Age estimation from the os coxae in black South Africans

By

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A dissertation submitted to the

Faculty of Health Sciences, the University of the Witwatersrand,

30 April 2014,

in fulfilment of the requirements for the degree

Master in Science of Medicine

DECLARATION

I, Melissa Pininski, hereby declare that this work is my own. It is being submitted for, or in contribution to, the fulfilment of the requirements of a Masters in Science of Medicine degree in the Faculty of Health Sciences at the University of Witwatersrand.

This work has not been submitted before, or as part of any degree or examination in any other course in this or any another Academic Institution.

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ABSTRACT

The accurate estimation of age is considered important from an ethical, legal and archaeological perspective. Among the numerous methods based on macroscopic skeletal studies for age estimation, the Suchey-Brooks (1990) method for aging from the pubic symphysis and the Buckberry and Chamberlain (2002) method for aging from the auricular surface are considered more reliable. However, both these methods have been derived from American populations. In saying this, the following study aimed to evaluate whether it is possible to accurately estimate the age-at-death from morphological age-related changes seen on the pubic symphysis and the auricular surface in a black South African population. A total of 197 individuals of both sexes utilising both left and right os coxae were investigated. Age was estimated using descriptions stipulated by Brooks and Suchey (1990) and Buckberry and Chamberlain (2002). Both methods indicated moderate to high inter-and intra-observer errors. Descriptive statistics indicated a sample distribution of predominantly middle aged individuals. Correlation coefficients, inaccuracies and bias as well as Principal Components Analysis (PCA) were calculated for both skeletal elements for both sexes and sides. Statistical analyses indicated no significant differences between sexes and sides for both the pubic symphysis and the auricular surface. When comparing accuracies of each method, inaccuracies and bias were lower in the pubic symphysis than in the auricular surface thus making the pubic symphysis a more reliable age estimator. Similarly, males indicated lower inaccuracies and bias than did females. Principal Component Analysis indicated variance between certain features found on the pubic symphysis and the auricular surface. Overall, the pubic symphysis outperformed the auricular surface, even though the method described by Buckberry and Chamberlain (2002) is considered more reliable. Further investigation of these two methods on a white South African

population will be beneficial. In addition, it is desirable to have an evenly distributed sample for correct analyses between males and females.

ACKNOWLEDGEMENTS

Great appreciation goes to Mr B. Billings and Mr D. Shangase for their assistance in the Raymond A. Dart Collection of Human Skeletons. I would also like to thank Dr P. Randolph-Quinney and Miss C. Small for all their statistical input, assistance and interpretation. Lastly, thanks needs to be given to Miss T. Mahon for her assistance with the inter-observer repeabilities. The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the NRF.

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CHAPTER 1: INTRODUCTION

The fields of forensic science and archaeology have grown noticeably over the past century. Bones contain vast amounts of information and along with developments in the literature and the development of new techniques, an individual's "story" can be told from their skeletal remains. Skeletal remains found in a medico-legal context are examined by forensic anthropologists who are faced with complete, damaged or fragmented, unidentified skeletal remains and their role is then to assist and provide information that may contribute to the positive identification of an individual (Scheuer, 2002). Successfully determining the identity of an individual is important from an ethical, legal and criminal perspective (Franklin, 2010; Schmeling *et al.*, 2007). One of the first steps in the identification process is formulating the biological profile which mainly includes the estimation of population affinity, sex, stature and age-at-death (Franklin, 2010; Scheuer, 2002). Apart from sex, which can potentially exclude almost half of the population, age is also an important measure, as it can exclude a considerable portion of individuals that have either gone missing or are victims (Sinha and Gupta, 1995). Forensic anthropologists strive for an accurate estimation of age-at-death. Such "accuracy" involves estimations as close as possible to the chronological age of the individual, which ultimately aids in the identification process (Ubelaker, 2007). The estimation of age-at-death does, however, prove more challenging once adulthood has been reached, which can have an impact on the accuracy of age estimation (Loth and İşcan, 2000).

The most accurate methods for estimating age-at-death from adult skeletal remains are based on the identification of morphological and degenerative changes in bones and teeth throughout life (Hens *et al.*, 2008). The rate and degree of change can be highly variable between different individuals and populations and it is, therefore, important to acquire the life history of an individual. Furthermore, interactions between genes, culture and the environment contribute to the range of variation between males and females and between young and old individuals (Hens *et al.,* 2008; Buckberry and Chamberlain, 2002).

Additionally, age estimation also depends in part on the skeletal elements available for analysis. Not only are different bones more resilient than others to damaging taphonomic processes but some produce more accurate estimations of age than others (Franklin, 2010; Loth and İşcan, 2000; Brooks, 1955). In a mature adult, age has been assessed using changes in the fusion of the cranial sutures (Dayal, 2009a; Brooks, 1955) as well as the morphological changes that occur with age in the ribs (Oettlé and Steyn, 1999), pubic symphysis (Brooks and Suchey, 1990; Brooks, 1955) and the sacro-iliac joint (Buckberry and Chamberlain, 2002; Lovejoy e*t al*., 1985a). The interest in using cranial suture closure is not only due to the interest in the skull but also because the cranium is often the better preserved skeletal element in recovered remains. However, ages obtained from cranial suture closure either produce skewed mortality rates or do not correlate well with known age-at-death (Brooks, 1955). Apart from the cranium for estimating age-at-death, two other more frequently used locations/sites include the pubic symphyseal joint and the auricular surface of the ilium. Both these sites exhibit morphological changes that are related to the aging process (Hens *et al*., 2008; Buckberry and Chamberlain, 2002; Brooks and Suchey, 1990).

The pubic symphysis has proven to be more reliable than cranial suture closure and is one of the most frequently used methods for estimating age (Hens *et al*., 2008; Telmon *et al.,* 2005; Loth and İşcan, 2000; Meindl *et al.,* 1985). Initially, the surface of the joint is characterized by a series of deep horizontal ridges which gradually begins to become smooth or flattened as an individual ages (Sauer and Lackey, 2000). Among many methods available for estimating age-at-death from the pubic symphysis, the Suchey-Brooks method is considered the most reliable (Telmon *et al.*, 2005). This method focuses on the total pattern of the symphyseal face and requires the comparison of the morphology of the symphysis to 6 sex-specific reference phases

(Franklin, 2010; Brooks and Suchey, 1990). Although it was found that sex and population differences have an impact on the reliability of the method, it can still be considered the best way for age estimation in American populations (Hens *et al.*, 2008).

As with the pubic symphysis, the auricular surface has proven to be reliable for age estimation (Hens *et al.*, 2008; Lovejoy *et al.*, 1985a). In addition to the preservation of the auricular surface, the morphological changes continue well into the sixth decade of life (Hens *et al.*, 2008; Brooks, 1955). Lovejoy and colleagues (1985a) developed a method which is the most commonly used method today. The authors formulated eight morphological phases, where they described the general nature of individual surface changes such as surface granulation, microporosity, macroporosity, transverse organization, billowing and striations (Lovejoy *et al.*, 1985a). However, this method is difficult to apply and has a low inter-observer repeatability (Loth and İşcan, 2000). A revised method was developed by Buckberry and Chamberlain (2002) whereby the auricular surface features described by Lovejoy and colleagues (1985a) were combined to provide a composite score from which an age estimate is derived. It was found that this method is easier to apply than that of Lovejoy and colleagues (1985a) and it also produced better inter-observer repeatabilities.

Studies have noted that age is dependent on sex and ancestry (Garvin *et al.*, 2012; Saunders, 2007). Unfortunately most methods for estimating age have predominantly been developed on American and European population groups and due to the lack of methods for estimating age in other populations, it is important to develop population and sex-specific standards. For this reason, both the pubic symphysis and auricular surface require further investigation and therefore, the purpose of this study was to assess whether the Suchey-Brooks (1990) method for aging the pubic symphysis and the revised method described by Buckberry and Chamberlain (2002) for aging from the auricular surface, can be used for estimating age on a South African population. Furthermore, the study will also assess any differences in the accuracies of age estimation between sexes as well as left and right sides of the os coxae. Daubert standards not only encourage establishing the accuracy of methods but also stress for testable, replicable, reliable and scientifically valid methods which can be presented in court (Dirkmaat *et al.*, 2008). As the accuracies of these two methods have not been tested on a South African population, it does not adhere to these standards. This further addresses the need for accurate age estimation methods for the South African population.

CHAPTER 2: LITERATURE REVIEW

Individual age estimation in skeletal remains involves estimating the individual's age-at-death and not the time elapsed since death. Age related changes in the skeleton may reflect three different phases of the lifespan: growth and development as well as equilibrium and old age (Scheuer, 2002). Ages for individuals that are younger than 25 years can be estimated with relative accuracy as developmental markers are more predictable and well-documented. However, when faced with individuals that are older than 25 years, the estimation of age becomes more difficult (Franklin, 2010; Scheuer, 2002; Brooks and Suchey, 1990). This can be explained by the fact that in older individuals, most standards rely on the highly variable deterioration of morphological markers and in the absence of key developmental markers, age estimation in adults depends mainly on the degeneration of bones (Franklin, 2010).

2.1. Age estimation in juveniles and young adults

In juvenile individuals, age can be estimated through the use of a number of markers from the teeth and the skeleton (Franklin, 2010; Scheuer, 2002). Researchers have noted that dentition is influenced less by environmental factors than is skeletal development (Saunders, 2007; Ubelaker, 2007) and that most dental age estimations are found to be closer to chronological age than skeletal age (Scheuer, 2002). Skeletal growth and development are more exposed to external factors such as environmental and cultural factors, whereas, most of the development of deciduous teeth occur before birth, in a protected environment (Scheuer, 2002).

Tooth eruption as well as mineralization are considered better methods for estimating age in juveniles and sub adults (up to the age of 18 years) (Franklin, 2010; Scheuer, 2002; Sauer and Lackey, 2000). Tooth eruption of both deciduous and permanent teeth show regularity in the timing and sequence of eruption, making it a very good age marker (Loth and İşcan, 2000). It is considered a continuous process whereby teeth move from the alveolar bone to full occlusion in the mouth. Mineralization, however, provides a more accurate estimation of age and is advantageous as it can be observed at any stage during an individual's lifespan (Scheuer, 2002; Scheuer and Black, 2000). It is also less affected by intrinsic (i.e. Hormoane levels) and extrinsic (i.e. nutrition)factors, whereas tooth eruption is often affected by nutrition and "local conditions" such as space in the jaws or early loss of deciduous teeth (Scheuer and Black, 2000). Upon examination of tooth formation and dental age assessment, Smith (1991) emphasised the need for population specific standards, as it was found that age estimation on non-European populations often resulted in lower accuracies when European standards were applied. Blankenstein and colleagues (1990) support this by observing later tooth eruption in black South African individuals, emphasising the need for population specific standards.

Skeletal development, although considered less accurate, is still important for estimating age as it is distinct form chronological age and indicates the physiological development of the juvenile.(Franklin, 2010). Age estimation from skeletal elements have been based on a number of methods and skeletal elements and literature has shown that juveniles can be aged from the appearance of ossification centres (Scheuer, 2002; Scheuer and Black, 2000; Krogman and İşcan, 1986), epiphyseal fusion (Sheuer and Black, 2002; McKern and Stewart, 1957) as well as long bone lengths (Scheuer, 2002; Scheuer and Black, 2000). The fusion of the spheno-occipital synchrondrosis, the fusion on the medial clavicle as well as the fusion of S1 and S2 of the sacrum are sometimes used as markers of adulthood (Garvin *et al.*, 2012; Scheuer, 2002).

There are three features of primary and secondary centres of ossification that can be used to estimate age in juveniles and these include the time at which the centre appears, the size and morphology of the centres as well as the fusion time of the primary and secondary ossification centres (Scheuer, 2002; Scheuer and Black, 2000). During the embryonic and foetal periods, primary ossification centres originate in the centre or diaphysis of the skull, vertebrae, long bones, ribs, sternum and well as bones of the shoulder and pelvic girdles, whereas, the secondary centres begin to develop in the epiphyses of the ribs, vertebral column, sternum, the shoulder and pelvic girdles and long bones (Scheuer, 2002; Scheuer and Black, 2000). In general, ossification centres develop as ovoid nodules of bone and can only be identified by it's anatomical position (Scheuer, 2002). Therefore, ageing becomes limited as there needs to be adequate soft tissue to hold these ossification centres in place (Scheuer, 2002; Scheuer and Black, 2000). Once an ossification centre begins to show distinct morphology, it has reached its second phase of development. However, the accuracy of estimating age from this will depend on the skeletal element available. The skull, vertebrae, ribs and long bones are distinguishable from mid-foetal life onwards, whereas, certain tarsal bones and carpal bones are identifiable from the early years to late childhood (Scheuer, 2002; Scheuer and Black, 2000). Lastly, one can estimate a juveniles' age by the fusion between ossification centres. However, the timing of fusion varies greatly. For example, primary centres of the temporal and sphenoid bones fuse around the time of birth, whereas complete fusion of the vertebral column and occipital bone occur at about 6 years of age. Bones involved in locomotion, typically fuse during late adolescent and early adulthood (Scheuer and Black, 2000).

In addition, it is possible to estimate age using epiphyseal fusion. Stevenson (1924) stated that the peak of epiphyseal activity occurs between the ages of 15 and 23 years. However, McKern and Stewart (1957) state that there is much debate regarding the timing of epiphyseal fusion. McKern and Stewart (1957) noted that complete fusion of the distal epiphysis of the humerus occurs around the ages of 17 and 18 years and fusion of the proximal epiphysis of the humerus is complete by 24 years of age, whereas complete fusion of the distal epiphyses of the radius and ulna occur at the age of 23 years. However, Scheuer and Black (2000) state that the fusion of the distal epiphysis of the humerus occurs between the ages 15 and 17 years and fusion the proximal epiphysis of the humerus is complete by 20 years of age. Additionally, McKern and

Stewart (1957) reported that the proximal end of the femur fuses by the age of 20 and the distal end of the femur fuses by the age of 22 years.

The diaphyseal lengths of long bones such as the femur, humerus and tibia can also be used to estimate age in juveniles. There are two types of methods available when using long bone lengths for age estimation. The first includes the formulation of regression equations from diaphyseal measures (Scheuer *et al.,* 1980). The second method involves using a table based on long bone length standards. The length of each long bone is measured and compared to recorded lengths in a table and subsequently the corresponding age can be observed.

Going into adulthood, the union of the medial clavicular epiphysis, which occurs between 20 and 30 years of age, can be used to estimate age (Garvin *et al.*, 2012 Brooks, 1955). Recently, Langley-Shirley and Jantz (2010) provided a concise historical account of medial clavicular aging methods. The authors used transition analysis as well as Bayesian statistics to estimate age. The authors found sexual differences and noted that in females the onset of fusion occurred at least a year earlier than in males (Langley-Shirley and Jantz, 2010). It must be kept in mind that epiphyseal closure varies between individuals, sexes and populations (Scheuer and Black, 2000).

Growth and development in several areas of the skeleton is not complete until the second or third decade of life. One such area is the spheno-occipital synchondrosis. The closure of the spheno-occipital synchondrosis occurs by 25 years of age (Krogman and İşcan, 1986; Brooks, 1955). Scheuer (2002) however notes that this is an overestimate, as the closure of this area coincides with the eruption of the second molar which occurs between the ages of 17 and 21 years. The closure of the spheno-occiptal synchondrosis also differs between sexes. Shirley and Jantz (2011) along with other investigators (Scheuer and Black 2000; Sahni *et al.,* 1998; Okamoto *et al.*, 1996) found that in females, closure can occur from as early as 11 to 14 years of age, while closure in males can occur anywhere from 13 to 18 years of age. Kahana and colleagues (2003) concluded that the closure of the spheno-occiptal synchondrosis is not a reliable age indicator due to the high variability of fusion.

There are however, a number of disadvantages when using juvenile skeletons for estimating age. Juvenile skeletons are very fragile and as such are often damaged or fragmented when found. In addition, most skeletal collections do not have a vast juvenile collection, which often also lack demographic information and therefore it becomes difficult when developing new aging techniques. Described above are a number of methods available for the estimation of age in this juveniles and young adults. As this study focuses on adult age estimation, the next section will explain this in more detail.

2.2. Age estimation in adults

Age estimation in adults becomes more difficult in the absence of key developmental markers. In addition to this, the age estimation process can be further complicated by influences of human behaviour and the environment (Franklin, 2010; Loth and İşcan, 2000). Consequently, different parts of the skeleton can age at different rates both between and within individuals (Franklin, 2010). The primary methods for estimating age in an adult skeleton are either based on non-invasive assessment of morphological changes or the application of more destructive techniques such as histomorphometry (Robling and Stout, 2007).

A number of skeletal elements have been used to estimate age, however, it must be kept in mind that the skeletal element that is available for analysis will have an effect on the estimation of age as different bones are essentially better preserved than others or provide more accurate age estimations (Franklin, 2010). One must also keep in mind the sex and population affinity of the individual as these both can affect the accuracy of age estimation, as there are differences in sex and population developmental rates in both juveniles and adults (Franklin, 2010; Saunders, 2007).

2.2.1. Histomorphometry

Bone remodelling continues well into adulthood and can be used as an age estimator (Robling and Stout, 2007). Histomorphometry involves quantifying features, namely: osteon size, osteon type and osteon density; the size and number of Haversian canals as well as cortical thickness (Loth and İşcan, 2000; Sauer and Lackey, 2000; Kerley, 1965). In 1965, Kerley developed a method for age estimation based on the microscopic analysis of the cortex of long bones. This method analysed four cortical components in male and female femora, tibiae and fibula. These components included complete osteons, fragmentary osteons, and the percentage of circumferential lamellar bone as well as non-Haversian canals. These four components were examined in four fields of the outer zone of each cross-section for each long bone; i.e. anterior, posterior, medial and lateral fields. The number of osteons, the number of fragmentary osteons and the number of non-Haversian canals were counted in each field. The numbers for each component were totalled for all the four fields and a single value was calculated. The percentage of circular lamellar bone was estimated in all four fields and was averaged. These composite values were then plotted against age for the femur, tibia and fibula. It was found that overestimation of 5 years occurred in both males and females (Kerley, 1965).

When using Kerley's (1965) method, a number of difficulties were found which included; the size of the circular visual field, difficulties in distinguishing whole osteons from fragmentary osteons as well as the percentage of circumferential lamellar bone (Krogman and İşcan, 1986). In attempting to modify Kerley's (1965) method based on these difficulties, Ahlqvist and Damsten (1969) only included osteons and osteon fragments in their method. It was found that the circumferential lamellar bone was not affected and was not necessary for their study.

However, although this new method was simpler, it proves inferior to the method developed by Kerley (1965).

As with most age estimation methods, researchers have found that the bone remodelling process varies between populations and sexes and therefore population specific standards have been developed (Keough, *et al.*, 2009; Cho *et al.*, 2002). Keough *et* al., (2009) analysed age-related histomorphometric changes in a South African population. They looked at 10 histomorphometric traits that could be used to estimate age, of which only 6 indicated a relationship to age estimation. Although correlations to age were found, these traits resulted in moderate to low correlations (r = 0.11 to 0.50). They concluded that nutritional factors as well as lifestyle play an important role in bone remodelling.

Although this technique is believed to provide a more accurate estimation of age than other aging methods on skeletal elements, it is an invasive, time consuming technique that requires specialised training and equipment (Ubelaker, 2007; Loth and İşcan, 2000).

2.2.2. Age estimation from adult dentition

The least destructible elements in the body are teeth. Methods based on degenerative changes in teeth have been considered better methods for estimating age in adults than other skeletal elements (Scheuer, 2002; Solheim, 1993). In 1947, Gustafson (as cited by Solheim, 1993) investigated changes in adult dentition and produced linear regression equations. Features that were investigated included: dental attrition, periodontal recession, dentin formation, cementum apposition, apical translucency as well as external root resorption. Correlations for this study, were strong (r = 0.98), however, many researchers have criticised this method (Solheim, 1993; Maples and Rice, 1979; Burns and Maples, 1976; Dalitz, 1962). Apart from being a subjective assessment, the statistics regarding the standard deviations have been considered incorrect as they provide ranges that are too narrow (Solheim, 1993; Burns and Maples, 1976). Gustafson

(1947) only developed one formula which was considered valid for all types of teeth, not taking into account that different teeth show different age related changes. Regression equations were also incorrectly calculated (Solheim, 1993; Dalitz, 1962).

Lovejoy (1985) developed a new age estimation method using dental wear from a Libben population. Phases were allocated to wear patterns and it was found that this new method produced correlations comparable to the pubic symphysis, the auricular surface as well as cranial sutures (Lovejoy, 1985). Although it was concluded that dental wear is highly reliable, Lovejoy (1985) noted that the study is population specific, which may limit its usefulness in a forensic context. In addition, the dietary habits of modern populations differ from that of past populations, in that most diets of today consist of refined, processed foods. This will not necessarily cause extreme dental wear due to the lack of grit in the diet (Loth and İşcan, 2000).

2.2.3. Age estimation from cranial suture closure

The bones of the skull are separated by sutures which progressively fuse as an individual ages. Various methods/systems of scoring the degree of closure for both ecto- and endo-cranial sutures have been developed (Dayal, 2009a; Krogman and İşcan, 1986). Most of these methods involve macroscopically rating the degree of suture closure, ranging from completely open through to complete obliteration (Franklin, 2010; Dayal, 2009a; Krogman and İşcan, 1986). A composite score is then calculated and used to derive a mean age estimate.

A well-known method for estimating age from the cranium was developed by Todd and Lyon in 1925. Based on different populations, this study investigated the obliteration of three major sutures on the cranial vault (Tadd and Lyon, 1925). The degree of suture closure has been considered the most popular and commonly used method for estimating age in the past (Dayal, 2009a). However, as cranial suture closure has been based on the assumption that it progresses with age (Todd and Lyon, 1925), it has shown to be an unreliable indicator (Brooks, 1955).

Brooks (1955), when testing Todd and Lyon's method of complete obliteration of cranial suture closure, found no correlation between known age and estimations made from cranial sutures closure.

Due to the unreliability of cranial suture closure as an age estimator, modifications on previous work done on cranial suture closure were necessary. Meindl and Lovejoy (1985), among others, decided that instead of using the entire suture to estimate age, it would be beneficial to section it. They decided to assess cranial suture closure in the vault as well as along the lateral anterior ecto-cranial sutures. Meindl and Lovejoy (1985) concluded that age estimation from the lateral anterior sites is more accurate. They also noted that, sex and population affinity do not affect the age estimation process. Dayal (2009a) investigated cranial suture obliteration patterns in black and white adult South Africans. The author used two methods, the Ascadi- Nemerski (1970) method, which looks at endo- and ecto-cranial suture closure, as well as the Meindl and Lovejoy (1985) method which uses lateral anterior ecto-cranial sutures and vault system age estimation. No significance was found between cranial suture obliteration and age (Dayal, 2009a). Contradictory to this, McKern and Stewart (1957) noted that the progress of cranial suture closure has a general relationship with age. It was concluded that, although correlations between endo-cranial suture closure and age estimation was found, these correlation were too low to be of any use and as such Dayal (2009a) stated that these methods cannot be used as an age estimator in a South African population.

Although the usefulness of cranial suture closure has been considered many times before, studies have concluded that the technique is too imprecise to be of practical use in forensic investigations and will more likely be of use in archaeological investigations (Franklin, 2010; Scheuer, 2002).

2.2.4. Age estimation from the sternal ends of ribs

The sternal end of a rib is another useful age marker. Age-related changes in the sternal ends of ribs have been investigated by a number of researchers using radiography (Michelson, 1934) as well as direct morphological observation (Oettlé and Steyn, 2000; İşcan and Loth, 1986; Michelson, 1934).

Calcification of the first costal cartilage of ribs was studied by Michelson (1934) on white and black Americans. Michelson (1934) noted no sexual differences until the age of 15 years, however, at 16 years, males indicated more intensive calcification. It was also concluded that black Americans of both sexes indicated a more rapid calcification process than white Americans.

The existing method for estimating age from the sternal ends of ribs was developed in the 1980's by İşcan and Loth for American populations. They examined the form, shape, texture and overall quality of the sternal end of the fourth rib and defined a series of phases. They believe this method to be more reliable than other methods generally used to estimate age as the ribs are not directly affected by the stress of pregnancy as is the pelvic region (İşcan and Loth, 1986). Subsequently, the authors noted that morphological age changes differ among sexes and populations.

In light of this, Oettlé and Steyn (2000) investigated age estimation from the ribs of a black South African population. The authors noted that the existing method did not seem to estimate age accurately when applied to a South African population. It was also noted that estimations on female ribs were less reliable than for males. In general, it was found that age was underestimated in younger individuals and overestimated in older individuals. From these findings, they developed a new method specifically for the South African population (Oettlé and Steyn, 2000).

2.2.5. Age estimation from the scapula

Little research has investigated the age related changes of the scapula. The epiphyseal union of the scapula, which is complete by about 25 years of age, can be of use as an estimator for age in young adults (Krogman and İşcan, 1986). However, two of the most important age-related changes in the scapula are the post-maturity ossification and atrophic processes. These two changes were first studied by Graves (1922). He suggested that the ossification of cartilaginous structures surrounding the glenoid fossa, the clavicular facet, the tip of the acromion process, and the base of the spine area are as a result of advancing age. Furthermore, Graves (1922) stated that the variation in the degree and timing of cartilage ossification is determined by behavioural and intrinsic differences between individuals.

