients (r_s = 0.784; 0.739), no statistically significant differences were found between any of the methods. Additionally, the Hartnett-Fulginiti (2007; 2010) method was found to be a slightly better predictor of age for African-Americans ($\hat{p}$ = 0.4737).

Accuracy Based on Ancestry

An additional aim of this research was to determine if there were any differences in accuracy between African-Americans and European-Americans. This analysis was conducted based on previous studies that had demonstrated ancestral based differences in the rate and pattern of morphological age-related characteristics for African-Americans and South African blacks (İşcan et al., 1987; Oettlé and Steyn, 2000). From these results, it was expected that there would be statistically significant differences between the two ancestral groups. Analysis was conducted by examining the previously calculated correlation coefficients for African-Americans and European-Americans in order to determine if there were any statistically significant differences in accuracy between the groups. If major differences are found, it may require the use of separate standards on the basis of ancestry.

Correlation (İşcan et al. Method)

Correlation coefficients were calculated for three categories for the İşcan et al. (1984a; 1985) method, consisting of the entire sample, African-Americans, and European-Americans. Table 27 demonstrates the number of individuals, the correlation coefficients (r_S), and the significance for all groups for the İşcan et al. (1984a; 1985) method. For comparisons between the estimated and actual phase numbers, the entire sample had the highest correlation coefficient ($r_S = 0.780$), followed by European-Americans ($r_S = 0.762$), and then African-Americans ($r_S = 0.727$). Similar results were obtained from comparisons between the estimated and actual ages. The entire sample displayed the highest correlation coefficient ($r_S = 0.745$), followed by European-Americans ($r_S = 0.716$), and then African-Americans ($r_S = 0.704$). The entire sample had the highest correlation coefficients for the İşcan et al. (1984a; 1985) method, although all categories had strong (r_s = 0.7–0.89) and highly significant associations ($p < 0.0001$).

Table 27: Correlation based on ancestry for the İşcan et al. method

	Count	Est vs. Actual Phase Spearman's r	Est vs. Actual Age Spearman's r	Significance
Entire Sample	411	0.780	0.745	< 0.0001
African-Americans	209	0.727	0.704	< 0.0001
European-Americans	202	0.762	0.716	< 0.0001

Due to correlation coefficients that were all strong and highly significant, further analysis was required to determine if there were statistically significant differences in accuracy between the methods. This was conducted through a Fisher's z transformation, as all comparisons were made within the same method. This test allows for the comparison of two correlation coefficients by converting the r-values to normally distributed z-scores, with values that are greater than |1.96| indicating statistical significance. Table 28 demonstrates the correlation coefficients between the estimated and actual phase numbers for the first category and the second category, the z-scores, and the significance for each test. No significant values between ancestries were found for the İşcan et al. (1984a; 1985) method.

Table 28: Significance of the correlation coefficients for the İşcan et al. method based on ancestry (phase)

Test	r(1)	r(2)	z-score	Significance
Entire Sample / African-Americans	0.780	0.727	1.439	0.150
Entire Sample / European-Americans	0.780	0.762	0.514	0.608
African-Americans / European-Americans	0.727	0.762	- 0.791	0.429

2-tailed test, entire sample (n = 411), African-Americans (n = 209), European-Americans (n = 202)

Additional comparisons of the correlation coefficients between the estimated and actual ages were also made. Table 29 demonstrates the correlation coefficients between the estimated and actual ages for the first category and the second category, the z-scores, and the significance for each test. Again, no significant values were found between ancestries for the İşcan et al. (1984a; 1985) method, indicating that the technique was able to assess age equally well for both ancestral groups.

Table 29: Significance of the correlation coefficients for the İşcan et al. method based on ancestry (age)

Test		r(1)	r(2)	z-score	Significance
Entire Sample	**/ African-Americans**	0.745	0.704	1.011	0.312
Entire Sample	**/ European-Americans**	0.745	0.716	0.720	0.472
African-Americans	**/ European-Americans**	0.704	0.716	- 2.435	0.808

2-tailed test, entire sample (n = 411), African-Americans (n = 209), European-Americans (n = 202)

No statistically significant values were found for any of the comparisons for the İşcan et al. (1984a; 1985) method. This demonstrates that the method was able to assess age equally well for both African-Americans and European-Americans.

Correlation (Hartnett-Fulginiti Method)

Correlation coefficients for the Hartnett-Fulginiti (2007; 2010) method were calculated for three categories, consisting of the entire sample, African-Americans, and European-Americans. Table 30 demonstrates the number of individuals, the correlation coefficients (r_S), and the significance for all groups for the Hartnett-Fulginiti (2007; 2010) method. For comparisons between the estimated and actual phase numbers, the entire sample had the highest correlation coefficient (r_S = 0.832), followed by African-Americans (r_S = 0.784), and then

European-Americans ($r_S = 0.780$). Similar results were obtained from comparisons between the estimated and actual ages. The entire sample displayed the highest correlation coefficient ($r_S = 0.793$), followed by African-Americans ($r_S = 0.739$), and then European-Americans ($r_S = 0.731$). The entire sample has the strongest correlation coefficients for the Hartnett-Fulginiti (2007; 2010) method, although all categories had strong ($r_S = 0.7–0.89$) and highly significant associations ($p < 0.0001$).

Table 30: Correlation based on ancestry for the Hartnett-Fulginiti method

	Count	Est vs. Actual Phase Spearman's r	Est vs. Actual Age Spearman's r	Significance
Entire Sample	411	0.832	0.793	< 0.0001
African-Americans	209	0.784	0.739	< 0.0001
European-Americans	202	0.780	0.731	< 0.0001

Due to all correlations that were strong and highly significant, a Fisher's z transformation was utilized in order to determine if there were any statistically significant differences in accuracy between the groups. Table 31 demonstrates the correlation coefficients between the estimated and actual phase numbers for the first category and the second category, the z-scores, and the significance for each test. No statistically significant values were found between the groups, indicating that the technique was able to assess age equally well for both ancestral groups.

Table 31: Significance of the correlation coefficients for the Hartnett-Fulginiti method based on ancestry (phase)

Test	r(1)	r(2)	z-score	Significance
Entire Sample / African-Americans	0.832	0.784	1.625	0.104
Entire Sample / European-Americans	0.832	0.780	1.726	0.084
African-Americans / European-Americans	0.784	0.780	0.104	0.917

2-tailed test, entire sample (n = 411), African-Americans (n = 209), European-Americans (n = 202)

Correlation coefficients between the estimated and actual ages were also compared. Table 32 demonstrates the correlation coefficients between the estimated and actual ages for the first category and the second category, the z-scores, and the significance for each test. Again, no significant values between ancestries were found for the Hartnett-Fulginiti (2007; 2010) method, indicating that the technique was able to assess age equally well for both ancestral groups.

Table 32: Significance of the correlation coefficients for the Hartnett-Fulginiti method based on ancestry (age)

Test	r(1)	r(2)	z-score	Significance
Entire Sample / African-Americans	0.793	0.739	1.535	0.125
Entire Sample / European-Americans	0.793	0.731	1.719	0.086
African-Americans / European-Americans	0.739	0.731	0.175	0.861

2-tailed test, entire sample (n = 411), African-Americans (n = 209), European-Americans (n = 202)

No statistically significant values were found for any of the comparisons for the Hartnett-Fulginiti (2007; 2010) method. This demonstrates that the method was able to assess age equally well for both African-Americans and European-Americans.

Correlation (Oettlé and Steyn Method)

Correlation coefficients were calculated for three categories for the Oettlé and Steyn (2000) method, consisting of the entire sample, African-Americans, and European-Americans. Table 33 demonstrates the number of individuals, the correlation coefficients (r_S), and the significance for all groups for the Oettlé and Steyn (2000) method. For comparisons between the estimated and actual phase numbers, the entire sample had the highest correlation coefficient ($r_S = 0.746$), followed by European-Americans ($r_S = 0.701$), and then African-Americans ($r_S = 0.696$). Similar results were obtained from comparisons between the estimated and actual ages. The entire sample displayed the highest correlation coefficient ($r_S = 0.741$), followed by European-Americans ($r_S = 0.692$), and then African-Americans ($r_S = 0.666$). The entire sample contained the strongest correlation coefficients, although all categories had strong ($r_S = 0.7–0.89$) and highly significant associations ($p < 0.0001$).

Table 33: Correlation based on ancestry for the Oettlé and Steyn method

	Count	Est vs. Actual Phase Spearman's r	Est vs. Actual Age Spearman's r	Significance
Entire Sample	411	0.746	0.741	< 0.0001
African-Americans	209	0.696	0.692	< 0.0001
European-Americans	202	0.701	0.666	< 0.0001

All three groups displayed correlation coefficients that were all strong and highly significant. Therefore in order to determine if there was a difference in accuracy between the groups, a Fisher's z transformation was utilized. Table 34 demonstrates the correlation coefficients between the estimated and actual phase numbers for the first category and the second category, the z-scores, and the significance for each method. No significant values were found, indicating that the Oettlé and Steyn (2000) method was able to assess age equally well for both ancestral groups.

Table 34: Significance of the correlation coefficients for the Oettlé and Steyn method based on ancestry (phase)

Test	r(1)	r(2)	z-score	Significance
Entire Sample / African-Americans	0.746	0.696	1.221	0.222
Entire Sample / European-Americans	0.746	0.701	1.094	0.274
African-Americans / European-Americans	0.696	0.701	- 0.098	0.922

2-tailed test, entire sample (n = 411), African-Americans (n = 209), European-Americans (n = 202)

Correlation coefficients between the estimated and actual ages were also compared. Table 35 demonstrates the correlation coefficients between the estimated and actual ages for the first category and the second category, the z-scores, and the significance for each test. Again, no significant values between ancestries were found for the Oettlé and Steyn (2000) method, indicating that the method was able to assess age equally well for both ancestral groups.

Table 35: Significance of the correlation coefficients for the Oettlé and Steyn method based on ancestry (age)

Test	r(1)	r(2)	z-score	Significance
Entire Sample / African-Americans	0.741	0.692	1.167	0.243
Entire Sample / European-Americans	0.741	0.666	1.745	0.081
African-Americans / European-Americans	0.692	0.666	0.485	0.627

2-tailed test, entire sample (n = 411), African-Americans (n = 209), European-Americans (n = 202)

No statistically significant values were found for any of the comparisons for the Hartnett-Fulginiti (2007; 2010) method. This demonstrates that the method was able to assess age equally well for both African-Americans and European-Americans within the sample.

For all three methods, no statistically significant differences were found between African-Americans and European-Americans, demonstrating that each technique was able to assess age equally well for both ancestral groups. These results therefore reject the hypothesis that there would be significant differences between African-Americans and European-Americans within the sample. This suggests that although differences in the rate and pattern of aging may be present, separate standards for African-Americans and European-Americans may not be necessary.

Accuracy Based on Sex

The fifth research question addressed the rates of accuracy between males and females for each method. Each method contains a separate set of standards for males and females due to differences in degenerative changes of the fourth sternal right rib that were noticed. It was therefore hypothesized that would be differences in accuracy for each sex, especially when divided on the basis of ancestry.

Correlation (İşcan et al. Method)

Spearman's coefficient of rank was used to calculate accuracy rates for all categories, including African-American males, European-American males, total males, African-American females, European-American females, and total females. Table 36 shows the correlation of the estimated and actual phase numbers and estimated and actual ages for the İşcan et al. (1984a; 1985) method. African-American males had the highest correlation ($r_S = 0.835; 0.823$) and African-American females had the lowest ($r_S = 0.617; 0.571$). All categories, except African-American females, had strong ($r_S = 0.7–0.89$) and highly significant correlations ($p < 0.0001$), although the moderate correlation for African-American females may have been due to small sample size.

Table 36: Correlation based on sex and ancestry for the İşcan et al. method

	Count	Est vs. Act Phase Spearman's r	Est vs. Act Age Spearman's r	Significance
African-American Males	143	0.835	0.823	< 0.0001
European-American Males	149	0.702	0.681	< 0.0001
Total Males	292	0.800	0.788	< 0.0001
African-American Females	66	0.617	0.571	< 0.0001
European-American Females	53	0.795	0.792	< 0.0001
Total Females	119	0.755	0.735	< 0.0001
Total Sample	411	0.780	0.745	< 0.0001

To determine if the differences between the correlation coefficients for each category were significant for the İşcan et al. (1984a; 1985) method, a Fisher's z transformation was used, as comparisons were made within the same method. Table 37 shows the tests, correlation coefficients between the estimated and actual phase numbers for the first and second categories, z-scores, and significance for all comparisons for the İşcan et al. (1984a; 1985) method. No statistically significant values were found, indicating that the İşcan et al. (1984a; 1985) method was able to assess age equally well for both males and females within the sample.

Table 37: Significance of the İşcan et al. method based on sex (phase)

Test	r(1)	r(2)	z-score	Significance
Entire Sample / Total Males	0.780	0.800	- 0.692	0.489
Entire Sample / Total Females	0.780	0.755	0.579	0.563
Total Males / Total Females	0.800	0.755	1.038	0.299

2-tailed test, entire sample (n = 411), total males (n = 292), total females (n = 119)

Correlation coefficients between the estimated and actual ages were also compared. Table 38 demonstrates the correlation coefficients between the estimated and actual ages for the first second categories, the z-scores, and the significance for each test. Again, no significant values between ancestries were found for the İşcan et al. (1984a; 1985) method, indicating that the technique was able to assess age equally well for males and females.

Table 38: Significance of the İşcan et al. method based on sex (age)

Test	r(1)	r(2)	z-score	Significance
Entire Sample / Total Males	0.745	0.788	- 1.259	0.174
Entire Sample / Total Females	0.745	0.735	0.210	0.834
Total Males / Total Females	0.788	0.735	1.152	0.249

2-tailed test, entire sample (n = 411), total males (n = 292), total females (n = 119)

No statistically significant values were found for any of the comparisons for the İşcan et al. (1984a; 1985) method. This indicates that the method was able to assess age equally well for both males and females within the sample.

Correlation (Hartnett-Fulginiti Method)

Spearman's coefficient of rank was used to calculate accuracy rates for all categories for the Hartnett-Fulginiti (2007; 2010) method. Table 39 shows the correlation coefficients between the estimated and actual phase numbers and the estimated and actual ages. European-American females had the highest correlations (r_s = 0.854; 0.844) and African-American females had the lowest (r_s = 0.645; 0.672). All categories, except African-American females, had strong (r_s = 0.7–0.89) and highly significant correlations ($p < 0.0001$), although the moderate correlation for African-American females may have been due to small sample size.

Table 39: Correlation based on sex and ancestry for the Hartnett-Fulginiti method

	Count	Est vs. Act Phase Spearman's r	Est vs. Act Age Spearman's r	Significance
African-American Males	143	0.829	0.777	< 0.0001
European-American Males	149	0.747	0.705	< 0.0001
Total Males	292	0.825	0.783	< 0.0001
African-American Females	66	0.645	0.672	< 0.0001
European-American Females	53	0.854	0.844	< 0.0001
Total Females	119	0.833	0.844	< 0.0001
Total Sample	411	0.832	0.793	< 0.0001

In order to determine if there were any statistically significant differences in accuracy between each category for the Hartnett-Fulginiti (2007; 2010) method, a Fisher's z transformation was used, as the comparisons were made within the same method. Table 40 shows the tests, correlations coefficients between the estimated and actual phase numbers for the first and second categories, z-scores, and significance for all comparisons of the Hartnett-Fulginiti (2007; 2010) method. No statistically significant values were found, indicating that the Hartnett-Fulginiti (2007; 2010) method was able to assess age equally well for males and females.

Table 40: Significance of the Hartnett-Fulginiti method based on sex (phase)

Test	r(1)	r(2)	z-score	Significance
Entire Sample / Total Males	0.832	0.825	0.290	0.772
Entire Sample / Total Females	0.832	0.833	- 0.031	0.975
Total Males / Total Females	0.825	0.833	- 0.233	0.816

2-tailed test, entire sample (n = 411), total males (n = 292), total females (n = 119)

Correlation coefficients between the estimated and actual ages were also compared. Table 41 demonstrates the correlation coefficients between the estimated and actual ages for the first category and the second category, the z-scores, and the significance for each test. Again, no significant values between ancestries were found for the Hartnett-Fulginiti (2007; 2010) method, demonstrating that the method was able to assess age equally well for males and females.

Table 41: Significance of the Hartnett-Fulginiti method based on sex (age)

Test	r(1)	r(2)	z-score	Significance
Entire Sample / Total Males	0.793	0.783	0.343	0.731
Entire Sample / Total Females	0.793	0.844	- 1.477	0.140
Total Males / Total Females	0.783	0.844	- 1.654	0.098

2-tailed test, entire sample (n = 411), total males (n = 292), total females (n = 119)

No statistically significant values were found for any of the comparisons for the Hartnett-Fulginiti (2007; 2010) method. This demonstrates that the method was able to assess age equally well for both males and females within the sample.

Correlation (Oettlé and Steyn Method)

Spearman's coefficient of rank was used to calculate accuracy rates for all categories for the Oettlé and Steyn (2000) method. Table 42 shows the correlation coefficients between the estimated and actual phase numbers and estimated and actual ages for the Oettlé and Steyn (2000) method. Total males had the highest correlations for both comparisons ($r_S = 0.762$; 0.763). African-American females had the lowest for comparisons between phases ($r_S = 0.598$), and European-American females had the lowest for comparisons between ages ($r_S = 0.533$). All categories, except African-American females and European-American females, had strong (r_S = 0.7–0.89) and highly significant correlations ($p < 0.0001$). Again, these moderate and low correlations may have been due to small sample size.

Table 42: Correlation based on sex and ancestry for the Oettlé and Steyn method

	Count	Est vs. Act Phase Spearman's r	Est vs. Act Age Spearman's r	Significance
African-American Males	143	0.741	0.737	< 0.0001
European-American Males	149	0.708	0.704	< 0.0001
Total Males	292	0.762	0.763	< 0.0001
African-American Females	66	0.598	0.583	< 0.0001
European-American Females	53	0.668	0.533	< 0.0001
Total Females	119	0.755	0.671	< 0.0001
Total Sample	411	0.746	0.741	< 0.0001

Due to similar correlation coefficients for many categories, further tests were required in order to determine if there are any statistically significant differences in accuracy for each category for the Oettlé and Steyn (2000) method. This was conducted through the use of a Fisher's z transformation, as comparisons were made within the same method. Table 43 shows the tests, the correlation coefficients between the estimated and actual phase numbers for the first and second categories, z-scores, and significance for all comparisons of the Oettlé and Steyn (2000) method. No statistically significant values were found, indicating that the Oettlé and Steyn (2000) method was able to assess age equally well for males and females within the sample.

Table 43: Significance of the Oettlé and Steyn method based on sex (phase)

Test	r(1)	r(2)	z-score	Significance
Entire Sample / Total Males	0.746	0.762	- 0.482	0.629
Entire Sample / Total Females	0.746	0.755	- 0.196	0.845
Total Males / Total Females	0.762	0.755	0.145	0.881

2-tailed test, entire sample (n = 411), total males (n = 292), total females (n = 119)

Correlation coefficients between the estimated and actual ages were also compared. Table 44 demonstrates the correlation coefficients between the estimated and actual ages for the first category and the second category, the z-scores, and the significance for each test. Again, no significant values between ancestries were found for the Oettlé and Steyn (2000) method, demonstrating that the technique was able to assess age equally well for males and females.

Table 44: Significance of the Oettlé and Steyn method based on sex (age)

Test	r(1)	r(2)	z-score	Significance
Entire Sample / Total Males	0.741	0.763	- 0.659	0.560
Entire Sample / Total Females	0.741	0.671	1.332	0.183
Total Males / Total Females	0.763	0.671	1.736	0.083

2-tailed test, entire sample (n = 411), total males (n = 292), total females (n = 119)

No statistically significant values were found for any of the comparisons for the Hartnett-Oettlé and Steyn (2000) method. This demonstrates that the method was able to assess age equally well for both males and females.

The fifth research hypothesis addressed differences in accuracy based on sex. It was expected that there would be significant differences between each sex for every method. No significant differences between males and females were found for any method, rejecting this hypothesis. This suggests that separate standards based on sex are necessary and that this separation does not appear impact accuracy rates for either sex.

Correlation (All Methods)

Comparisons of accuracy based on sex were also conducted between methods using the categories of males and females conducted through the use of a Steiger's z transformation. Table 45 demonstrates the correlation coefficients for males of the first and second methods, the correlation coefficient of the estimated ages between the first and second methods, the z-scores, and the significance. When examining the differences in significance of accuracy rates between males for all three methods, no statistically significant differences were found, indicating that all methods were able to assess age equally well for males within the sample.

Table 45: Significance of the correlation coefficients for males

Test		r(1)	r(2)	r(3)	z-score	Significance
İşcan et al.	**/ Hartnett-Fulginiti**	0.788	0.783	0.785	0.230	0.818
İşcan et al.	**/ Oettlé and Steyn**	0.788	0.763	0.815	1.195	0.232
Hartnett-Fulginiti	**/ Oettlé and Steyn**	0.783	0.763	0.784	0.891	0.373

2-tailed test, n = 292

Comparing the correlations of all three methods for females was also conducted using a Steiger's z transformation. Table 46 demonstrates the correlation coefficients of the first and second methods, the correlation coefficient of the estimated ages between the first and second methods, the z-scores, and the significance. Two statistically significant differences were found. The first was between the Hartnett-Fulginiti (2007; 2010) method and the İşcan et al. (1984a; 1985) method (p = 0.004). The second was between the Hartnett-Fulginiti (2007; 2010) method and the Oettlé and Steyn (2000) method (p = 0.000). This demonstrates that the Hartnett-Fulginiti (2007; 2010) method was able to more accurately assess age for females in the sample in comparison to the other two methods.

Table 46: Significance of the correlation coefficients for females

Test		r(1)	r(2)	r(3)	z-score	Significance
İşcan et al.	**/ Hartnett-Fulginiti**	0.735	0.844	0.678	- 2.847	**0.004***
İşcan et al.	**/ Oettlé and Steyn**	0.735	0.671	0.620	1.237	0.216
Hartnett-Fulginiti	**/ Oettlé and Steyn**	0.844	0.671	0.658	4.118	**0.000***

*** p < 0.05; 2-tailed test, n = 119**

Sex was further assessed on the basis of ancestry. The correlation coefficients for African-American males between methods were first compared for each method using a Steiger's z transformation. Table 47 demonstrates the correlation coefficients of the first and second methods, the correlation coefficient of the estimated ages between the first and second methods, the z-scores, and the significance. Statistically significant differences were found between the İşcan et al. (1984a; 1985) method and the Oettlé and Steyn (2000) method (p = 0.006). This indicates that the İşcan et al. (1984a; 1985) method was able to assess age more accurately than the Oettlé and Steyn (2000) method for African-American males.