Additionally, atrophic processes observed in the human scapula represent a chronological aging process (Dabbs and Moore-Jansen, 2012; Graves, 1922). Structures which display age changes attributed to an atrophic process in the scapula include: reduction and eventual loss of surface vascularity; decrease and alteration in deep vascularity; the occurrence of localized areas of bone atrophy; buckling or pleating of the body (mainly of its dorsal surface above and below the spine), and distortion of the body mainly below the spine (Graves, 1922). However, the generalized age changes described by Graves (1922) are not universally applicable across different population groups or sexes (Dabbs and Moore-Jansen, 2012).

2.2.6. Age estimation from the vertebral column

The vertebral column is more commonly used to estimate the stature of an individual, however, degenerative changes seen in the vertebral column can be used to estimate age-at-death (Van der Merwe, 2006). It has been shown that vertebral ring epiphyseal union correlates to a known age-at-death (Albert, 1998). The epiphyses of the thoracic and first two lumbar vertebral bodies are amongst the last epiphyses of the skeleton to fuse, beginning as early as 14 years of age and completely fusing by about ages 26 to 27 years (Albert, 1998). In older individuals, the most useful age criterion in the vertebrae is "lipping" or osteophytosis (Van der Merwe *et al.*, 2006; Krogman and İşcan, 1986). Osteophytosis/osteophyte formation of the vertebral column is very specific to each individual and occurs when bony outgrowths form along the margins of the vertebral column (Van der Merwe *et al.*, 2006; Watanabe and Terazawa, 2006). However, the appearance of degenerative joint disease as signalled by lipping of vertebral bodies does not usually appear before the age of 40 years (Scheuer, 2002).

Osteophyte development was explored by Van der Merwe and colleagues (2006). The authors investigated the pattern of osteophtye development in a South African population. They found that particularly in the cervical and lumbar regions, males displayed more pronounced osteophytic development than females. They noted that osteophytes are less likely to form on vertebrae where the spine crosses the centre of gravity. Due to the curvature of the spine, where pressure is more evenly distributed, osteophytes are more likely to form where there is greatest pressure (Nathan, 1962). In conclusion to their study, Van der Merwe and colleagues (2006) noted several reasons for differences in osteophytic development which included weight bearing and the mobility of the vertebral joints. As osteophytic development has been associated with age, the authors suggested that a description of normal pattern development in an African population would be beneficial.

2.2.7. Estimating age from the os coxae

The os coxae provide two main sites for the estimation of age: the pubic symphysis and the auricular surface. These two sites are amongst the most accurate markers for age estimation in adults (Buckberry and Chamberlain, 2002; Brooks and Suchey, 1990; Krogman and İşcan, 1986). Methods involving these two independent sites have been based on the visual scoring of morphological signs of age, such as the degenerative changes of the pubic symphyseal joint and sacro-auricular joints (Martins, *et al.*, 2011).

2.2.7.1. The pubic symphysis (pre Suchey-Brooks method)

The left and right pubic bones, separated from each other by symphyseal cartilage, meet anteriorly in the midline to form the pubic symphysis (Krogman and İşcan, 1986). Each pubic bone presents a symphyseal face or surface which undergoes variations in dimension and texture with age (Todd, 1920). A young adult pubic symphysis has a rugged surface with indications of horizontal ridges and grooves. With age, this surface gradually becomes smoother and is bounded by a symphyseal rim with further erosion and deterioration in later phases of life (White and Folkens, 2005; Todd, 1920). These age-related changes have been recognized for many years and the pubic symphysis has undergone extensive analysis.

Todd (1920) was the first to evaluate age changes in the pubic symphysis and published clear descriptions of a 10 phase method for estimating age. He considered each pubic symphysis to have a more or less oval outline, having 5 main features: a surface, a ventral border, a dorsal border, a superior extremity and an inferior extremity. Additional features found mainly on the surface were described as “billowing”, “ridging” and “ossific nodules” and were analysed as subsidiary features (Todd, 1920). Using variations and combinations of the above features, a method for estimating age from the pubic symphysis was developed. The phases produced age intervals, with the first three phases having age ranges of 2 to 3 years (ages 18 through to 24 years), and thereafter, phases having 5 year intervals or more. The last phase includes all ages over 50 years. Todd (1920) suggested that the phases could be grouped into three periods namely, the post-adolescent stages (phases I to III), the various processes by which the symphyseal outline is built up (phases IV to VI) and the period of gradual quiescence and secondary change (phases VII to X). However, Todd (1920) did note that theses phases were more reliable from 20 to 40 years than after 40 years and suggested that the pubic symphysis should be used in conjunction with other skeletal elements. This method is however limited in its application as Todd's (1920) sample included white males only.

As Todd's method only investigated male individuals, Brooks (19955) decided to investigate Todd's method on male and female pubic symphyses. Brooks (1955) noted that Todd's method tended to overestimate age, particularly in the later phases of life. In addition, Brooks (1955) found that correlations between estimated age and actual age were higher in males than in females. The author then adjusted Todd's method and suggested a shift in the age ranges. Additionally, Brooks (1955) observed a pattern among female pubic bones in that the excessive slenderness of the pubic symphysis gives the appearance of increased age.

In 1957, McKern and Stewart published their three component age estimation system for males. Their approach was to divide the symphyseal surface into three components: dorsal plateau, ventral rampart and symphyseal rim with each component displaying 5 developmental phases. The dorsal surface/margin is convex and the ventral surface is concave. The dorsal plateau and ventral rampart are found on their corresponding surfaces. The symphyseal rim can be described as the extension of the oval outline that is slightly elevated from the symphyseal surface. In using this method, a developmental stage for each component is calculated and then added together resulting in an age of death for that particular individual (McKern and Stewart, 1957). The authors stated that component analysis is easier to use and less restricting than a phase analysis as each feature can be scored independently. However, this method described by McKern and Stweart (1957), as with Todd's (1920) method, was derived from an all-male sample and had a tendency to under-age older individuals.

In order to address this problem, Gilbert and McKern (1973) formulated a similar three component method for female pubis symphyses. It was concluded that because female pubic symphyses are subject to trauma during childbirth, there is a potential for premature changes in the bone surface which may result in the overestimation of age. In addition, McKern and Stewart (1957) noted that although their method works well, it was not intended for a female sample. Therefore, Suchey (1979) tested Gilbert and McKern's method (1973) for aging female pubic symphyses and found it to be highly unreliable. Only 51% of the age estimations produced an age range which included the known age of the specimen. Suchey (1979) further established that judging whether the ventral rampart was being built up or breaking down was a major problem with the Gilbert and McKern (1973) method. The location and definition of the dorsal and ventral aspects of the pubic symphysis between males and females can cause some confusion when estimating age. Therefore, it is more likely that females, when compared to males, may not reach a comparable stage of development until 10 years later (McKern and Stewart, 1957).

In 1978, Hanihara and Suzuki evaluated age estimation from the pubic symphysis using multiple regression analyses on males and females. They adopted seven morphological features on the pubic symphysis which corresponded well with features pointed out by Todd (1920) as showing evident age changes. Each feature was then scored on a scale of 1 through 4. This method/scoring system is relatively easy for users with little experience as morphological differences between the adjacent scores are fairly distinct (Hanihara and Suzuki, 1978). However, it was concluded that when applied to individuals younger than 18 years or older than 38 years, the method cannot be used as the specimens of their study only ranged from 18 to 38 years. Although Hanihara and Suzuki (1978) based their age selection criteria on a statement by Todd (1920), in which Todd (1920) suggested that the pubic symphysis is a much more reliable age indicator from 20 to 40 years, it would have been advisable to widen their ages for their specimens.

Following the 1970's, Meindl and colleagues (1985) re-evaluated the effectiveness of age estimation using methods derived by Todd (1920), McKern and Stewart (1973), Gilbert and McKern (1973) as well as Hanihari and Suzuki (1978). Their analysis was carried out on samples selected from the Hamman-Todd collection on both sexes. They found that the original Todd (1920) method was the most reliable but that all methods tended to underage an individual. From this, they formulated 5 biological stages with the belief that the simplicity of Todd's (1920) 10 phase method would remain intact but still account for variation (Meindl *et al.*, 1985).

2.2.7.2. Suchey-Brooks (1990) pubic age estimation method

In response to many limitations of pubic symphysis age standards, the Suchey-Brooks method (1990) is based on an extensive, well-documented sample of pubic bones for skeletal age estimation. Male pubic bones were first studied using linear regression analysis (Katz and Suchey, 1986). Several problems were noticed by Katz and Suchey (1986) regarding those methods developed by Todd (1920) and McKern and Stewart (1957). Katz and Suchey (1986) found that the age ranges were much wider than those reported in the original studies. It was also observed that the Todd's (1920) 10 phase system tends to overestimate age in older individuals. Additionally, the three component method described by McKern and Stewart (1957) was rejected by Katz and Suchey (1986). The authors stated that the components described by McKern and Stewart (1957), i.e. dorsal plateau, ventral rampart and symphyseal rim, do not vary independently and that it would be easier to focus on the entire pattern of morphological change as seen in phase analysis. Therefore, it was suggested by Katz and Suchey (1986) that a modified Todd (1920) method using 6 phases would be more appropriate.

Consequently, Suchey and Brooks began focusing on refinements of the morphological descriptions. Through this, the Suchey-Brooks method was developed in 1990 (Brooks and

Suchey, 1990). As the method was developed from a male sample, the need for female descriptions arose. Prior studies (Gilbert and McKern, 1973; Todd, 1920) noted that morphology and rates of maturation differ between sexes. This was emphasised when female samples were analysed (Brooks and Suchey, 1990). In female pubic bones, the region/area of the symphysis lying between the ventral aspect of the symphyseal rim and the ventral arc show age related changes (Anderson, 1990). However, there is no such area on the male pubic bone (Brooks and Suchey, 1990; Anderson, 1990). In addition, in many females dorsal changes occur, which may not necessarily be due to age but rather related to pregnancy. It was noted that lipping of the dorsal rim, in particular, cannot be considered a reliable feature for age estimation in females (Brooks and Suchey, 1990). It has been noted that the degree of traumatic change during birth can alter the appearance of the dorsal aspect of the pubic symphysis, resulting in an 'older' estimation of age (McKern and Stewart, 1957). From this evaluation, a set of similar descriptions was developed for female pubic bones. Following the refinements of the male pubic symphysis and development of similar female descriptions, a set of unisex descriptions was developed. These descriptions focus on key age changes observed in both males and females. In applying these unisex descriptions, it helps eliminate features that have proven to be problematic (Brooks and Suchey, 1990). This method is regarded as one of the most important and reliable aging methods used today (Buckberry and Chamberlain, 2002).

2.2.7.3. The auricular surface (pre-Buckberry and Chamberlain method)

The ear-shaped sacral articulation on the medial surface of the ilium is known as the auricular surface (White and Folkens, 2005). The auricular surface has also been known to change with age (Sashin, 1930), however it has not been under such scrutiny as has the pubic symphysis.

Although age changes in the auricular surface are slightly more difficult to interpret than those used in the pubic symphysis, accurate estimations of age-at-death can be determined due to the regular and well-defined age changes that are seen in this area (Lovejoy *et al*., 1985a). These difficulties associated with the estimation of age can be attributed to the complexity of the age changes as well as the lack of a definite "delayed epiphysis" stage as found in the pubic symphysis i.e.: "ventral rampart" (Lovejoy *et al.,* 1985a p.15). There are, however, advantages of auricular surface aging. Such advantages include: the post-mortem preservation of the auricular surface; the interpretable changes extend well over 50 years of age and the fact that these changes are equally accurate in the estimation of age-at-death (Lovejoy *et al.,* 1985a).

A few studies have investigated the auricular surface and its change with age. Sashin (1930) was one of the first to describe age related changes seen on the auricular surface. The author noted that changes seen in the articular cartilage of the sacro-iliac joint are "progressive and increase in extent and intensity with the age of the individual" (Sashin, 1930, p.909). Sashin (1930) found that in both sexes aged between 30 and 59 years, degenerative changes in the joint become more evident and more pronounced with age. In addition, it was observed that particularly in men, this process starts earlier and progresses faster with a greater intensity.

The most common and widely used method for estimating age from the auricular surface is the method described by Lovejoy *et al.,* (1985a). Their study sample consisted of 250 well preserved auricular surface specimens from a Libben population, 500 specimens from the Hamman-Todd Collection as well as some forensic cases. The authors formulated eight morphological phases, mostly divided into 5 year intervals, where they described the general nature of individual surface changes such as surface granulation, microporosity, macroporosity, transverse organization, billowing and striations (Lovejoy *et al.,* 1985a). The method is designed to be applied in the same manner as Todd's (1920) 10 phase method for the pubic symphysis. The changes described by Lovejoy *et al.,* (1985a) associated with young adult auricular surface are a finely grained surface texture with marked transverse organization, while most of the surface is covered by billowing. With age, the surface becomes more coarsely granulated with a general loss of billowing. Into the later phases of life, all granularity is lost and replaced with a dense surface. Macroporosity and irregularity of the surface is more prominent later on in life. The authors noted that while the auricular surface may be distinguishable as falling into one of the eight morphological phases, the remaining details must then be used to refine the age estimate. For example, billowing can extend well into later life and as such, this feature needs to be considered in conjunction with other features. Lovejoy and colleagues (1985a) made note of the sex specific application of the method and stated that the method could be applied to both sexes. Although this method produced higher correlations (0.76 to 0.81) between morphological changes seen on the auricular surface and age, it is more difficult to use than the pubic symphysis (Lovejoy *et al.*, 1985a).

The Lovejoy *et al.* (1985a) method has been tested and revised several times. Murray and Murray (1991) tested the reliability on a sample of skeletons from the Terry Collection (as cited by Buckberry and Chamberlain, 2002). They noted that the method is not dependent upon population or sex. They concluded that the method consistently underestimated the age of older individuals and overestimated age of younger individuals. They felt that this may be due to differences in age structures between the Todd Collection (on which the method was developed) and the Terry Collection. However, Murray and Murray (1991) determined that the rate of degenerative change is too variable to be used as a single criterion for the estimation of age (as cited by Buckberry and Chamberlain, 2002).

Similarly, Saunders and colleagues (1992) tested the auricular surface method on an archaeological sample. They found that the underestimation of age occurred in the older portion of the sample yet the estimation of age for the younger portion was fairly reliable. Furthermore, they found that for many of the individuals, the estimates of age at death did not fall into the correct modal stages. This may indicate that the method of Lovejoy *et al.* (1985a) may not allow for individual variation in skeletal aging. Intra-observer errors were also high; indicating the difficulty found in applying the method (Saunders *et al.*, 1992).

Later, the method described by Loveyjoy *et al.* (1985a) was tested by Bedford and colleagues (1993). The method was tested on a sample of known-aged skeletons from the Grant Collection at the University of Toronto. In line with results found by Murray and Murray (1991), they found that the method overestimated age in younger individuals and underestimated age in older individuals. The authors concluded that multifactorial age estimation will produce better estimates of age than single factors (Bedford *et al.*, 1993).

2.2.7.4. The revised method described by Buckberry and Chamberlain (2002)

In light of the problems found with the Lovejoy *et al.* (1985a) method, Buckberry and Chamberlain (2002) believed that a quantitative scoring system, which examines each different feature of the auricular surface independently, should not only be easier to apply but should also accommodate the overlap often seen between different stages. Their revised method was developed from that of Lovejoy and colleagues (1985a) using the categories of age-related changes seen on the auricular surface.

The auricular surface was described using the same terminology as described by Lovejoy *et al.* (1985a) and features included: transverse organization; surface texture; microporosity; macroporosity as well as changes in the morphology of the apex of the auricular surface. Each of the features was recorded independently and assigned a series of numerical scores. These numerical scores correspond to successive stages of degrees of expression (Buckberry and Chamberlain, 2002). This use of standardized criteria, allows the features to be assessed objectively, even if one feature may be obscured by another. The retro-auricular area was considered a poor estimator of age and was therefore excluded from the revised method (Buckberry and Chamberlain, 2002).

This revised method was tested on 180 archaeological specimens with younger individuals being underrepresented due to the age structure of the Spitalfields Collection. Buckberry and Chamberlain (2002) stated that the method did not demonstrate whether it was equally applicable for different populations. Therefore, the authors concluded that this revised method needs to be tested and redefined on a larger, multiracial, known-aged modern population. However, they did find that there was no significant difference between sexes and sides and, therefore, allows for the same method to be applied to both sexes (Buckberry and Chamberlain, 2002).

2.2.8. Combined methods

A number of studies have investigated whether combining various methods/techniques would result in a more precise estimation of age (Krogman and İşcan, 1986). Todd (1920) emphasised that the most accurate estimation of age can only be made after examination of the entire skeleton. However, this proves difficult as, more often than not, forensic anthropologists are faced with incomplete or fragmentary skeletal remains.

Nemeskéri and colleagues (1960) developed a "complex method" for age estimation in which they combined the use of four areas of the skeleton: endo-cranial suture closure; the pubic symphysis; cancellous portion of the femoral head as well as the cancellous portion of the humeral head. They found that this complex method was more reliable as an age estimator and should take preference over the use of individual skeletal age indicators.

Another alternative way of approaching age estimation includes transition analysis (Garvin *et al.*, 2012; Milner and Boldsen, 2012). Transition analysis relies on the estimated age of transition. In other words, the morphological phases must progress along with age at a consistent rate of identifiable phases with no phases being skipped or reconsidered (Garvin *et al.*, 2012). Any age indicator which is arranged into a series of stages can use transition analysis. The method is considered valuable in age estimation as most commonly used methods such as the Suchey-Brooks (1990) method for aging the pubic symphysis, use discrete phases. However, as transition analysis is fairly straight forward when using a single trait, it can become more complicated when involving several skeletal traits. Milner and Boldsen (2012) evaluated 252 American males and females using transition analysis. They found that the pubic symphysis outperformed the sacroiliac joint, followed by cranial sutures. However, it has been noted that transition analysis, like any aging technique, only works as well as the associated reference samples and their scoring systems (Milner and Boldsen, 2012; Garvin *et al.*, 2012).

As mentioned before and by multiple researchers, methods which are based on multiple indicators of age will provide more information and essentially may be more reliable (Konigsberg *et al.*, 2008). This thus highlights the importance of the current study, in which two age indicators will be investigated.

2.3. Aim and Objectives

Phase analyses of the pubic symphysis and the auricular surface have been described as accurate methods for the estimation of age-at-death. The revised method described by Buckberry and Chamberlain (2002) on age estimation from the auricular surface generated results that had a higher correlation and higher inter-observer repeatability with age than did the Suchey-Brooks (1990) method, with age ranges that are similar to those of the Suchey-Brooks method. As stated before, Buckberry and Chamberlain (2002) believed that a quantitative scoring system should not only be easier to apply, especially for inexperienced users, but should also accommodate the overlap often seen between different stages.

However, these methods have been developed from samples derived mainly from American populations and it is still unclear how well they perform on other populations around the world (Wärmländer and Sholts, 2011). Therefore, the aim of this study was to test the accuracy of these age estimation methods, i.e. the Suchey-Brooks method (1990) for the pubic bone and the revised method described by Buckberry and Chamberlain (2002) for the auricular surface, on black South Africans. In addition, differences in the accuracies between males and females as well as left and right sides of both the pubic symphysis and auricular surfaces were assessed.

The objectives of the study were as follows:

1. To estimate age in a sample of black South Africans using the Brooks and Suchey (1990) method for the pubic symphysis and the revised Buckberry and Chamberlain (2002) method for the auricular surface.
2. To test the accuracy of these two methods in black South Africans
3. To determine any significant differences in the accuracies of age estimation between black males and females as well as left and right sides of the pubic symphysis and the auricular surface.

CHAPTER 3: MATERIALS AND METHODS

A total of 197 os coxae of known age and sex from cadaver skeletons were randomly selected from the Raymond A. Dart Collection of Human Skeletons, housed in the School of Anatomical Sciences at the University of the Witwatersrand. The Raymond A. Dart Collection of Human Skeletons is covered by the Humans Tissue Act No. 65 of 1983, which allows for teaching and research within the university. It is widely known that this collection is a known-age collection (Dayal *et al.*, 2009b), however, a large number of individuals housed in this collection are pauper bodies with no form of identification. However, the accuracy of age data is questionable. The os coxae represented black South Africans and were distributed between males (n = 99) and females (n = 98). Ages ranged from 16 years to 87 years (43.99 ± 16.22 years). These ages were selected as it corresponds to age changes seen in the pubic symphysis and auricular surface phases. Younger individuals (from 15 years) show key developmental markers with age and as individuals get older more degenerative changes can be seen in the os coxae (Krogman and İşcan, 1986).

As recent studies have suggested that right/left asymmetry of the pubic bone is a source of error in the Suchey-Brooks method (Wärmländer and Sholts, 2011), both left and right os coxae were analysed. Any os coxae indicating signs of damage, pathology or inconsistencies in documentation were excluded from the study.

3.1. Data collection

Analysis of age estimation using the pubic symphysis and the auricular surface was done blind and as such the researcher was unaware of the ages of the specimens being examined. This was done in order to eliminate researcher bias. In order to ensure that the data collection was done blind, known ages were removed from the data sheet, so as to have no indication of the recorded age of the individual. All 197 pubic symphyses were analysed first, followed by the analyses of the auricular surfaces. Again, this eliminated any researcher bias. Additionally, left and right sides were also analysed independently to further control for bias. Lastly, 20 random samples were re-assessed by the initial researcher and an independent observer in order to determine inter- and intra-observer errors.

3.1.1. The pubic symphysis

As described previously (Literature Review, p.20-22) the Suchey-Brooks method is the most common method used to estimate age when the pubic bone is present. With regards to this method, different phases of age-related morphological changes in the pubic bone are related to intervals of chronological age (Brooks, 1955). There are a number of features which are examined when estimating age using the pubic symphysis and these morphological changes and descriptions outlined by Brooks and Suchey (1990) are based on a set of unisex descriptions which can be applied to both male and female pubic bones. Firstly, age was estimated according to this set of unisex descriptions provided by Brooks and Suchey (1990). Along with these descriptions, 10 features that more commonly show age related changes on the pubic symphysis, were selected. These included: surface appearance of the pubic symphysis, ventral bevelling, ossific nodules, upper and lower extremities, dorsal plateau, ventral rampart, symphyseal rim, lipping, ligamentous outgrowths and the pubic tubercle. These 10 features were assigned a score according to the degree of expression (Table 1). This ‘scoring system’ allowed for easier interpretation of age related changes of the pubic symphysis as well as for statistical purposes.

Phase 1: This phase is characterised by deep groves and distinct ridges on the symphyseal face as seen in Figure 1. Another predominant characteristic of the phase includes the lack of definition of the upper or lower extremity (Figure 1). In other words, there is no definite ‘line’ separating the extremity from the adjacent bone. Other features which can be seen during this phase include ventral bevelling, and if any, the presence of ossific nodules beginning to form the upper extremity. Ventral bevelling is characterised by a ‘slant/bevel’ occurring along the ventral margin of the pubic symphysis. Ossific nodules are identified as small masses/lumps of bone found on the pubic symphysis.

Figure 1: Left male pubic symphysis illustrating distinct ridges and grooves (red arrow) associated with phase 1, as observed in the current study. Note the lack of definition of the lower and upper extremities (blue arrows)

Phase 2: Although similar to phase 1, billowing and ridge development on the surface is less pronounced. The ventral rampart, which is identified as a distinct outgrowth of bone along the ventral margin, may be in the beginning stages during this phase where bony extensions can be seen on either extremity (Figure 2). During this phase it can be seen that the extremities may still not be clearly defined, or one extremity may show definition. Ventral bevelling along the ventral margin is more distinct and ossific nodules begin to form the upper extremity at this point. During this phase, the dorsal plateau, which was identified as the “flattening/smoothing” of the surface along the dorsal aspect, may begin to develop along the dorsal margin. Figure 2 shows signs of the dorsal aspect becoming smooth or "flattening".

Figure 2: Left female pubic symphysis illustrating phase 2 for the current study. The dorsal plateau is in beginning stages of development, characterised by smoothness along the dorsal margin (red arrow), ventral rampart in beginning stages of developments (blue arrow) along the ventral margin

Phase 3: The ventral rampart is complete or in the process of completion during this phase as seen in Figure 3. The upper and lower extremities are more clearly defined. There may be remnants of ridges and grooves on the symphyseal surface, however, the surface begins to become smoother during at this stage. The dorsal plateau is complete once the dorsal margin on the pubic symphysis is smooth or flat and a clear distinction can be made between the dorsal and ventral aspects. During this phase there are no signs of ligamentous outgrowths or lipping.

Phase 4: The oval outline, which can be characterised as the outer margin of the symphyseal surface, is almost complete at this stage, however a hiatus may be found in the upper ventral rim. Again, remnants of the old ridges and furrows may still exist, however, the symphyseal surface is generally smooth at this stage as seen in Figure 4. A distinct symphyseal rim can be seen surrounding the symphyseal surface at this stage. The symphyseal rim is identifiable by being slightly elevated from the symphyseal surface. Both extremities are well-defined and the pubic tubercle is fully separated from the pubic symphysis.

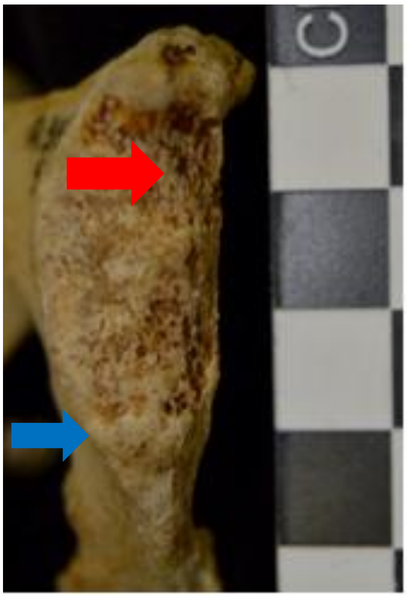

Figure 3: Left female pubic syphysis, illustrating phase 3 of the current study. The ventral rampart which is in the process of completion (red arrow) and a better defined lower extremity (blue arrow) are evident

Figure 4: Left female pubic symphysis during phase 4 of the current study, with an oval outline **(**red arrow**)** and remnants of ridges and grooves (blue arrow)

Phase 5: During this phase, the symphyseal rim is well-marked with a slight depression of the symphyseal surface. Lipping along the dorsal margin is moderate and more prominent ligamentous outgrowths are found along the ventral border. Slight erosion of the symphyseal rim may occur at this stage. However, breakdown may occur on the superior ventral border. As with phase 4, a fully separated pubic tubercle is evident during this phase as can be seen in Figure 5.

Figure 5: Left male pubic symphysis during phase 5 of the current study. The symphyseal surface is slightly depressed surrounded by the symphyseal rim (red arrow) with a separate pubic tubercle (blue arrow)

Phase 6: Depression of the symphyseal surface is more prominent during this phase and may be pitted or porous, indicative of a disfigured surface with erratic ossification. Well-marked, ligamentous outgrowths can be seen along the ventral margin and the pubic tubercle is fully separated. The pubic symphysis is irregularly shaped (Figure 6). Symphyseal rim erosion is evident, with the breakdown along the ventral border as seen in Figure 6 below.

Figure 6: Irregularly shaped left female pubic symphysis demonstrating a pubic symphysis in phase 6 of the current study. Symphyseal rim erosion (red arrows) as well as breakdown along the ventral margin (blue arrow) is evident

After assigning a phase to each of the pubic symphyses, age as well as an age range corresponding to the phases described by Brooks and Suchey (1990), was reported, depending on the sex of the individual. These age ranges can be seen in Table 2 below. While assigning phases to each pubic symphysis, each of the 10 features, as described in Table 1, were given a score, accordingly. The "scoring system" was developed in order to assist with statistical analyses later on. It must be emphasised that the Suchey-Brooks (1990) method describes each phase without giving a certain trait/feature a numerical score. Therefore, it was deemed necessary to assign certain features a numerical score. This was done by selecting 10 features on the pubic symphysis which show age related changes. The selection of the features was done after an extensive evaluation of the literature and each feature was individually selected due to its age related changes shown throughout adulthood. Each of these features were analysed separately and a score was given depending on the degree of expression of the feature as seen on the pubic symphysis. These features and their degree of expression, listed in Table 1, are described below.

Table 1: The pubic symphysis 'scoring system' modified based on age estimation characteristics described by Brooks and Suchey (1990)

Feature	**Score**	**Description**
Surface appearance	1	Distinct and deep billowing and ridges
	2	Surface still shows signs of ridges and grooves
	3	Remnants of ridge development
	4	Smooth surface with no ridges
	5	Depressed surface, may be pitted or porous
Ventral bevelling	1	No signs of ventral bevelling
	2	Slight bevelling along ventral margin
	3	Ventral bevelling more pronounced
	4	Clearly defined along ventral border
Ossific nodules	1	No signs of ossific nodules
	2	Ossific nodules forming the upper extremity
	3	Presence of ossific nodules on surface
Extremities	1	No signs of an upper / lower extremity
	2	Slight signs of the formation of an upper and/or lower extremity
	3	Lower extremity clearly defined
	4	Both the upper and lower extremity are clearly defined
Dorsal plateau	1	No signs of dorsal plateau formation
	2	Dorsal plateau begins to develop
	3	Complete dorsal plateau found along dorsal margin
Ventral rampart	1	Ventral rampart in beginning phases of formation
	2	Ventral rampart is in process of completion
	3	Ventral Rampart complete / presence of a hiatus
Symphyseal rim	1	No signs of a symphyseal rim
	2	Signs of symphyseal rim development
	3	Pubic surface completely rimmed
	4	Slight erosion seen along rim
	5	Rim erosion more prominent
Lipping	1	No signs of lipping
	2	Slight lipping along dorsal margin
	3	Moderate lipping along dorsal margin
Ligamentous outgrowths	1	No signs of ligamentous outgrowths
	2	Ligamentous outgrowths found on the inferior portion of the pubic surface
	3	Ligamentous outgrowths are more prominent
	4	Erratic ossification and ligamentous outgrowths present
Pubic tubercle	1	No signs of pubic tubercle
	2	Presence of the formation of pubic tubercle
	3	Pubic tubercle fully separated for pubis symphysis

Table 2: Age ranges for males (n = 739) and females (n = 273) for the pubic symphysis as reported by Brooks and Suchey (1990)

Phase	Female Age Ranges	Female Mean	Female SD*	Male Age Ranges	Male Mean	Male SD*
I	15 – 24	19.4	2.6	15 – 23	18.5	2.1
II	19 – 40	25.0	4.9	19 – 34	23.4	3.6
II	21 – 53	30.7	8.1	21 – 46	28.7	6.5
IV	26 – 70	38.2	10.9	23 – 57	35.2	9.4
V	25 – 83	48.1	14.6	27 – 66	45.6	10.4
VI	42 – 87	60.0	12.4	34 – 86	61.2	12.2

*SD, Standard Deviation

Surface Appearance: Surface appearance refers to the topography of the entire surface of the pubic symphysis. In young individuals, this surface has deep ridges and groves. With age, these ridges and grooves begin to smooth out, with the surface eventually depressing and possibly becoming pitted or porous. This feature was scored on a scale of 1 to 5 depending on the topography present.

Ventral Bevelling: Ventral bevelling occurs along the ventral/anterior margin of the pubic symphysis. It can be described as a 'slant' along the ventral margin. It was scored on a scale of 1 to 4 where 1 indicates no ventral bevelling and 4 indicates a clear and more pronounced bevel along the ventral margin.

Ossific Nodules: Ossific nodules are defined as lumps of bone formation found on the pubic symphysis. This feature was scored on a scale of 1 to 3. If no ossific nodules were present a score of 1 would have been given whereas a score of 3 would indicate the presence of ossific nodules.

Extremities: The upper and lower borders of the pubic symphysis are referred to as the extremities. No clear definition of the extremities is present in young individuals, however, with age these extremities become more pronounced and clearly defined. A clearly defined extremity is characterised by an elevated rim along the upper and lower extremities. These features were scored on a scale of 1 to 4 where 1 indicates no upper or lower extremity and 4 indicates clearly defined extremities.

Dorsal Plateau: The dorsal plateau forms along the dorsal/posterior margin of the pubic symphysis. The ridges and grooves begin to smooth out along the dorsal aspect resulting in a dorsal plateau. This feature was scored on a scale of 1 to 3. A score of 1 indicated no signs of the dorsal plateau and 3 a complete distinct dorsal plateau with a clear distinction between the dorsal and ventral margins.

Ventral Rampart: The ventral rampart is identifiable as a distinct outgrowth of bone along the ventral/anterior aspect of the pubic symphysis. This feature was scored on a scale of 1 to 3. If the ventral rampart was in the beginning phases a score of 1 was given. A complete ventral rampart was given a score of 3. It is important to note that a hiatus may be present and should not be confused as an incomplete ventral rampart.

Symphyseal Rim: The symphyseal rim is characterised by an elevated border/rim that forms along the outer edges of the pubic surface. Once completely formed, the syphyseal rim will then begin to erode. This feature was scored on a scale of 1 to 5. A score of 1 indicates no symphyseal rim whereas a score of 5 indicates the presence of the rim but with erosion along the margins.

Lipping: Lipping refers to the ‘extension’ of bone along the dorsal/posterior margin of the pubic symphysis. It was scored on a scale of 1 to 3 where 1 indicates no lipping and 3 indicates moderate lipping.

Ligamentous Outgrowths: Ligamentous outgrowths are characterised by bony extensions along the ventral/posterior margin of the pubic symphysis. It was scored on a scale of 1 to 4 depending on the presence and extent of the ligamentous outgrowths with a score of 1 indicating no outgrowths and 4 indicating pronounced outgrowths.

Pubic Tubercle: This refers to the formation of the pubic tubercle seen with age. In younger individuals the pubic tubercle is not yet fully fused or present. With age however, this feature begins to form and eventually separates form the pubic symphysis. This feature was scored on a scale of 1 to 3. If no pubic tubercle was present a score of 1 is given. If the pubic tubercle is fully separated from the pubic symphysis than a score of 3 is given.

3.1.2. The auricular surface

As stated before (Literature Review, p.24-25), not only does the revised method for estimating age from the auricular surface as described by Buckberry and Chamberlain (2002) provide better correlations to age, but it is also easier to apply (Buckberry and Chamberlain, 2002). Auricular surfaces were scored according to descriptions stipulated by Buckberry and Chamberlain (2002) which are as follows:

Transverse Organization: Transverse organization refers to the amount of horizontally organized billows and straie that run transversely along the auricular surface. Depending on the percentage of transverse organization found on the auricular surface, a score on a level from 1 to 5 was allocated. A score of 1 indicated 90% or more of the surface is transversely organized and a score of 5 indicating no transverse organization (Figure 7).

Surface Texture: Surface texture refers to the ‘grain’ of the auricular surface, whether it is finely grained as seen in younger individuals or if the grain is coarser as seen in older individuals. Again, this feature was scored in terms of the percentage of the auricular surface affected. There are three types of texture: finely granular, coarsely granular or dense. Finely granular bone has grains that are less than 0.5mm in diameter, whereas, coarsely granular bone has grains that is more than 0.5mm in diameter. Dense bone can be defined as areas indicative of smooth or compact bone. Surface texture was scored on a level from 1 to 5, where 1 indicates 90% or more of the surface to be finely grained and 5 indicating 50% or more of the surface having dense bone.

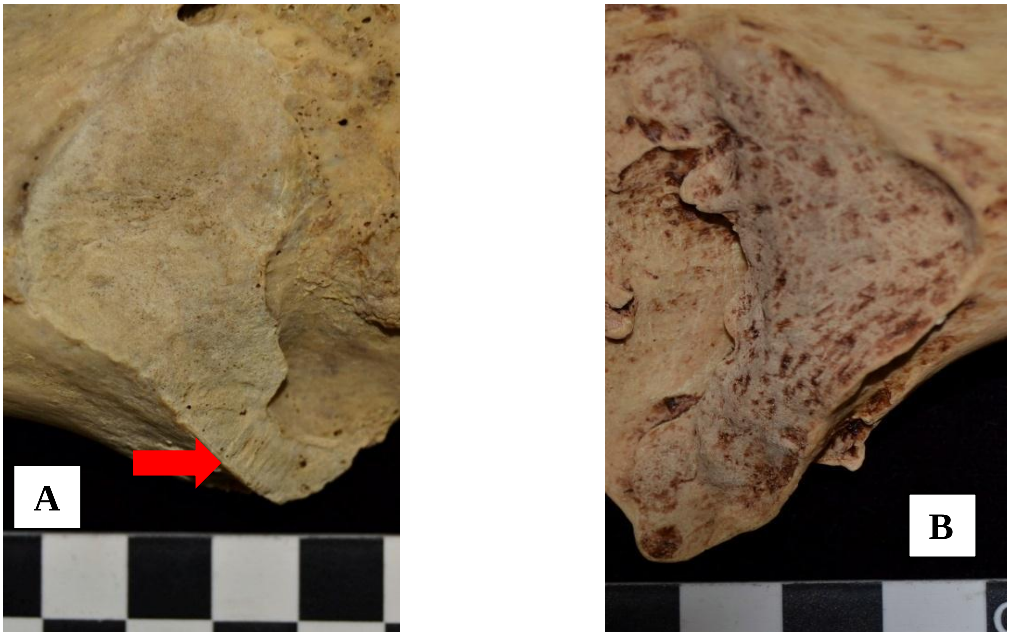

Figure 7: Figure A illustrates transverse organization (red arrow) found on a right female auricular surface in the current study. Figure B illustrates no transverse organization on a left female auricular surface in the current study

Microporosity: Microporosity refers to the porosity of the bone surface and is indicative of pores having a diameter of less than 1mm. This feature may be localized or spread over large areas. It was scored on a level from 1 to 3, with 1 indicating no microporosity and 3 indicating microporosity on both demifaces. The demifaces can be described as the auricular areas above and below the apex (Buckberry and Chamberlain, 2002).

Macroporosity: Macroporosity is similarly defined but the pore have a diameter of more than 1mm. As with microporosity, this feature may be localized or spread over large areas. It was scored on a level from 1 to 3, with 1 indicating no macroporosity and 3 indicating macroporosity on both demifaces (Figure 8). It is important to note that this feature must not be confused with cortical defects on the auricular surface. Cortical defects occur where certain areas of the cortex are incomplete and are usually identifiable by the smooth edges. One must also keep in mind postmortem damage, where the edges are sharp and often irregular.

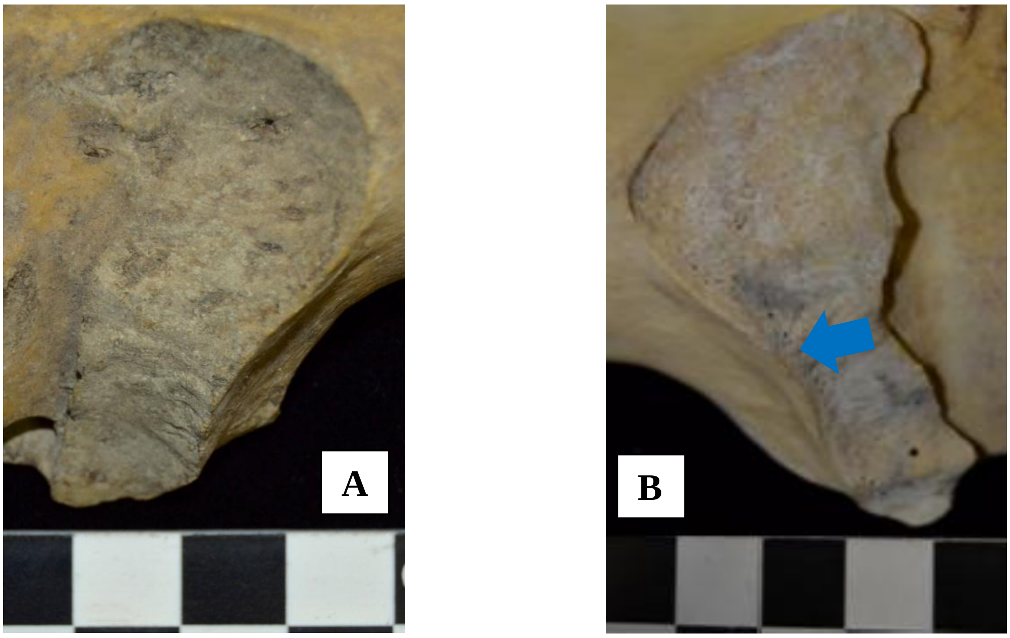

Figure 8: Figure A illustrates a left male auricular surface with no signs of porosity. Figure B illustrates macroporosity (blue arrow) found on a right female auricular surface in the current study

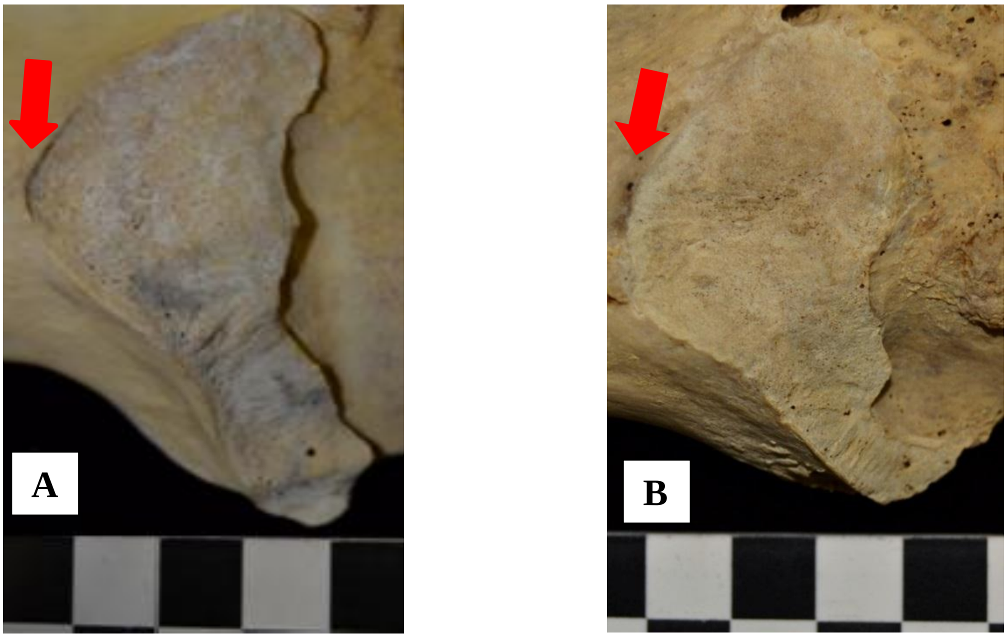

Figure 9: Figure A represents a right female auricular surface indicating a sharp, distinct apex (red arrow) in the current study. Figure B represents a right female auricular surface indicating an irregularly shaped apex (red arrow) in the current study

Apical Changes: The last feature assessed was apical changes within the auricular surface. This refers to the contour of the apex of the auricular surface and was scored on a level from 1 to 3 where 1 indicated a sharp and distinct apex and 3 indicated an irregularly shaped apex (Figure 9).

Table 3: The scoring system of each variable for the auricular surface as stipulated by Buckberry and Chamberlain (2002)

Variable	Score	Description
Transvers Organization	1	90% or more of the surface is transversely organized
	2	50–89% of the surface is transversely organized
	3	25- 49% of the surface is transversely organized
	4	<25% of the surface is transversely organized
	5	No signs of transverse organization
Surface Texture	1	90% or more of the surface is finely granular
	2	50-90% of the surface is finely granular, coarsely granular bone can replace some areas, no dense bone present
	3	50% or more of the surface is coarsely granular with no signs
	4	of dense bone
	5	<50% of surface has dense bone
		>50% of surface has dense bone
Microporosity	1	No signs of micporosity
	2	One demiface has signs of microporosity
	3	Both demifaces have signs of microporosity
Macroporosity	1	No signs of macporosity
	2	One demiface has signs of macroporosity
	3	Both demifaces have signs of macroporosity
Apical Changes	1	Sharp and distinct apex, a slightly raised auricular surface may occur relative to adjacent bone
	2	Distinct and smooth shape with some lipping at the apex, the outline of the apex is a continuous arc
	3	Irregular shape of contours, no longer a smooth arc

Once each of the 5 features were allocated a score, the scores were added together to form a composite score. The full descriptions and scoring system of the above features as stipulated by Buckberry and Chamberlain (2002) are represented in Table 3. The age ranges corresponding with each composite score can be seen in Table 4 below.

Table 4: Composite scores as calculated by Buckberry and Chamberlain (2002) with corresponding age ranges

Composite Score	Stage	Age Range
5 – 6	I	16 – 19
7 – 8	II	21 – 38
9 – 10	III	16 – 65
11 – 12	IV	29 – 81
13 – 14	V	29 – 88
15 – 16	VI	39 – 91
17 -19	VII	53 – 92

3.2. Statistical analysis

All statistical analyses were performed on SPSS for Windows version 20.0. All graphs were constructed using Office Excel 2010. In order to determine the intra- and inter-observer errors, both the Suchey-Brooks method (1990) and the revised Buckberry and Chamberlain method (2002) were reapplied to 20 random samples. The level of reproducibility was then calculated using Lin's Concordance Correlation Coefficient (Lin, 1989). This was done for both the pubic symphysis and the auricular surface. Following this, a Shapiro-Wilk test for normality was performed on the raw data. As the data was not normally distributed, nonparametric statistical tests were selected for analyses.

Male and female, left and right sides of both the pubic symphysis and the auricular surface were analysed separately. Descriptive statistics, which included the minimum and maximum age, mean age, standard deviation and mode, were calculated for each feature of both the pubic symphysis and the auricular surface. Following the descriptive statistics, a Wilcoxon Signed Rank test was performed in order to determine whether any differences existed between males and females as well as left and right pubic symphyses and auricular surfaces. A p value of more than 0.05 indicated no statistically significant difference between the sexes or the sides.

In order to test the accuracy of each method, inaccuracy and bias were calculated. This was done for males, females as well as left and right sides of the pubic symphysis and the auricular surface. Inaccuracy is described as the mean absolute difference between the age-at-death and the estimated age (Meindl *et al.*, 1985). Whereas, bias is described as the under- or overestimation in an age group. A low bias is desirable (Meindl *et al.*, 1985). For comparison purposes, individuals were grouped according to age ranges of 10 year intervals. Inaccuracy and bias are calculated as follows:

Accuracy:

$$\frac{\sum |\text{estimated age} - \text{age at death}|}{\text{n}}$$

Bias:

$$\frac{\sum (\text{estimated age} - \text{age at death})}{\text{n}}$$

In order to test the strength of the relationship between each feature and the estimated age, a Spearman's Correlation Coefficient was used. Each of the 10 selected features of the pubic symphysis was correlated against age-at-death, for males and females as well as left and right sides. Similarly, each feature for the auricular surface as well as composite scores, were correlated to age-at-death for males and females and left and right sides. Any p-values which were higher than 0.05 indicated no statistically significant correlation to age estimation.

Furthermore, in order to define the nature of the relationship within the set of variables and age, a Principal Component Analysis (PCA) was performed. A PCA is a dimension-reduction tool that is used to reduce a large set of variables to a small set of variables while still retaining most of the information on the large set (Harris, 1975). PCA describes the maximum possible variance within a sample (Harris, 1975). A PCA extracts variables that have the highest loading on a principal component. In the present study, PCA was used to extract principal components (PC1, PC2 PC3 and so on) and was then followed by a varimax rotation. Varimax rotation maximizes the variance of the squared loadings of a factor on all the variables in a factor matrix.

Each factor will have either large or small loadings for any particular variable. A varimax solution produces results which make it as easy as possible to identify each variable with a single factor (Harris, 1974). This is the most commonly used rotation.

As mentioned above, principal components are extracted to represent the variables which have the highest loading in the sample. The first principal component (PC1) accounts for as much of the variability in the data set as possible while principal components PC2, PC3 and so on, account for as much of the remaining variability as possible (Harris, 1975). PCA calculates communalities as well as correlation coefficients. In some cases, a variable may result in a negative loading on a principal component. A negative loading only indicates the position on the axes. Therefore, a variable can be negative but still have a high loading on that principal component. Communalities measure the percent of variance in a certain variable explained by the factors combined and can be described as the reliability of the variable (Harris, 1975). Correlation coefficients describe the factor loading between the variables and the factor (Harris, 1975). Analogous to Pearson's Correlation Coefficient, the squared factor loading is the percentage of variance in that r variable explained by the factor (Harris, 1975).

CHAPTER 4: RESULTS

A number of statistical analyses were performed for the following study. Chapter 4 has been divided into four major sections. The first and second sections include the age distribution of the sample and differences found between males and females and left and right sides. The last two sections describe the descriptive statistics and correlations as well as PCA for the pubic symphysis and the auricular surface, separately.

In order to test the repeatability of both methods, the principle investigator as well as an independent observer re-applied the Suchey-Brooks method (1990) for the pubic symphysis and the revised Buckberry and Chamberlain method (2002) for the auricular surface to 20 randomly selected specimens. Table 5 below describes inter- and intra-observer errors for the following study. Results indicated a moderate to high level of repeatability with the left pubic symphysis having the highest level of intra-repeatability (Pc = 0.829). Intra-observer repeatability was slightly better than inter-observer repeatability, except for the aging of the auricular surface on the right side. Left pubic symphyses and auricular surfaces indicated slightly higher levels of repeatability than the right sides. Furthermore, results indicated a greater level of repeatability for left and right pubic symphyses compared to the left and right auricular surfaces.

Table 5: A Lin's Concordance Correlation Coefficient (Pc) for the assessment of inter- and intra-observer errors for the aging from the pubic symphyses and auricular surfaces (n=20)

Skeletal Element	Inter-observer error	Intra-observer error
Pubic Symphysis		
Left	0.791	0.829
Right	0.746	0.804
Auricular Surface		
Left	0.684	0.718
Right	0.655	0.632

As mentioned above, the pubic symphysis and auricular surface were analysed separately. For each skeletal element, age distributions for age-at-death, descriptive statistics, inaccuracy and bias, correlations and principal component analyses (PCA) were calculated.

4.1. Age distribution

Table 6 and Figure 10 below illustrate the descriptive statistics and age distributions for age-at-death for males and females. When looking at Figure 10, it can be seen that males represented predominantly younger individuals and older individuals, whereas, females consisted mainly of middle aged individuals. It can also be seen from Figure 10 that the age-at-death distribution is not normally distributed and this is further supported by the Shapiro-Wilk test for normality ($p > 0.05$). The age distributions shown in Figure 10 represent the recorded ages of the individuals from the Raymond A. Dart collection.