Table 47: Significance of the correlation coefficients for African-American males

Test		r(1)	r(2)	r(3)	z-score	Significance
İşcan et al.	**/ Hartnett-Fulginiti**	0.823	0.777	0.772	1.512	0.130
İşcan et al.	**/ Oettlé and Steyn**	0.823	0.737	0.780	2.736	**0.006***
Hartnett-Fulginiti	**/ Oettlé and Steyn**	0.777	0.737	0.712	1.065	0.287

*** p < 0.05; 2-tailed test, n = 143**

Comparisons of European-American males between methods were also made using a Steiger's z transformation. Table 48 demonstrates the correlation coefficients of the first and second methods, the correlation coefficient of the estimated ages between the first and second methods, the z-scores, and the significance. No statistically significant differences were found between methods, indicating that all three methods were able to assess age equally well for European-American males.

Table 48: Significance of the correlation coefficients for European-American males

Test	r(1)	r(2)	r(3)	z-score	Significance
İşcan et al. / Hartnett-Fulginiti	0.681	0.705	0.733	- 0.588	0.556
İşcan et al. / Oettlé and Steyn	0.681	0.704	0.800	- 0.640	0.522
Hartnett-Fulginiti / Oettlé and Steyn	0.705	0.704	0.767	0.027	0.979

2-tailed test, n = 149

African-American females were also compared between methods using a Steiger's z transformation. Table 49 demonstrates the correlation coefficients of the first and second methods, the correlation coefficient of the estimated ages between the first and second methods, the z-scores, and the significance. No statistically significant differences were found for African-American females between the methods, indicating that all three methods were able to assess age equally well for African-American females.

Table 49: Significance of the correlation coefficients for African-American females

Test	r(1)	r(2)	r(3)	z-score	Significance
İşcan et al. / Hartnett-Fulginiti	0.571	0.672	0.465	- 1.091	0.275
İşcan et al. / Oettlé and Steyn	0.571	0.583	0.599	- 0.137	0.891
Hartnett-Fulginiti / Oettlé and Steyn	0.672	0.583	0.521	1.014	0.311

2-tailed test, n = 66

Finally, European-American females were also compared between methods using a Steiger's z transformation. Table 50 demonstrates the correlation coefficients of the first and second methods, the correlation coefficient of the estimated ages between the first and second methods, the z-scores, and the significance. Two statistically significant values were found. The first was between the Hartnett-Fulginiti (2007; 2010) method and the Oettlé and Steyn (2000) method (p = 0.000). The second was between the İşcan et al. (1984a; 1985) method and Oettlé and Steyn (2000) method (p = 0.007). This indicates that for European-American females, the

Hartnett-Fulginiti (2007; 2010) method and İşcan et al. (1984a; 1985) method were more accurate assessors of age than the Oettlé and Steyn (2000) method.

Table 50: Significance of the correlation coefficients for European-American females

Test	r(1)	r(2)	r(3)	z-score	Significance
İşcan et al. / Hartnett-Fulginiti	0.792	0.844	0.726	- 1.022	0.306
İşcan et al. / Oettlé and Steyn	0.792	0.533	0.422	2.716	**0.007***
Hartnett-Fulginiti / Oettlé and Steyn	0.844	0.533	0.623	4.245	**0.000***

*** $p < 0.05$; 2-tailed test, n = 53**

It was found that for African-American males, the İşcan et al. (1984a; 1985) method more accurately assessed age than the Oettlé and Steyn (2000) method. No statistically significant differences were found between methods for European-American males and African-American females. For European-American females it was found that the Hartnett-Fulginiti (2007; 2010) method and the İşcan et al. (1984a; 1985) method were both more accurate assessors of age than the Oettlé and Steyn (2000) method.

Accuracy for All Categories

Table 51 displays the number of individuals and correlation coefficients for each category of each method. The values in bold indicate the methods that were statistically more accurate for each category. As can be seen from the table, the Hartnett-Fulginiti (2007; 2010) method most accurately assessed age for almost all categories.

Table 51: Correlation of estimated and actual ages for the entire sample

	Count	İşcan et al.	Hartnett-Fulginiti	Oettlé and Steyn
African-American Males	143	**0.823***	0.777	0.737
African-American Females	66	**0.571**	**0.672**	**0.583**
Total African-Americans	209	**0.704**	**0.739**	**0.692**
European-American Males	149	**0.681**	**0.705**	**0.704**
European-American Females	53	**0.792**	**0.844**	0.533
Total European-Americans	202	**0.716**	**0.731**	**0.666**
Total Males	292	**0.788**	**0.783**	**0.763**
Total Females	119	0.735	**0.844**	0.671
Total Sample	411	0.745	**0.793**	0.741

*** Only significant between the İşcan et al. and Oettlé and Steyn methods**

Inaccuracy

Inaccuracy was calculated for all groups and all methods in order to further demonstrate the accuracy of all three methods. Inaccuracy, also known as the absolute mean error, was calculated for multiple categories and for every method. This was conducted through the use of the equation Σ |estimated phase - actual phase| / N, which measures the differences between the estimated and actual phases. It represents the average error from the actual phase number without regard to whether the error is positive or negative (Russell et al., 1993; Martrille et al., 2007).

Table 52 displays the number of individuals and phase inaccuracy of each method for multiple categories. The least amount of inaccuracy is in bold for each subsample. The Hartnett-Fulginiti (2007; 2010) contained the least amount of inaccuracy for each category, while the Oettlé and Steyn (2000) method displayed the most amount of inaccuracy.

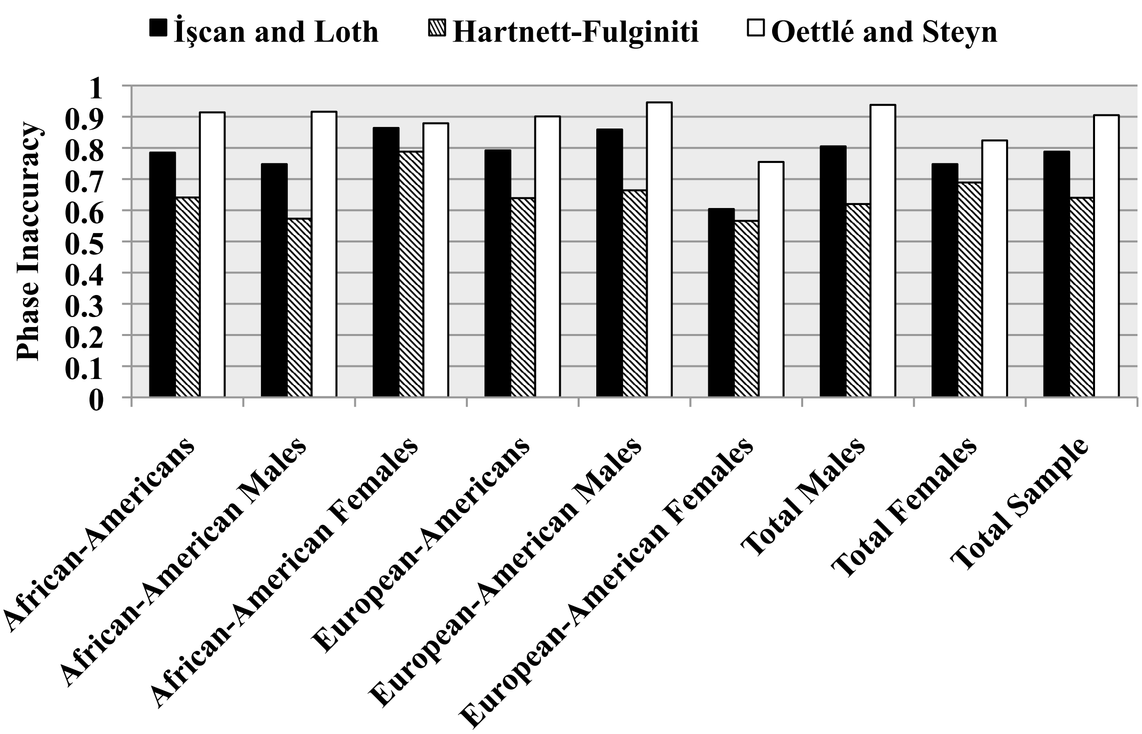
Table 52: Phase inaccuracy* for all methods

	Count	İşcan et al.	Hartnett-Fulginiti	Oettlé and Steyn
African-American Males	143	0.748	**0.573**	0.916
African-American Females	66	0.864	**0.788**	0.879
Total African-Americans	209	0.785	**0.641**	0.914
European-American Males	149	0.859	**0.664**	0.946
European-American Females	53	0.604	**0.566**	0.755
Total European-Americans	202	0.792	**0.639**	0.901
Total Males	292	0.805	**0.620**	0.938
Total Females	119	0.748	**0.689**	0.824
Total Sample	411	0.788	**0.640**	0.905

*** Inaccuracy (Absolute Mean Error): Σ |estimated phase - actual phase| / N**

Figure 2 shows a visual representation of this data. All three methods contained an inaccuracy of less than one phase from the actual phase number, indicating that most methods accurately assessed age within one phase.

Figure 2: Phase inaccuracy for all methods



Inaccuracy was also calculated in terms of the age by specifically examining error in terms of years. Age inaccuracy is determined through the equation Σ |mean age - actual age| / N and is evaluated by the sums of the absolute values of the difference between the mean ages of the estimated phases and the chronological, or actual, ages, divided by the number of individuals.

In order to calculate inaccuracy in regards to age, the sample was divided by method and into multiple subsamples based on ancestry and sex. Table 53 displays the number of individuals and the age inaccuracy for all three methods. The least amount of inaccuracy is in bold for each subsample. Rates of inaccuracy ranged from 6.74 to 9.37 years for the İşcan et al. (1984a; 1985) method, with the lowest rates for African-American males. Rates of inaccuracy for the Hartnett-Fulginiti (2007; 2010) method ranged from 6.87 to 9.54 years, with the lowest rates for African-American females. Finally, rates of inaccuracy ranged from 7.52 to 14.55 years for the Oettlé and Steyn (2000) method, with the lowest rates for African-American males.

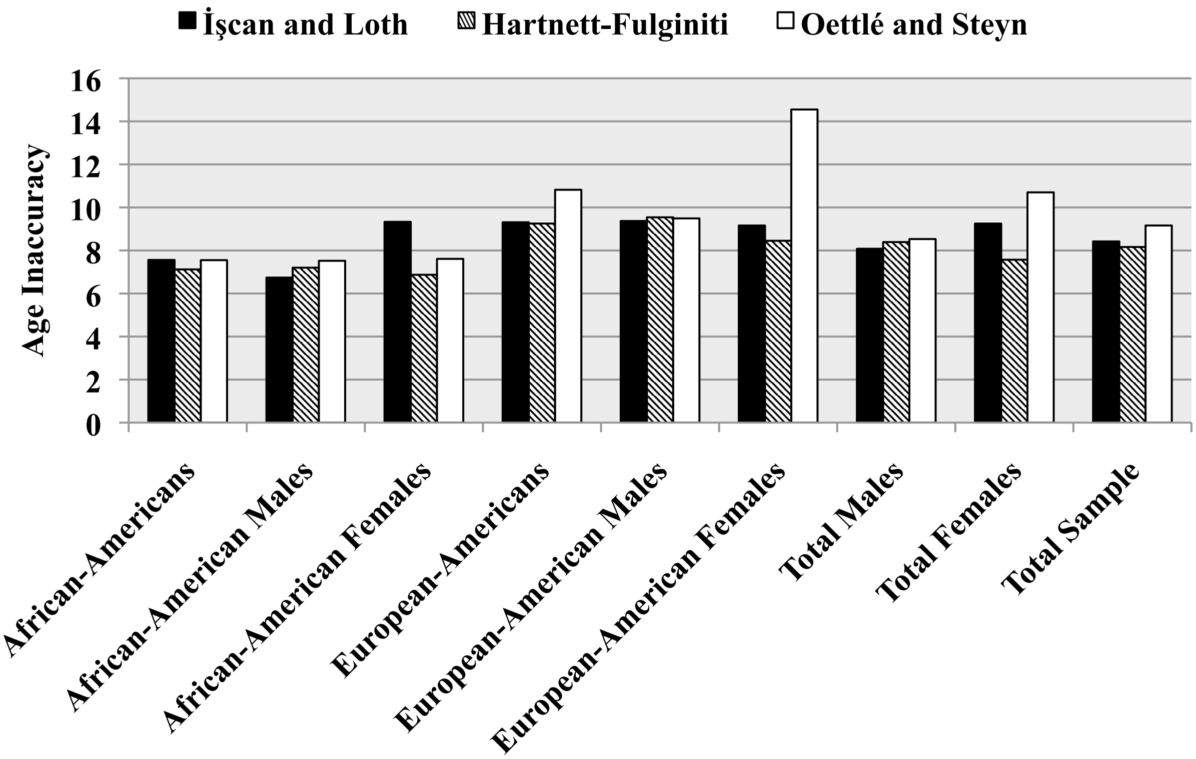
Table 53: Age inaccuracy* for all methods

	Count	İşcan et al.	Hartnett-Fulginiti	Oettlé and Steyn
African-American Males	143	**6.74**	7.20	7.52
African-American Females	66	9.33	**6.87**	7.61
Total African-Americans	209	7.56	**7.12**	7.55
European-American Males	149	**9.37**	9.54	9.49
European-American Females	53	9.16	**8.45**	14.55
Total European-Americans	202	9.31	**9.25**	10.82
Total Males	292	**8.08**	8.39	8.53
Total Females	119	9.25	**7.57**	10.70
Total Sample	411	8.42	**8.16**	9.16

*** Inaccuracy (Absolute Mean Error): Σ |mean age - actual age| / N**

For the purposes of comparison, inaccuracy was plotted for the three methods for all subsamples and is displayed in Figure 3. For the total sample, African-Americans, and European-Americans, the Hartnett-Fulginiti (2007; 2010) method had the lowest amount of inaccuracy.

Figure 3: Age inaccuracy for all methods



Bias

Bias was also calculated for the entire sample for each method. While inaccuracy measures the difference between the estimation and actual phases, bias instead represents the tendency to either overage or underage an individual. It is calculated from the difference between the estimated and actual phase numbers and is calculated through the equation Σ (estimated phase - actual phase) / N. Phase bias demonstrates the average error between the estimated and actual phase.

Table 54 demonstrates the number of individuals and the phase bias of each method for multiple categories. The numbers in bold represent the lowest amount of bias for each category in terms of phase, with all methods that over or underestimated each category by less than one phase.

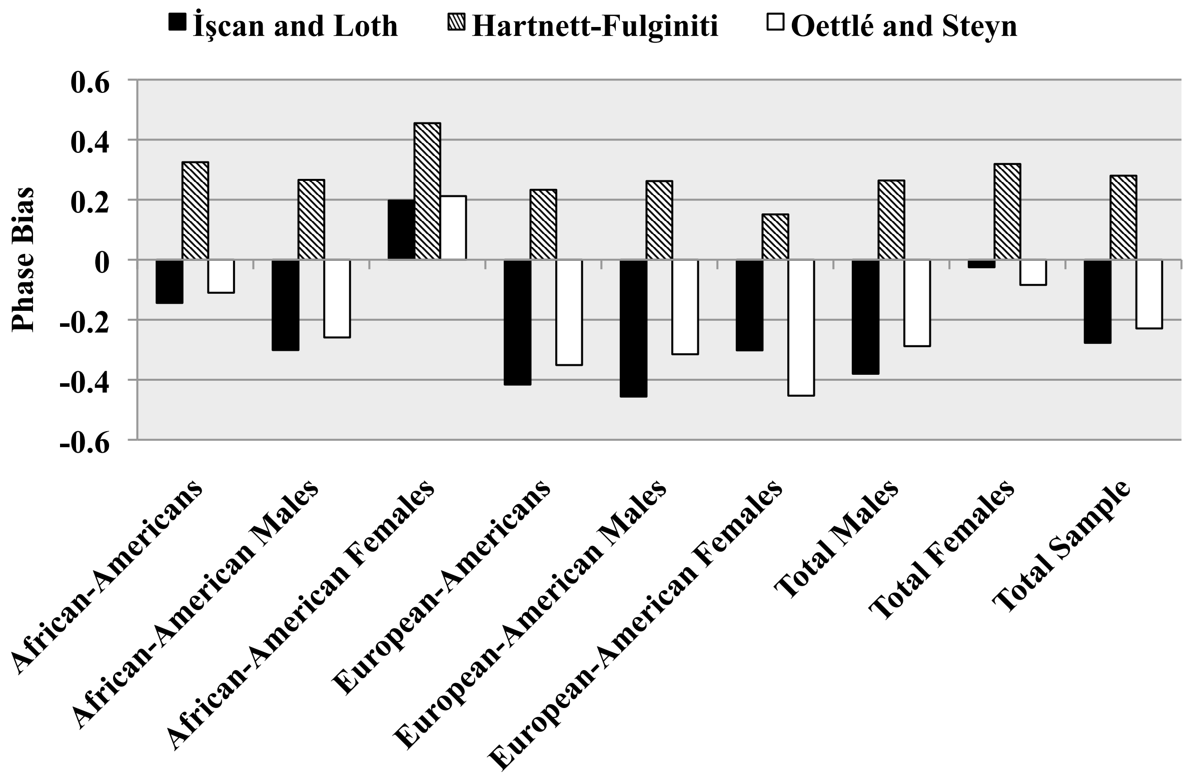
Table 54: Phase bias* for all methods

	Count	İşcan et al.	Hartnett-Fulginiti	Oettlé and Steyn
African-American Males	143	- 0.301	0.266	**- 0.259**
African-American Females	66	**0.197**	0.455	0.212
Total African-Americans	209	- 0.144	0.325	**- 0.110**
European-American Males	149	- 0.456	**0.262**	- 0.315
European-American Females	53	- 0.302	**0.151**	- 0.453
Total European-Americans	202	- 0.416	**0.233**	- 0.351
Total Males	292	- 0.380	**0.264**	- 0.288
Total Females	119	**- 0.025**	0.319	- 0.084
Total Sample	411	- 0.277	0.280	**- 0.229**

*** Bias: Σ (estimated phase - actual phase) / N**

Figure 4 gives a visual representation of this data. All three methods contained a bias of less than one phase than the actual phase, indicating all methods accurately assessed age within one phase.

Figure 4: Phase bias for all methods



Bias on the basis of age was also calculated using the equation Σ (estimated age - actual age) / N. This demonstrates the average error in age between the estimated and actual age with regards to the direction of the error. In order to determine for inaccuracy and bias in terms of age, mean ages of each phase were used in substitute for an estimated age, as each phase contains an age range. For example, for the Hartnett-Fulginiti (2007; 2010) method, if a female is estimated to be a Phase 1, that individual has an estimated age range of 18 to 22 years; therefore she is approximately 19.57 years, which is the mean age for that phase (Russell et al., 1993; Martrille et al., 2007).

Table 55 demonstrates the number of individuals and the age bias of each method for multiple categories. For the İşcan et al. (1984a; 1985) method bias ranged from 3.93 years under to 2.03 years over the actual ages, with the lowest amount for total females. Bias for the Hartnett-

Fulginiti (2007; 2010) method ranged from 1.27 to 3.31 years over the actual ages, with the lowest amount of bias for African-American males. Finally, bias for the Oettlé and Steyn (2000) method ranged from 11.14 years under to 0.79 years over the actual ages, with the lowest amount of bias for African-American females.

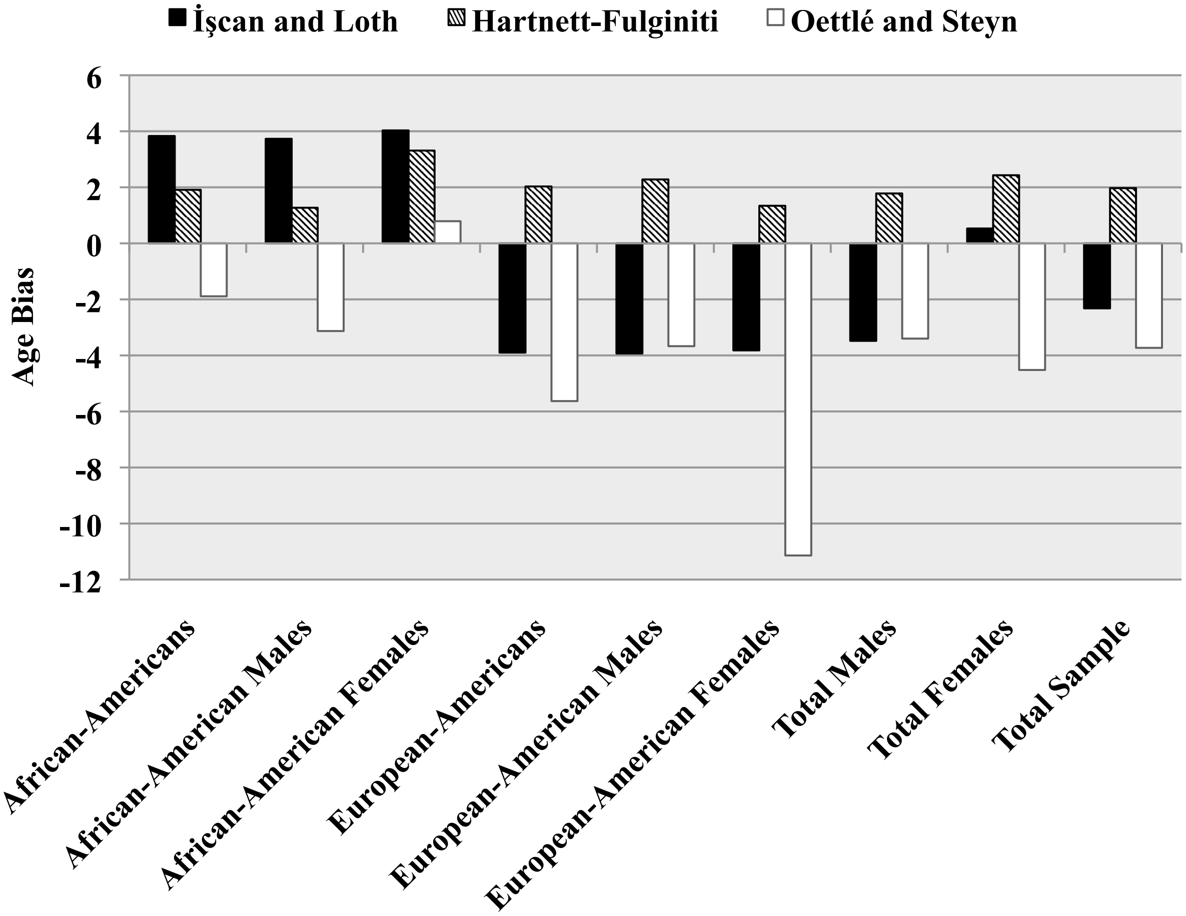
Table 55: Age bias* for all methods

	Count	İşcan et al.	Hartnett-Fulginiti	Oettlé and Steyn
African-American Males	143	3.73	**1.27**	- 3.13
African-American Females	66	4.03	3.31	**0.79**
Total African-Americans	209	3.83	1.91	**- 1.89**
European-American Males	149	- 3.93	**2.28**	- 3.67
European-American Females	53	- 3.82	**1.34**	- 11.14
Total European-Americans	202	- 3.90	**2.03**	- 5.63
Total Males	292	- 3.48	**1.78**	- 3.40
Total Females	119	**0.53**	2.43	- 4.52
Total Sample	411	- 2.32	**1.97**	- 3.73

*** Bias: Σ (estimated age - actual age) / N**

Figure 5 displays the tendency to over- and underage each category for all methods. The Oettlé and Steyn (2000) method and the İşcan et al. (1984a; 1985) method tended to underestimate age for most categories, while the Hartnett-Fulginiti (2007; 2010) method overestimated age for all categories. Additionally, the Hartnett-Fulginiti (2007; 2010) method had the least amount of bias for almost all categories.