Looking at the total sample, which includes males and females, age-at-death ranged between 16 and 87 years of age, with a mean age of 43.99 ± 16.22 years. When separated into males and females, means ranged from 43.94 ± 16.09 years and 44.04 ± 16.44 years for males and females respectively (Table 6). Age-at-death refers to the recorded ages from the Raymond A. Dart collection, whereas estimated age refers to age that was estimated by the researcher. Ages that were estimated according to the auricular surface and pubic symphysis, ranged from 17.5 to 73 years. It must be kept in mind that age estimations between left and right sides may have differed, therefore it was necessary to determine mean and standard deviations for both sides for each method. This explains the increase in sample sizes when looking at estimated age in Table 6. The auricular surface resulted in slightly greater mean ages of 52.15 ± 10.21 years and 48.34 ± 12.50 years for females and males respectively when compared to mean ages of the pubic symphysis (47.22 ± 12.37 years and 39.53 ± 12.37 years for females and males respectively). Standard deviations for age-at-death were higher than those for estimated age.

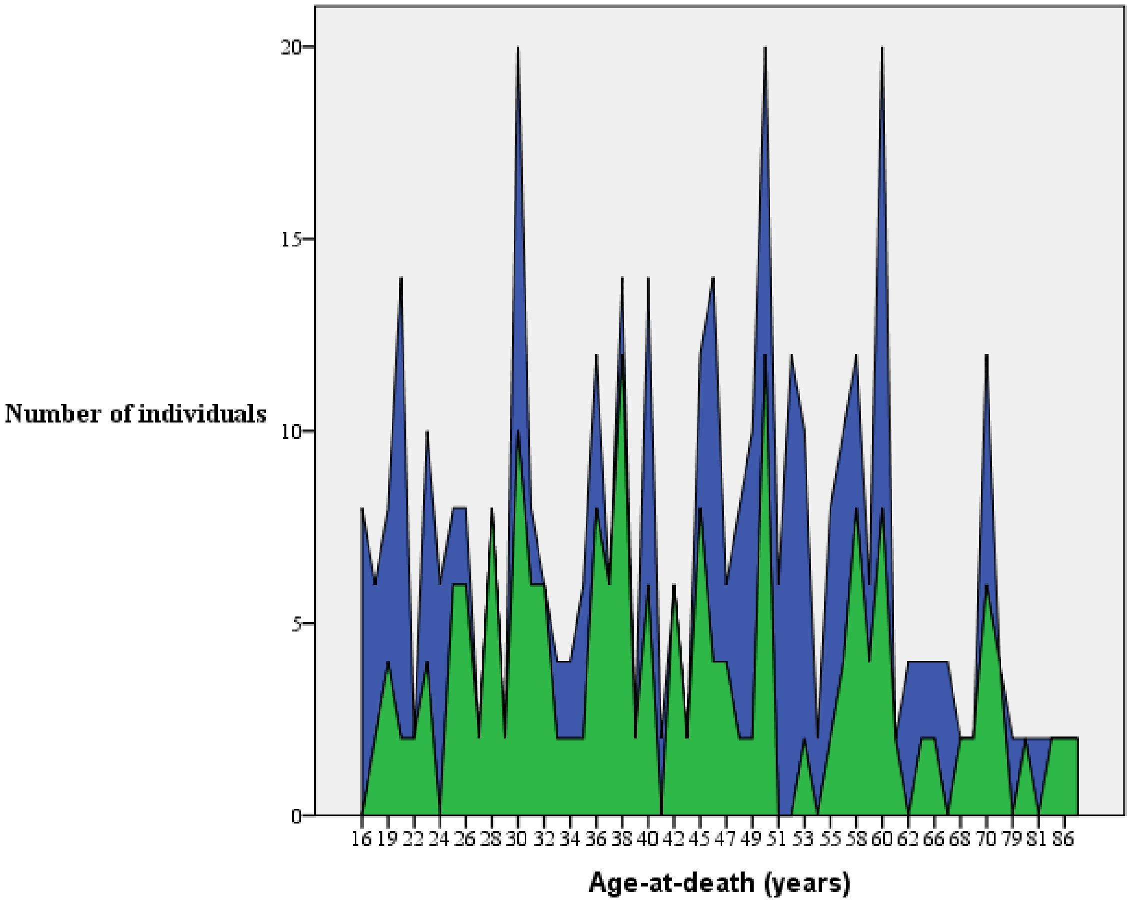

Figure 10: A stacked area graph representing the number of individuals and age-at-death distribution for males (blue) and females (green)

Table 6: Age-at-death and estimated age distributions for the sample

Sex	Method	Group	*n*	Minimum Age	Maximum Age	Mean Age	SD*
Female		Age-at-death	98	18	87	44.04	16.44
	Auricular Surface	Estimated Age	196	17.5	73	52.15	10.21
	Pubic Symphysis	Estimated Age	196	19.5	64.5	47.22	12.37
Male		Age-at-death	99	16	81	43.94	16.09
	Auricular Surface	Estimated Age	198	17.5	72.5	48.34	12.50
	Pubic Symphysis	Estimated Age	198	19	60	39.53	12.37
Total Sample		Age-at-death	197	16	87	43.99	16.22

*SD, Standard Deviation

4.2. Differences between sexes and sides

In order to determine whether any differences exist between sexes and sides of both the pubic symphysis and the auricular surface, a Wilcoxon Sign Ranked test was performed. A p-value of 0.05 or less indicated a statistically significant difference.

4.2.1. Pubic symphysis

Differences between each of the 10 variables i.e. surface appearance, ventral bevelling, ossific nodules etc. as listed in Table 1 (p.36), were tested using the above statistical test. Table 7 describes differences between male and female pubic symphyses as well as left and right sides. It must be kept in mind that age-at-death distributions differed slightly between males and females, however, it was still necessary to further establish whether any differences existed between the features and the sexes.

Table 7: Wilcoxon sign ranked test to assess differences between sexes, male left and right sides and female left and right sides for the pubic symphysis

Variables	Sexes	Male sides	Female sides
Surface appearance	0.250	0.053	0.412
Ventral bevelling	0.207	0.080	0.054
Ossific nodules	0.921	0.194	0.001*
Extremities	0.676	0.278	0.569
Dorsal Plateau	0.210	0.361	0.035*
Ventral Rampart	0.330	0.218	0.888
Symphyseal Rim	0.303	0.749	0.805
Lipping	0.527	0.385	0.009*
Ligamentous outgrowths	0.265	0.577	0.992
Pubic tubercle	0.361	0.121	0.340

*Significant at level $p = 0.05$

No statistically significant differences were observed between the sexes ($p > 0.05$). Although, no statistically significant differences were found between males and females, the separation between the sexes was done in order to assess whether any differences might exist between left and right sides in each sex. However, when sexes were separated according to sides, males revealed no significant difference, whereas females resulted in a statistically significant difference between left and right sides with regards to ossific nodules (p = 0.001), dorsal plateau (p = 0.035) and lipping (p = 0.009).

4.2.2. Auricular surface

Table 8 describes significant differences for each variable between males and females and left and right auricular surfaces. Statistically significant differences were found between the sexes with regards to transverse organization (p = 0.001), macroporosity (p = <0.001), apical changes (p = 0.042) as well as composite scores (p = 0.003). When separated into left and right sides, both males and females revealed no significant difference except for apical changes in females (p = 0.041). Again, age distribution between males and females must be kept in mind as with the pubic symphysis.

Table 8: Wilcoxon signed rank test to assess differences between sexes, male left and right sides and female left and right sides for the auricular surface

Variables	Sexes	Male sides	Female sides
Transverse organization	0.001*	0.535	0.294
Surface texture	0.394	0.857	0.572
Microporosity	0.400	0.998	0.732
Macroporosity	<0.001*	0.808	0.640
Apical Changes	0.042*	0.987	0.041*
Composite scores	0.003*	0.585	0.866

*Significant at level p = 0.005

4.3. Pubic symphysis

4.3.1. Descriptive statistics

As the sample represents categorical data, due to the "scoring system" applied when estimating age from the pubic symphysis, mode was calculated for the descriptive statistics. Table 9 describes the mode for each individual variable between female left and right sides and male left and right sides. Results revealed that the mode for females was generally the same as those for male. However, exceptions can be seen for left female surface appearance, symphyseal rim and ventral bevelling as well as right male ventral bevelling. These central tendencies or modes were higher than their respective sides (Table 9).

Table 9: Descriptive statistic (mode) for each variable for the pubic symphysis

Variables	Female		Male	
	Left	Right	Left	Right
Sample Size (*n*)	98	98	99	99
Surface Appearance	3	4	4	4
Ventral Bevelling	2	1	1	4
Ossific Nodules	1	1	1	1
Extremities	4	4	4	4
Dorsal Plateau	3	3	3	3
Ventral Rampart	3	3	3	3
Symphyseal Rim	1	3	3	3
Lipping	1	1	1	1
Ligamentous Outgrowths	1	1	1	1
Pubic Tubercle	3	3	3	3

4.3.2. Inaccuracy and bias

Table 10 describes the inaccuracy and bias for estimated ages from the pubic symphysis for males and females, left and right sides as well as for a sample of pooled sexes. In the following table, "*n*" refers to the number of individuals falling within the allocated age range. Inaccuracy refers to the mean absolute difference between the age-at-death and the estimated mean age, while bias describes the under- or overestimation of age for each of the age groups.

4.3.2.1. Females versus males

In general, ages of individuals younger than 50 years were overestimated and ages of individuals older than 50 years were underestimated, except for individuals aged 70 to 79 years where an overestimation occurred. However, an underestimation of age was observed for male individuals aged 40 to 49 years. Females aged 20 to 49 years resulted in higher bias scores than males of the same age group. However, males aged 50 years and older indicated higher inaccuracy and bias than females of the same age group. Males in the youngest age group (15 to 19 years) revealed higher inaccuracy and bias scores than females aged 15 to 19 years (Table 10). In females, the youngest age group (15 to 19 years) showed the lowest bias (0.8), whereas, in males, the lowest bias (-5.1 years) was found in individuals aged 40 to 49 years (Table 10). A very high bias score (-34.5 years was observed in males aged 80 to 89 years. This suggests that individuals in this age group are underestimated by 35 years. Females of the same age group resulted in an underestimation of 24 years. In general, pooled sexes resulted in lower inaccuracies and bias for individuals aged 20 to 49 years when compared to females and for individuals aged 15 to 19 years and 40 years onwards when compared to males. An increase in inaccuracy and bias can be seen from 40 years onwards when sexes are pooled (Table 10). However, these values are lower than individual male values for the same ages.

4.3.2.2. Left versus right

Although no differences between left and right male pubic symphyses were observed, significant differences were found between left and right female pubic symphyses. Thus, it was deemed important to distinguish between left and right sides of the pubic symphysis. When separated into left and right sides (Table 10), inaccuracy and bias values became comparable. Overestimation occurred in younger individuals (15 to 39 years) and underestimation occurred in middle aged and older individuals (40 to 89 years) when age was estimated for left pubic symphyses. When age was estimated for right pubic symphyses, overestimation occurred in individuals aged 15 to 49 years and underestimation occurred in individuals aged 50 to 89 years. The lowest inaccuracy and bias values were observed in individuals aged 40 to 49 years with values of 7.6 and -0.4 years and 7.4 and 1.5 years for left and right sides respectively (Table 10). When all the age groups were grouped together, age was underestimated for the left and right sides (-0.6 and -0.7 years for left and right sides respectively). Individuals aged 80 to 89 years revealed the highest inaccuracy and bias values. The highest bias value (-29.5) was found in individuals aged 80 to 89 years for the left pubic symphysis (Table 10), which suggests an underestimation of age by as much as 29 years.

Table 10: Inaccuracy and bias (years) for age estimation from the pubic symphysis in female, males, left and right sides as well as pooled sexes

Age-at-death (years)	Females	Males	Left	Right	Pooled sexes
15-19					
n	6	16	11	11	22
Inaccuracy	0.8	12.4	9.2	9.2	9.2
Bias	0.8	12.4	9.2	9.2	9.2
20-29					
n	32	28	30	30	60
Inaccuracy	10.8	7.9	10.4	8.9	9.6
Bias	10.9	6.6	9.6	8.1	8.7
30-39					
n	56	26	41	41	82
Inaccuracy	10.2	7.1	9.3	9.1	9.2
Bias	9.7	5.3	8.6	7.8	8.3
40-49					
n	34	40	37	37	74
Inaccuracy	9.7	5.9	7.6	7.4	7.6
Bias	6.9	-5.1	-0.4	1.5	0.5
50-59					
n	32	54	43	43	86
Inaccuracy	9.4	11.4	11.1	10.3	10.7
Bias	-1.1	-9.6	-6.3	-6.7	-6.5
60-69					
n	18	24	21	21	42
Inaccuracy	9.7	16.1	13.7	13.0	13.4
Bias	-8.4	-16.1	-12.9	-12.7	-12.8
70-79					
n	10	8	9	9	18
Inaccuracy	13.6	26.4	18.3	20.2	19.3
Bias	-13.6	-26.4	-18.3	-20.2	-19.3
80-89					
n	8	2	5	5	10
Inaccuracy	24.1	34.5	29.5	22.9	26.2
Bias	-24.1	-34.5	-29.5	-22.9	-26.2
All ages					
n	196	198	197	197	394
Inaccuracy	10.5	10.7	10.9	10.3	10.6
Bias	3.3	-4.4	-0.6	-0.7	-0.5

4.3.3. Correlations

To determine correlations between each variable of the pubic symphysis and age, a Spearman's Rank Correlation Coefficient was used. Both males and females as well as left and right pubic symphysis were analysed. Each feature was analysed against the age-at-death of the individual as recorded in the Raymond A. Dart Collection of Human Skeletons. This was done in order to determine which variable produced the best correlations to age-at-death. Table 11 describes the r-values as well as the p-values for these correlations for both females and males. A p-value higher than 0.05 indicated no statistically significant correlation to age.

4.3.3.1. Females

All variables, except for ventral bevelling, ossific nodules and right lipping, resulted in a statistically significant positive correlation ($p<0.05$) to age-at-death. The strengths of these positive significant correlations (r) ranged from a weak to moderate correlation (0.217 to 0.652) (Table 11). The surface appearance of the right pubic symphysis had the strongest correlation to age-at-death ($r = 0.652$), whereas, the weakest correlation was found to be ligamentous outgrowths of the right pubic symphysis to age-at-death ($r = 0.217$) (Table 11). In most cases, the right pubic symphyses revealed slightly stronger correlations to age-at-death than the left pubic except for extremities and ligamentous outgrowths.

4.3.3.2. Males

All variables for the pubic symphysis, except ventral bevelling, were statistically significantly correlated to age-at-death ($p<0.05$) (Table 11). Similar to females, the correlation coefficient (r) ranged from weak correlations to moderate correlations (0.291 to 0.658). Again, right pubic symphyses displayed stronger correlations than the left sides (Table 11). Although ossific nodules indicated a weak statistically significant correlation (-0.357 and -0.367 for left and right sides respectively), this variable had a negative correlation to age-at-death. Once more, the surface appearance of the right pubic symphysis revealed the strongest correlation to age-at-death (r = 0.658) whereas ligamentous outgrowths of the left pubic symphysis resulted in the weakest correlation to age-at-death (r = 0.291).

Table 11: Spearman's Rank Correlation Coefficients for female left and right pubic symphyses and male left and right pubic symphyses variables and age-at-death

Variable	Statistics	Female		Male	
		Left	Right	Left	Right
Surface Appearance	r value	0.636	0.652	0.505	0.658
	p value	<0.001*	<0.001*	<0.001*	<0.001*
Ventral Bevelling	r value	-0.053	-0.033	0.081	-0.112
	p value	0.603	0.744	0.426	0.269
Ossific Nodules	r value	-0.132	-0.022	-0.357	-0.367
	p value	0.194	0.831	<0.001*	<0.001*
Extremities	r value	0.594	0.541	0.457	0.613
	p value	<0.001*	<0.001*	<0.001*	<0.001*
Dorsal Plateau	r value	0.402	0.561	0.465	0.546
	p value	<0.001*	<0.001*	<0.001*	<0.001*
Ventral Rampart	r value	0.529	0.563	0.454	0.551
	p value	<0.001*	<0.001*	<0.001*	<0.001*
Symphyseal Rim	r value	0.598	0.601	0.474	0.632
	p value	<0.001*	<0.001*	<0.001*	<0.001*
Lipping	r value	0.430	0.188	0.426	0.450
	p value	<0.001*	0.064	<0.001*	<0.001*
Ligamentous Outgrowths	r value	0.247	0.217	0.291	0.342
	p value	0.014*	0.032*	0.004*	0.001*
Pubic Tubercle	r value	0.486	0.504	0.526	0.622
	p value	<0.001*	<0.001*	<0.001*	<0.001*

*Significant at level p = 0.05

Scatter plots have been given to visually represent the correlations between each of the variables of the pubic symphysis and age-at-death. The right sides were selected as these indicated stronger correlations than the left sides for both males and females (Figure 11 to Figure 30). As can be seen from the scatter plots below, all variables except for right female ossific nodules and lipping and both right female and male ventral bevelling were not correlated to age-at-death. Most correlated variables had a positive correlation except for ossific nodules in males (Figure 16) which indicated a negative correlation to age-at-death. The strengths of the correlations are comparable between males and females. Males presented stronger correlations to age-at-death with regards to surface appearance, ossific nodules, extremities, symphyseal rim, lipping, ligamentous outgrowths and pubic tubercle (Figures 12, 16, 18, 24, 26, 28 and 30) than did females. However, the dorsal plataue and ventral rampart presented a stronger correlation to age-at-death in females (Figure 19 and Figure 21).

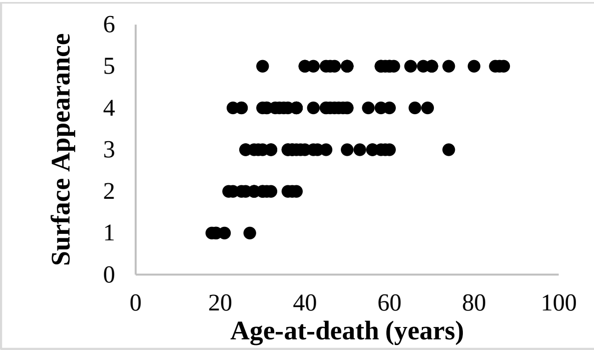

Figure 11: Scatter plot representing the correlations between surface appearance and age-at-death for the right female pubic symphyses (r = 0.652; p = <0.001)

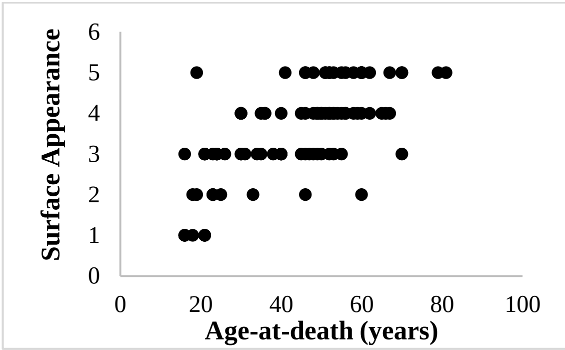

Figure 12: Scatter plot representing the correlations between surface appearance and age-at-death for the right male pubic symphyses (r = 0.658; p = <0.001)

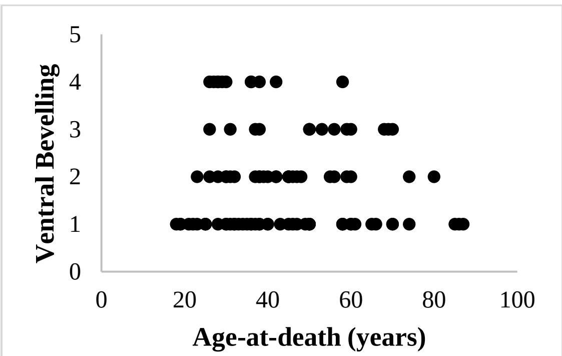

Figure 13: Scatter plot representing the correlations between ventral bevelling and age-at-death for the right female pubic symphyses (r = -0.033; p = 0.744)

Figure 14: Scatter plot representing the correlations between ventral bevelling and age-at-death for the right male pubic symphyses (r = -0.112; p = 0.269)

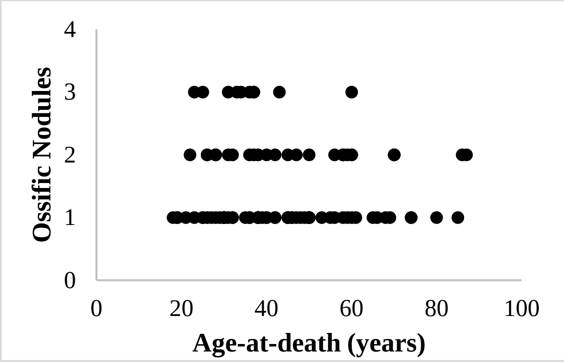

Figure 15: Scatter plot representing the correlations between ossific nodules and age-at-death for the right female pubic symphyses (r = -0.022; p = 0.831)

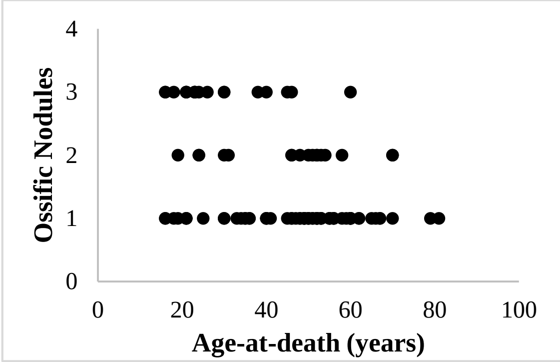

Figure 16: Scatter plot representing the correlations between ossific nodules and age-at-death for the right male pubic symphyses (r = -0.367; p = <0.001)

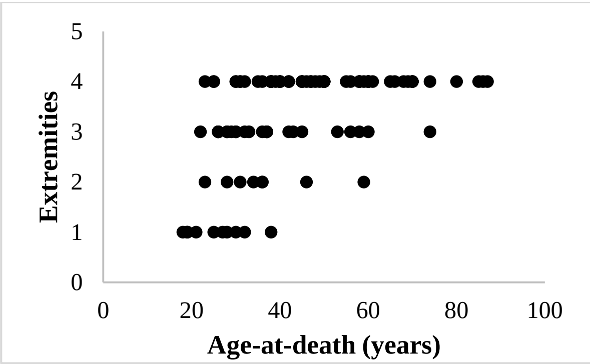

Figure 17: Scatter plot representing the correlations between extremities and age-at-death for the right female pubic symphyses (r = 0.541; p = <0.001)

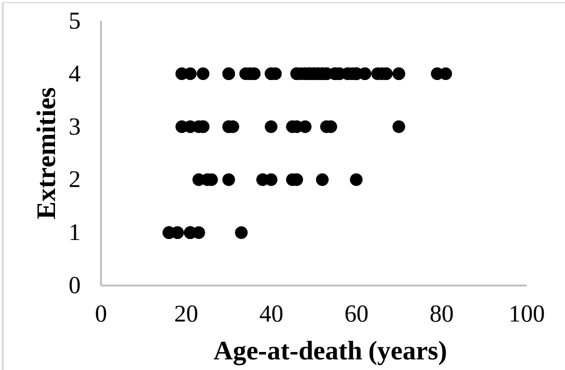

Figure 18: Scatter plot representing the correlations between extremities and age-at-death for the right male pubic symphyses (r = 0.613; p = <0.001)

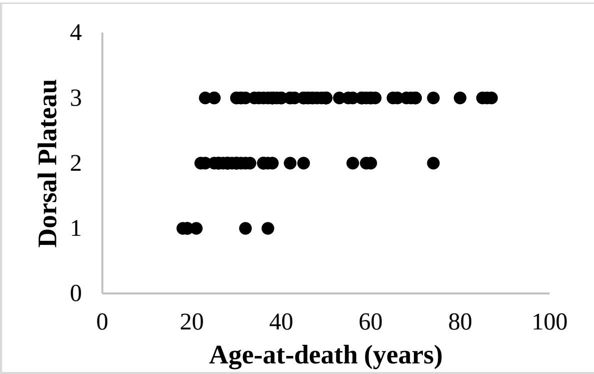

Figure 19: Scatter plot representing the correlations between dorsal plateau and age-at-death for the right female pubic symphyses (r = 0.561; p = <0.001)

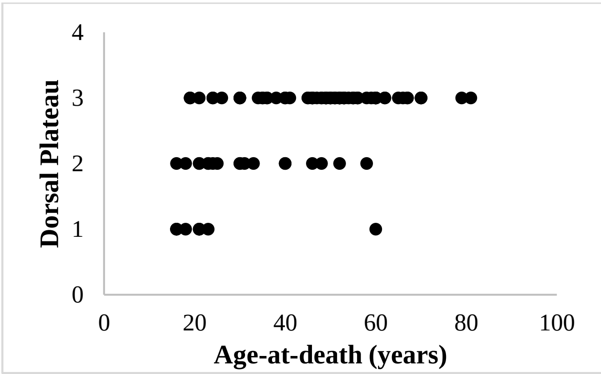

Figure 20: Scatter plot representing the correlations between dorsal plateau and age-at-death for the right male pubic symphyses (r = 0.546; p = <0.001)

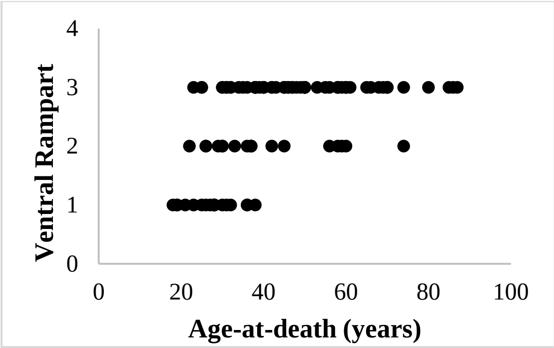

Figure 21: Scatter plot representing the correlations between ventral rampart and age-at-death for the right female pubic symphyses (r = 0.563; p = <0.001)