Figure 5: Age bias for all methods



Intra-observer Error

Intra-observer error rates were calculated for all three methods on a total of 105 individuals. The author re-examined a selection of sixty individuals from the Hamann-Todd Osteological Collection, consisting of 15 African-American males, 15 African-American females, 15 European-American males, and 15 European-American females. Additionally, a total of 45 individuals from the William M. Bass Donated Skeletal Collection were re-examined, consisting of eleven African-American males, four African-American females, 15 European-American males, and 15 European-American females.

Correlation

The İşcan et al. (1984a; 1985), Hartnett-Fulginiti (2007; 2010), and Oettlé and Steyn (2000) methods were examined for intra-observer error rates using a Spearman's coefficient of rank correlation. Table 56 displays the number of individuals, the correlation coefficients (r_S), and the significance for the three methods. All correlations were strong (r_S = 0.7–0.89), indicating a low intra-observer error rate for the author. The highest intra-observer agreement was found for the Hartnett-Fulginiti method (r_S = 0.888), followed by the Oettlé and Steyn method (r_S = 0.882), and then the İşcan et al. method (r_S = 0.831).

Table 56: Correlation of estimate 1 and estimate 2 for the entire sample

	Count	Spearman's r	Significance
İşcan et al.	105	0.831	< 0.0001
Hartnett-Fulginiti	105	0.888	< 0.0001
Oettlé and Steyn	105	0.882	< 0.0001

Additional tests using Cohen's Kappa measure of agreement were also used. Table 57 displays the number of individuals, the Kappa value (κ), the standard error, and the significance of all methods. Results displayed a moderate association (κ = 0.4–0.75) for the Hartnett-Fulginiti (2007; 2010) method and Oettlé and Steyn (2000) method, while the İşcan et al. (1984a; 1985) displayed a low association (κ = < 0.4).

Table 57: Cohen's Kappa between estimate 1 and estimate 2 for the entire sample

	Count	Kappa	Std Error	Significance
İşcan et al.	105	0.354	0.057	< 0.0001
Hartnett-Fulginiti	105	0.582	0.056	< 0.0001
Oettlé and Steyn	105	0.448	0.059	< 0.0001

Cross-tabulation

Cross-tabulation tables were also used in order to visually compare the first estimation and the second estimation. Table 58 demonstrates the 105 individuals that were re-examined for the İşcan et al. (1984a; 1985) method. A total of 48 cases (45.7%) were given the same phase estimate as the first estimation. Estimations within one phase of the original estimate included 42 individuals (40.0%), either one phase over (n = 23) or one phase under (n = 19). Therefore the author successfully reassessed 85.7% of individuals within one phase of the original estimate. Finally, 13 individuals (12.4%) were within two phases over (n = 8) or under (n = 5) the original estimate.

Table 58: Cross-tabulation of estimate 1 and estimate 2 for the İşcan et al. method for the entire sample

		Estimate 2								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Estimate 1	**0**	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0
	2	0	0	1	2	0	0	0	0	0
	3	0	2	3	1	1	2	1	0	0
	4	0	0	1	3	11	2	0	0	0
	5	0	0	0	2	3	11	4	2	0
	6	0	0	0	1	2	9	6	5	1
	7	0	0	0	0	0	0	3	7	5
	8	0	0	0	0	0	0	1	2	11

Table 59 demonstrates the 105 individuals that were re-examined for the Hartnett-Fulginiti (2007; 2010) method. A total of 69 cases (65.7%) were given the same phase estimate as the first estimation. Estimations within one phase of the original estimate included 29 individuals (27.6%), either one phase over (n = 13) or one phase under (n = 16). Therefore the author successfully reassessed 93.3% of individuals within one phase of the original estimate. Finally, 7 individuals (6.7%) were within two phases over (n = 2) or under (n = 5) the original estimate.

Table 59: Cross-tabulation of estimate 1 and estimate 2 for the Hartnett-Fulginiti method for the entire sample

		Estimate 2							
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Estimate 1	**0**	0	0	0	0	0	0	0	0
	1	0	0	1	0	0	0	0	0
	2	0	0	3	3	1	0	0	0
	3	0	0	1	15	5	1	0	0
	4	0	0	0	4	10	4	2	0
	5	0	0	0	1	3	13	2	1
	6	0	0	0	0	1	3	12	1
	7	0	0	0	0	0	0	2	16

Table 60 demonstrates the 105 individuals that were re-examined for the Oettlé and Steyn (2000) method. A total of 57 cases (54.3%) were given the same phase estimate as the first estimation. Estimations within one phase of the original estimate included 42 individuals (40.0%), either one phase over (n = 18) or one phase under (n = 24). Therefore the author successfully reassessed 93.3% of individuals within one phase of the original estimate. Finally, 6 individuals (5. 7%) were within two phases over (n = 2) or under (n = 4) the original estimate.

Table 60: Cross-tabulation of estimate 1 and estimate 2 for the Oettlé and Steyn method for the entire sample

		Estimate 2								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Estimate 1	**0**	0	0	0	0	0	0	0	0	0
	1	0	0	0	1	0	0	0	0	0
	2	0	0	0	1	0	0	0	0	0
	3	0	0	1	12	2	1	0	0	0
	4	0	0	0	3	10	7	1	0	0
	5	0	0	0	1	8	12	5	0	0
	6	0	0	0	0	0	3	8	4	1
	7	0	0	0	0	0	1	0	8	5
	8	0	0	0	0	0	0	0	3	7

For all three methods tests indicated a high level of correlation (r_s = 0.7–0.89) and a moderate level of agreement (κ = 0.4–0.75). These results show that all methods do not suffer from a significant amount of intra-observer error.

DISCUSSION

This research addressed the accuracy of three sternal rib aging techniques: the İşcan et al. (1984a; 1985), the Hartnett-Fulginiti (2007; 2010), and the Oettlé and Steyn (2000) methods. Results indicated that the three methods are reliable and accurate, all demonstrating strong and highly significant correlations between the actual and estimated ages ($p < 0.0001$). Specifically, when the correlation values for the entire sample were examined, the Hartnett-Fulginiti (2007; 2010) method contained the strongest associations ($r_S = 0.831; 0.793$). The method was also determined to be a slightly better predictor of age compared to the other techniques analyzed ($\hat{p} = 0.4842$). Further analysis of overall accuracy rates showed statistical significance for the Hartnett-Fulginiti (2007; 2010) method, indicating that it was the most accurate at assessing age for the entire sample ($p = 0.011, 0.022$).

Although all methods had strong correlation coefficients, cross-tabulation tables showed a relatively low accuracy rate for correct phase association, with less than half of the sample that was correctly assigned for each method. Most of the sample was assigned within two phases either above or below the actual phase number. This may indicate that the confidence intervals and age ranges for each phase are too narrow and therefore should be expanded in order to include more individuals.

Accuracy for European-Americans

Additional tests of accuracy were conducted on European-Americans within the sample. These individuals were specifically addressed as part of this research due to the majority of methods that have been developed exclusively or mostly on individuals of European ancestry. This research especially addressed the İşcan et al. (1984a; 1985) method, which was developed on only European-Americans, and the Hartnett-Fulginiti (2007; 2010) method, which was developed on individuals of multiple ancestries, consisting of mostly Caucasians. It was expected that the Hartnett-Fulginiti (2007; 2010) method would more accurately assess age for individuals of European ancestry, as it was developed as a modification and replacement of the İşcan et al. (1984a; 1985) method.

Statistical analysis was conducted on the European-American subsample ($n = 202$). All three methods displayed correlation coefficients that were strong and highly significant. ($p < 0.0001$). Further analysis was conducted in order to determine if there were any statistically significant differences in accuracy among the methods. No significant differences were found, indicating that all three methods were able to assess age equally well for European-Americans within the sample. Additionally, each method was tested to determine how well it could predict age. Although no statistically significant differences were found, the Hartnett-Fulginiti (2007; 2010) method was determined to be a slightly better predictor of age when compared to the other techniques analyzed ($\hat{\rho} = 0.4901$).

Finally, cross-tabulation tables were also used to give a visual representation of the data. Again, a relatively low accuracy rate for classifying ribs into the correct age phase was found for each method. The Hartnett-Fulginiti (2007; 2010) method displayed the highest accuracy, with 49.3 percent of the sample correctly assigned. These results suggest that all three methods can be utilized on a European-American sample, as they all performed equally well at assessing age for this population.

Accuracy for African-Americans

In addition to determining accuracy rates of all methods for the entire sample, rates of accuracy for African-Americans within the sample were also addressed per differences in accuracy based on ancestry as seen in the literature. Specifically, İşcan et al. (1987) developed a rib aging method for African-Americans due to differences found in the morphological age-related characteristics. Additionally, Oettlé and Steyn (2000) found poor accuracy rates of the İşcan et al. (1984a; 1985) methods for South African blacks, prompting a new technique to be developed for this population. Due to similar features found in the degeneration process of the sternal end of the rib for both South African blacks and African-Americans, a main objective of this research was to determine if there were differences in accuracy between the methods for African-Americans. Based on these observations, it was expected that the Oettlé and Steyn (2000) method would improve the technique's accuracy rates for African-Americans.

Statistical analysis was conducted on the African-American subsample ($n = 209$). All three methods displayed correlations that were strong and highly significant ($p < 0.0001$). Further tests were utilized to determine if there were any statistically significant differences in accuracy between the methods. No statistically significant values were found, indicating that all methods were able to accurately assess age for African-Americans in the sample, although the Hartnett-Fulginiti (2007; 2010) method was determined to be a slightly better predictor of age when compared to the other techniques analyzed ($\hat{\rho} = 0.4737$).

Finally, cross-tabulation tables were also used to give a visual representation of the data. A relatively low accuracy rate for classifying ribs into the correct age phase was found for each method. The Hartnett-Fulginiti (2007; 2010) method displayed the highest accuracy, with 47.9

percent of the sample phased correctly. These results suggest that all three methods can be used on African-Americans, as they all performed equally well as assessing age for this population.

Accuracy Based on Ancestry

An additional research question addressed whether the differences in the rates of accuracy for African-Americans and European-Americans were statistically significant. As previously mentioned, the literature had indicated possible ancestral differences in the rate of aging, prompting new standards for specific populations. Therefore an additional aim of this research was to determine if there were any differences in the rates of accuracy, which would provide a basis for separate rib aging standards for African-Americans and European-Americans.

Statistical analysis was conducted on the African-American subsample (n = 209) and the European-American subsample (n = 202). Comparisons were made in order to determine if there were differences in accuracy between the correlation coefficients obtained for African-Americans and those obtained for European-Americans for each method. No statistically significant differences were found for any method, indicating that if differences in the rate of aging are present, they are not significant enough to impair accuracy rates or require separate standards.

Accuracy Based on Sex

Comparisons between males and females were examined within each method, with no statistically significant differences found between males and females for any method. Correlation coefficients were also compared for males and females between each method. When examining males, no statistically significant values were found, indicating that for males, all methods were able to assess age equally well. When examining females, statistically significant values were found for the Hartnett-Fulginiti (2007; 2010), indicating that for females, the Harnett-Fulginiti (2007; 2010) method was able to assess age more accurately than the other techniques.

Sex was then further divided on the basis of ancestry in order to make additional comparisons within and between all three methods. No statistically significant differences were found between methods for European-American males and African-American females, indicating that all three methods were able to assess age equally well for these groups. It was also found that for African-American males, the İşcan et al. (1984a; 1985) method was able to assess age more accurately than the Oettlé and Steyn (2000) method. Finally, for European-American females it was found that the Hartnett-Fulginiti (2007; 2010) method and the İşcan et al. (1984a; 1985) method were able to assess age more accurately than the Oettlé and Steyn (2000) method.

Inaccuracy and Bias

Rates of inaccuracy and bias were also calculated for multiple categories for each method. Phase inaccuracy, or the average error from the actual phase number without regard to the direction of the error, was determined for all methods (Russell et al., 1993; Martrille et al., 2007). Less than a one phase difference was found for each technique, indicating that all methods can correctly estimate an individual's age within one phase of the actual phase number. Age inaccuracy was also calculated, which determines the average error in terms of age. The Hartnett-Fulginiti (2007; 2010) method and İşcan et al. (1984a; 1985) method showed the least amount of inaccuracy, overestimating age between six and ten years. The Oettlé and Steyn (2000) method displayed the most inaccuracy, overestimating age between seven and fifteen years.

Bias was also calculated for both phase and age differences. All three methods displayed a phase bias for less than one phase difference either above or below the actual phase. For age bias, the Hartnett-Fulginiti (2007; 2010) method displayed the least amount of bias for almost all categories while the Oettlé and Steyn (2000) method displayed the least amount of bias for African-Americans and African-American females.

Intra-observer Error

Finally, intra-observer error rates were calculated for each method on a subsample of 105 individuals. Statistical tests included Spearman's coefficient of rank correlation and Cohen's Kappa measure of agreement. Tests indicated a high level of correlation (r_S = 0.7–0.89) and a moderate level of agreement (κ = 0.4–0.75) for all three methods. These results show that all methods do not suffer from a significant amount of intra-observer error.

Limitations

One limitation of this study was that rates of inter-observer error were not calculated. This limitation can be attributed to the use of multiple collections; therefore, it was not be possible for the same observers to analyze both collections. This also prevented further conclusions addressing the level of experience needed to perform each method. Additionally, although the author had practiced each method extensively, intra-observer error rates may be a more accurate reflection of the author's experience than of the method itself.

An additional limitation comes from the conversion of a phase number to a mean age for the purposes of comparison. This was conducted for both Spearman's rank correlation and for inaccuracy and bias. Although this was conducted in accordance with the literature, it may bring a source of error to this research. This is because a phase method is designed to give an age range in order to include many individuals. Therefore the mean for each phase may significantly under- or over-estimate the age of that individual. To accommodate for this error, comparisons between the estimated and actual phase numbers were also included in the analysis for both the Spearman's coefficient of rank correlation and for the calculation of inaccuracy and bias. This comparison was made between the estimated phase number, as determined by the author's evaluation, and the actual phase number, as determined by the individual's actual age-at-death.

A third limitation of this research was that the three methods have problems of sample bias. When testing a method it is important to make an attempt to match the distribution of the original sample. Unfortunately, this was not possible, as this research utilized the same sample of individuals for the three methods. Therefore some error may have been introduced into the analysis.

Finally, it was a goal to obtain at least 15 individuals for each phase to maintain statistically accuracy. This was not possible based on the material available, therefore many of the younger phases contain less than 15 individuals, while the older and middle-aged phases may contain significantly more. Again, this may bias the results, as more emphasis may be placed on the accuracy of the older phases.

CONCLUSION

The purpose of this research was to evaluate the accuracy of three sternal rib aging techniques: İşcan et al. (1984a; 1985), Hartnett-Fulginiti (2007; 2010), and Oettlé and Steyn (2000), as well as to evaluate any differences in accuracy between methods when applied to African-Americans and European-Americans. The results of this research were expected to support all hypotheses. Particularly important was the hypothesis that there would be statistically significant differences in the accuracy of the aging techniques between African-American and European-American specimens.

The first and second hypotheses of this research addressed the Hartnett-Fulginiti (2007; 2010) method. The first stated that the Hartnett-Fulginiti (2007; 2010) method would more accurately assess age for all individuals. According to Garvin and Passalacqua (2012), the most accepted method for sternal rib aging is the İşcan et al. (1984a; 1985) method. The Hartnett-Fulginiti (2007; 2010) method is a more recent technique developed as a revision in order to improve accuracy rates. It was therefore expected that the Hartnett-Fulginiti (2007; 2010) method would be the most accurate at assessing age for the entire sample. This research supported this hypothesis, as the Hartnett-Fulginiti (2007; 2010) method contained a significantly higher association between the estimated and actual phase numbers compared to the other methods in question.

The second hypothesis also addressed the Hartnett-Fulginiti (2007; 2010) method, specifically if it would more accurately assess age for European-Americans within the sample. It was expected that this method would more accurately assess age for this group, as it was developed on a collection consisting mostly of individuals classified as Caucasian (Hartnett, 2007). Results rejected this hypothesis, with no significant differences in accuracy found between the three methods for European-Americans, although the Hartnett-Fulginiti (2007; 2010) method was determined to be a slightly better predictor of age.

The third hypothesis stated that the Oettlé and Steyn (2000) method would more accurately assess the age of African-Americans within the sample, as this method was designed specifically on South African blacks. Due to similar features that were found in the degeneration process of both South African blacks and African-Americans, it was expected that the Oettlé and Steyn (2000) method would be the most accurate at assessing age for African-Americans in the sample. This hypothesis was rejected, as no significant differences in accuracy were found between the three methods for African-Americans, although the Hartnett-Fulginiti (2007; 2010) method was a slightly better predictor of age.

An additional goal of this research was to determine if there were any differences in accuracy between African-Americans and European-Americans, which was addressed in the third hypothesis. No statistically significant differences were found between the two groups for any method, demonstrating that if differences in the rate of aging are present, they do not appear to be significant enough to impair accuracy rates or require separate standards.

The fourth hypothesis examined differences in accuracy based on sex. Sex-based differences were first examined within each method, with no significant differences found, therefore rejecting this hypothesis. Additional differences in accuracy were examined for males and females between the three methods. For males, no statistically significant differences in accuracy were found, indicating that all three methods can assess age equally well for males. In contrast, for females, the Hartnett-Fulginiti (2007; 2010) method performed the best in comparison to both the İşcan et al. (1984a; 1985) and Oettlé and Steyn (2000) methods.

Sex was further divided on the basis of ancestry for each method in order to address the fifth hypothesis. No statistically significant differences were found between methods for European-American males or African-American females. For African-American males, the İşcan et al. (1984a; 1985) method more accurately assessed age than the Oettlé and Steyn (2000) method. For European-American females, the Hartnett-Fulginiti (2007; 2010) method and the İşcan et al. (1984a; 1985) method were able to assess age equally well and more accurately than the Oettlé and Steyn (2000) method.

Finally, the sixth research hypothesis addressed the rates of intra-observer error, stating that for all methods, the rates would be low. Intra-observer error was calculated for all methods, as well as specifically for the subsamples of African-Americans and European-Americans within each method. All three methods demonstrated strong correlations and moderate agreement, indicating low levels of intra-observer error. Additionally, no differences in the rates of intra-observer error were found between African-Americans and European-Americans for each method.

Although strong correlation coefficients were obtained for all methods, relatively low accuracy rates for classifying ribs into the correct phase were found, with less than half of the sample correctly assigned for each method. Instead, most of the sample was assigned within two phases, which may suggest that the confidence intervals and age ranges for each phase are too narrow. Rib aging techniques have incredibly small age ranges; some phases are as limited as two years (e.g. İşcan et al., 1984a). Therefore it may be useful to either categorize a rib into the two closest phases or expand the age ranges for each phase in order to include more individuals. Additionally, it may be beneficial to revise the rib end aging methods further to either a non-phase system or to a general young, middle, old age classification system.

In order to enhance this study, further research should be conducted on the Hartnett-Fulginiti (2007; 2010) method and the İşcan et al. (1984a; 1985) method using a sample that includes a larger quantity of modern individuals. Tests of inter-observer error, especially for the Hartnett-Fulginiti (2007; 2010) method, should also be conducted, as it was not possible for this research. More research should also be conducted on specific populations, including African-Americans to further test if separate aging standards are necessary. Finally, examining the aging process of the costal cartilage and sternal rib in more depth may also be helpful, as the current sternal rib aging techniques rely purely on segregating ribs into phases based on morphological features seen and ignore the biomechanical processes behind the changes.

To conclude, this research demonstrated that the İşcan et al. (1984a; 1985), Hartnett-Fulginiti (2007; 2010), and Oettlé and Steyn (2000) methods performed well on the samples of both European-Americans and African-Americans. Specifically for African-Americans, the Oettlé and Steyn (2000) method performed similarly to the other three methods and did not significantly improve accuracy rates. Therefore the method, or a variation of it, is not recommended for use within the United States. Additionally, although no significant differences were found between African-Americans and European-Americans for any method, differences in the aging process were noticed between the two ancestral groups during examination. These differences were seen specifically in African-American males, in that they typically retained scalloping patterns and bone quality throughout age compared to their European-American counterparts. These findings indicate that even if differences are present between individuals of African and European ancestry, these differences are do not appear to be significant enough to require the use of separate standards, although further testing should be conducted. This may also suggest that variation within ancestries is just as great as variation between ancestries, which may have prevented these differences from showing significance.

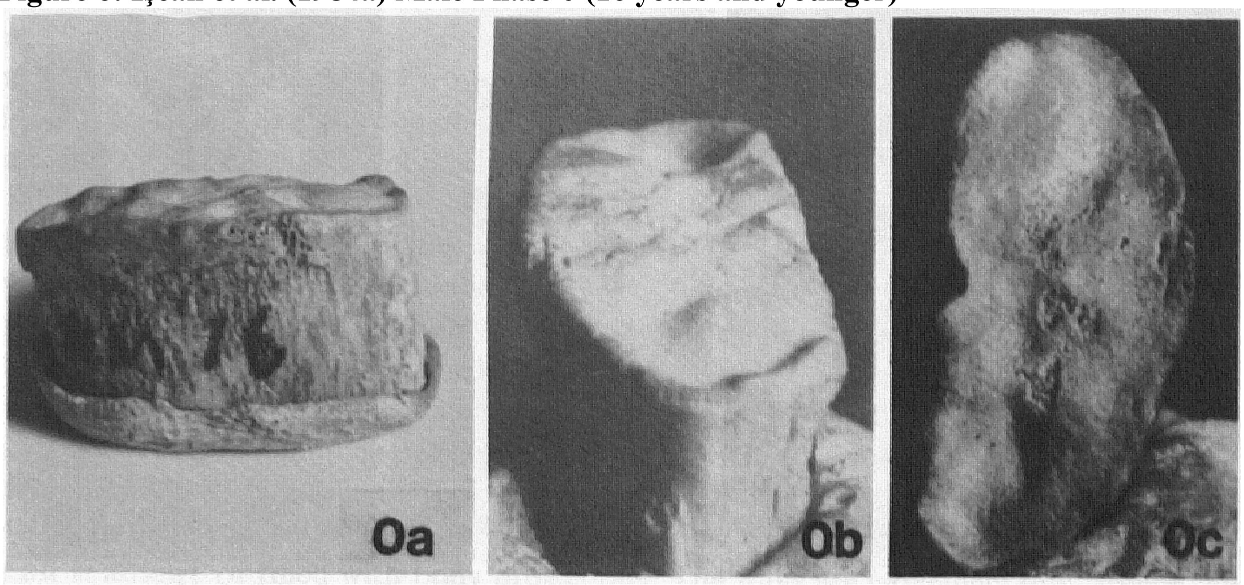
Additionally, the Hartnett-Fulginiti (2007; 2010) method was determined to be a better assessor of age when compared to the İşcan et al. (1984a; 1985) method, which is currently the most accepted method in the field (Garvin and Passalacqua, 2012). For the author, the Hartnett-Fulginiti (2007; 2010) method was easier to apply than the other two methods. And although casts are not available as they are for the İşcan et al. (1984a; 1985) method, they were not needed since this method places more emphasis on bone quality that cannot be demonstrated in a bone cast. During examination there were several instances where the morphological features did not correspond to the texture and quality of the bone, and for all cases, the bone quality was always a more accurate reflection of age. Therefore, it is recommended that bone quality be the most important factor in the determination of age from the sternal end of the rib.

Finally, although accuracy rates were slightly enhanced using the Hartnett-Fulginiti (2007; 2010) method, they were not drastically improved. Therefore, a total replacement of the Hartnett-Fulginiti (2007; 2010) method is unrealistic. Instead it is recommended that when utilizing a rib aging technique, practitioners should decide which method to use based on their own level of experience and preference.

APPENDICES

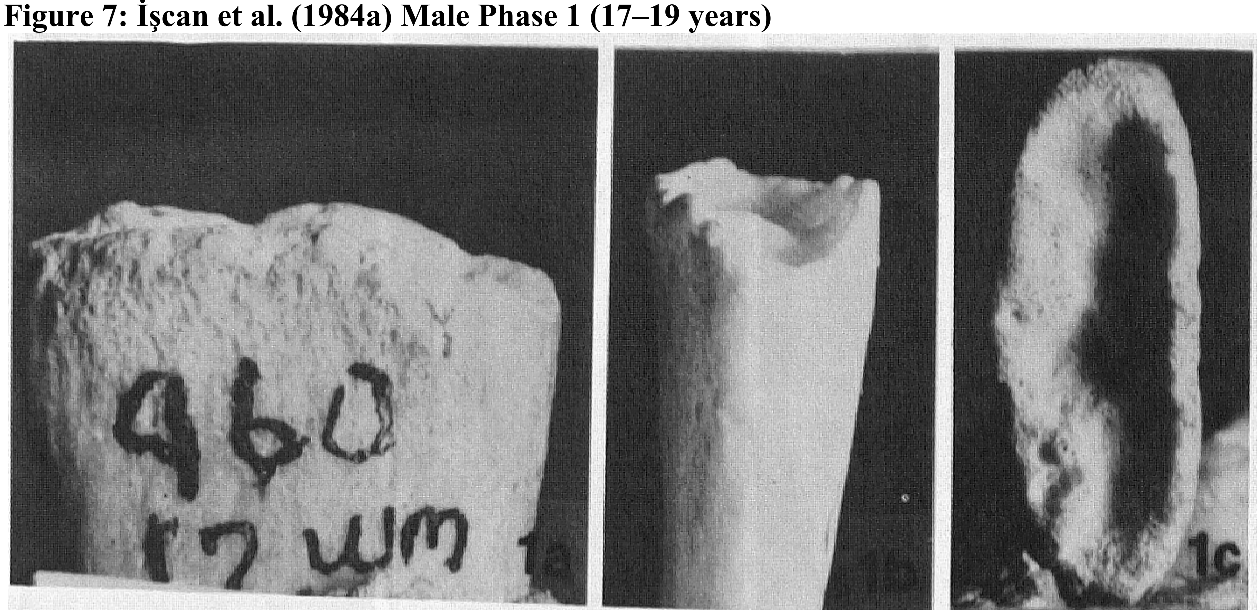
Appendix A: İşcan et al. Male Phase Descriptions and Photographs

Figure 6: İşcan et al. (1984a) Male Phase 0 (16 years and younger)



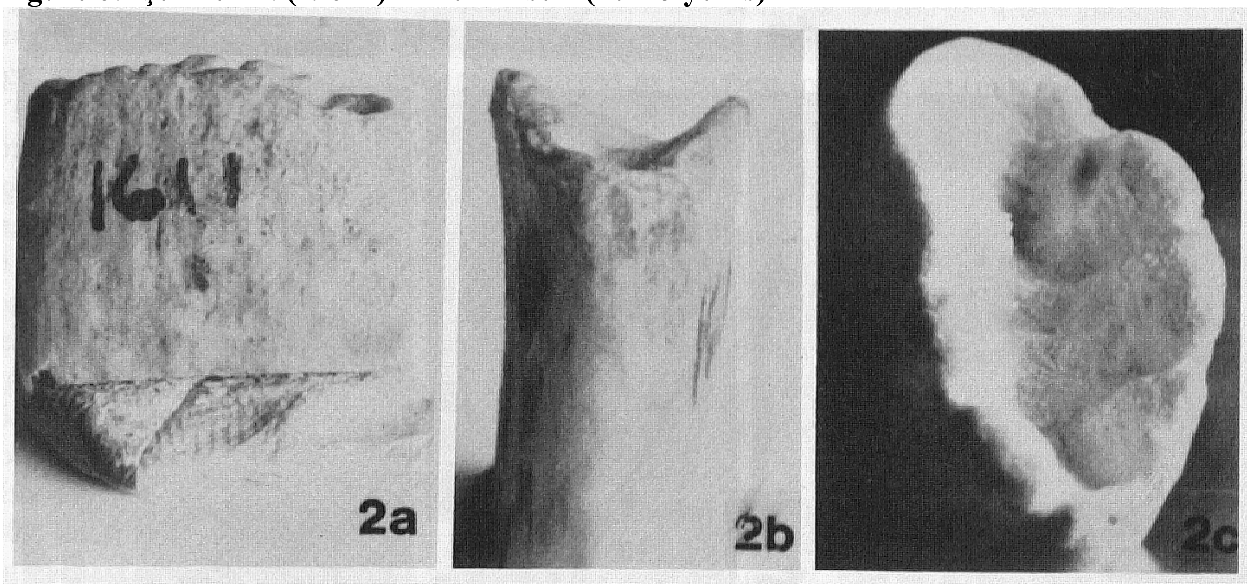
"The articular surface is flat or billowy with a regular rim and rounded edges. The bone itself is smooth, firm, and very solid" (İşcan et al. 1984a:1096).

Figure 7: İşcan et al. (1984a) Male Phase 1 (17–19 years)



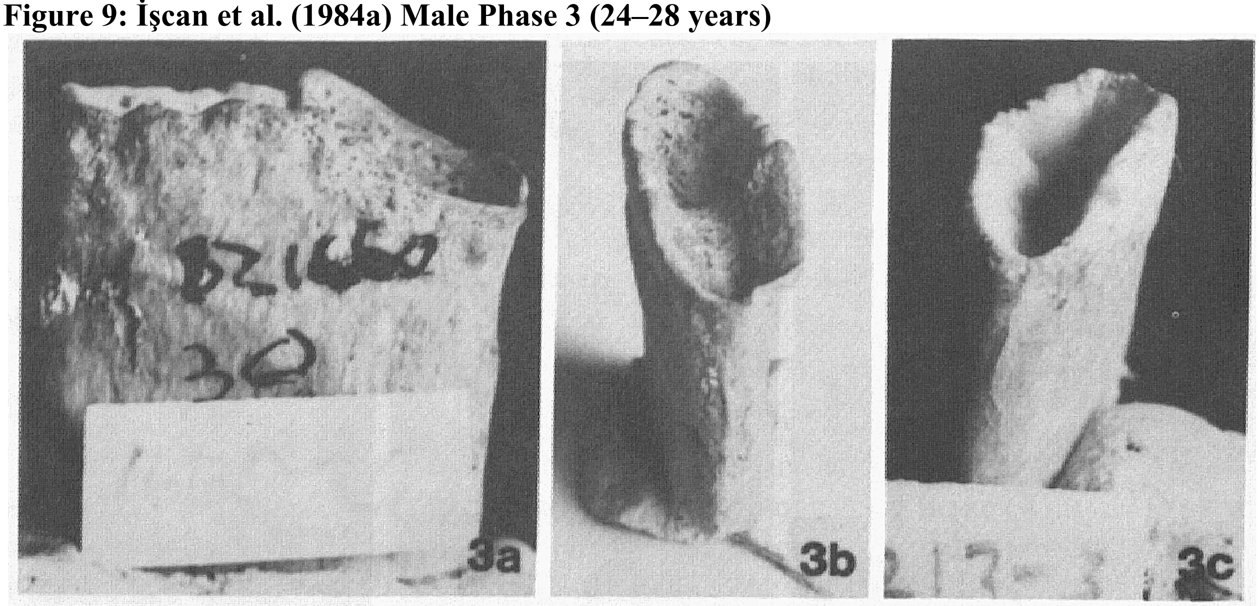
"There is a beginning amorphous indentation in the articular surface, but billowing may also still be present. The rim is rounded and regular. In some cases scallops may start to appear at the edges. The bone still firm, smooth, and solid" (İşcan et al. 1984a:1096).

Figure 8: İşcan et al. (1984a) Male Phase 2 (20–23 years)



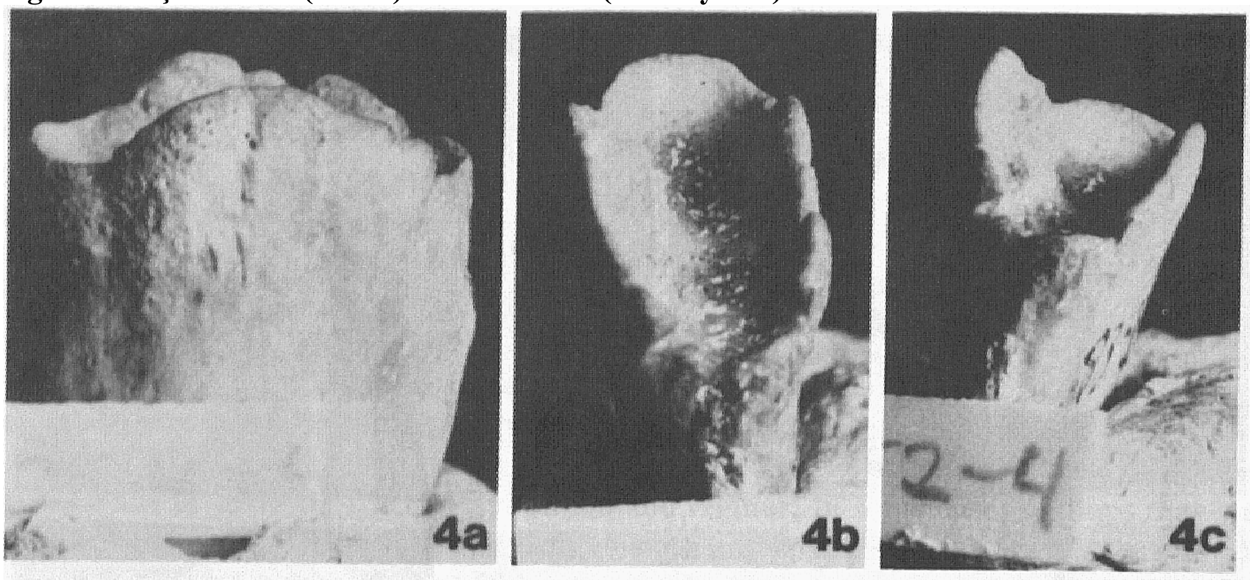
"The pit is now deeper and has assumed a V-shape appearance formed by the anterior and posterior walls. The walls are thick and smooth with a scalloped or slightly wavy rim with rounded edges. The bone is firm and solid" (İşcan et al. 1984a:1096).

Figure 9: İşcan et al. (1984a) Male Phase 3 (24–28 years)



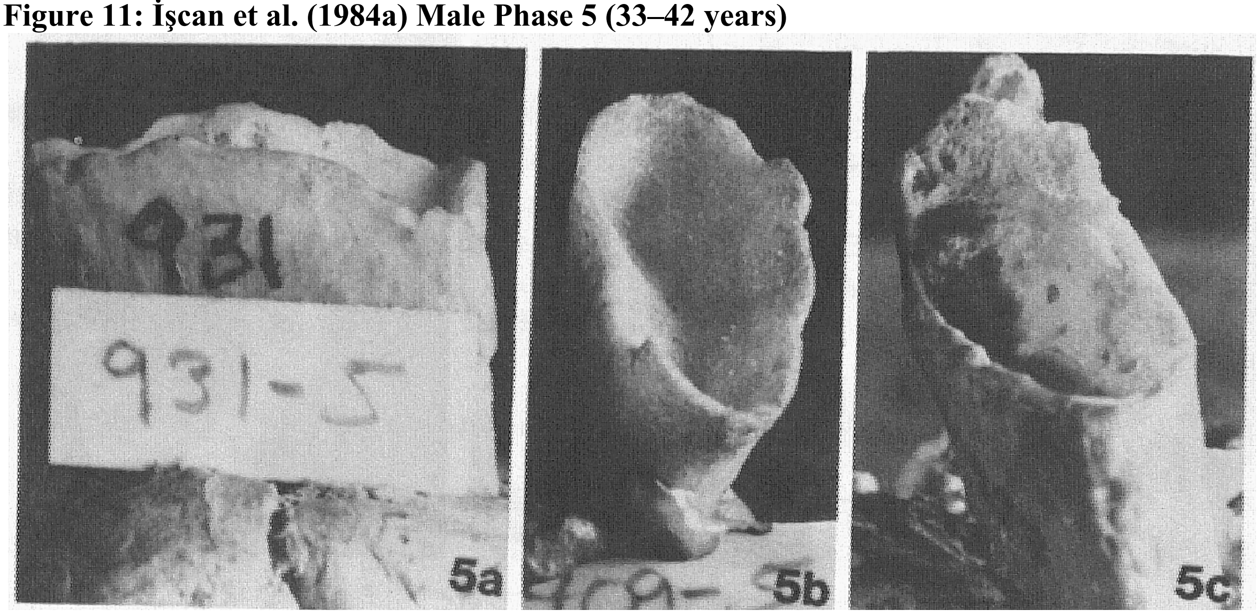
"The deepening pit has taken on a narrow to moderately U-shape. Walls are still fairly thick with rounded edges. Some scalloping may still be present but the rim is becoming more irregular. The bone is still quite firm and solid" (İşcan et al. 1984a:1096).

Figure 10: İşcan et al. (1984a) Male Phase 4 (26–32 years)



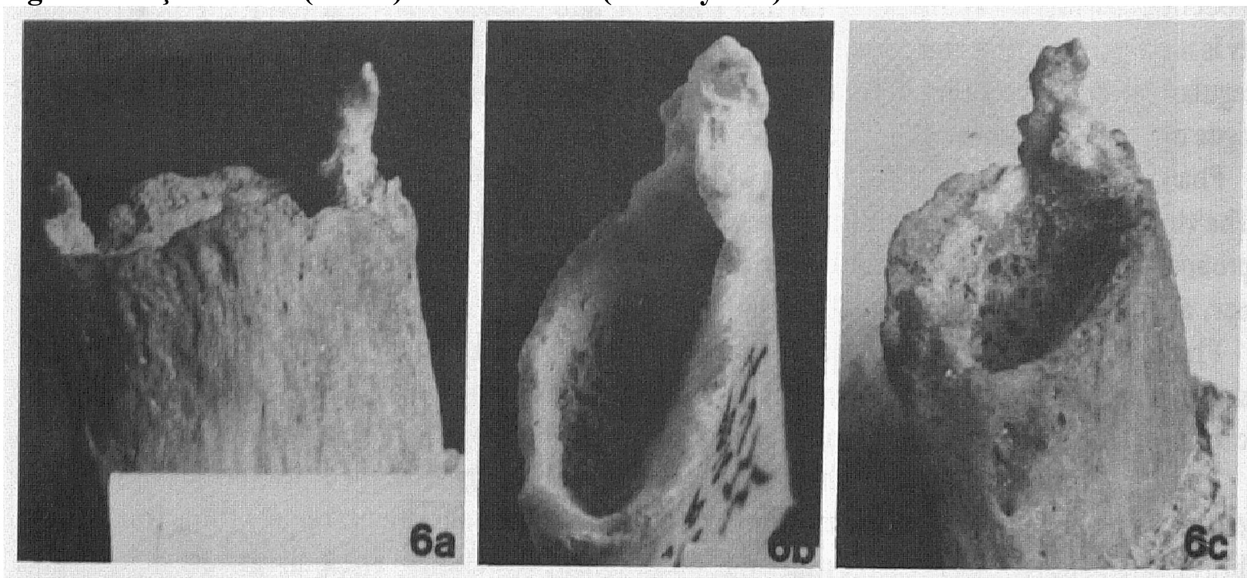
"Pit depth is increasing, but the shape is still a narrow to moderately wide U. The walls are thinner, but the edges remain rounded. The rim is more irregular with no uniform scalloping pattern remaining. There is some decrease in the weight and firmness of the bone, however, the overall quality of the bone is still good" (İşcan et al. 1984a:1096,1099).

Figure 11: İşcan et al. (1984a) Male Phase 5 (33–42 years)



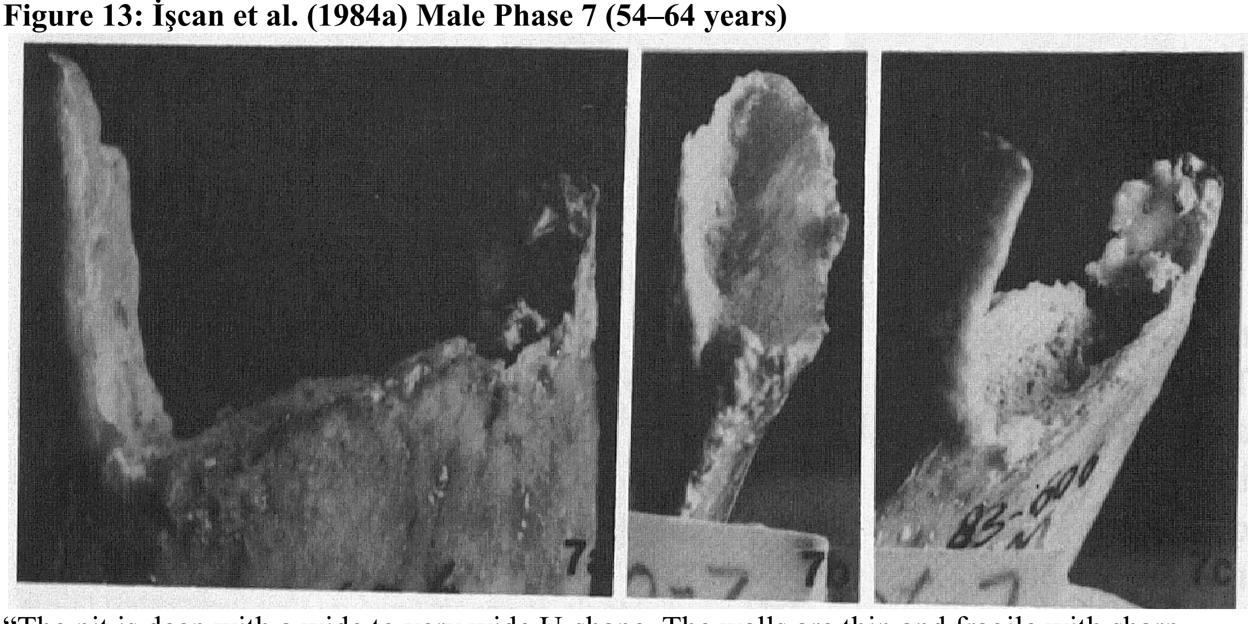
"There is little change in pit depth, but the shape in this phase is predominantly a moderately wide U. Walls show further thinning and the edges are becoming sharp. Irregularity is increasing in the rim. Scalloping pattern is completely gone and has been replaced with irregular bony projections. The condition of the bone is fairly good, however, there are some signs of deterioration with evidence of porosity and loss of density" (İşcan et al. 1984a:1099).