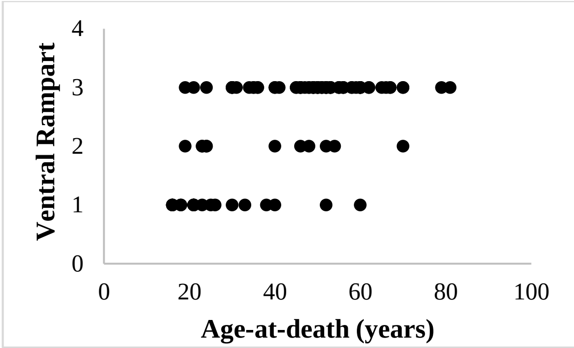

Figure 22: Scatter plot representing the correlations between ventral rampart and age-at-death for the right male pubic symphyses (r = 0.551; p = <0.001)

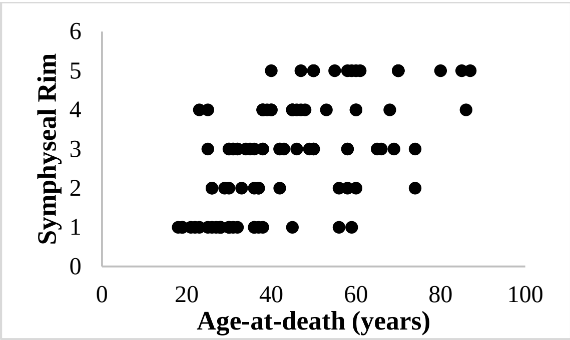

Figure 23: Scatter plot representing the correlations between symphyseal rim and age-at-death for the right female pubic symphyses (r = 0.601; p = <0.001)

Figure 24: Scatter plot representing the correlations between symphyseal rim and age-at-death for the right male pubic symphyses (r = 0.632; p = <0.001)

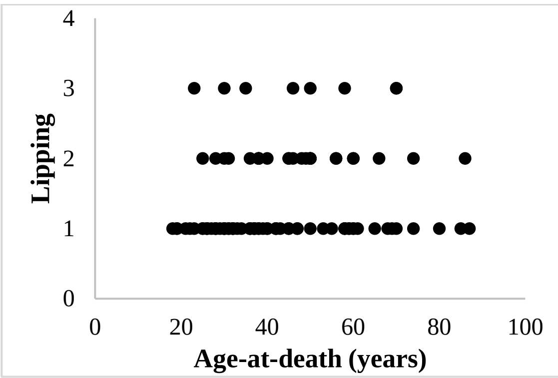

Figure 25: Scatter plot representing the correlations between lipping and age-at-death for the right female pubic symphyses (r = 0.188; p = 0.064)

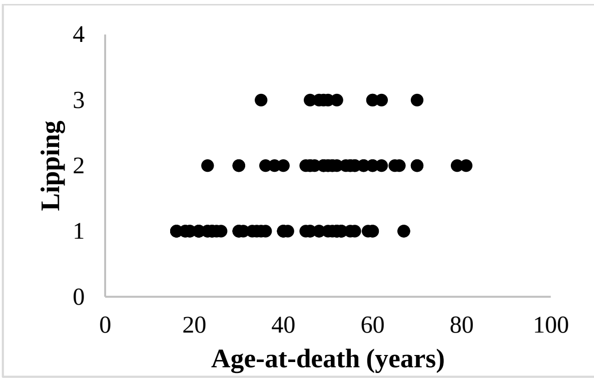

Figure 26: Scatter plot representing the correlations between lipping and age-at-death for the right male pubic symphyses (r = 0.450; p = <0.001)

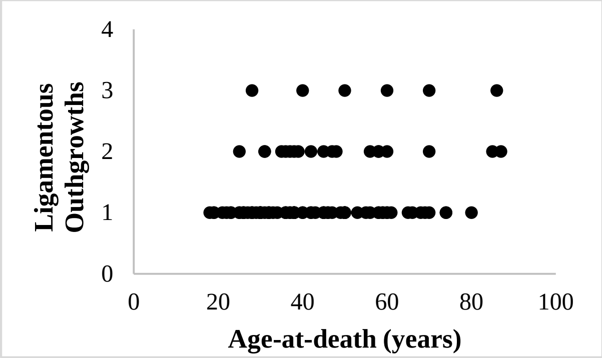

Figure 27: Scatter plot representing the correlations between ligamentous outgrowths and age-at-death for the right female pubic symphyses (r = 0.217; p = 0.032)

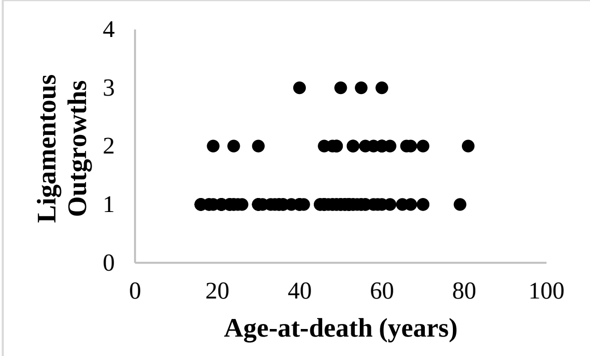

Figure 28: Scatter plot representing the correlations between ligamentous outgrowths and age-at-death for the right male pubic symphyses (r = 0.342; p = 0.001)

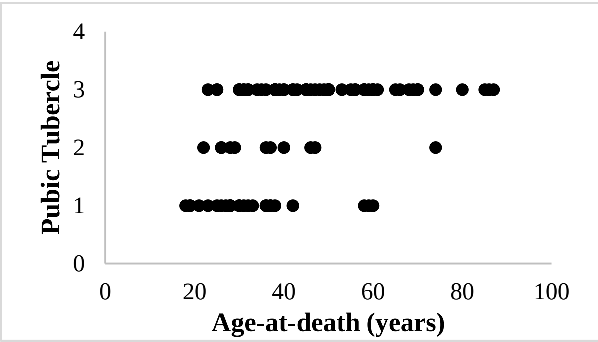

Figure 29: Scatter plot representing the correlations between pubic tubercle and age-at-death for the right female pubic symphyses (r = 0.504; p = <0.001)

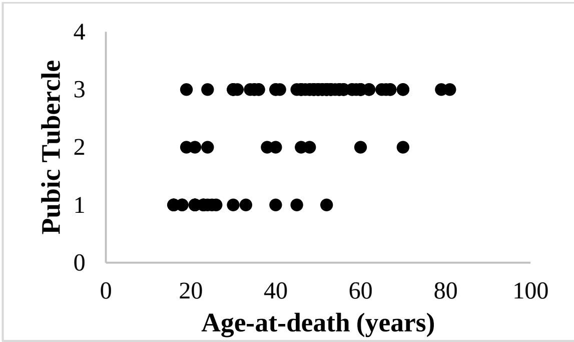

Figure 30: Scatter plot representing the correlations between pubic tubercle and age-at-death for the right male pubic symphyses (r = 0.622; p = <0.001)

4.3.4. Principal Component Analysis (PCA)

In order to define the nature of the relationship within the set of variables, a Principal Component Analysis (PCA) was performed. PCA was performed on both the left and right pubic symphyses for males and females. PCA was used to extract principal components (PC's) that have the highest loading in the set of variables. This means that the highest loading variable contributes to the most variation in that principal component. This was then followed by a varimax rotation which maximizes the sum of the variances of the squared loadings. The uniqueness of the coefficients derived in PCA is achieved by requiring a descending order of importance among the PCs (Harris, 1975). In other words, when interpreting PCA, one needs to select the variables which indicate the strongest correlation to each principal component i.e. PC1, PC2 and so on.

Tables 12-13 and Tables 14-15 below describes the percentage of variance accounted for in each principal component as well as the loadings of each variable for females and males respectively. Communalities describe how much of the variance in each of the original variables is explained by the extracted factors. Ultimately, one aims for high communalities however, communalities lower than 0.4 are considered low and should be excluded from the analyses (Stevens, 2009).

4.3.4.1. Females

The results for the PCA for left female pubic symphyses are represented in Table 12. Of all 10 original variables for left female pubic symphyses, only eight were included in the PCA. When PCA was run the first time, ventral bevelling and ossific nodules resulted in communalities lower than 0.4 and were therefore excluded from the analysis. Once the PCA was rerun excluding those two variables, two principal components were extracted (PC1 and PC2). Combined, PC1 and PC2 accounted for 76.72% of the total variance between the original variables and age estimation for the left female pubic symphyses. Variables and their corresponding factor loadings are represented in Table 12. A strong correlation to the principal components, is indicated by a value larger than 0.5. Extremities presented the highest communality which indicates that this variable accounted for the highest amount of variance explained by PC1, whereas, lipping had the lowest communality. PC1 was strongly correlated to 6 of the original variables. These included: the surface appearance, extremities, dorsal plateau, ventral rampart, symphyseal rim, and the pubic tubercle. The strongest correlations were found between the extremities (0.873) and PC1, followed by the ventral rampart (0.858) and the dorsal plateau (0.843). The strongest correlations between the original variables and

PC2 included: the symphyseal rim, lipping and ligamentous outgrowths. The strongest correlation was found between ligamentous outgrowths (0.891) and PC2.

Table 12: Principal Component Analysis for left female pubic symphyses

	Communalities	**PC1**	**PC2**
% variance accounted for		63.00	13.72
Surface Appearance	0.758	**0.747**	0.447
Extremities	0.851	**0.873**	0.299
Dorsal Plateau	0.713	**0.843**	-0.040
Ventral Rampart	0.817	**0.858**	0.285
Symphyseal Rim	0.808	**0.695**	**0.570**
Lipping	0.682	0.318	**0.762**
Ligamentous Outgrowths	0.801	0.077	**0.891**
Pubic Tubercle	0.708	**0.784**	0.305

Table 13 represents the results for the PCA for right female pubic symphyses. Ventral bevelling and lipping revealed communalities lower than 0.4 for the first PCA and were therefore excluded. Upon the exclusion of these two variables, two principal components were extracted (PC1 and PC2) and combined they accounted for 79.23% of the total variance. Variables and their corresponding factor loading can be seen in Table 13. The ventral rampart accounted for the highest amount a variance explained by PC1 and PC2 (0.913), whereas, ligamentous outgrowths account for the least amount of variance in the principal components (0.509) (Table 13). Variables indicating the strongest correlation to PC1 included: the surface appearance, extremities, dorsal plateau, ventral rampart, symphyseal rim and pubic tubercle. Furthermore, PC1 correlates most strongly with ventral rampart (0.957), dorsal plateau (0.916), extremities (0.913) and the pubic tubercle (0.903). PC2 correlates strongly with two of the original variables. These are ossific nodules and ligamentous outgrowths. Ossific nodules (0.777) revealed the strongest correlation with PC2.

Table 13: Principal Component Analysis for right female pubic symphyses

	Communalities	**PC1**	**PC2**
% variance accounted for		65.32	13.91
Surface Appearance	0.765	**0.886**	0.088
Ossific Nodules	0.664	-0.318	**0.777**
Extremities	0.826	**0.913**	0.027
Dorsal Plateau	0.820	**0.916**	0.018
Ventral Rampart	0.913	**0.957**	-0.044
Symphyseal Rim	0.789	**0.893**	0.034
Ligamentous Outgrowths	0.509	0.368	**0.700**
Pubic Tubercle	0.824	**0.903**	-0.086

4.3.4.2. Males

Results for the PCA for males are represented in Table 14 and Table 15 below. Two principal components (PC1 and PC2) were extracted for both left and right pubic symphyses. For left pubic symphyses, the combined principal components accounted for 70.57% of the total variance (Table 14) whereas, for right pubic symphyses, the combined principal components accounted for 75.68% of the total variance (Table 15).

For left male pubic symphyses, only the ossific nodules resulted in a communality of less than 0.4 and was therefore excluded. The highest amount of variance explained by the principal components was observed by the extremities (0.878). The least amount of variance was accounted by lipping (0.443). For left male pubic symphyses, PC1 indicated strong correlations to seven of the original variables. These included: the surface appearance, extremities, dorsal plateau, ventral rampart, symphyseal rim, lipping and pubic tubercle. Four of the variables had a strong correlation to PC1 and these were extremities (0.932), ventral rampart (0.928), pubic tubercle (0.907) and surface appearance (0.900). Only two variables were strongly correlated to PC2. These included ventral bevelling (-0.733) and ligamentous outgrowths (0.708). A negative value indicates the position of the PC on the axes.

Table 14: Principal Component Analysis for left male pubic symphyses

	Communalities	PC1	PC2
% variance accounted for		57.04	13.53
Surface Appearance	0.822	**0.900**	0.107
Ventral Bevelling	0.605	0.260	**-0.733**
Extremities	0.878	**0.932**	-0.098
Dorsal Plateau	0.550	**0.736**	-0.090
Ventral Rampart	0.865	**0.928**	-0.060
Symphyseal Rim	0.768	**0.817**	0.316
Lipping	0.443	**0.608**	0.270
Ligamentous Outgrowths	0.597	0.310	**0.708**
Pubic Tubercle	0.822	**0.907**	-0.011

For right male pubic symphyses, ventral bevelling was excluded from the PCA as it had a communality lower than 0.4. The ventral rampart accounted for the most variance in the principal components (0.882), whereas, the ossific nodules accounted for the least amount of variance (0.524).

Table 15: Principal Component Analysis for right male pubic symphyses

	Communalities	PC1	PC2
% variance accounted for		63.94	11.74
Surface Appearance	0.749	**0.808**	0.309
Ossific Nodules	0.524	**-0.720**	0.075
Extremities	0.857	**0.881**	0.282
Dorsal Plateau	0.780	**0.854**	0.224
Ventral Rampart	0.882	**0.895**	0.285
Symphyseal Rim	0.845	**0.788**	0.474
Lipping	0.654	0.207	**0.782**
Ligamentous Outgrowths	0.664	0.136	**0.804**
Pubic Tubercle	0.857	**0.885**	0.271

For the right male pubic symphysis, the variables which were strongly correlated to PC1 included surface appearance, ossific nodules, extremities, dorsal plateau, ventral rampart, symphyseal rim and pubic tubercle. The strongest correlation to PC1 was the ventral rampart (0.895), followed by the pubic tubercle (0.885), extremities (0.881), dorsal plateau (0.854), and the surface appearance (0.808). A negative correlation to PC1 (-0.720) was found in ossific nodules (Table 15). Lipping and ligamentous outgrowths were strongly correlated to PC2. The strongest correlation was found between ligamentous outgrowths and PC2 (0.804).

4.4. Auricular surface

4.4.1. Descriptive statistics

As mentioned before, due to the data being nonparametric, mode was calculated for the descriptive statistics (Table 16). This was done for female left and right auricular surfaces and male left and right auricular surfaces. In general, the modes or central tendencies for each variable were the same between left and right female auricular surfaces as well as for left and right male auricular surfaces. The only exception observed were for left female apical changes which was higher than right female apical changes (Table 16). The modes for composite scores differed slightly between left and right auricular surfaces for both females and males. Right composite scores for females were slightly higher than that for the left, whereas the opposite occurred in males with the left indicating higher mode than the right.

Table 16: Descriptive statistic (mode) for each variable of the auricular surface for both males and females

Variable	**Female**		**Male**	
	Left	**Right**	**Left**	**Right**
Sample Size (*n*)	98	98	99	99
Transverse Organisation	5	5	4	4
Surface Texture	3	3	3	3
Microporosity	2	2	1	1
Macroporosity	1	1	1	1
Apical Changes	2	1	1	1
Composite Score	12	13	12	11

4.4.2. Inaccuracy and Bias

Table 17 shows the inaccuracy and bias for male and female, left and right as well as pooled sexes and pooled age-at-death groups for the auricular surface.

4.4.2.1. Females versus males

In general, results showed an overestimation in individuals 50 years or younger and underestimation in individuals 50 years or older. The lowest bias (-0.8 years) for both males and females was found in the age group 50 to 59 years (Table 17), which suggests that age estimation for this age group is more accurate. In females, higher inaccuracy and bias was found in the younger age groups (15 to 19 years and 20 to 29 years) (26 years and 26.2 years repectively) and the older age group (80 to 89 year) (14.5 and -14.5 years). The highest inaccuracy and bias (26 and -26 years) in males was found in the older age groups (80 to 89 years) (Table 17). Overall, females had higher overestimation than males (8.1 and 4.4 years for females and males respectively).

4.4.2.2. Left versus right

Again, although no differences were observed in males (Table 8, p.48), significant differences were found in females. Therefore, it was deemed important separate the left and right sides of the auricular surface. For both left and right sides, overestimation occurred in individuals aged 15 to 49 years whereas underestimation occurred in individuals aged 50 to 89 years (Table 17). The lowest bias values were found in individuals aged 50 to 59 years for left and right sides (-1.1 and -2.1 years respectively). Left and right sides are comparable with 1 or 2 year differences occurring when estimating age. However, an underestimation by as much as 33 years occurred in individuals aged 80 to 89 years when using the right auricular surface. Overall, left and right auricular surfaces were overestimated for both the left and right sides (6.4 and 6.1 respectively) (Table 17).

Table 17: Inaccuracy and bias (years) for age estimation from the auricular surface in females, males, left and right sides as well as pooled sexes

Age-at-death (years)	Females	Males	Left	Right	Pooled sexes
15-19					
n	6	16	11	11	22
Inaccuracy	26.0	12.8	16.5	16.2	16.4
Bias	26.0	12.8	16.5	16.2	16.4
20-29					
n	32	28	30	30	60
Inaccuracy	26.2	14.9	20.5	21.4	20.9
Bias	26.2	14.9	20.5	21.4	20.9
30-39					
n	56	26	41	41	82
Inaccuracy	15.0	17.4	16.0	15.6	15.8
Bias	14.1	16.8	14.7	15.1	14.9
40-49					
n	34	40	37	37	74
Inaccuracy	14.0	8.7	11.3	10.9	11.1
Bias	13.0	6.4	9.9	8.9	9.4
50-59					
n	32	54	43	43	86
Inaccuracy	7.7	8.5	8.1	8.2	8.2
Bias	-2.8	-0.8	-1.1	-2.1	-1.6
60-69					
n	18	24	21	21	42
Inaccuracy	7.5	9.4	8.5	8.7	8.6
Bias	-6.9	-7.1	-6.9	-7.2	-7.0
70-79					
n	10	8	9	9	18
Inaccuracy	14.5	21.8	16.9	18.6	17.8
Bias	-14.5	-21.8	-16.9	-18.6	-17.8
80-89					
n	8	2	5	5	10
Inaccuracy	34.1	26	31.7	33.2	32.5
Bias	-34.1	-26	-31.7	-33.2	-32.5
All ages					
n	196	198	197	197	394
Inaccuracy	15.9	11.8	13.8	13.9	13.8
Bias	8.1	4.4	6.4	6.1	6.2

4.4.3. Correlations

A Spearman's Signed Ranked Correlation Coefficient was used to determine any correlations between the variables and age-at-death of the auricular surface. As with the pubic symphysis, both the left and right auricular surfaces were analysed separately. This was done in order to assess whether any differences could be observed between the left and right sides. Once again, each feature was analysed against the age-at-death of the individual as recorded in the Raymond A. Dart Collection of Human Skeletons.

Table 18 describess the r-values as well as the p-values for both females and males. As previously stated, a p-value higher than 0.05 indicated no statistically significant correlation to age estimation.

4.4.3.1. Females

Apical changes and composite score resulted in a significant correlation to age estimation for the left auricular surface ($p = 0.011$ and $p = 0.010$, respectively) and macroporosity of the right auricular surface ($p = 0.014$). However, the r values for those variable (0.256, 0.259 and 0.248 respectively) were weakly correlated to age estimation.

4.4.3.2. Males

Transverse organisation, surface texture, microporosity, apical changes and composite score of the left auricular surfaces revealed a significant correlation to age estimation ($p < 0.05$) (Table 18). All variables for the right auricular surfaces were statistically significantly correlated to age-at-death except for macroporosity. The r-values for both the left and right sides ranged between 0.249 and 0.429, indicating weak to moderate correlations.

Again, scatter plots have been provided to visually assist with the interpretation between the correlations of each variable and age-at-death (Figure 31 to Figure 42). Female and male correlations have been plotted for comparison purposes. Transverse organization, surface texture as well as microporosity presented a positive correlation to age-at-death in males (Figures 32, 34 and 36), whereas these variables were not correlated in females. Macroporosity presented no correlations to either of the sexes. Although apical changes in both males and females were correlated to age-at-death, females showed a stronger correlation (Figure 39). However, overall males presented a stronger correlation to age-at-death than females with regards to composite scores (Figures 41 and 42). The left auricular surfaces were selected as no statistically significant differences were found between left and right sides (Table 6, p.48).

Table 18: Spearman's Rank Correlation Coefficients for female left and right pubic symphyses and male left and right pubic symphyses variables and age-at-death

Variable	Statistics	Female		Male	
		Left	**Right**	**Left**	**Right**
Transverse Organization	r value	0.105	0.022	0.354	0.359
	p value	0.305	0.829	<0.001*	<0.001*
Surface Texture	r value	0.050	-0.050	0.307	0.249
	p value	0.624	0.632	0.002*	0.013*
Microporosity	r value	0.187	0.101	0.284	0.299
	p value	0.065	0.323	0.004*	0.003*
Macroporosity	r value	0.183	0.248	0.091	0.091
	p value	0.071	0.014*	0.371	0.371
Apical Changes	r value	0.256	0.197	0.177	0.249
	p value	0.011*	0.052	0.080	0.013*
Composite Score	r value	0.259	0.160	0.405	0.429
	p value	0.010*	0.116	<0.001*	<0.001*

*Significant at level p = 0.05

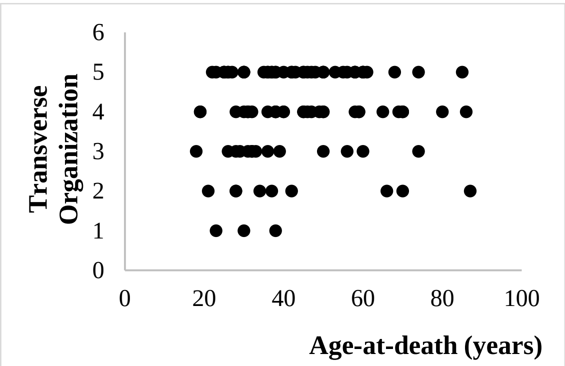

Figure 31: Scatter plot representing correlations between transverse organization and the left female auricular surface (r = 0.105; p = 0.305)

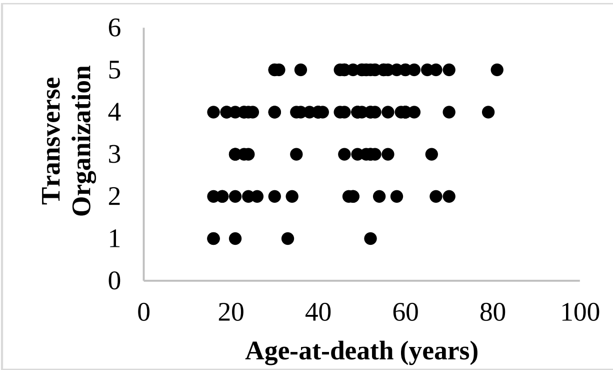

Figure 32: Scatter plot representing correlations between transverse organization and the left male auricular surface (r = 0.354; p = <0.001)

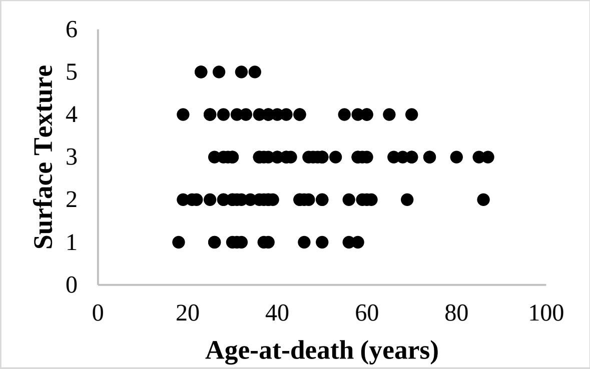

Figure 33: Scatter plot representing correlations between surface texture and the left female auricular surface (r = 0.050; p = 0.624)

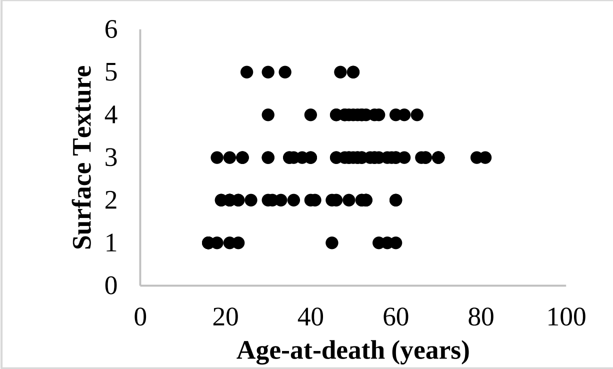

Figure 34: Scatter plot representing correlations between surface texture and the left male auricular surface (r = 0.307; p = 0.002)