Figure 12: İşcan et al. (1984a) Male Phase 6 (43–55 years)



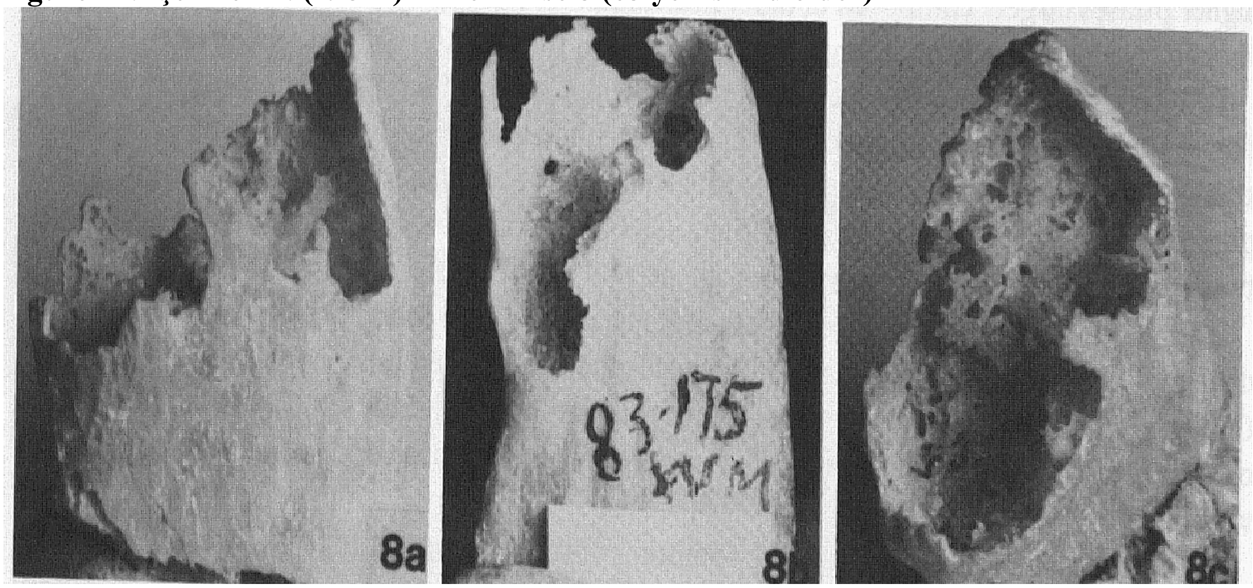
"The pit is noticeably deep with a wide U-shape. The walls are thin with sharp edges. The rim is irregular and exhibits some rather long bony projections that are frequently more pronounced at the superior and inferior borders. The bone is noticeably lighter in weight, thinner, and more porous, especially inside the pit" (İşcan et al. 1984a:1099).

Figure 13: İşcan et al. (1984a) Male Phase 7 (54–64 years)



"The pit is deep with a wide to very wide U-shape. The walls are thin and fragile with sharp, irregular edges and bony projections. The bone is light in weight and brittle with significant deterioration in quality and obvious porosity" (İşcan et al. 1984a:1099).

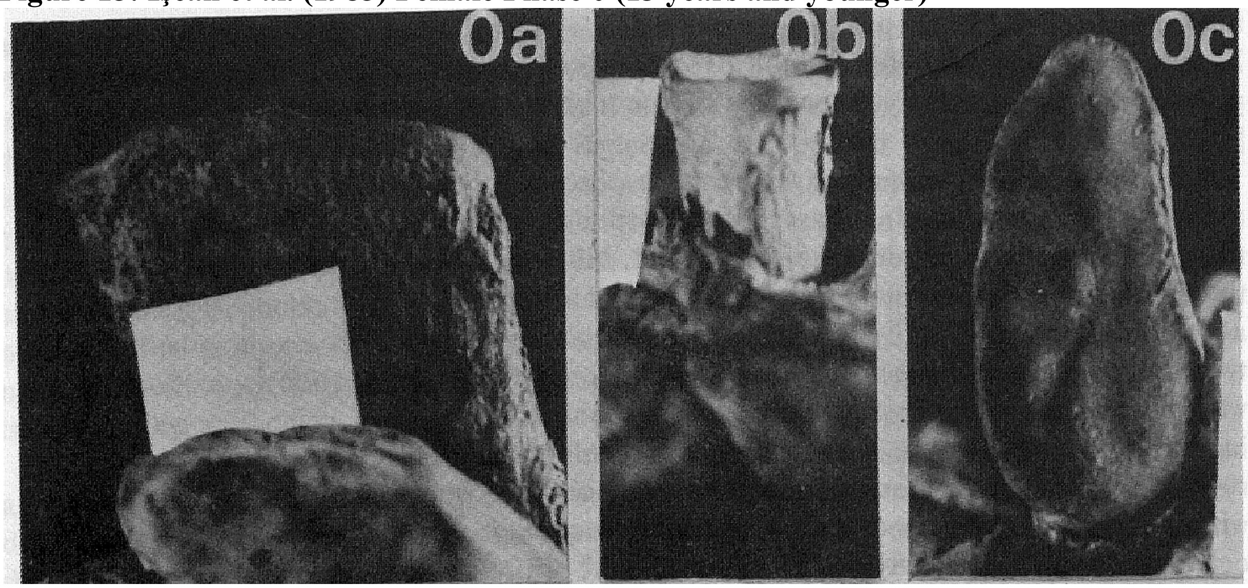
Figure 14: İşcan et al. (1984a) Male Phase 8 (65 years and older)



"In this final phase the pit is very deep and widely U-shaped. In some cases the floor of the pit is absent or filled with bony projections. The walls are extremely thin, fragile, and brittle with sharp, highly irregular edges and bony projections. The bone is very lightweight, thin, brittle, friable, and porous. "Window" formation is sometimes seen in the walls" (İşcan et al. 1984a:1099).

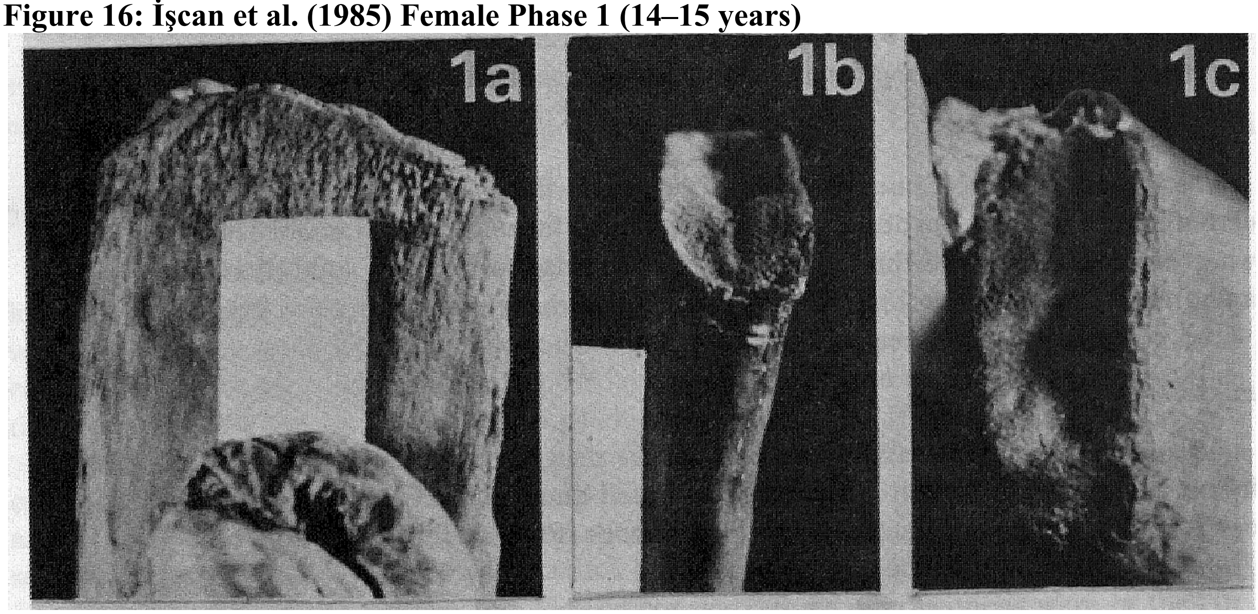
Appendix B: İşcan et al. Female Phase Descriptions and Photographs

Figure 15: İşcan et al. (1985) Female Phase 0 (13 years and younger)



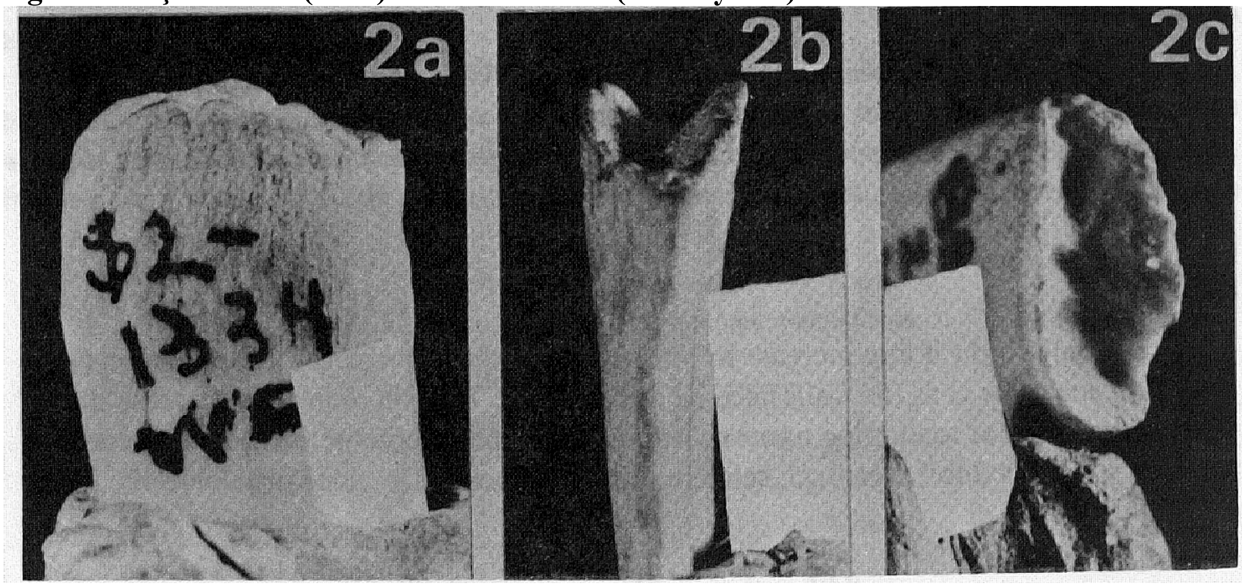
"The articular surface is nearly flat with ridges or billowing. The outer surface of the sternal extremity of the rib is bordered by what appears to be an overlay of bone. The rim is regular with rounded edges, and the bones itself is firm, smooth, and very solid" (İşcan et al. 1985:855).

Figure 16: İşcan et al. (1985) Female Phase 1 (14–15 years)



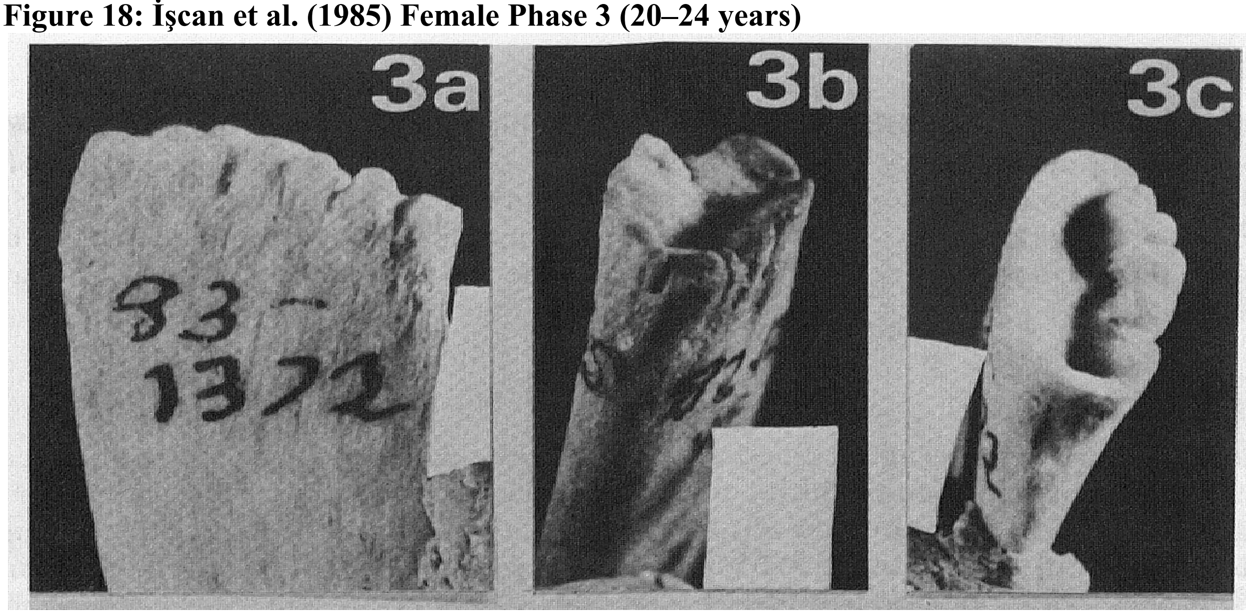
"A beginning, amorphous indentation can be seen in the articular surface. Ridges or billowing may still be present. The rim is rounded and regular with a little waviness in some cases. The bone remains solid, firm, and smooth" (İşcan et al. 1985:855).

Figure 17: İşcan et al. (1985) Female Phase 2 (16–19 years)



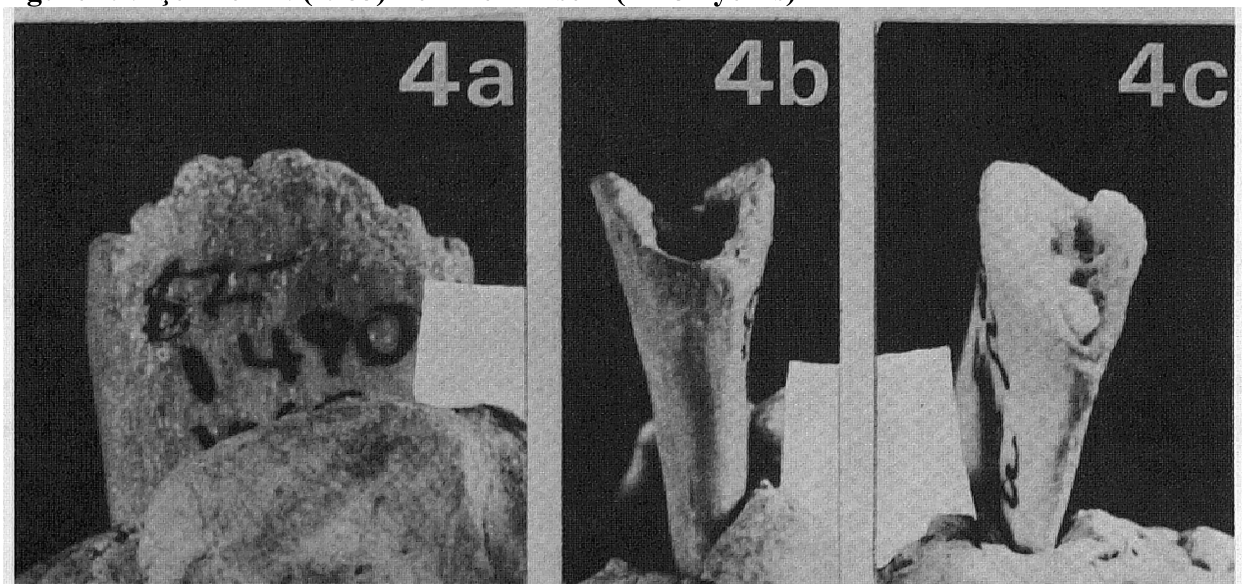
"The pit is considerably deeper and has assumed a V-shape between the thick, smooth anterior and posterior walls, Some ridges or billowing may still remains inside the pit. The rim is wavy with some scallops beginning to form at the rounded edge. The bone itself is firm and solid" (İşcan et al. 1985:855).

Figure 18: İşcan et al. (1985) Female Phase 3 (20–24 years)



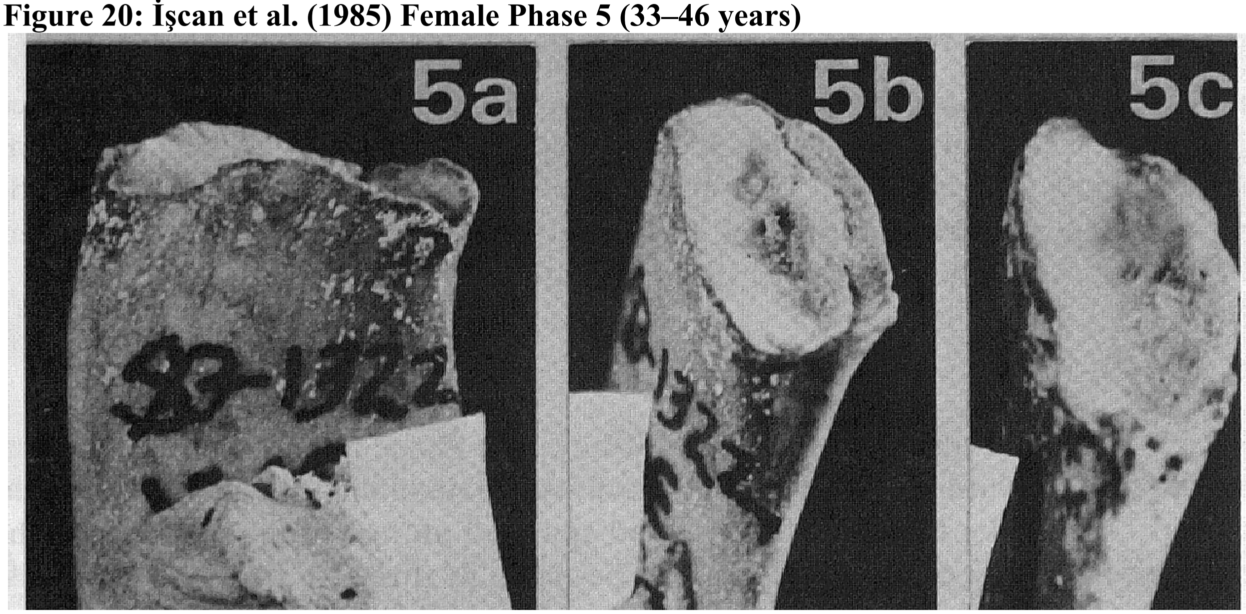
"There is only slight if any increase in pit depth, but the V-shape is wider, sometimes approaching a narrow U as the walls become a bit thinner. The still rounded edges now show a pronounced, regular scalloping pattern. At this stage, the anterior or posterior walls or both may first start to exhibit a central, semicircular arc of bone. The rim is firm and solid" (İşcan et al. 1985:855).

Figure 19: İşcan et al. (1985) Female Phase 4 (24–32 years)



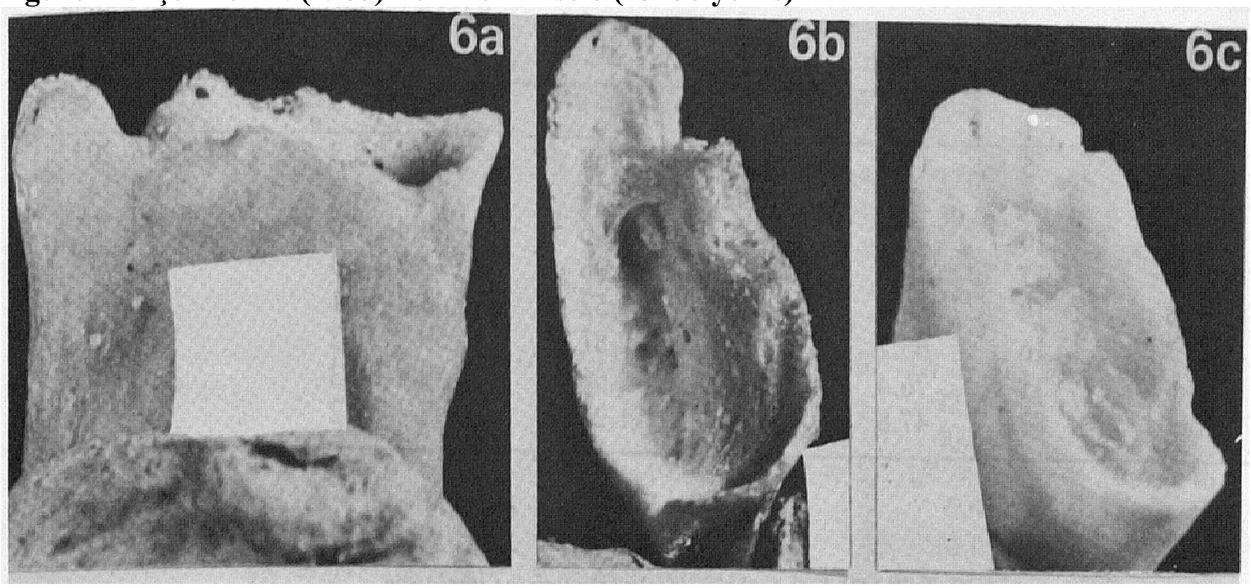
"There is a noticeable increase in the depth of the pit, which now has a wide V- or narrow U-shape with, at time, flared edges. The walls are thinner but the rim remains rounded. Some scalloping is still present, along with the central arc; however, the scallops are not as well defined and the edges look somewhat worn down. The quality of the bone is fairly good but there is some decrease in density and firmness" (İşcan et al. 1985:855).

Figure 20: İşcan et al. (1985) Female Phase 5 (33–46 years)



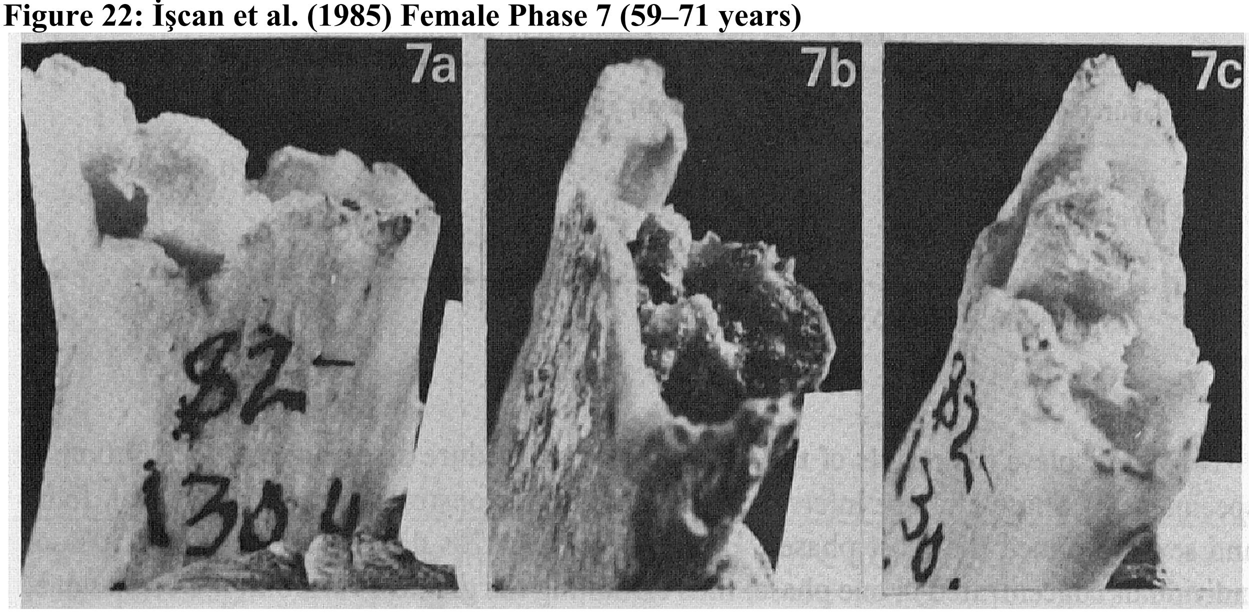
"The depth of the pit stays about the same, but the thinning walls are flaring into a wider V- or U-shape. In most cases, a smooth, hard, plaque-like deposit lines at least part of the pit. No regular scalloping remains and the edge is beginning to sharpen. The rim is becoming more irregular, but the central arc is still the most prominent projection. The bone is noticeably lighter in weight, density and firmness. The texture is somewhat brittle" (İşcan et al. 1985:858).

Figure 21: İşcan et al. (1985) Female Phase 6 (43–58 years)



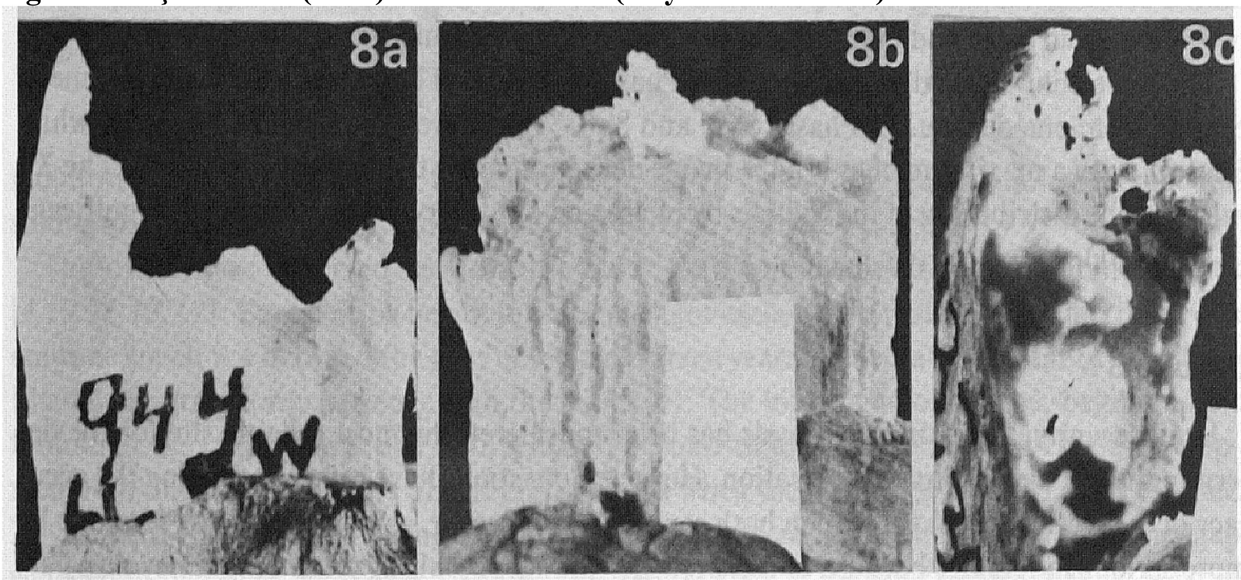
"An increase in pith depth is again noted, and its V- or U-shape has widened again because of pronounced flaring at the end. The plaque-like deposit may still appear but is rougher and more porous. The walls are quite thin with sharp edges and an irregular rim. The central arc is less obvious and, in many cases, sharp points project from the rim of the sternal extremity. The bone itself is fairly thin and brittle with some signs of deterioration" (İşcan et al. 1985:858).

Figure 22: İşcan et al. (1985) Female Phase 7 (59–71 years)



"The depth of the predominantly flared U-shaped pit not only shows no increase, but actually decreases slightly. Irregular bony growths are often seen extruding from the interior of the pit. The central arc is still present in most cases but is now accompanied by pointed projections, often at the superior and inferior borders, yet may be evidenced anywhere around the rim. The very thin walls have irregular rims with sharp edges. The bone is very light, thin, brittle, and fragile, with deterioration inside the pit" (İşcan et al. 1985:858).

Figure 23: İşcan et al. (1985) Female Phase 8 (70 years and older)

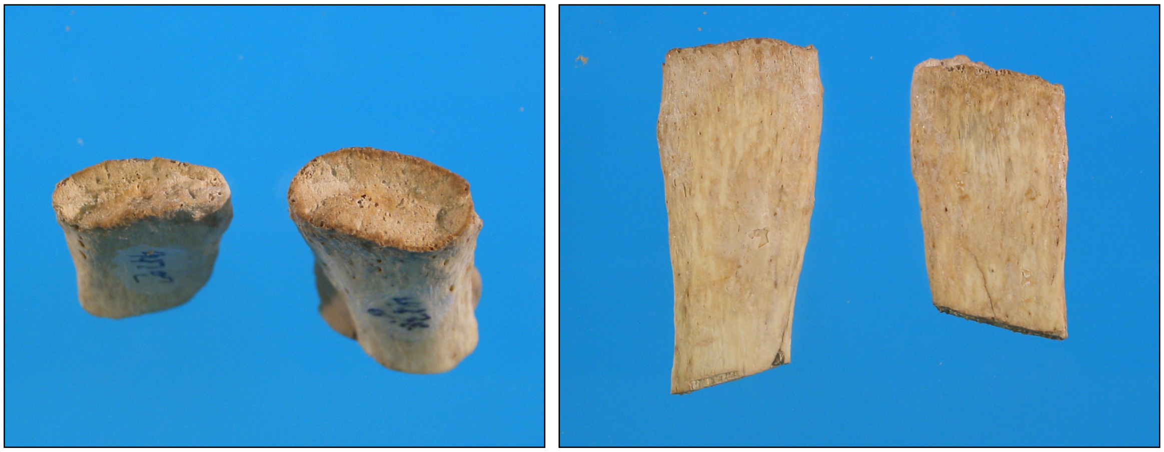


"The floor of the U-shaped pit in this final phase is relatively shallow, badly deteriorated, or completely eroded. Sometimes it is filled with bony growths. The central arc is barely recognizable. The extremely thin, fragile walls have highly irregular rims with very sharp edges, and often fairly long projections of bone at the inferior and superior borders. "Window" formation sometimes occurs in the walls. The bone itself is in poor condition – extremely thin, light in weight, brittle, and fragile" (İşcan et al. 1985:858).

Appendix C: Hartnett-Fulginiti Male Phase Descriptions and Photographs

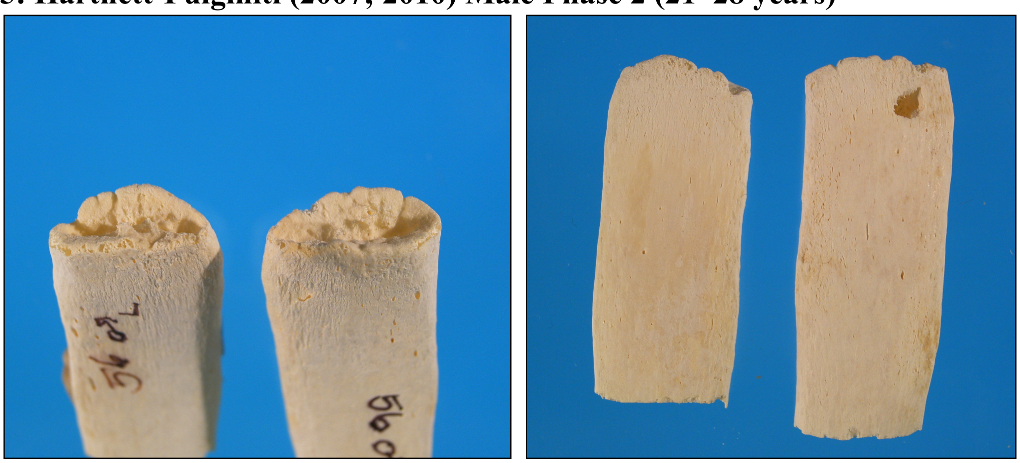
"Bone quality is a major determining factor in placing each specimen in a group. An individual may be moved up or down phases based solely on bone quality" (Hartnett, 2007:373).

Figure 24: Hartnett-Fulginiti (2007; 2010) Male Phase 1 (18–22 years)



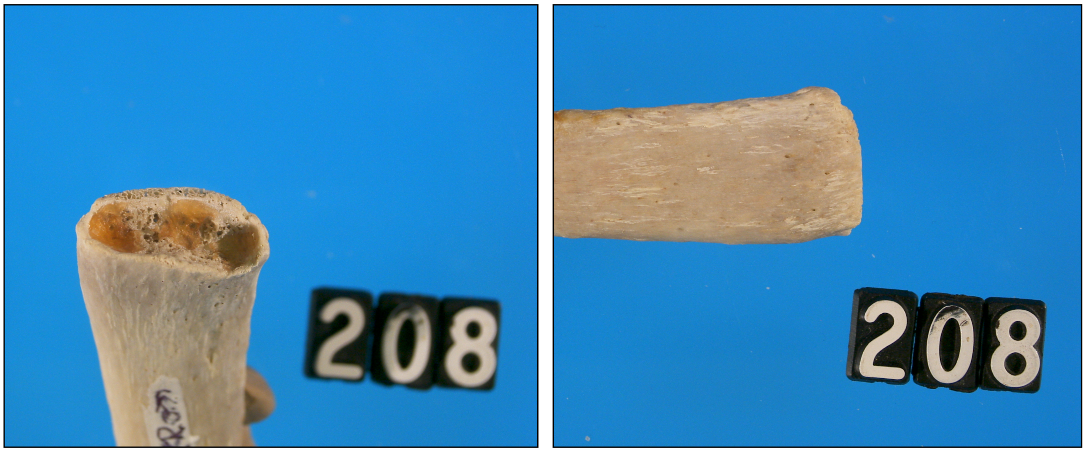
"The pit is shallow and flat, and there are billows in the pit. The pit is shallow U-shaped in cross-section. The bone is very firm and solid, smooth to the touch, dense, and of good quality. The walls of the rim are thick. The rim may show the beginnings of scalloping" (Hartnett, 2010:1156). For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

Figure 25: Hartnett-Fulginiti (2007; 2010) Male Phase 2 (21–28 years)



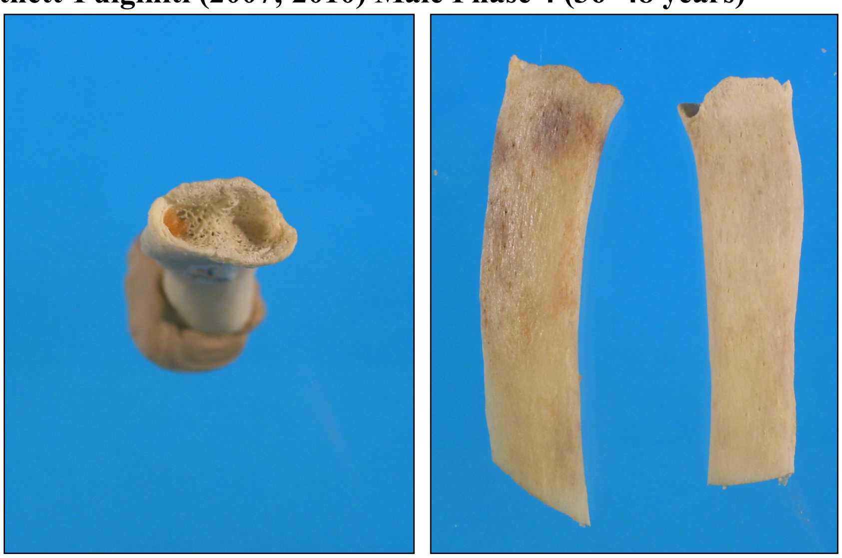
"There is an indentation to the pit. The pit is V-shaped in cross-section, and the rim is well defined with round edges. The rim is regular with some scalloping. The bone is firm and solid, smooth to the touch, dense, and of good quality. There is no flare to the rim edges; they are parallel to each other. The pit is still smooth inside, with little to no porosity" (Hartnett, 2010:1156).

Figure 26: Hartnett-Fulginiti (2007; 2010) Male Phase 3 (27–37 years)



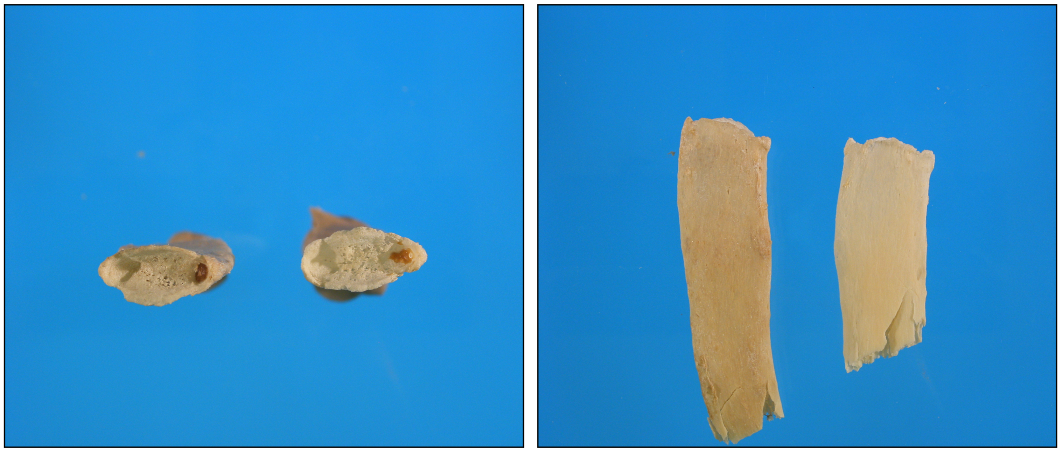
"The pit is V-shaped, and there is a slight flare to the rim edges. The rim edges are becoming undulating and slightly irregular, and there may be remnants of scallops, but they look worn down. There are no bony projections from the rim. There is porosity inside the pit. The bone quality is good; it is firm, solid, and smooth to the touch. The rim edges are rounded, but sharp" (Hartnett, 2010:1156).

Figure 27: Hartnett-Fulginiti (2007; 2010) Male Phase 4 (36–48 years)



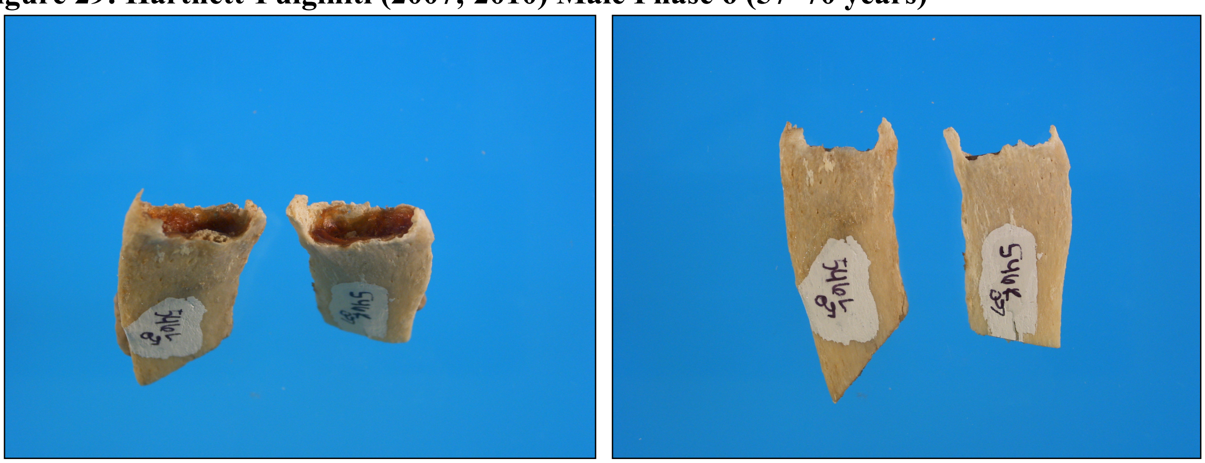
"The pit is deep and U-shaped. The edges of the pit flare outwards, expanding the oval area inside the pit. The rim edges are not undulating or scalloped but are irregular. There are no long bony projections from the rim, and the rim edges are thin, but firm. The bone quality is good but does not feel dense or heavy. There is porosity inside the pit. In some males, two distinct depressions are visible in the pit" (Hartnett, 2010:1156).

Figure 28: Hartnett-Fulginiti (2007; 2010) Male Phase 5 (45–59 years)



“There are frequently small bony projections along the rim edges, especially at the superior and inferior edges of the rim. The pit is deep and U-shaped. The rim edges are irregular, flared, sharp, and thin. There is porosity inside the pit. The bone quality is fair; the bone is coarse to the touch and feels lighter than it looks” (Hartnett, 2010:1156).

Figure 29: Hartnett-Fulginiti (2007; 2010) Male Phase 6 (57–70 years)

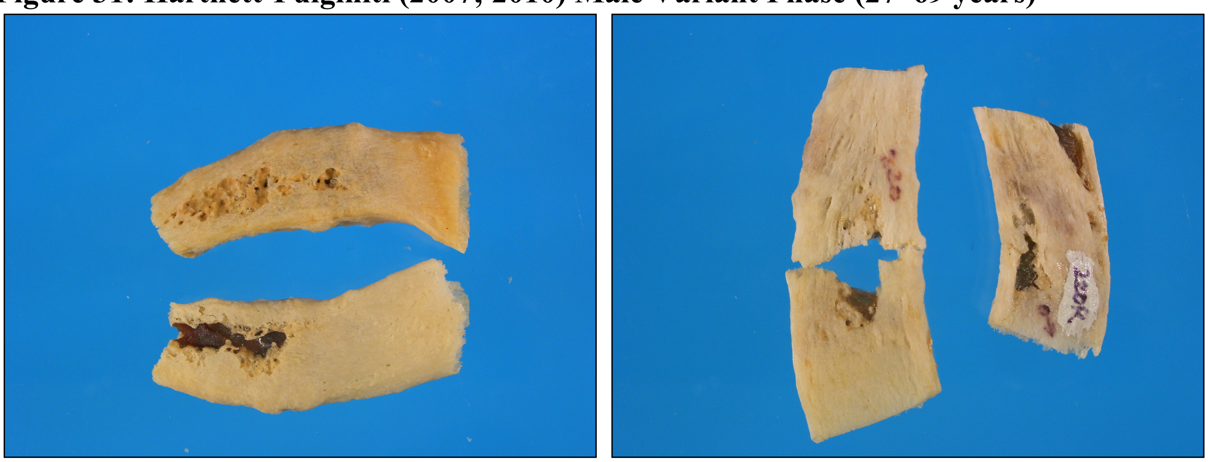


“The bone quality is fair to poor, light in weight, and the surfaces of the bone feel coarse and brittle. There are bony projections along the rim edges, especially at the superior and inferior edges, some of which may be over 1 cm long. The pit is deep and U-shaped. The rim is very irregular, thin, and fragile. There is porosity inside the pit. In some cases, there may be small bony extrusions inside the pit” (Hartnett, 2010:1156).

Figure 30: Hartnett-Fulginiti (2007; 2010) Male Phase 7 (70–97 years)

"The bone is very poor quality, and in many cases, translucent. The bone is very light, sometimes feeling like paper, and feels coarse and brittle to the touch. The pit is deep and U-shaped. There may be long bony growths inside the pit. The rim is very irregular with long bony projections. In some cases, much of the cartilage has ossified and window formation occurs" (Hartnett, 2010:1156).

Figure 31: Hartnett-Fulginiti (2007; 2010) Male Variant Phase (27–69 years)



"In some males, the cartilage has completely or almost completely ossified. The ossification tends to be a solid extension of bone, rather than a thin projection. All of the bone is of very good quality, including the ossification. It is dense, heavy, and smooth. In these instances, bone quality should be the determining factor. There are probably other factors, such as disease, trauma, or substance abuse that caused premature ossification of the cartilage. When the individual is truly very old, the bone quality will be very poor. Be aware of these instances where a rib end may appear very old because of ossification of the cartilage but is really actually a young individual, which can be ascertained by bone quality. In these cases, consult other age indicators in conjunction with the rib end" (Hartnett, 2010:1156).