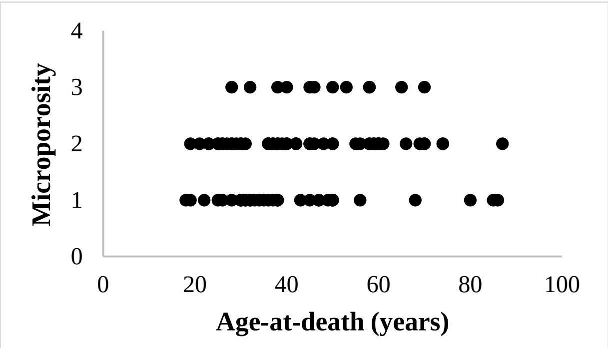

Figure 35: Scatter plot representing correlations between microporosity and the left female auricular surface (r = 0.187; p = 0.065)

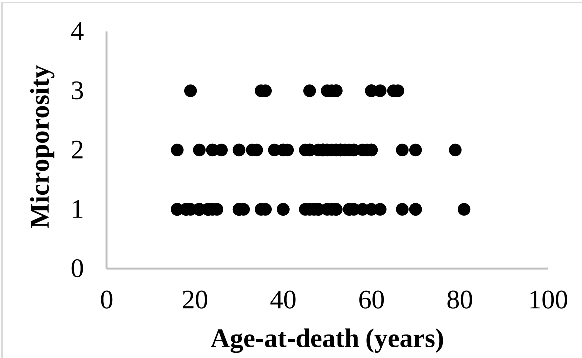

Figure 36: Scatter plot representing correlations between microporosity and the left male auricular surface (r = 0.284; p = 0.004)

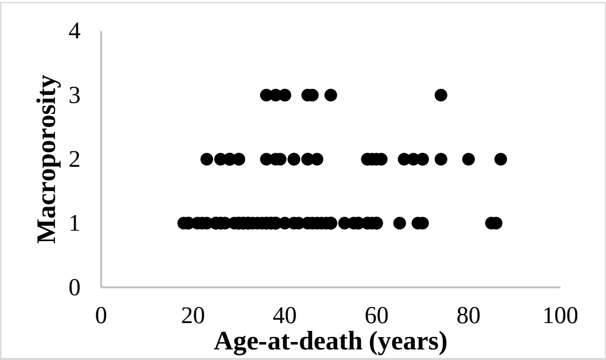

Figure 37: Scatter plot representing correlations between macroporosity and the left female auricular surface (r = 0.183; p = 0.071)

Figure 38: Scatter plot representing correlations between macroporosity and the left male auricular surface (r = 0.091; p = 0.371)

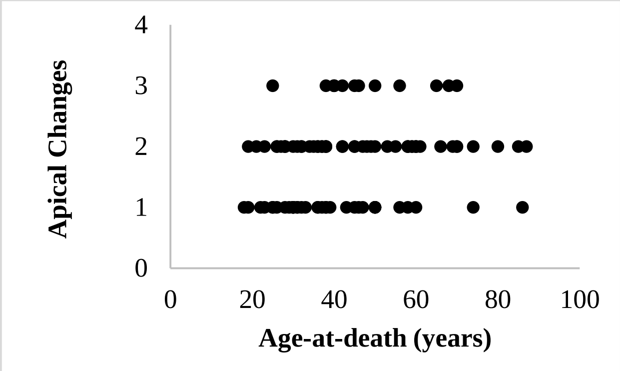

Figure 39: Scatter plot representing correlations between apical changes and the left female auricular surface (r = 0.256; p = 0.011)

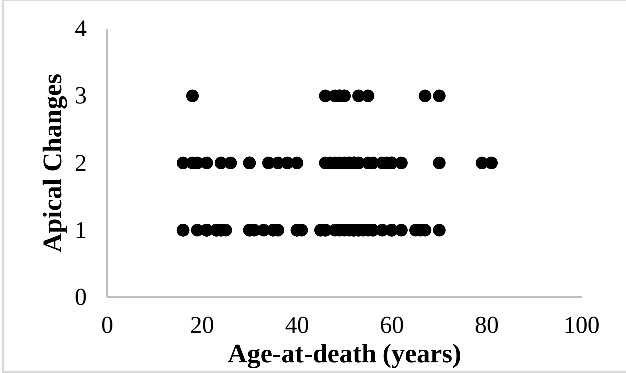

Figure 40: Scatter plot representing correlations between apical changes and the left male auricular surface (r = 0.177; p = 0.080)

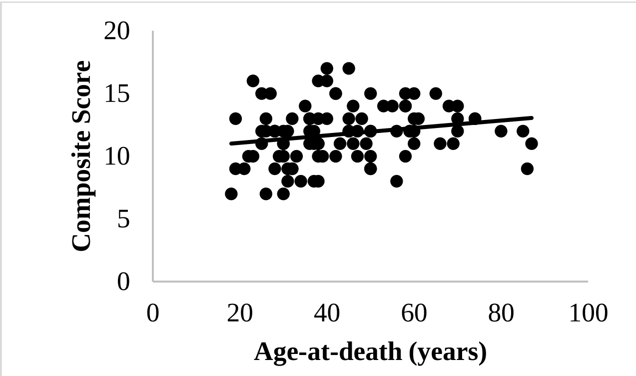

Figure 41: Scatter plot representing correlations between composite score and the left female auricular surface (r = 0.259; p = 0.010)

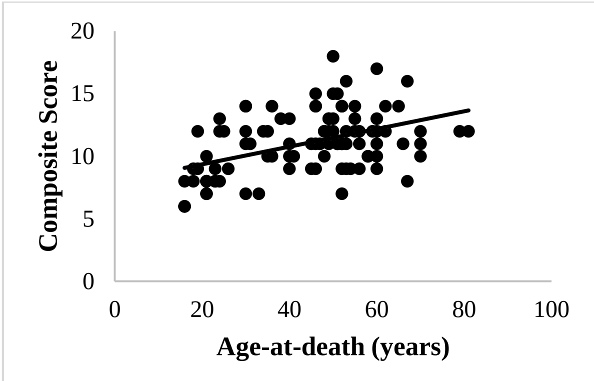

Figure 42: Scatter plot representing correlations between composite score and the left male auricular surface (r = 0.405; p = <0.001)

4.4.4. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was performed on both the left and right auricular surfaces for males and females. Principal Component Analysis (PCA) was used to extract the components which consist of variables which have the highest loadings and was then followed by a varimax rotation. Again, any communalities lower than 0.4 were excluded from the PCA.

4.4.4.1. Females

Results for the PCA for females are represented in Table 19 and Table 20 below. Two principal components (PC1 and PC2) were extracted for both left and right auricular surfaces. For left auricular surfaces, the combined principal components accounted for 52.86% of the total variance between the original variables and age estimation whereas, for right auricular surfaces, the combined principal components accounted for 78.91% of the total variance.

When analysing left auricular surfaces, a number of variables were strongly correlated to PC1 which included three variables namely; microporosity, macroporosity and apical changes. Transverse organization and surface texture had the strongest correlation to PC2 (Table 19). Transverse organization accounted for the highest amount of variance in the PCs (0.721). Microporosity, macroporosity and apical changes all account for less than 50% of the variance explained by the PCs.

Table 19: Principal Component Analysis for left female auricular surfaces

	Communalities	**PC1**	**PC2**
% variance accounted for		32.26	20.60
Transverse Organization	0.721	0.317	**0.788**
Surface Texture	0.582	0.416	**-0.640**
Microporosity	0.427	**0.654**	-0.007
Macroporosity	0.458	**0.677**	0.010
Apical Changes	0.455	**0.674**	0.022

For right auricular surfaces, transverse organization and apical changes were exclude from the PCA due to low communalities. When analysing right auricular surfaces, microporosity and macroporosity showed the strongest correlation to PC1, whereas, surface texture showed the strongest correlation to PC2 (Table 20). Almost all of the variance within the PCs is explained by surface texture (0.999).

Table 20: Principal Component Analysis for right female auricular surfaces

	Communalities	**PC1**	**PC2**
% variance accounted for		45.57	33.34
Surface Texture	0.999	0.005	**0.999**
Microporosity	0.684	**0.826**	0.030
Macroporosity	0.684	**0.827**	-0.021

4.4.4.2. Males

Results for the PCA for males are represented in Table 21 and Table 22 below. Only one principal component was extracted for left auricular surfaces whereas, two principal components (PC1 and PC2) were extracted for right auricular surfaces. Although all the variables, except for surface texture, resulted in communalities less than 0.4, these were not excluded as a PCA could not be run on one variable. Hence, PCA for left male auricular surfaces must be used with caution due to the low communalities.

Table 21: Principal Component Analysis for left male auricular surfaces

	Communalities	PC1
% variance accounted for		35.48
Transverse Organization	0.325	**0.570**
Surface Texture	0.542	**0.736**
Microporosity	0.262	**0.511**
Macroporosity	0.355	**0.596**
Apical Changes	0.291	**0.540**

For left auricular surfaces, the principal component (PC1) accounted for 35.48% of the total variance whereas, for right auricular surfaces, the combined principal components accounted for 65.88% of the total variance. When analysing left auricular surfaces alone, all the variables were strongly correlated to PC1. However, the strongest correlation was seen for surface texture (0.736) (Table 21).

As mentioned above, two principal components were extracted for right auricular surfaces. Macroporosity was excluded from the PCA due to its low communality. Two of the original variables were strongly correlated to PC1. These included transverse organization and apical changes (0.677 and 0.808 respectively). Surface texture and microporosity accounted for the strongest correlation to PC2 (0.647 and 0.873 respectively) (Table 22). Microporosity accounted for the highest amount of variance (0.776) and transverse organization accounted for the least amount of variance (0.533).

Table 22: Principal Component Analysis for right male auricular surface

	Communalities	**PC1**	**PC2**
% variance accounted for		39.13	26.75
Transverse Organization	0.533	**0.677**	0.273
Surface Texture	0.642	0.474	**0.647**
Microporosity	0.776	-0.117	**0.873**
Apical Changes	0.684	**0.808**	-0.177

As can be seen from the above results, inaccuracies and bias differed not only between the two methods but also between sexes and sides. Certain variables displayed better correlations to age estimation than others and thus the results will be discussed in the following chapter.

CHAPTER 5: DISSCUSION

Age, amongst other criteria, is one of the most important aspects within the biological profile, as it assists in reducing the possible number of individuals which need to be identified. Many skeletal elements display age-related changes which progress at different rates with age (Krogman and İşcan, 1968; Todd, 1920). As described in previous chapters, two of the most commonly used skeletal elements for estimating age-at-death include the pubic symphysis and the auricular surface (Mulhern and Jones, 2005; Buckberry and Chamberlain, 2002; Brooks and Suchey, 1990; Lovejoy *et al.*, 1985b). Studies have shown that the pubic symphysis and the auricular surface show age-related changes over time, and that methods such as the Suchey-Brooks (1990) method for aging the pubic symphysis and the revised method described by Buckberry and Chamberlain (2002) for aging the auricular surface, created from these skeletal elements, can assist in the estimation of age-at-death of an individual (Buckberry and Chamberlain, 2002; Brooks and Suchey, 1990; Krogman and İşcan, 1986). Differences in the rate and degree of age related changes in the os coxae have been noted in different populations (Martins *et al.,* 2011; Franklin, 2010; Krogman and İşcan, 1986) and as most aging techniques have predominantly been developed on American or European population groups, it is essential to test their accuracy and reliability on other populations around the world (Hens *et al.*, 2008). The aim of this study was therefore to determine whether the pubic symphysis and the auricular surface can be used to accurately estimate age in a black South African population. In addition, differences between males and females as well as left and right sides of both the pubic symphysis and the auricular surface were analysed.

Intra- and inter-observer errors were calculated for both the pubic symphysis and the auricular surface in order to determine the repeatability of the methods described above. Table 5 (p.45) represents a moderate to high level of repeatability ranging from 0.632 to 0.829. The pubic symphysis revealed a higher repeatability than did the auricular surface for both intra- and inter-observer errors. It has been noted that age related changes in the pubic symphysis are easier to interpret than those for the auricular surface (Hens *et a*l., 2008; Lovejoy *et al*., 1985). Intra-observer errors for both the pubic symphysis and the auricular surface were slightly higher than those for inter-observer errors. It is often difficult to distinguish between certain features on both the pubic symphysis and the auricular surface which could affect the repeatability of the method. When assessing certain age related features, the estimation of age becomes quite subjective in nature. For example, one individual may score surface texture of the auricular surface as being finely granular and another may score it as being coarsely granular. These own individual interpretations of the surface become subjective and may ultimately affect the repeatability of the methods. With regards to the auricular surface, inter-observer errors found for the present study were moderate. This is comparable to Buckberry and Chamberlain (2002) who, using a Cohen's weighted kappa (k = 0.66), also found moderate levels of repeatability. The revised method described by Buckberry and Chamberlain (2002) has been reported to have better repeatability than the original method described by Lovejoy and colleagues (1985a). Left sides, for the pubis symphysis and the auricular surface, resulted in better repeatability than the right sides. This can be due to pelvic asymmetry where different influences can ultimately alter the appearance of certain joints and features of the pelvis which subsequently could affect the scoring and ageing thereof (Wärmländer and Sholts, 2011; Boulay *et al*., 2006).

As mentioned before it is important to assess the accuracy of the methods on a South African population to ensure that the methods can be used to estimate age accurately in this population group. In the present study, inaccuracy and bias was calculated for both the pubic symphysis and the auricular surface for both sexes and both sides. Inaccuracy can be described as the mean absolute difference between the age-at-death and the estimated age, whereas, bias is described as the under- or overestimation of age in a particular age group (Meindl *et al.*, 1985). If inaccuracy and bias values are too high, the method cannot be used, especially not for forensic purposes. Higher bias values not only explain whether ages were underestimated or overestimated but also give an idea of the magnitude of the under- or overestimation. Moreover, higher inaccuracy and bias values therefore do not result in a true reflection of the age-at-death of an individual.

Before discussing the accuracy of the methods, it is important to mention the modes of the scoring systems. The modes give an indication of which “phase” of a feature on the pubic symphysis and the auricular surface is more commonly scored. The modes for pubic symphyses were indicative of middle aged individuals where the features were most commonly scored for individuals falling within an age range of 30 to 50 years of age. In other words, surface appearance was smoother and no ossific nodules, lipping or ligamentous outgrowths were present. Additionally, the dorsal plateau, ventral rampart and symphyseal rim were complete and the pubis tubercle was fully separated. This can be explained by the distribution of the sample, in which the majority of individuals were middle aged and ultimately affected the modes for the sample. The same is true for the auricular surface where each “phase” of a feature fell within individuals aged 30 to 50 years. Again, this can be attributed to the distribution of the sample. Statistically significant differences, if any, between sexes and sides needs to be noted. In the current study, a Wilcoxon sign ranked test revealed no statistically significant differences between males and females for the pubic symphysis (Table 7, p.48) and the auricular surface (Table 8, p.49). This is not surprising as the sample distribution between males and females differed and thus could not be compared correctly to one another. Males showed no differences between left and right sides for both the pubic symphysis and the auricular surface whereas differences were found between female left and right sides. Buckberry and Chamberlain (2002) found no significant differences between males and females and therefore stated that the method can be used on both sexes. However, the opposite can be said for the present study, particularly for females.

5.1. Inaccuracy and bias

Ultimately, forensic anthropologists aim for a method that is both accurate and precise when estimating age (Dirkmaat *et al.*, 2008). However, this proves difficult due to the large amount of human variation with the aging process (Garvin *et al.* 2012). Thus, inaccuracy and bias was calculated for both the pubic symphysis and the auricular surface. This was done in order to assess the accuracies of each method as a whole as well as the accuracies of each method when applied to males and females and left and right sides.

5.1.1. Pubic symphysis

When estimating age using pubic symphyses, it was observed that ages were overestimated by as much as 10.9 years for females aged between 20 and 49 years. Similarly, males exhibited a 12.4 year overestimation of age for individuals aged between 15 and 19 years (Table 10, p.52). Underestimation occurred in individuals aged 50 years and older in females and 40 years and older in males with an increase in underestimation as individuals get older. Similar results were found by Hens and colleagues (2008). They found that age predictions for individuals 60 years and over were noticeably underestimated. After the age of 50 years, one must rely on degenerative processes to estimate age, making the aging process more difficult (Hens *et al.*, 2008; Meindl *et al.*, 1985; Brooks, 1955). Based on results from the current study, for individuals aged 80 to 89 years, an underestimation of 24 years and 35 years occurred in females and males respectively (Table 10, p.52). This can be due to different maturation and aging processes found between males and females (Katz and Suchey, 1986; Gilbert and McKern, 1973; Brooks and Suchey, 1990). Interestingly, Krogman and İşcan (1986) noticed that Todd's 10 phase system tends to overestimate age especially in the older individuals.

Furthermore, the current study found that males resulted in larger underestimations and overestimations of age than females, except for individuals aged 20 to 49 years. This is in line with results by Hens *et al*., (2008) where females exhibited less bias than males. Similar to this, both Todd (1920) and Brooks (1955) found that age estimation was less reliable in older individuals where overestimation occurred. Gilbert (1973) states that the trauma of child birth may have an impact on the dorsal appearance and, on occasion, the surface of the pubic symphysis in females which may result in differences seen between sexes and within sexes. Due to this, the accuracies of age estimation in females will then decrease, ultimately decreasing its usefulness in a forensic context. At around age 45, the symphyseal rim is complete and thereafter a steady breakdown occurs. As with the previous features, the pubic tubercle is fully separated by the age of 40 years. Some presence of a pubic tubercle may be identifiable in younger individuals aged between 21 and 39 years but no pubic tubercle is present in individuals younger than 20 years. Thus, these features make age estimation within this age group slightly easier and will then result in age being estimated more accurately. After 50 years of age, the inaccuracy and bias values increase. Supporting this, literature has noted that the accuracy of age estimation decreases as an individual get older (Brooks and Suchey, 1990; Katz and Suchey, 1986).

When separated into left and right pubic symphyses, inaccuracies and bias values became comparable (Table 10, p.52). Overestimation occurred in individuals 40 years and younger and underestimation occurred in individuals 40 years and over when estimating age from the left pubic symphysis. When using the right side, overestimation only began after 50 years of age. The most accurate age estimation occurred in individuals aged 40 to 49 years for both the left and right pubic symphyses.

5.1.2. Auricular surface

Although not as reliable as the pubic symphysis, age estimation from the auricular surface indicated similar findings but with larger inaccuracies and bias. Overestimation occurred in individuals aged 15 to 49 years and underestimation occurred in individuals aged 50 years onwards, for both sexes. This is similar to results found by Saunders and colleagues (1992), where underestimation occurred in older individuals. Furthermore, in the current study, an underestimation of as much as 26 years in younger individuals (15 to 19 years and 20 to 29 years) and 34 years in older individuals (80 to 89 years) occurred in females (Table 17, p.65). Overestimation and underestimation in males, although following a similar pattern to females, was slightly lower. As with the pubic symphysis, this can be attributed to differences found between male and female os coxae (Krogman and İşcan, 1986). Greater variability is found in female os coxae which can be attributed to reproductive changes in hormones as well as trauma of child birth which can ultimately change the sacroiliac joint morphology (Chamberlain, 2000). Pitting at the margins of the sacroiliac joint have been found in females who have given birth (Chamberlain, 2000). These findings are comparable to Hens and colleagues (2008) where both sexes were overestimated under the age of 39 years by between 1 and 4 years, with considerable underestimation by between 4 and 30 years, over the age of 40 years. Furthermore, almost no bias occurred in individuals aged 50 to 59 years in the current study (Table 17, p.65). The same was noted by Mulhern and Jones (2005) where the lowest bias was found between ages 50 and 59 years. However, Lovejoy and colleagues (1985b) found an underestimation by 8 years in individuals aged 50 to 59 years whereas the most accurate estimation of age was seen in individuals aged 18 to 29 years. Upon, testing the revised method described by Buckberry and Chamberlain (2002) as well as the original method described by Lovejoy *et al*. (1985b), Mulhern and Jones (2008) found that although the revised method is easier to use, the original method is more accurate for aging younger and middle aged individuals. Contrary to this, the current study found that the inaccuracies for younger individuals (15 to 29 years) was substantially high (an overestimation by as much as 26 years), concluding that the method is not very accurate for that particular age group, especially in females. However, very low inaccuracy and bias values were found for ages 50 to 59 years, concluding that this method is more accurate and reliable for that particular age group.

When separated into left and right sides, bias and inaccuracy values were comparable. As with males and females, overestimation occurred in individuals aged 15 to 49 years and underestimation occurred in individuals aged 50+ years. The most accurate estimation of age occurred in individuals aged 50 to 59 years for both the left and right auricular surfaces. An underestimation of as much as 33 years occurred in individuals aged 80 to 89 years (Table 17, p.65). This shows that individuals within this age group are often aged 33 years younger than the actual age further emphasising the need future research and the development of new methods for estimating age from the auricular surface.

5.1.3. Pubis symphysis versus auricular surface

From Table 10 (p.52) and Table 17 (p.65**)** it can be concluded that the pubic symphysis outperformed the auricular surface. Inaccuracy and bias values were lower when using the pubic symphysis. Over all, when observing the entire sample (i.e. pooled sexes and aged groups), it was found that the pubic symphysis only underestimated age by half a year, whereas, the auricular surface overestimated age by 6 years. Age related changes seen in the pubic symphysis are easier to identify than those seen in the auricular surface. In addition, even though literature has stated that the revised method described by Buckberry and Chamberlain (2002) is easier to apply, age estimation from the auricular surface is considered subjective in nature. Thus, resulting in different outcomes and phase allocations. When using the pubic symphysis, the most accurate age estimation occurred in individuals aged 40 to 49 years, whereas the most accurate estimation of age using the auricular surface occurred in individuals aged 50 to 59 years. As mentioned before, certain features in the pubic symphysis are easier to identify between ages 40 and 49 years. Overall, the pubic symphysis revealed lower inaccuracies and bias than the auricular surface (Table 10, p.52 and Table 18, p.67). As mentioned before, literature has noted that, although age changes in the auricular surface are relatively well-defined, they are more difficult to interpret than those of the pubic symphysis (Sinha and Gupta, 1995; Lovejoy *et al.*, 1985b). This could account for the higher inaccuracy and bias found in the auricular surface in the present study. Females revealed higher inaccuracy and bias than did males. As mentioned before, this can be due different rates of morphology and maturation between the sexes (Katz and Suchey, 1986; Gilbert and McKern, 1973; Brooks and Suchey, 1990; Todd, 1920). Full maturation of an adult female occurs, on average, 10 years earlier than in males (Gilbert, 1973). Therefore, the age of fully matured females will then be underestimated when male standards are applied. Lovejoy and colleagues (1985b) found distinct changes along the inferior margins and apex of female auricular surfaces. They concluded that the effects of these should be disregarded when estimating age in females. However, Buckberry and Chamberlain (2002) found no significant differences between the sexes.

5.2. Correlations

Correlations assess the relationship as well as the strength of the relationship between certain variables. For the present study, correlations were calculated for each method and their respective variables. Again, males, females and left and right sides were compared. If no correlations were found between a variable and estimated age-at-death, those variables cannot be used accurately to estimate age.

5.2.1. Pubic symphysis

Upon analysis of the separate variables; i.e. the surface appearance, ventral bevelling, ossific nodules, extremities, dorsal plateau, ventral rampart, symphyseal rim, lipping, ligamentous outgrowths and pubic tubercle, results of the present study found that correlations for age-at-death were comparable between male and female pubic symphyses (Table 11, p.54). The surface appearance of the right pubic symphysis in males had the strongest correlation ($r = 0.658$, $p = <0.001$) to age-at-death compared to other variables. The same can be said for right female pubic symphyses ($r = 0.652$, $p = <0.005$). Surfaces appearances for ages of individuals younger than 30 years of age were relatively easy to identify. This is attributed to the distinct billowing and ridges found on the surface of younger individuals (Brook and Suchey, 1990; Katz and Suchey, 1986; Gilbert and McKern, 1973). However, surface appearance becomes more difficult to interpret as the individual reaches 40 years and over due to the progression of degenerative changes in older individuals. The same was observed by Brooks and Suchey (1990) where they stated that the appearance of deep ridges and grooves is more useful when aging individuals younger than 24 years. Other features which could be considered reliable age indicators include the formation of the ventral rampart, the formation and breakdown of the symphyseal rim and the presence or absence of the pubic tubercle. Again, the ventral rampart is relatively easy to score in younger individuals but becomes more difficult from 35 years onwards. The same was noted by Hens and colleagues (2008), where, after fusion of the ventral rampart, only degenerative changes can be seen, thus making interpretation more difficult after 35 years of age. These degenerative changes indicate large amount of variation because of lifestyle, environment and genetics (Hens *et al.,* 2008). Furthermore, the current study noted that ventral bevelling for both females and males showed no correlation to age estimation. Possible reasons for this could be due to the confusion in the location and definition of the dorsal and ventral aspects of the pubic symphysis between males and females as was also suggested by McKern and Stewart (1957). The same is true for ossific nodules for female pubic symphyses, were no correlations to age estimation were found. Interestingly, Brooks and Suchey (1990) noted that ossific nodules, without the formation of the ventral rampart, can be useful to estimate age-at-death in individuals under the age of 39 years.

Other features which have not yet been mentioned resulted in very low correlations to age estimation. Prior studies (Gilbert and McKern, 1973; Todd, 1920) have shown that morphology and rates of maturation differ between sexes. In female pubic bones, the region/area of the symphysis lying between the ventral aspect of the symphyseal rim and the ventral arc show age related changes (Anderson, 1990). However, there is no such area on the male pubic bone (Brooks and Suchey, 1990; Anderson, 1990). In addition, in many females dorsal changes occur, which may not necessarily be due to age but rather related to pregnancy (Brooks and Suchey, 1990). It has also been noted that lipping of the dorsal rim, in particular, cannot be considered a reliable feature for age estimation in females due to pregnancy (Brooks and Suchey, 1990). Furthermore, the degree of traumatic change during birth can alter the appearance of the dorsal aspect of the pubic symphysis, resulting in an ‘older’ estimation of age (McKern and Stewart, 1957). Overall the features assessed from the pubic symphyses in males were better correlated to age than those for females in the current study. This is in line with Brooks (1955), who concluded that in males, estimates of age from the pubic symphysis have a high correlation to age-at-death (recorded age). Contrary to this, Hartnett (2010) stated that females resulted in higher correlations to age-at-death than males and suggested that females may undergo a more regular and predictable pattern of aging (Hartnett, 2010). This could possibly be explained by manual labour in males where the pubic symphysis will alter and become more difficult to age. Population differences in the development morphology of the pubic symphysis have been noted. Sinha and Gupta (1995) found significant differences in the mean age of phases for individuals from India. Particularly phases II, III and VI exhibited significantly lower mean ages of development than the reference sample of Todd (1920). Furthermore, comparison of the Indian sample using McKern and Stewart (1957) component analysis resulted in inconsistent differences in the developmental timing of certain features found on the pubic symphysis.

Virtual anthropology, which involves computed tomography (CT), has offered many advantages in age estimation techniques. Using CT allows for the exclusion of lengthy bone preparation, no deterioration of data with time, allows for application on living individuals as well as the ease of data sharing and storing (Telmon *et al.*, 2005). However, Telmon and colleagues (2005), upon the investigation of the Suchey-Brooks method, found that although these advantages exist, the accuracy of age estimation did not significantly differ between the Suchey-Brooks method when applied to bones or when applied to CT images.

5.2.2. Auricular surface

Lovejoy and colleagues (1985a) were one of the first authors to note the high correlations between morphological changes of the auricular surface and skeletal age. However, their study was based on an American population and it is unknown how well their method would perform on other population groups. Therefore, it was important to test these age related changes and their correlation to age changes on a black South African population. In males, both left and right auricular surface composite scores were significantly correlated to age in the current study ($p < 0.05$) (Table 18, p.67). However, the strength of these correlations were moderate. In females, only the left auricular surface composite scores were correlated to age. However, the strength of the correlation is very low (0.212) and should be used with caution. Buckberry and Chamberlain (2002) also calculated correlations for auricular surface traits and age. Their findings had higher correlations ($r = 0.319$ to 0.609; $p < 0.005$) to age than those for the current study. This could be due to population differences as it has been noted that differences in skeletal morphology exist between different population groups (Hoppa, 2000). Consequently, their revised method, which was originally developed on American and European populations, may not perform as well on South African populations. In addition, secular trends can affect skeletal remains and such secular trends may account for differences observed between the current study and the study by Buckberry and Chamberlain (2002). Buckberry and Chamberlain's (2002) findings are lower than those found by Mulhern and Jones (2008), who found composite score correlations for females and males to be $r = 0.636$ and $r = 0.694$ respectively ($p < 0.05$). Furthermore the current study found that, in males, transverse organization, surface texture, microporosity and apical changes were correlated to age. Again, as with the pubis symphysis, the pelvic region and its associated joints change during pregnancy (Scheuer, 2000; Brooks and Suchey, 1990).

5.2.3. Pubic symphysis versus auricular surface

Buckberry and Chamberlain (2002) concluded that their revised method had higher correlations to age than the Suchey-Brooks method (1990) for the pubic symphysis. The opposite can be said for the current study as seen from Table 11 (p.54) and Table 18 (p.67). As mentioned before, literature has noted that, although age changes in the auricular surface are relatively well-defined, they are more difficult to interpret than those of the pubic symphysis (Sinha and Gupta, 1995; Lovejoy *et al*., 1985b). This could account for lower correlations found in the auricular surface in the present study. One must keep in mind other factors which could influence the correlations to age. These could include pregnancy, hard labour, health and nutrition (Scheuer, 2002)**.**

5.3. Principal Component Analysis

Principal Component Analysis (PCA) defines the nature of the relationship within the set of variables. A PCA is a dimension-reduction tool that is used to reduce a large set of variables to a small set of variables while still retaining most of the information on the large set and describes the maximum possible variance within a sample (Harris, 1975). In the present study, PCA was used to extract principal components (PC1, PC2, PC3 and so on) for the pubic symphysis and the auricular surface. Once more, males and females and left and right sides were analysed.

5.3.1. Pubic symphysis

As mentioned before (Materials and Methods, p.42 - 44), principal components are extracted to indicate the variable/variables which have the highest loading on a component as well as those variables which account for the most variation within the data set.

Results obtained from PCA differed slightly between males and females. In general, surface appearance, extremities, symphyseal rim, and pubic tubercle all expressed loading on principal component 1 (PC1) for both males and females and left and right sides. Left male pubic symphysis correlations/loadings were higher than those found in left female pubic symphyses. Once more, this could be due to higher variations found between individuals.

As mentioned before, the surface appearance of the pubic symphysis is relatively easy to describe. As an individual ages, the changes seen on the surface move from having distinct ridges and grooves, becoming more smooth with age and eventually breaking down in later years (Buckberry and Chamberlain, 2002; Lovejoy *et al.*, 1985a). Males revealed higher correlations/loadings between surface appearance and PC1 than did females. In other words, the amount of variance in males with regards to this feature is higher than in females. Another feature which exhibited steady age related changes is the pubic tubercle. While collecting data for the study, it was noted that the pubic tubercle is fully separated from the symphyseal surface by phase 4 (approximately 30+ years). PCA indicated strong correlations/loadings between the pubic tubercle and PC1 in males and females. However, this feature resulted in more variance to PC1 in right female pubic symphyses. Ventral bevelling and ossific nodules accounted for the variation seen in PC2. This is not surprising as these two features are highly variable between sexes and sides of the pubic symphysis.

5.3.2. Auricular surface

PCA was performed on both the left and right auricular surfaces for males and females. Once more, principal components are extracted to indicate the variable/variables which have the highest loading on a component as well as those variables which account for the most variation within the data set.

In general, microporosity and macroporosity accounted for the most variation found in the sample. All variables accounted for variation seen in left female auricular surfaces whereas, only surface texture, microporosity and macroporosity accounted for the variation seen in right auricular surfaces. In addition, loadings in right female auricular surfaces was higher than in left female auricular surfaces. Left and right asymmetry exists in the os coxae (Wärmländer and Scholtz, 2011), which could explain the differences seen between the left and right sides in the present study. Garvin *et al.*, (2012) also noted that morphological changes do not always progress symmetrically. Similar findings were seen in males, except only macroposoity was excluded from the PCA in right auricular surfaces. Macroporosity is often confused with cortical defects (Buckberry and Chamberlain, 2002) and thus could have an impact on the variance seen in the auricular surface. In some cases, a variable resulted in a negative loading on a principal component. A negative loading only indicates the position on the axes. A variable can be negative but still have a high loading on that principal component. Males, especially left and right sides, resulted in lower communalities than did females. As described earlier, communalities refer to the proportion of variance in the original variables explained by a factor. This shows that the proportion of variance in the original variables in males lower than in females. This could be due to variation in the timing of age-related changes in the auricular surface (Katz and Suchey, 1986; Gilbert and McKern, 1973; Brooks and Suchey, 1990; Todd, 1920). Overall, PCA for the auricular surface indicated less variation than did the pubic symphysis.

5.4. Other considerations

Sample distribution is an important factor to consider when evaluating methods of age estimation. In the present study, the sample is not normally distributed with the majority of individuals falling within the ages of 30 and 50 years (Figure 10, p.47 and Table 6, p.47). Additionally, distributions between males and females also differed. The same was true for Buckberry and Chamberlain (2002) where younger individuals were underrepresented. A more evenly distributed sample is desirable and as such further research on these underrepresented age groups will ultimately provide better evaluations of the methods.

A number of studies have investigated whether combining various methods/techniques would result in a more precise and accurate estimation of age (Krogman and İşcan, 1986). Todd (1920) emphasised that the most accurate estimation of age can only be made after examination of the entire skeleton. However, this proves difficult as, more often than not, forensic anthropologists are faced with incomplete or fragmentary skeletal remains. The pubic symphysis and auricular surface alone cannot be used to accurately estimate age as the methods performed poorly on a black South African population.

Inherent variation in the biological process is a major error for present osteological aging criteria (Hoppa, 2000). Most aging techniques are developed predominantly from American or European samples. This reiterates the need for population specific standards. Upon investigation of age estimation from the pubic symphysis and the auricular surface from a European population as well as an African population, Martins and colleagues (2011) noted different morphological age related changes between the two populations. They noted that European populations "exhibit a rather common trend of variation" (p.6), and therefore more accurate than the African population. The current study further supports this statement. However, one must keep in mind admixture within South African populations. Admixture of populations further complicates the variations found in populations and further investigations of this are advised.

One of the most important criteria for the accurate estimation of age research includes the accurate documentation of age-at-death. The current study used ages documented for the skeletal remains in the Raymond A. Dart Collection of Human Skeletons. It is widely known that this collection is a known-age collection (Dayal *et al.*, 2009b) however, a large number of individuals housed in this collection are pauper bodies with no form of identification. In these cases, population affinity as well as age-at-death had to be estimated by other means. Many times, age is estimated by the pathologist or by an anatomist resulting in inaccurate age-at-death documentation. In addition, Dayal and colleagues (2009b) observed certain peaks in the documented ages in the Raymond A. Dart Collection at 5 and 10 year intervals. This suggests that age-at-death may have been rounded off in most cases to the nearest 5 or 10 year interval, ultimately resulting in inaccuracies in recorded age-at-death (Dayal *et al.*, 2009b). Effort was made to retrieve the accurate ages of the individuals, however, out of the 394 individuals; only two identification numbers (ID number) were available. Differences in accuracies seen between the current study and the Suchey-Brooks method (1990) and Buckberry and

Chamberlain method (2002), could be a result of inaccurate age documentation. Brooks and Suchey (1990) collected a well-documented sample where age was obtained from birth- and/or death certificates. The same is true for Buckberry and Chamberlain (2002). Their sample was derived from a known-age archaeological skeletal sample from the Spitalfield Collection. Emphasising the fact that documented ages in the Raymond A. Dart Collection of Human Skeletons are not known for all the individuals, particularly black individuals, a new and more accurate method specific to South Africans could not be calculated. However, these ages were still useful is assessing the correlations of different features/ traits seen on the pubic symphysis and the auricular surface and age estimation. It must be kept in mind, that if a feature is not correlated to age, it would not be necessary to alter the method as that feature will still not correlate to age.

Lastly, due to the large amount of human variation in the aging process as well as the need for narrow estimates of age, forensic anthropologists are constantly compromising between precision and accuracy (Garvin *et al.*, 2012). The narrower the age estimate the more useful it is when identifying individuals. However, as the age estimate narrows, it is more likely that the true age of the individual can be eliminated. Yet, if a broader age estimate is provided, the usefulness of it is decreased (Garvin *et al*., 2012; Buckberry and Chamberlain, 2002). While precise and accurate age estimation methods are desirable, none of the current age estimation methods are able to provide estimates that fall within in narrower age ranges.

CHAPTER 6: CONCLUSION

The current study aimed to assess/test the accuracies of two age estimation methods, i.e. the Suchey-Brooks (1990) method for age estimation from the pubic symphysis and the revised method described by Buckberry and Chamberlain (2002) for age estimation from the auricular surface, on a black South African population. Furthermore, to asses any differences between male and female pubic symphyses and auricular surfaces as well as left and right sides. Both the pubic symphysis and the auricular surface show age-related changes throughout life. The preservation and the morphological age-related changes seen on both these sites make them useful when estimating the age of an individual. A number of conclusions could be drawn from the current study and are listed below.

1. Both the Suchey-Brooks (1990) method the revised Buckberry and Chamberlain (2002) method for age estimation can be used to estimate age on a black South African population. However, both these methods must be used with caution as the above mentioned methods were performed on American populations and ultimately performed poorly on the black South African population.
2. The most commonly scored traits were that of middle aged individuals. This was due to the distribution of the sample in which the majority of individuals were middle aged.
3. No statistically significant differences were found between males and females for both the pubic symphyses and the auricular surfaces. However, the distribution of the sample between sexes differed.
4. No statistically significant differences between left and right sides the pubic symphysis were noted except for two features of the pubic symphysis i.e. ossific nodules and lipping in females. The auricular surface showed no signs of difference between left and right sides.

5. The Suchey-Brooks method (1990) resulted in better repeatability than did the revised method described by Buckberry and Chamberlain (2002). Age related changes seen on the pubic symphysis are easier to identify and describe than those for the auricular surface.
6. Although the Buckberry and Chamberlain (2002) method for aging the auricular surface is easier to apply, the Suchey-Brooks method (1990) indicated higher age estimation accuracies, making it a more reliable method for estimating age particularly when applied to a South African population.
7. The Suchey-Brooks (1990) method overestimated older individuals by as much as 35 years in males and 24 years in females. The same method underestimated younger individuals by as much as 10 years. The most accurate age estimation occurred in middle aged individuals (approximately 35 to 55 years of age).
8. The Buckberry and Chamberlain (2002) method underestimated older individuals by as much as 34 years in females and 26 years in males. Overestimation of 26 years in females and 13 years in males occurred in younger individuals. The most accurate age estimation occurred in middle aged individuals (approximately 35 to 55 years of age).
9. Differences in the accuracies between males and females were obtained. In most cases, males resulted in better accuracies of age estimation than did females.
10. The accuracies between left and right were similar with only 1 or 2 year difference. Therefore, the both methods could be applied to either side, depending on which side is available for analysis.

From the following conclusions, the pubic symphysis outperformed the auricular surface and as such could be applied to a South African population, with caution. However, it is advised that the auricular surface not be used in a forensic context. Analyses on a more evenly distributed sample, with regards to sexes, is needed in order to further assess any differences between males and females. Moreover, age estimation in middle aged individuals is more accurate than in younger and older individuals. Furthermore, to asses any population differences within South African populations, both methods should be applied to white and black South Africans. Lastly, analyses of combined methods needs to be performed which may alter the accuracies of the methods.

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APPENDIX A

Table 23: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left female pubic symphyses

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
18	19.5	1	1	1	1	1	1	1	1	1	1	1
21	19.5	1	1	1	1	1	2	1	1	1	1	1
19	19.5	1	1	1	1	1	1	1	1	1	1	1
19	19.5	1	1	2	1	1	1	1	1	1	1	1
40	29.5	2	2	1	2	3	1	3	3	2	1	1
27	29.5	2	3	3	2	1	2	1	1	1	1	1
23	29.5	2	3	4	1	3	1	1	1	3	1	1
28	29.5	2	2	2	3	1	1	1	1	1	1	1
26	29.5	2	2	3	3	2	1	1	1	1	1	1
28	37.0	3	2	2	2	2	2	2	1	1	2	1
32	37.0	3	2	3	1	2	2	2	1	1	1	2
58	37.0	3	3	1	2	3	2	2	2	1	1	1
23	37.0	3	2	4	3	1	2	1	1	1	1	2
26	37.0	3	2	2	1	3	1	3	2	1	1	1
37	37.0	3	2	3	3	2	2	2	1	1	1	2
30	37.0	3	3	3	1	2	2	2	1	1	1	1
30	37.0	3	3	2	2	2	2	1	1	1	1	3
38	37.0	3	3	3	3	3	2	1	1	1	1	2
42	37.0	3	3	4	3	3	2	2	2	1	1	2
60	37.0	3	3	2	3	2	1	1	1	1	1	2
56	37.0	3	2	2	3	2	2	1	1	1	1	1
47	37.0	3	4	2	1	4	3	3	3	1	1	1
28	37.0	3	3	1	2	3	3	3	3	1	1	2
31	37.0	3	2	4	2	2	1	1	1	1	1	1
36	37.0	3	3	2	3	2	2	1	1	1	1	1

APPENDIX A

Table 23: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left female pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
33	37.0	3	3	2	3	2	1	2	1	1	1	1
40	37.0	3	3	4	1	2	3	2	1	1	1	1
26	37.0	3	3	2	3	3	1	1	2	1	1	3
25	37.0	3	3	1	2	3	3	3	3	1	1	2
25	37.0	3	2	2	2	3	2	2	1	1	1	2
32	37.0	3	3	1	2	3	3	2	2	2	1	2
34	37.0	3	2	4	3	2	3	1	1	1	1	2
37	37.0	3	3	3	3	3	2	2	1	1	1	2
22	37.0	3	2	3	3	2	1	1	1	1	1	2
36	37.0	3	2	4	2	2	2	1	1	1	1	2
30	48.0	4	4	1	2	4	3	3	2	2	1	3
45	48.0	4	3	2	3	3	3	3	2	2	1	3
70	48.0	4	4	2	3	3	3	3	2	2	1	3
39	48.0	4	3	1	2	4	3	3	3	2	2	3
38	48.0	4	3	2	1	4	3	2	2	2	1	3
80	48.0	4	4	4	1	4	3	3	4	2	1	3
66	48.0	4	3	2	3	4	2	3	3	1	1	3
32	48.0	4	3	2	2	4	3	3	3	1	1	3
58	48.0	4	5	1	1	4	1	3	5	3	2	3
60	48.0	4	4	2	1	4	3	3	3	2	1	3
58	48.0	4	4	3	1	3	3	2	2	2	1	3
38	48.0	4	3	1	2	4	3	3	3	2	1	3
30	48.0	4	4	3	1	2	3	2	2	2	2	3
86	48.0	4	5	1	1	4	3	3	3	3	2	3

APPENDIX A

Table 23: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left female pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
45	48.0	4	4	1	1	4	3	3	3	1	1	3
30	48.0	4	4	1	1	4	3	3	3	3	3	3
50	48.0	4	5	1	1	4	3	3	3	2	1	3
35	48.0	4	4	2	1	4	3	3	3	2	2	3
50	48.0	4	4	4	1	4	3	3	4	2	1	3
38	48.0	4	4	1	1	4	3	3	3	1	1	3
45	48.0	4	4	1	1	4	3	3	3	2	1	3
42	48.0	4	4	2	1	4	3	3	4	2	1	3
42	48.0	4	3	1	1	4	3	3	3	1	1	3
46	48.0	4	5	1	2	4	3	3	4	2	1	3
31	48.0	4	4	1	1	4	3	3	3	1	1	3
43	48.0	4	4	1	1	4	3	3	3	1	1	3
60	48.0	4	5	3	1	4	2	3	4	2	2	3
37	48.0	4	3	1	3	4	3	3	3	1	1	3
25	48.0	4	4	2	2	4	3	3	4	1	1	3
53	48.0	4	3	3	2	4	2	3	4	1	2	2
58	48.0	4	5	1	1	4	3	3	3	1	1	3
36	48.0	4	4	3	3	2	2	3	4	1	2	3
46	54.0	5	5	2	1	4	3	3	3	3	1	3
29	54.0	5	2	4	2	2	1	1	1	1	1	3
38	54.0	5	4	1	1	4	3	3	2	2	1	3
69	48.0	5	4	2	2	4	3	3	3	1	1	3
55	54.0	5	4	2	1	4	3	3	3	1	1	3
31	54.0	5	3	2	2	3	2	3	4	2	2	3

APPENDIX A

Table 23: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left female pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
74	54.0	5	5	3	2	4	3	3	5	2	1	2
45	64.5	6	5	3	1	4	3	3	4	2	2	3
60	64.5	6	4	2	1	4	3	3	5	2	1	3
65	64.5	6	5	2	1	4	3	3	4	2	1	3
50	64.5	6	5	2	2	4	3	3	4	3	2	3
38	64.5	6	4	1	2	4	3	3	4	2	1	3
36	64.5	6	3	3	2	4	3	3	4	2	2	3
74	64.5	6	4	2	1	4	3	3	3	2	1	3
56	64.5	6	5	2	2	4	3	3	5	1	2	3
50	64.5	6	5	1	2	4	3	3	5	1	1	3
49	64.5	6	3	1	1	4	3	3	4	1	2	3
48	64.5	6	4	2	1	4	3	3	4	3	1	3
50	64.5	6	5	1	2	4	3	3	5	3	2	3
61	64.5	6	3	3	3	4	2	2	5	3	2	3
87	64.5	6	5	1	2	4	3	3	5	3	3	3
59	64.5	6	4	4	1	4	3	3	5	2	2	3
40	64.5	6	5	1	1	4	3	3	5	2	3	3
59	64.5	6	3	3	2	4	3	3	5	2	2	3
28	64.5	6	5	2	2	4	3	3	5	3	2	3
70	64.5	6	5	1	3	4	1	3	5	2	2	3
50	64.5	6	4	1	1	4	3	3	4	3	2	3
68	64.5	6	5	2	2	4	3	3	4	3	2	3
47	64.5	6	5	2	2	4	1	3	4	3	2	3
85	64.5	6	5	2	1	4	3	3	4	2	1	3
70	64.5	6	5	2	1	3	3	3	5	2	2	3

APPENDIX B

Table 24: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right female pubic symphyses

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
18	19.5	1	4	2	1	2	3	3	4	2	1	2
21	19.5	1	4	1	1	4	3	3	4	2	1	3
19	19.5	1	3	4	2	1	2	1	1	1	1	1
19	19.5	1	4	1	2	4	3	3	3	2	2	3
38	29.5	2	5	2	1	4	3	3	3	2	1	3
30	29.5	2	2	3	3	3	2	2	2	1	1	1
27	29.5	2	2	4	1	1	2	1	1	1	1	1
28	29.5	2	5	3	1	4	3	3	3	2	3	3
31	29.5	2	2	4	1	2	2	1	1	1	1	2
28	29.5	2	5	1	2	4	3	3	5	1	2	3
26	29.5	2	4	1	1	4	3	3	3	2	1	3
25	29.5	2	2	4	2	3	2	1	1	1	1	2
32	29.5	2	2	1	3	1	2	1	1	1	1	1
22	29.5	2	5	1	2	4	3	3	5	3	2	3
28	37.0	3	5	1	1	4	3	3	3	1	1	3
58	37.0	3	5	1	1	4	3	3	3	1	1	3
23	37.0	3	4	3	1	4	3	3	3	2	1	3
26	37.0	3	3	2	1	4	3	3	4	1	2	3
36	37.0	3	3	2	2	3	2	2	2	1	1	1
37	37.0	3	3	3	1	4	3	3	2	2	1	3
30	37.0	3	1	4	1	1	2	1	1	1	1	1
29	37.0	3	4	1	1	4	3	3	4	3	1	3
30	37.0	3	5	1	1	4	3	3	5	1	1	3
42	37.0	3	4	1	1	4	3	3	4	1	2	3
59	37.0	3	4	1	1	4	3	3	3	3	1	3

APPENDIX B

Table 24: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right female pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
28	37.0	3	3	1	1	4	3	3	3	1	1	3
36	37.0	3	5	2	1	4	3	3	3	1	1	3
74	37.0	3	3	1	3	3	3	3	3	1	1	3
33	37.0	3	3	1	1	3	2	2	2	1	1	2
26	37.0	3	5	3	2	4	3	3	4	2	2	3
37	37.0	3	3	3	1	3	2	2	2	1	1	2
37	37.0	3	4	1	3	2	3	3	3	1	1	3
36	37.0	3	2	1	2	3	2	2	1	1	1	2
30	48.0	4	1	1	1	1	1	1	1	1	1	1
40	48.0	4	2	1	2	3	2	1	1	2	3	1
45	48.0	4	5	2	1	4	3	3	4	1	1	3
32	48.0	4	5	1	1	4	3	3	4	1	1	3
39	48.0	4	5	1	2	4	3	3	5	3	1	3
66	48.0	4	5	2	1	4	3	3	5	1	1	3
32	48.0	4	4	2	1	4	3	3	4	2	2	3
69	48.0	4	3	1	2	3	3	3	3	1	1	3
55	48.0	4	5	1	2	4	3	3	5	2	1	3
31	48.0	4	4	2	1	4	3	3	5	1	1	3
58	48.0	4	4	1	1	4	3	3	3	2	1	3
38	48.0	4	5	1	1	4	3	3	5	3	2	3
60	48.0	4	5	1	2	4	3	3	5	1	3	3
30	48.0	4	3	2	3	3	2	2	2	1	1	1
56	48.0	4	3	2	2	2	2	2	1	1	1	1
50	48.0	4	3	2	2	3	2	2	1	2	2	3
35	48.0	4	3	1	1	4	3	3	3	1	1	3