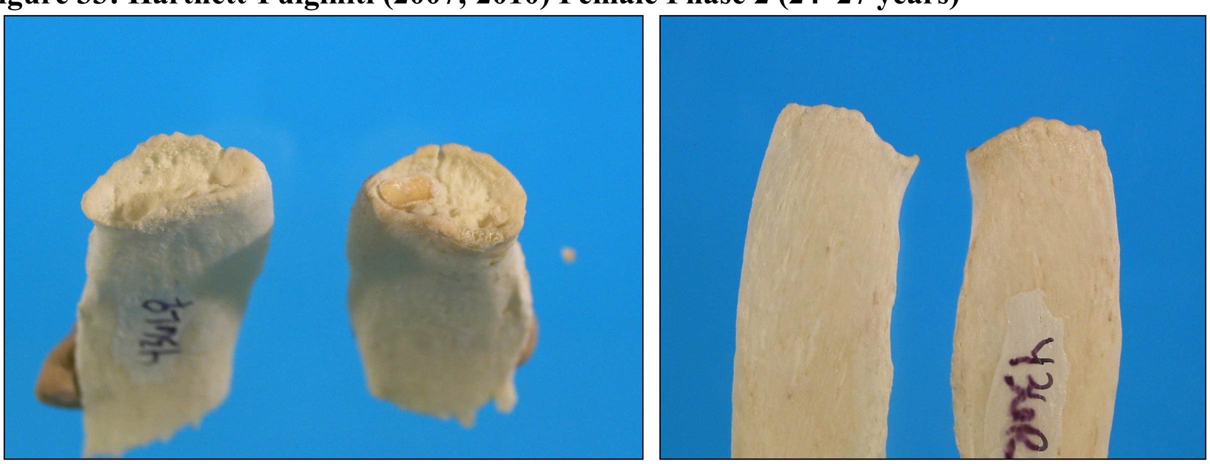
Appendix D: Hartnett-Fulginiti Female Phase Descriptions and Photographs

"Bone quality is a major determining factor in placing each specimen in a group. An individual may be moved up or down phases based solely on bone quality" (Hartnett, 2007:373).

Figure 32: Hartnett-Fulginiti (2007; 2010) Female Phase 1 (18–22 years)

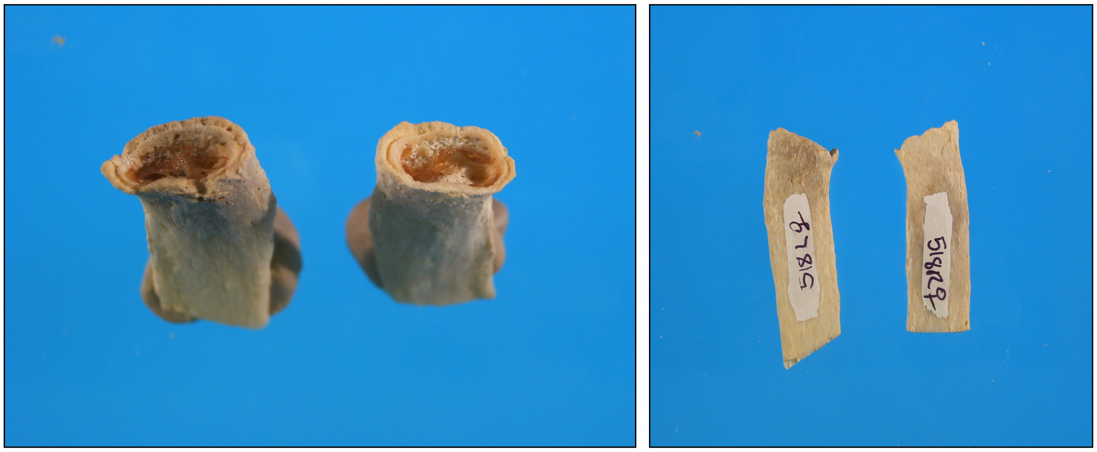
"The pit is shallow and flat, and there are billows in the pit. The pit is shallow U-shaped in cross-section. The bone is very firm and solid, smooth to the touch, dense, and of good quality. The walls of the rim are thick. The rim may show the beginnings of scalloping" (Hartnett, 2010:1156).

Figure 33: Hartnett-Fulginiti (2007; 2010) Female Phase 2 (24–27 years)



"There is an indentation to the pit. The pit is V-shaped in cross-section, and the rim is well defined with round edges. The rim is regular with some scalloping. The bone is firm and solid, smooth to the touch, dense, and of good quality. There is no flare to the rim edges; they are parallel to each other. The pit is still smooth inside, with little to no porosity. In females, the central arc, which manifests on the anterior and posterior walls as a semicircular curve, is visible" (Hartnett, 2010:1156).

Figure 34: Hartnett-Fulginiti (2007; 2010) Female Phase 3 (27–38 years)

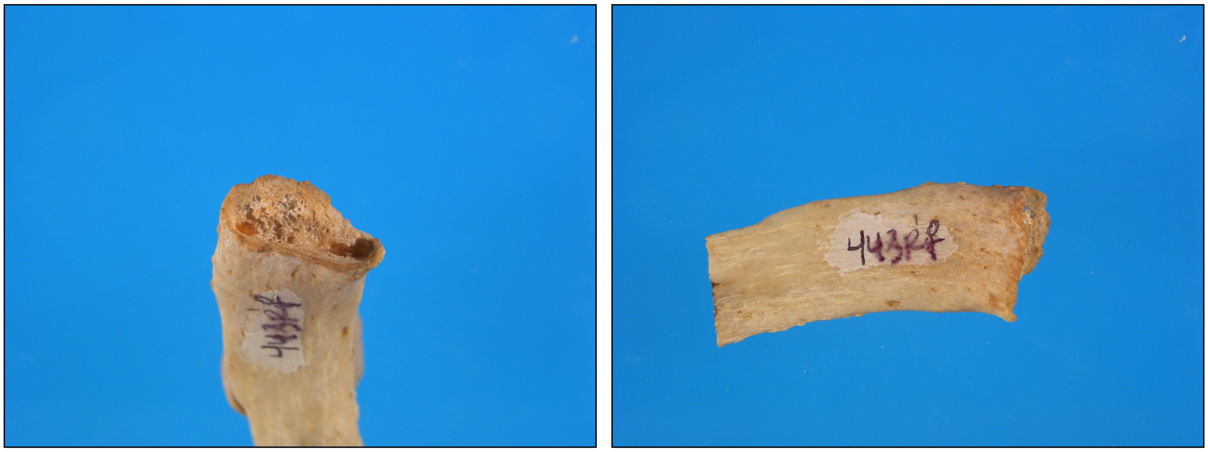


“The pit is V-shaped, and there is a slight flare to the rim edges. The rim edges are becoming undulating and slightly irregular, and there may be remnants of scallops, but they look worn down. There are no bony projections from the rim. There is porosity inside the pit. The bone quality is good; it is firm, solid, and smooth to the touch. The rim edges are rounded, but sharp. In many females, there is a build-up of bony plaque, either in the bottom of the pit or lining the interior of the pit, creating the appearance of a two-layer rim. An irregular central arc may be apparent” (Hartnett, 2010:1156).

Figure 35: Hartnett-Fulginiti (2007; 2010) Female Phase 4 (39–49 years)

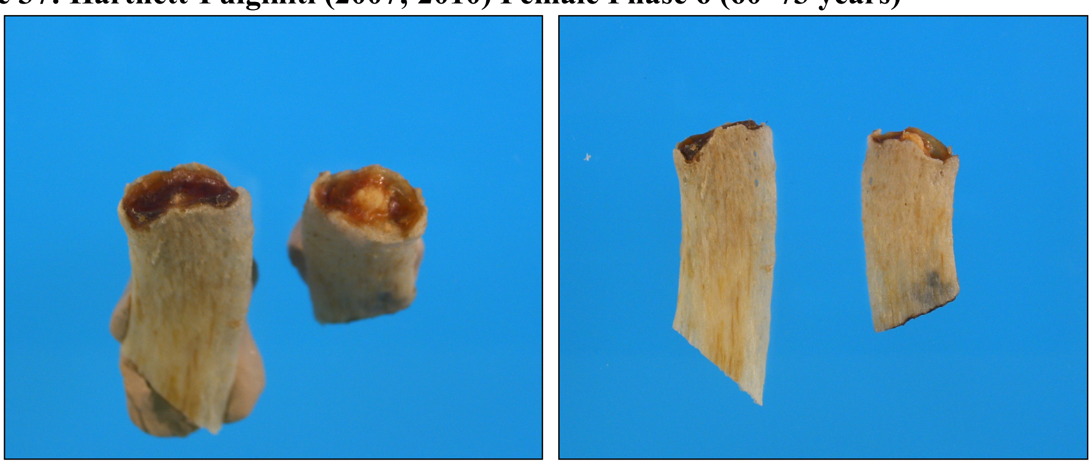
“The pit is deep and U-shaped. The edges of the pit flare outwards, expanding the oval area inside the pit. The rim edges are not undulating or scalloped but are irregular. There are no long bony projections from the rim, and the rim edges are thin, but firm. The bone quality is good but does not feel dense or heavy. There is porosity inside the pit… In females, the central arc may be present and irregular; however, the superior and inferior edges of the rim have developed, decreasing the prominence of the central arc” (Hartnett, 2010:1156).

Figure 36: Hartnett-Fulginiti (2007; 2010) Female Phase 5 (47–58 years)



"There are frequently small bony projections along the rim edges, especially at the superior and inferior edges of the rim. The pit is deep and U-shaped. The rim edges are irregular, flared, sharp, and thin. There is porosity inside the pit. The bone quality is fair; the bone is coarse to the touch and feels lighter than it looks" (Hartnett, 2010:1156).

Figure 37: Hartnett-Fulginiti (2007; 2010) Female Phase 6 (60–73 years)



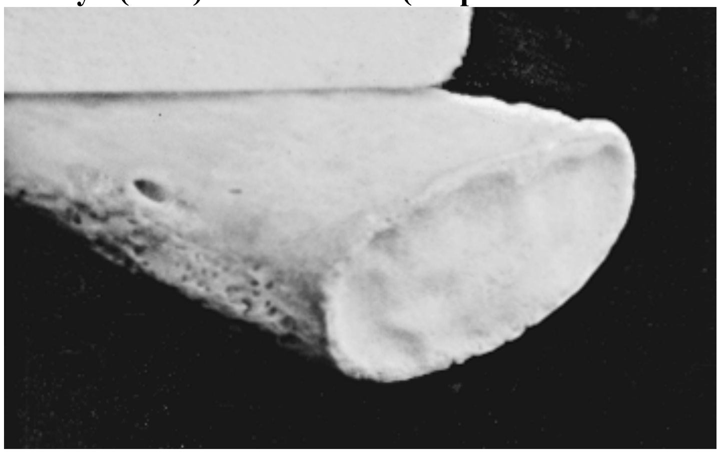
"The bone quality is fair to poor, light in weight, and the surfaces of the bone feel coarse and brittle. There are bony projections along the rim edges, especially at the superior and inferior edges, some of which may be over 1 cm long. The pit is deep and U-shaped. The rim is very irregular, thin, and fragile. There is porosity inside the pit. In some cases, there may be small bony extrusions inside the pit. In females, the central arc is not prominent" (Hartnett, 2010:1156).

Figure 38: Hartnett-Fulginiti (2007; 2010) Female Phase 7 (65–99 years)

"The bone is very poor quality, and in many cases, translucent. The bone is very light, sometimes feeling like paper, and feels coarse and brittle to the touch. The pit is deep and U-shaped. There may be long bony growths inside the pit. The rim is very irregular with long bony projections. In some cases, much of the cartilage has ossified and window formation occurs. In some females, much of the cartilage in the interior of the pit has ossified into a bony projection extending more than 1 cm in length" (Hartnett, 2010:1156).

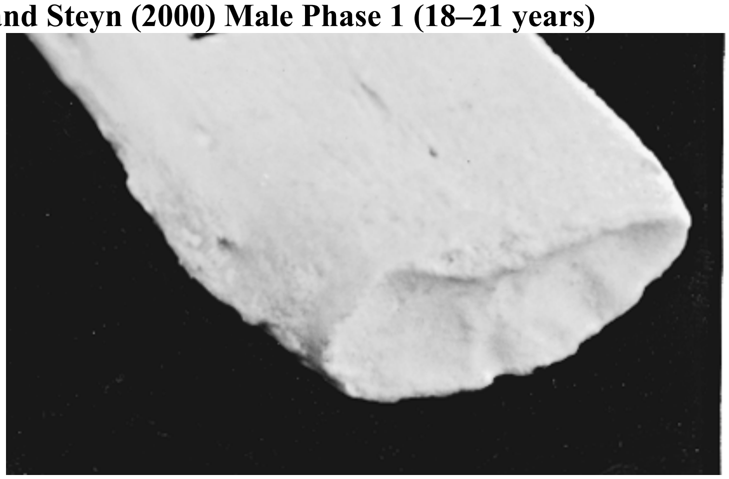
Appendix E: Oettlé and Steyn Male Phase Descriptions and Photographs

Figure 39: Oettlé and Steyn (2000) Male Phase 0 (Prephase seen in children)



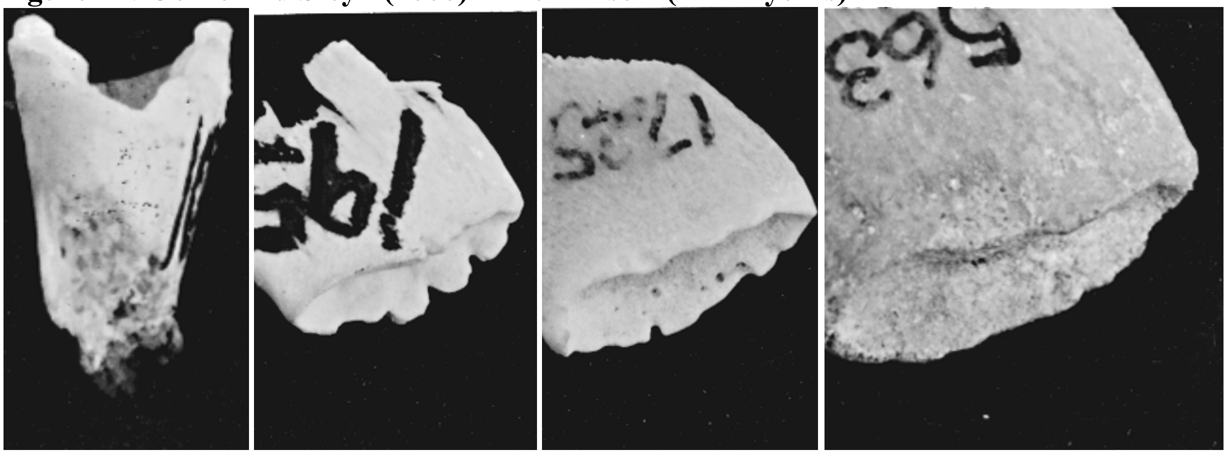
"The articular surface is flat or billowy with a regular rim and rounded edges. The bone itself is smooth, firm, and very solid, with an epiphyseal ring" (Oettlé and Steyn 2000:1073).

Figure 40: Oettlé and Steyn (2000) Male Phase 1 (18–21 years)



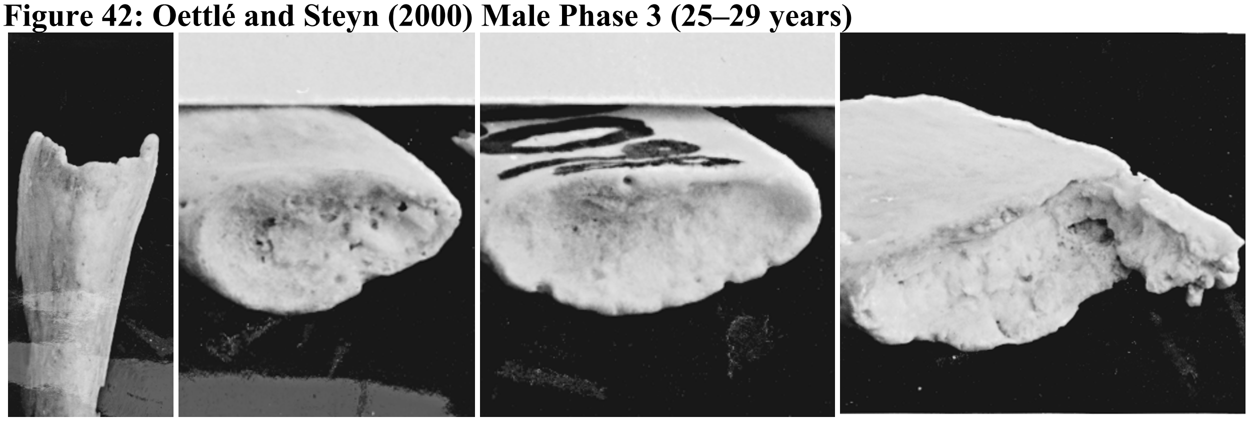
"An amorphous indentation in the articular surface is beginning. Parts of the pit can show more advanced features than the rest. The rim is rounded and regular. In some cases scallops may start to appear at the edges" (Oettlé and Steyn 2000:1073).

Figure 41: Oettlé and Steyn (2000) Male Phase 2 (22–24 years)



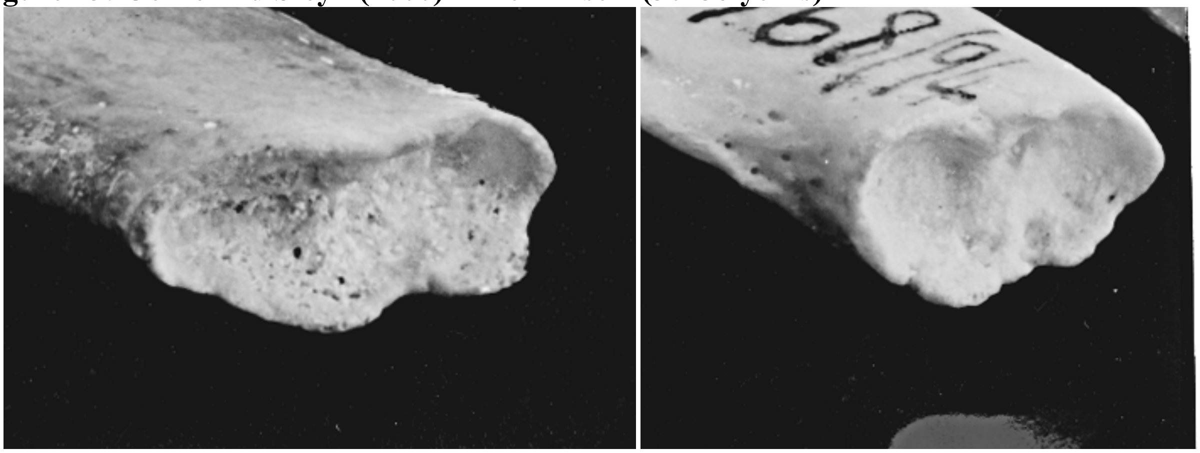
"The pit is deeper and has a V-shaped appearance formed by the anterior and posterior walls. The walls are thick and smooth and can exhibit a scalloped or slightly wavy rim with rounded edges. The scalloping features may be pointed, squared off, or flattened, or may be regular and receding" (Oettlé and Steyn 2000:1073).

Figure 42: Oettlé and Steyn (2000) Male Phase 3 (25–29 years)



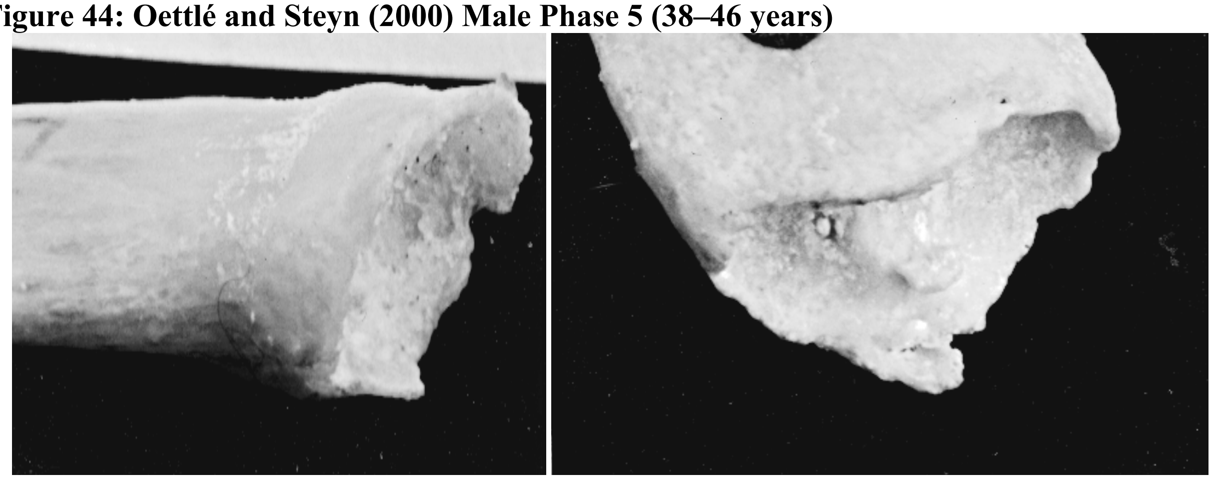
"The deepening pit has taken on a narrow to moderately U-shape. Walls are still fairly thick with rounded edges. The rim may be unscalloped, smooth, and regular, or may manifest some scalloping which are becoming more irregular. Bony projections from the rim and, occasionally, a plaque-like deposit from the interior of the pit may already be seen" (Oettlé and Steyn 2000:1073).

Figure 43: Oettlé and Steyn (2000) Male Phase 4 (30–37 years)



"Pit depth is increasing. The walls are thinner, but the edges remain rounded. The rim is more irregular with no uniform scalloping pattern remaining. There is some decrease in the weight and firmness of the bone; however, the overall quality of the bone is still good" (Oettlé and Steyn 2000:1073).

Figure 44: Oettlé and Steyn (2000) Male Phase 5 (38–46 years)

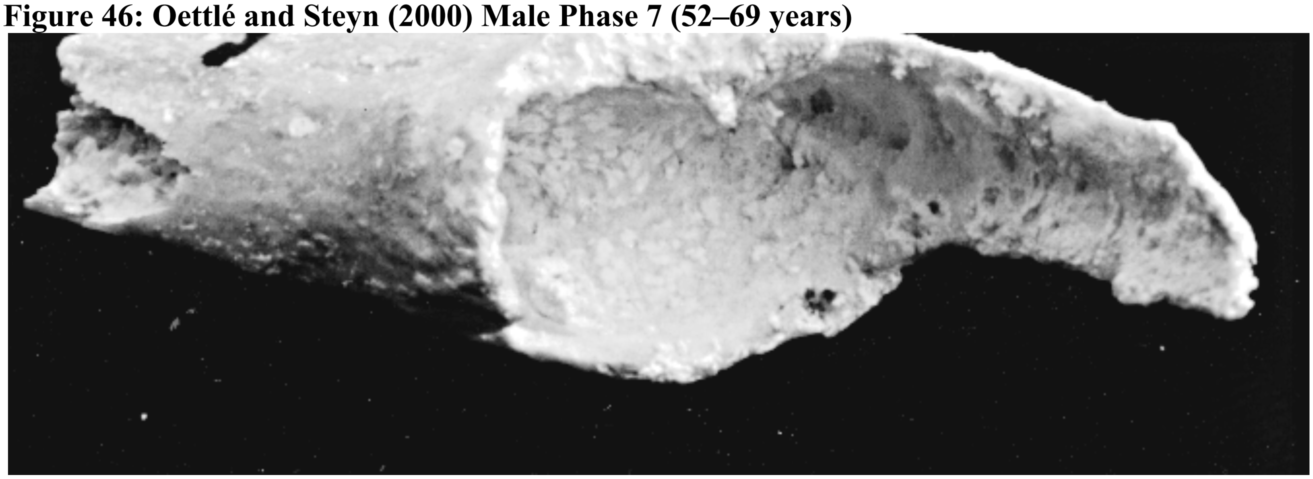


"The pit is predominantly a moderately wide U-shape. Walls show further thinning and the edges are becoming sharp. The scalloping pattern disappears and the rim is irregular with bony projections, or has a flattened and pointy appearance. The condition of the bone is fairly good, although there are some signs of deterioration with evidence of porosity and loss of density. Small bony growths from the pit interior are sometimes present" (Oettlé and Steyn 2000:1073,1075).

Figure 45: Oettlé and Steyn (2000) Male Phase 6 (47–55 years)

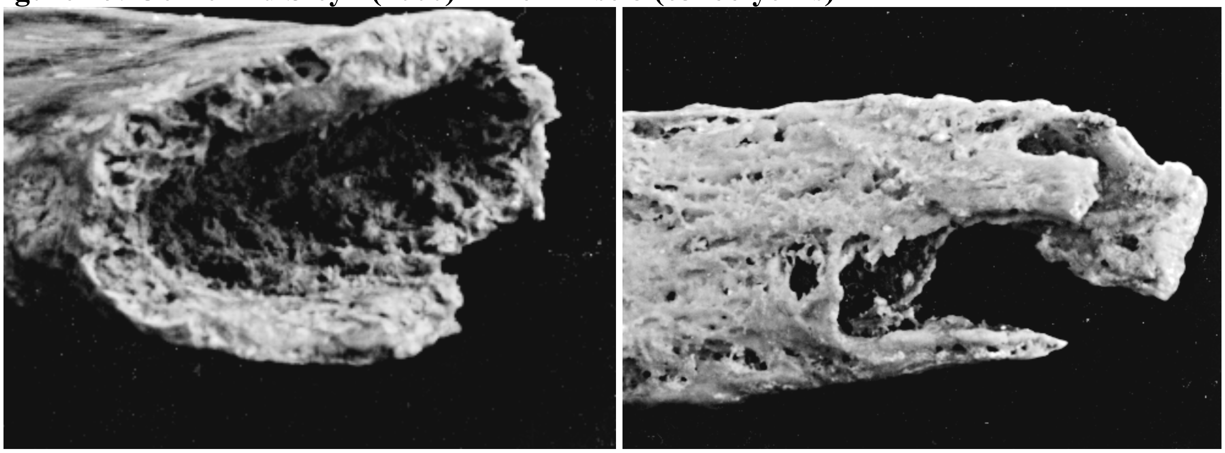
"The pit is noticeably deep with a wide U-shape. The walls are thin with sharp edges. The rim is irregular and exhibits some rather long bony projections that are frequently more pronounced at the superior and inferior borders. The bone is noticeably lighter in weight, thinner, and more porous, especially inside the pit" (Oettlé and Steyn 2000:1075).

Figure 46: Oettlé and Steyn (2000) Male Phase 7 (52–69 years)



"The pit is deep with a wide to very wide U-shape. The walls are thin and fragile with sharp, irregular edges and bony projections. The bone is light in weight and brittle with significant deterioration in quality and obvious porosity" (Oettlé and Steyn 2000:1075).

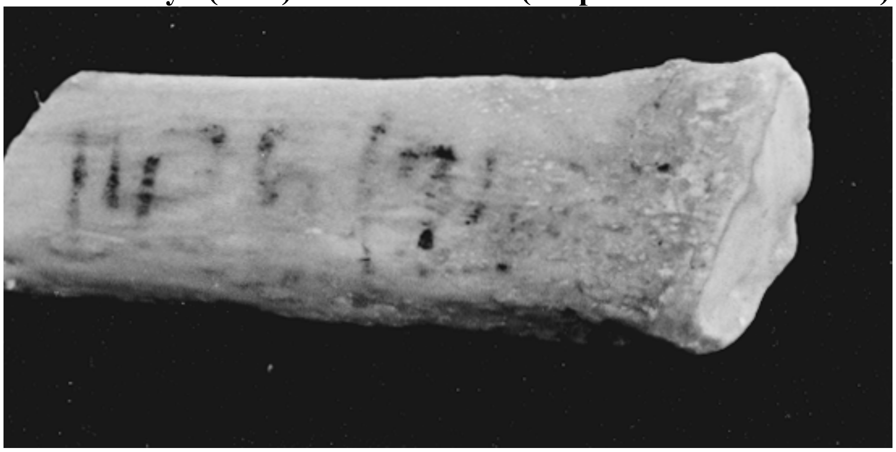
Figure 47: Oettlé and Steyn (2000) Male Phase 8 (63–77 years)



"The pit is very deep and widely U-shaped. In some cases the pit is absent or filled with bony projections. The walls are extremely thin, fragile, and brittle with sharp, highly irregular edges and bony projections. The bone is very lightweight, thin, brittle, friable, and porous. "Window" formation is sometimes seen in the walls" (Oettlé and Steyn 2000:1075).

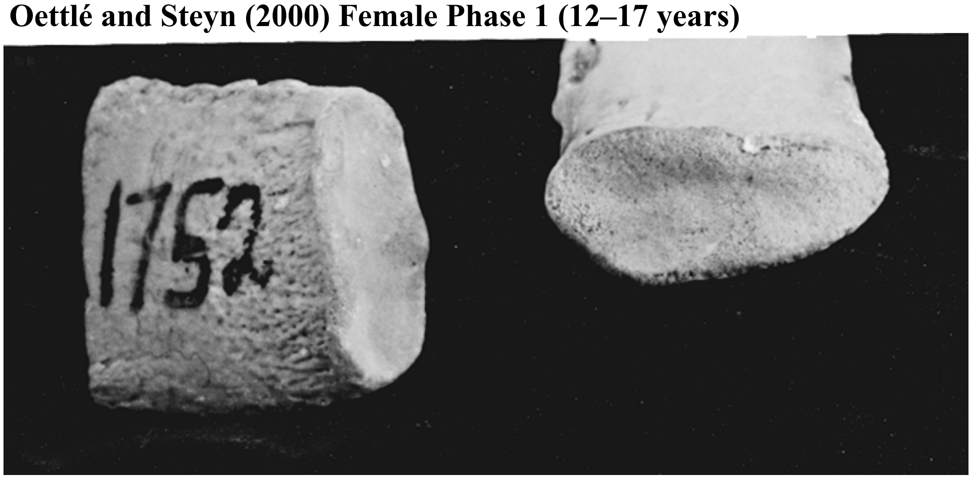
Appendix F: Oettlé and Steyn Female Phase Descriptions and Photographs

Figure 48: Oettlé and Steyn (2000) Female Phase 0 (Prephase seen in children)



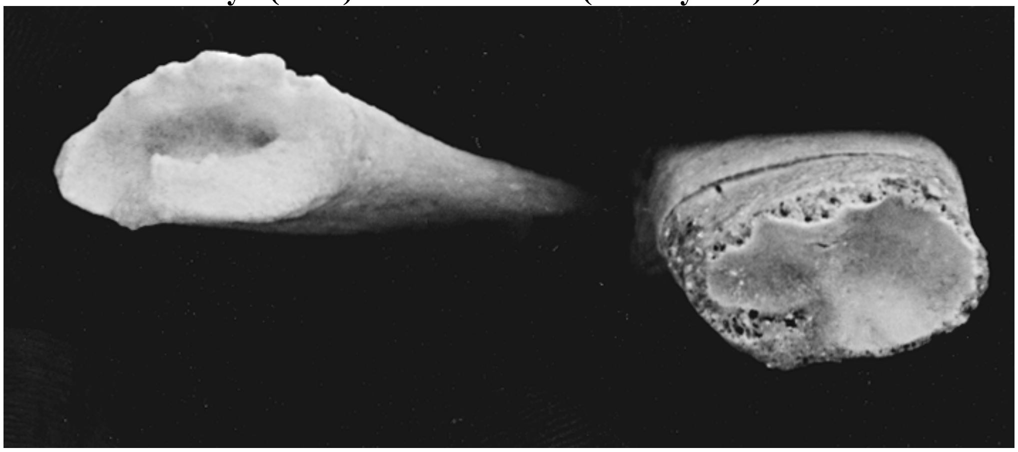
“The articular surface is nearly flat with ridges or billowing. The outer surface of the sternal extremity of the rib is bordered by what appears to be an overlay of bone, the epiphyseal growth plate. The rim is regular with rounded edges, and the bone itself is firm, smooth, and very solid” (Oettlé and Steyn 2000:1075).

Figure 49: Oettlé and Steyn (2000) Female Phase 1 (12–17 years)



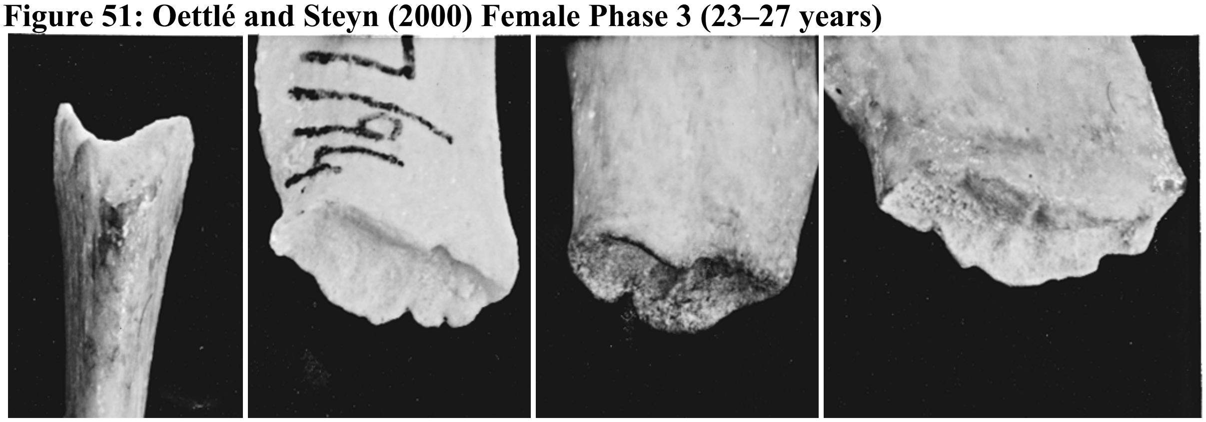
“An amorphous indentation is beginning in the articular surface. Ridges or billowing may still be present. The rim is rounded and regular with a little waviness in some cases. An epiphyseal growth plate or ring could still be noticed” (Oettlé and Steyn 2000:1075).

Figure 50: Oettlé and Steyn (2000) Female Phase 2 (16–26 years)



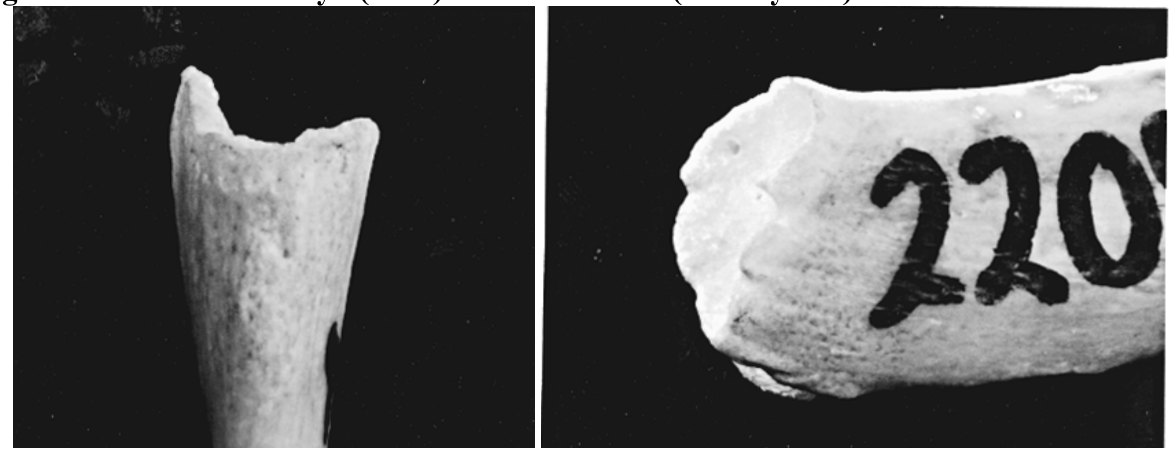
“The amorphous indentation becomes deeper at more than one point, and then continues to form a V-shaped pit between the thick, smooth anterior and posterior walls. Some ridges or billowing may still remain inside the pit. The rim is wavy with some scallops beginning to form at the rounded edge” (Oettlé and Steyn 2000:1075,1077).

Figure 51: Oettlé and Steyn (2000) Female Phase 3 (23–27 years)



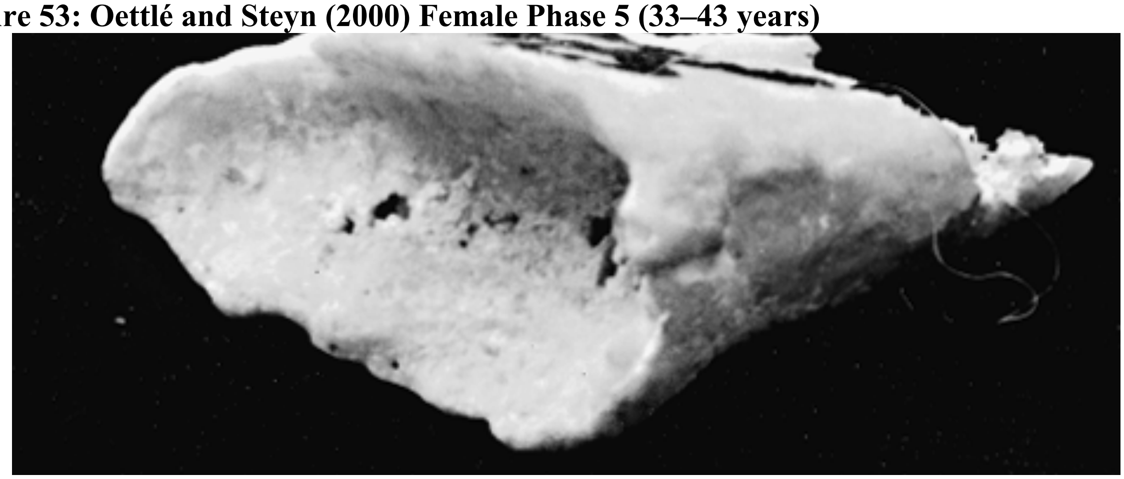
“There is only slight or no increase in pit depth, but the V-shape is wider, sometimes approaching a narrow U as the walls become a bit thinner. The rounded edges now show a pronounced, regular, scalloping pattern, or the rim may exhibit an irregular scalloping pattern, which gives it a pointy appearance” (Oettlé and Steyn 2000:1077).

Figure 52: Oettlé and Steyn (2000) Female Phase 4 (28–32 years)



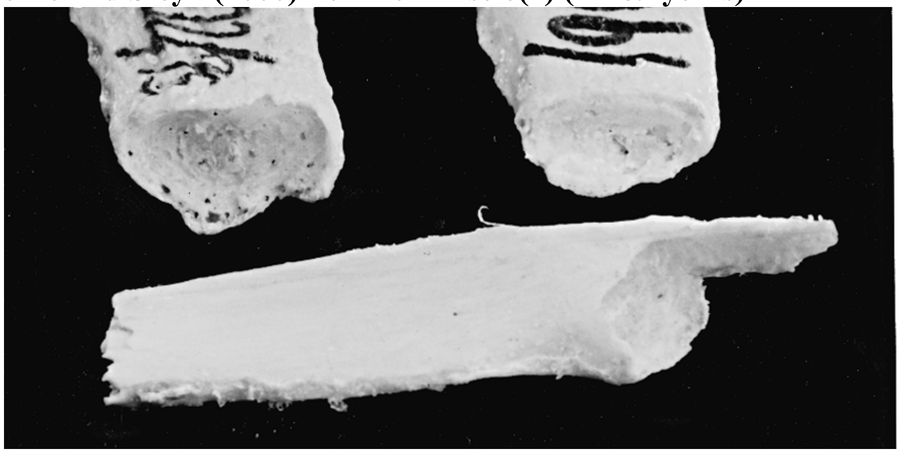
"The pit now has a narrow U-shape with at times, flared edges. The pit interior may contain plaque-like deposits. The walls are thinner and the rim remains rounded, but may also be flat and pointed. Some scalloping is still present, but this is not as well defined and the edges look somewhat worn down. There is some decrease in density and firmness of the bone" (Oettlé and Steyn 2000:1077).

Figure 53: Oettlé and Steyn (2000) Female Phase 5 (33–43 years)



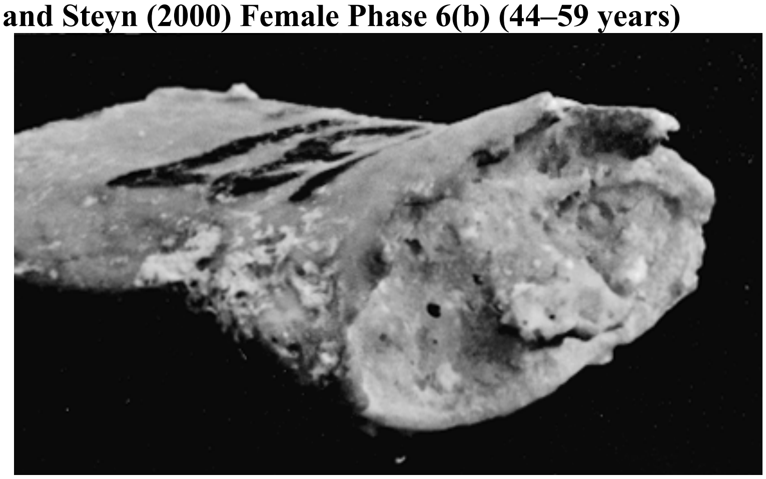
"The pit depth increases, and the thinning walls are flaring into a wider U-shape. A smooth, hard, plaque-like deposit lines at least part of the pit in some ribs. No regular scalloping pattern remains and the edge is beginning to sharpen. The rim is becoming more irregular. The bone is noticeably lighter in weight, density, and firmness. The texture is somewhat brittle" (Oettlé and Steyn 2000:1077).

Figure 54: Oettlé and Steyn (2000) Female Phase 6(a) (44–59 years)



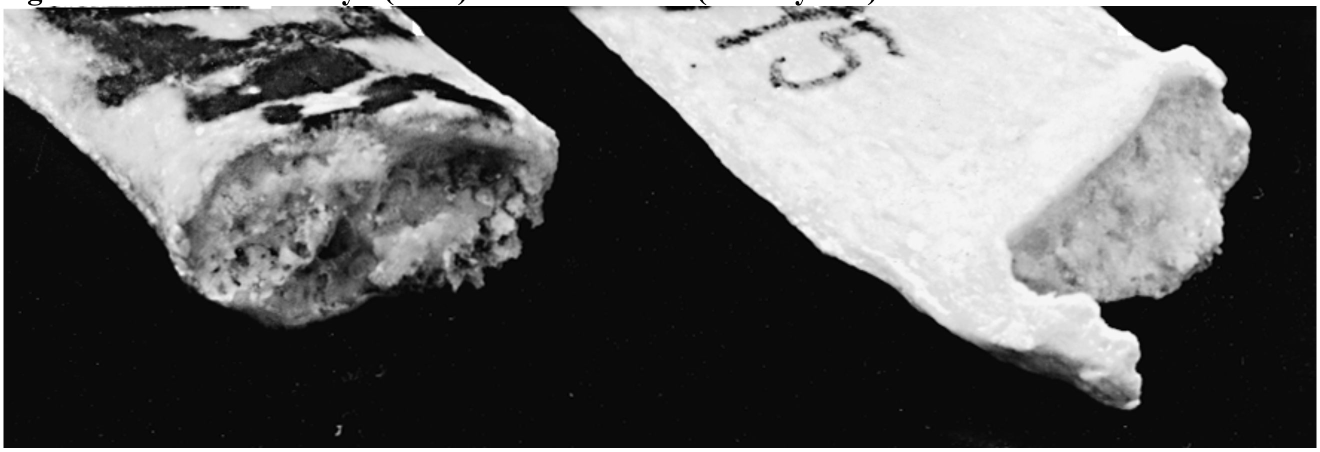
"An increase in pit depth is again noted, and its U-shape has widened again because of pronounced flaring at the end. The plaque-like deposits may still appear but are rougher and more porous. The walls are quite thin with sharp edges and an irregular rim. In many cases, sharp points or bony projections project from the rim of the sternal extremity. The bone itself is fairly thin and brittle with some signs of deterioration" (Oettlé and Steyn 2000:1077–1078).

Figure 55: Oettlé and Steyn (2000) Female Phase 6(b) (44–59 years)



The pit depth, although not increasing, does not decrease. Obvious bony growths from the pit interior can be seen. No central arc of bone is present. Pointed projections, often at the superior and inferior borders, or anywhere around the rim, are found. The very thin walls have irregular rims and sharp edges" (Oettlé and Steyn 2000:1078).

Figure 56: Oettlé and Steyn (2000) Female Phase 7 (56–79 years)



"The floor of the U-shaped pit in this final phase is relatively shallow, badly deteriorated, or completely eroded. Sometimes it is filled with bony growths. The central arc is barely recognizable. The extremely thin, fragile walls have highly irregular rims with very sharp edges. The bone itself is in a poor condition—extremely thin, light in weight, brittle, and fragile" (Oettlé and Steyn 2000:1077).

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