APPENDIX B

Table 24: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right female pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
47	48.0	4	4	1	1	4	3	3	3	3	2	3
38	48.0	4	5	3	2	4	3	3	5	1	3	3
45	48.0	4	2	3	3	2	2	1	1	1	1	1
42	48.0	4	4	1	1	4	3	3	5	3	1	3
43	48.0	4	2	2	2	3	2	1	1	1	1	1
40	48.0	4	4	1	3	3	2	2	2	1	1	1
25	48.0	4	3	1	2	3	3	2	1	1	2	2
53	48.0	4	4	1	1	4	3	3	4	1	2	3
58	48.0	4	5	1	1	4	3	3	5	1	2	3
25	48.0	4	5	1	2	4	3	3	3	1	2	3
34	48.0	4	2	1	1	1	1	1	1	1	1	1
60	54.0	5	3	2	2	3	2	2	1	2	1	3
70	54.0	5	1	1	1	1	1	1	1	1	1	1
23	54.0	5	2	2	1	3	2	2	1	1	1	3
38	54.0	5	4	1	1	4	3	3	3	2	1	3
38	54.0	5	4	2	1	4	3	3	4	2	2	3
60	54.0	5	4	3	1	4	3	3	4	2	1	3
58	54.0	5	4	1	2	4	3	3	5	2	3	3
50	54.0	5	4	2	1	4	3	3	3	2	1	3
45	54.0	5	5	1	2	4	3	3	4	2	3	3
50	54.0	5	4	2	1	4	3	3	4	1	1	2
42	54.0	5	4	2	1	4	3	3	4	2	1	3
50	54.0	5	2	1	3	3	2	2	2	1	1	2
46	54.0	5	4	2	1	4	3	3	3	1	2	3
31	54.0	5	5	1	1	4	3	3	3	3	1	3

APPENDIX B

Table 24: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right female pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
60	54.0	5	5	2	1	4	3	3	4	1	1	2
36	54.0	5	3	2	3	3	1	2	2	1	1	1
45	64.5	6	3	1	1	4	3	3	4	2	1	3
65	64.5	6	3	2	1	4	2	3	3	1	1	3
50	64.5	6	4	4	2	3	3	2	2	1	1	1
38	64.5	6	2	2	3	2	2	1	1	1	1	1
74	64.5	6	3	4	1	2	2	1	1	1	1	1
56	64.5	6	2	4	2	1	2	1	1	1	1	1
80	64.5	6	3	4	1	3	2	2	2	1	1	2
50	64.5	6	4	3	1	4	3	3	3	1	1	3
49	64.5	6	4	2	2	4	3	3	3	2	2	3
48	64.5	6	3	1	2	4	3	3	3	1	1	3
61	64.5	6	5	1	1	4	3	3	5	2	1	3
87	64.5	6	3	2	1	3	2	2	2	2	1	1
59	64.5	6	5	1	2	4	3	3	5	1	2	3
86	64.5	6	5	3	1	4	3	3	5	1	1	3
40	64.5	6	3	4	2	3	2	2	2	1	1	1
70	64.5	6	1	1	1	1	1	1	1	1	1	1
68	64.5	6	4	1	1	4	3	3	3	1	2	3
47	64.5	6	5	3	1	4	3	3	4	1	1	3
85	64.5	6	3	3	1	3	3	3	4	1	1	3
70	64.5	6	1	1	1	1	1	1	1	1	1	1
70	64.5	6	3	4	1	2	2	1	1	1	1	1

APPENDIX C

Table 25: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left male pubic symphyses

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
18	19.0	1	1	1	1	1	1	1	1	1	1	1
16	19.0	1	1	1	1	1	1	1	1	1	1	1
21	19.0	1	1	1	1	1	1	1	1	1	1	1
16	19.0	1	1	1	1	1	1	1	1	1	1	1
23	19.0	1	2	1	2	2	2	1	1	1	1	1
21	19.0	1	1	1	1	1	1	1	1	1	1	1
21	19.0	1	1	1	1	2	1	1	1	1	1	1
16	26.5	2	1	2	3	2	2	1	1	1	1	1
18	26.5	2	2	3	3	2	2	1	1	1	1	1
26	26.5	2	2	2	1	2	2	2	2	1	1	2
52	26.5	2	2	2	1	2	2	1	2	1	1	1
30	26.5	2	2	1	3	1	2	1	1	1	1	2
40	26.5	2	3	2	3	2	2	2	2	1	1	1
21	26.5	2	2	1	3	2	2	1	1	1	1	1
33	26.5	2	2	1	3	2	2	1	1	1	1	1
31	33.5	3	3	3	3	3	3	3	2	1	1	2
46	33.5	3	4	2	3	3	3	2	2	2	1	1
70	33.5	3	2	2	3	2	3	2	1	1	1	2
60	33.5	3	3	2	3	2	2	2	1	1	1	2
19	33.5	3	3	3	3	3	2	2	2	1	1	2
16	33.5	3	4	3	3	4	3	3	2	2	1	2
21	33.5	3	2	3	3	2	2	2	1	2	1	1
23	33.5	3	3	2	3	3	2	3	1	1	1	2
24	33.5	3	4	3	3	4	3	2	2	1	1	2

APPENDIX C

Table 25: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left male pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
52	33.5	3	3	2	3	3	2	2	1	1	1	3
53	33.5	3	3	2	3	3	3	2	2	2	2	2
45	33.5	3	3	2	3	3	2	2	2	1	1	2
25	33.5	3	3	1	3	2	2	3	2	1	1	2
48	33.5	3	2	2	2	3	2	2	2	1	1	2
23	33.5	3	5	2	3	3	3	2	2	1	1	2
40	33.5	3	3	1	1	2	2	2	2	1	1	2
24	40.0	4	4	1	3	4	3	3	3	2	2	3
50	40.0	4	5	3	1	4	3	3	3	2	1	3
66	40.0	4	4	1	1	4	3	3	3	1	1	3
49	40.0	4	4	1	1	4	3	3	3	2	1	3
46	40.0	4	5	1	1	4	3	3	3	1	1	3
46	40.0	4	3	1	1	4	3	3	3	2	1	3
53	40.0	4	4	4	1	4	3	3	3	2	1	3
36	40.0	4	4	3	3	3	3	3	3	2	1	3
24	40.0	4	4	4	2	4	3	3	2	1	1	3
38	40.0	4	4	1	3	4	3	3	3	2	1	3
56	40.0	4	4	4	1	4	3	3	3	2	1	3
41	40.0	4	3	2	1	4	2	3	2	2	1	3
36	40.0	4	4	2	1	4	3	3	3	1	1	3
45	40.0	4	5	1	2	3	3	3	2	2	1	3
35	40.0	4	4	4	1	4	3	3	3	2	2	3
51	40.0	4	4	2	1	4	3	3	3	2	2	3
58	40.0	4	4	1	1	4	3	3	3	3	3	3
30	40.0	4	3	3	1	3	3	3	3	2	1	3

APPENDIX C

Table 25: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left male pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
30	40.0	4	4	1	1	4	3	3	3	2	1	3
60	40.0	4	5	2	1	4	3	3	4	2	1	3
35	40.0	4	4	1	1	4	3	3	2	1	1	3
59	40.0	4	4	1	1	4	3	3	3	1	1	3
52	40.0	4	4	2	2	3	2	2	2	2	1	3
50	40.0	4	4	2	1	4	3	3	4	1	1	3
51	40.0	4	5	1	1	4	3	3	5	2	3	3
40	40.0	4	3	3	2	4	2	3	3	1	1	3
49	40.0	4	4	2	1	4	1	3	3	1	1	3
55	40.0	4	5	2	1	4	1	3	3	2	1	3
50	40.0	4	4	1	1	4	3	3	4	2	1	3
48	40.0	4	5	1	2	4	1	3	3	1	1	3
47	40.0	4	4	1	2	4	3	3	2	1	1	3
21	40.0	4	4	2	3	4	2	2	2	1	1	3
46	40.0	4	5	2	2	3	1	3	3	2	2	3
55	40.0	4	4	4	1	4	3	3	3	2	1	3
30	40.0	4	4	3	1	4	3	3	3	2	1	3
34	40.0	4	3	3	2	4	1	3	3	2	1	3
52	40.0	4	4	1	2	4	3	3	3	2	1	3
56	40.0	4	4	2	1	4	3	3	3	2	1	3
49	46.5	5	5	3	1	4	3	3	3	2	1	3
54	46.5	5	4	3	1	4	3	3	4	2	1	3
67	46.5	5	5	4	1	4	3	3	3	1	1	3
51	46.5	5	5	2	1	4	3	3	3	1	1	3
53	46.5	5	5	2	1	4	3	3	4	2	1	3

APPENDIX C

Table 25: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left male pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
60	46.5	5	5	3	1	4	3	3	3	3	2	3
62	46.5	5	5	2	1	4	3	3	3	2	1	3
30	46.5	5	5	1	1	4	3	3	4	2	1	3
60	46.5	5	3	2	2	3	3	2	3	1	2	3
49	46.5	5	5	2	1	4	3	3	4	2	1	3
79	46.5	5	4	2	1	4	3	3	3	2	1	3
52	46.5	5	4	4	1	4	3	3	2	1	1	3
58	46.5	5	5	2	1	4	3	3	3	3	1	3
67	46.5	5	5	2	1	4	3	3	1	1	2	2
62	46.5	5	4	3	1	4	3	3	3	2	1	3
70	46.5	5	4	4	2	4	3	3	3	3	1	3
52	46.5	5	5	1	1	4	3	3	3	2	1	3
65	46.5	5	5	1	1	4	3	3	3	3	1	3
48	46.5	5	5	2	1	4	3	3	4	3	1	3
46	46.5	5	4	4	1	4	3	3	3	2	1	3
40	46.5	5	5	2	2	4	3	3	4	2	3	3
81	46.5	5	5	1	2	4	3	3	3	3	2	3
19	60.0	6	5	1	1	4	3	3	5	1	1	3
60	60.0	6	5	1	1	4	3	3	5	3	3	3
55	60.0	6	5	3	1	4	3	3	5	1	3	3
53	60.0	6	4	1	1	3	3	3	2	2	1	3
50	60.0	6	5	1	1	4	3	3	4	1	2	3
70	60.0	6	5	1	1	4	3	3	5	3	2	3
60	60.0	6	5	1	1	4	3	3	4	2	1	3
56	60.0	6	5	1	1	3	2	3	5	2	2	3

APPENDIX D

Table 26: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right male pubic symphyses

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
18	19.0	1	1	1	1	1	1	1	1	1	1	1
16	19.0	1	1	1	1	1	1	1	1	1	1	1
21	19.0	1	1	1	1	1	1	1	1	1	1	1
16	19.0	1	1	1	1	1	1	1	1	1	1	1
23	19.0	1	2	1	3	1	1	1	1	1	1	1
21	19.0	1	3	4	1	1	2	1	1	1	1	1
21	19.0	1	1	2	3	1	1	1	1	1	1	1
16	26.5	2	1	2	3	1	1	1	1	1	1	1
18	26.5	2	2	2	3	1	2	1	1	1	1	1
26	26.5	2	3	4	3	2	3	1	1	1	1	1
52	26.5	2	3	2	2	2	2	1	1	1	1	1
30	26.5	2	3	3	3	3	2	1	2	1	1	1
25	26.5	2	2	4	1	2	2	1	1	1	1	1
21	26.5	2	1	1	3	1	1	1	1	1	1	1
33	26.5	2	2	4	1	1	2	1	1	1	1	1
70	33.5	3	3	2	2	3	3	2	2	2	1	2
60	33.5	3	2	2	3	2	1	1	1	1	1	2
19	33.5	3	2	1	2	4	3	2	2	1	1	2
16	33.5	3	3	1	3	1	2	1	1	1	1	1
21	33.5	3	3	2	3	3	2	1	1	1	1	1
23	33.5	3	2	3	3	2	2	2	1	1	1	1
24	33.5	3	3	2	3	3	2	2	1	1	1	1
38	33.5	3	3	4	3	2	3	1	1	2	1	2
45	33.5	3	3	4	1	2	3	3	1	1	1	1
40	33.5	3	3	2	3	2	2	1	1	1	1	1

APPENDIX D

Table 26: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right male pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
48	33.5	3	3	2	2	3	2	2	1	1	1	2
23	33.5	3	3	3	3	3	2	2	2	2	1	1
21	33.5	3	3	2	1	4	3	3	3	1	1	2
40	33.5	3	3	2	1	3	2	2	2	1	1	2
24	40.0	4	3	2	2	4	3	3	3	1	2	2
50	40.0	4	4	1	1	4	3	3	3	2	1	3
31	40.0	4	3	4	2	3	2	3	3	1	1	3
49	40.0	4	4	1	1	4	3	3	3	2	1	3
46	40.0	4	4	3	1	4	3	3	3	1	1	3
46	40.0	4	2	2	2	2	2	2	2	2	1	3
46	40.0	4	3	2	3	3	3	3	2	3	2	2
53	40.0	4	3	2	1	3	3	3	3	1	1	3
36	40.0	4	4	1	1	4	3	3	3	1	1	3
24	40.0	4	3	3	2	3	3	2	2	1	1	3
56	40.0	4	4	2	1	4	3	3	3	1	1	3
41	40.0	4	5	1	1	4	3	3	3	1	1	3
36	40.0	4	4	1	1	4	3	3	3	2	1	3
45	40.0	4	4	2	3	3	3	3	3	2	1	3
51	40.0	4	5	1	1	4	3	3	3	2	1	3
30	40.0	4	3	2	3	3	2	3	3	2	1	3
30	40.0	4	4	1	1	2	3	3	3	1	1	3
60	40.0	4	5	1	1	4	3	3	4	2	2	3
52	40.0	4	5	1	1	4	3	3	4	1	1	3
53	40.0	4	4	1	1	4	3	3	4	1	2	3

APPENDIX D

Table 26: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right male pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
79	40.0	4	5	1	1	4	3	3	3	2	1	3
58	40.0	4	5	2	1	4	3	3	5	2	1	3
35	40.0	4	3	1	1	4	3	3	3	1	1	3
59	40.0	4	4	1	1	4	3	3	4	1	1	3
52	40.0	4	4	1	2	4	3	2	2	1	1	3
50	40.0	4	3	2	1	4	3	3	3	1	1	3
40	40.0	4	3	1	1	4	3	3	4	1	3	3
49	40.0	4	3	2	1	4	3	3	4	2	2	3
55	40.0	4	3	1	1	4	3	3	3	2	1	3
50	40.0	4	4	1	1	4	3	3	4	2	1	3
47	40.0	4	3	2	1	4	3	3	4	2	1	3
55	40.0	4	4	4	1	4	3	3	3	1	1	3
30	40.0	4	4	1	1	4	3	3	3	1	1	3
34	40.0	4	3	1	1	4	3	3	3	1	1	3
52	40.0	4	5	1	1	4	3	3	3	2	1	3
49	46.5	5	4	1	1	4	3	3	3	3	1	3
66	46.5	5	4	3	1	4	3	3	5	2	2	3
54	46.5	5	4	3	2	3	3	2	3	2	1	3
67	46.5	5	5	3	1	4	3	3	4	1	2	3
51	46.5	5	5	3	1	4	3	3	3	1	1	3
53	46.5	5	4	1	2	4	3	3	3	1	1	3
35	46.5	5	4	1	1	4	3	3	3	3	1	3
60	46.5	5	5	2	1	4	3	3	3	1	2	3
58	46.5	5	4	1	2	4	2	3	4	2	2	3
62	46.5	5	5	2	1	4	3	3	4	2	1	3

APPENDIX D

Table 26: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right male pubic symphyses (continued)

Actual Age	Estimated Age	Estimated Phase	Surface Appearance	Ventral bevelling	Ossific Nodules	Extremities	Dorsal Plateau	Ventral Rampart	Symphyseal Rim	Lipping	Ligamentous Outgrowths	Pubic Tubercle
30	46.5	5	4	1	2	4	3	3	3	2	2	3
60	46.5	5	4	2	1	4	3	3	3	2	2	3
49	46.5	5	4	2	1	4	3	3	3	2	2	3
52	46.5	5	4	1	1	4	3	3	5	3	1	3
67	46.5	5	4	1	1	4	3	3	4	1	1	3
62	46.5	5	4	2	1	4	3	3	4	3	2	3
70	46.5	5	5	2	2	4	3	3	4	3	1	3
52	46.5	5	4	1	1	4	3	3	4	1	1	3
51	46.5	5	4	1	2	4	3	3	3	2	1	3
65	46.5	5	4	2	1	4	3	3	4	2	1	3
60	46.5	5	5	1	1	4	3	3	5	3	3	3
48	46.5	5	5	1	1	4	3	3	3	1	1	3
48	46.5	5	4	1	1	4	3	3	4	3	2	3
46	46.5	5	5	1	1	4	3	3	3	1	1	3
46	46.5	5	5	1	2	4	3	3	3	2	1	3
56	46.5	5	5	1	1	4	3	3	4	2	2	3
40	46.5	5	4	1	1	4	3	3	4	2	1	3
56	46.5	5	4	1	1	4	3	3	4	2	1	3
81	46.5	5	5	1	1	4	3	3	3	2	2	3
19	60.0	6	5	2	1	3	3	3	5	1	2	3
60	60.0	6	5	1	1	4	3	3	5	3	2	3
55	60.0	6	5	1	1	4	3	3	5	2	3	3
53	60.0	6	5	1	1	4	3	3	5	1	2	3
50	60.0	6	4	1	2	4	3	3	4	3	3	3
70	60.0	6	5	1	1	4	3	3	5	2	2	3

APPENDIX E

Table 27: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left female auricular surfaces

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
18	29.5	2	3	1	1	1	1	7
38	29.5	2	1	4	1	1	1	8
30	29.5	2	1	3	1	1	1	7
56	29.5	2	3	2	1	1	1	8
31	29.5	2	3	2	1	1	1	8
26	29.5	2	3	1	1	1	1	7
34	29.5	2	2	2	1	1	2	8
37	29.5	2	2	3	1	1	1	8
32	40.5	3	3	1	3	1	1	9
58	40.5	3	5	1	2	1	1	10
50	40.5	3	3	2	2	1	2	10
23	40.5	3	1	5	2	1	1	10
21	40.5	3	2	2	2	1	2	9
39	40.5	3	3	2	2	2	1	10
30	40.5	3	5	1	2	1	1	10
29	40.5	3	3	3	2	1	1	10
38	40.5	3	4	2	1	1	2	10
86	40.5	3	4	2	1	1	1	9
42	40.5	3	2	3	2	1	2	10
47	40.5	3	4	3	1	1	1	10
50	40.5	3	4	2	1	1	1	9
28	40.5	3	3	2	1	2	1	9
31	40.5	3	4	1	1	1	2	9
50	40.5	3	5	1	1	1	1	9
33	40.5	3	3	4	1	1	1	10

APPENDIX E

Table 27: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left female auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
32	40.5	3	3	2	1	1	2	9
19	40.5	3	4	2	1	1	1	9
22	40.5	3	5	2	1	1	1	10
28	55.0	4	2	4	2	2	2	12
30	55.0	4	4	2	2	2	1	11
45	55.0	4	4	2	3	2	1	12
26	55.0	4	5	1	2	2	2	12
56	55.0	4	5	1	2	1	3	12
37	58.5	4	5	1	2	1	2	11
30	58.5	4	5	2	1	1	2	11
80	55.0	4	4	3	1	2	2	12
66	55.0	4	2	3	2	2	2	11
38	55.0	4	5	1	2	2	1	11
69	55.0	4	4	2	2	1	2	11
31	55.0	4	4	4	2	1	1	12
49	55.0	4	4	3	1	1	2	11
38	55.0	4	4	2	2	1	2	11
60	55.0	4	5	2	2	1	2	12
50	55.0	4	4	3	1	1	3	12
30	55.0	4	5	3	1	2	1	12
87	55.0	4	2	3	2	2	2	11
59	55.0	4	4	2	2	2	2	12
45	55.0	4	4	2	2	2	2	12
59	55.0	4	4	3	2	1	2	12

APPENDIX E

Table 27: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left female auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
50	55.0	4	5	3	2	1	1	12
28	55.0	4	4	2	2	2	2	12
70	55.0	4	2	3	3	2	2	12
46	55.0	4	4	1	2	1	3	11
47	55.0	4	5	2	1	2	2	12
28	55.0	4	2	3	3	2	2	12
43	55.0	4	5	3	1	1	1	11
60	55.0	4	3	3	2	1	2	11
37	55.0	4	5	2	2	1	2	12
25	55.0	4	5	2	2	1	1	11
85	55.0	4	5	3	1	1	2	12
25	55.0	4	5	4	1	1	1	12
36	55.0	4	5	3	1	1	1	11
36	55.0	4	5	2	2	1	2	12
46	58.5	5	5	2	3	3	1	14
40	58.5	5	4	3	2	1	3	13
70	58.5	5	4	3	2	2	2	13
36	58.5	5	4	4	2	2	1	13
74	58.5	5	5	3	2	2	1	13
32	58.5	5	4	5	1	1	2	13
55	58.5	5	5	4	2	1	2	14
58	58.5	5	5	3	2	2	2	14
48	58.5	5	5	3	2	1	2	13
61	58.5	5	5	2	2	2	2	13

APPENDIX E

Table 27: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left female auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
60	58.5	5	5	4	2	1	1	13
35	58.5	5	5	5	1	1	2	14
19	58.5	5	4	4	2	1	2	13
38	58.5	5	4	3	3	1	2	13
45	58.5	5	5	4	1	1	2	13
36	58.5	5	3	3	2	3	2	13
68	58.5	5	5	3	1	2	3	14
74	58.5	5	3	3	2	3	2	13
26	58.5	5	5	3	2	1	2	13
53	58.5	5	5	3	3	1	2	14
58	58.5	5	4	4	3	1	2	14
70	58.5	5	4	4	2	1	3	14
60	65.0	6	5	4	2	2	2	15
65	65.0	6	4	4	3	1	3	15
38	65.0	6	5	4	1	3	3	16
27	65.0	6	5	5	2	1	2	15
23	65.0	6	5	5	2	2	2	16
50	65.0	6	5	3	3	3	1	15
58	65.0	6	5	3	3	2	2	15
40	65.0	6	5	3	2	3	3	16
42	65.0	6	5	3	2	2	3	15
42	65.0	6	5	4	2	2	2	15
25	65.0	6	5	4	2	1	3	15
45	72.5	7	5	4	2	3	3	17

APPENDIX E

Table 27: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left female auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
40	72.5	7	4	4	3	3	3	17

APPENDIX F

Table 28: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right female auricular surfaces

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
50	17.5	1	2	1	1	1	1	6
86	29.5	2	2	2	1	1	1	7
56	29.5	2	3	2	1	1	1	8
26	29.5	2	4	1	1	1	1	8
34	29.5	2	2	2	1	1	2	8
18	40.5	3	4	1	1	1	2	9
30	40.5	3	4	1	2	1	1	9
38	40.5	3	2	4	2	1	1	10
37	40.5	3	4	1	2	2	1	10
29	40.5	3	3	3	2	1	1	10
69	40.5	3	4	1	2	1	2	10
60	40.5	3	5	2	1	1	1	10
38	40.5	3	4	1	2	1	2	10
30	40.5	3	3	3	1	1	1	9
47	40.5	3	3	3	1	1	1	9
50	40.5	3	5	2	1	1	1	10
28	40.5	3	4	2	1	1	1	9
31	40.5	3	4	1	1	1	2	9
36	40.5	3	2	3	1	2	1	9
50	40.5	3	5	1	1	1	1	9
31	40.5	3	3	2	1	2	1	9
28	40.5	3	1	3	3	1	2	10
43	40.5	3	4	2	1	1	1	9
33	40.5	3	3	2	1	1	2	9
32	40.5	3	3	2	1	1	2	9

APPENDIX F

Table 28: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right female auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
37	40.5	3	3	3	1	1	1	9
36	40.5	3	3	4	1	1	1	10
19	40.5	3	4	2	1	1	1	9
22	40.5	3	5	1	1	1	1	9
40	55.0	4	4	2	2	1	3	12
45	55.0	4	5	2	2	2	1	12
32	55.0	4	4	2	2	2	1	11
58	55.0	4	5	1	2	2	1	11
23	55.0	4	2	5	2	1	1	11
70	55.0	4	3	3	1	1	3	11
39	55.0	4	4	2	3	2	1	12
74	55.0	4	4	3	2	2	1	12
56	55.0	4	3	2	2	1	3	11
30	55.0	4	5	2	2	1	1	11
30	55.0	4	5	2	1	1	2	11
80	55.0	4	3	2	2	2	2	11
38	55.0	4	5	2	2	2	1	12
31	51.0	4	4	4	2	1	1	12
49	55.0	4	4	4	1	1	1	11
48	51.0	4	5	3	1	1	2	12
38	55.0	4	5	1	3	1	1	11
50	55.0	4	4	3	1	1	2	11
87	55.0	4	4	3	2	1	2	12
59	55.0	4	4	3	2	1	1	11

APPENDIX F

Table 28: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right female auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
50	55.0	4	4	3	2	1	1	11
28	55.0	4	4	2	2	2	2	12
45	55.0	4	5	3	1	1	2	12
46	55.0	4	5	1	2	1	2	11
74	55.0	4	3	3	2	2	2	12
60	55.0	4	3	2	2	2	3	12
25	55.0	4	5	3	1	1	1	11
36	55.0	4	5	3	1	1	2	12
46	58.5	5	4	2	3	3	2	14
60	58.5	5	4	3	3	2	2	14
65	58.5	5	3	4	2	3	2	14
21	58.5	5	4	2	3	3	1	13
26	58.5	5	5	3	2	2	1	13
36	58.5	5	4	3	3	2	2	14
27	58.5	5	5	5	1	1	1	13
66	58.5	5	4	3	3	3	1	14
32	58.5	5	5	5	1	1	1	13
55	58.5	5	5	4	1	2	2	14
58	58.5	5	5	3	1	2	2	13
58	58.5	5	5	2	2	2	2	13
61	58.5	5	5	2	2	2	2	13
30	58.5	5	5	4	2	2	1	14
59	58.5	5	4	3	2	2	2	13
45	58.5	5	4	2	2	2	3	13

APPENDIX F

Table 28: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right female auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
42	58.5	5	4	4	2	1	2	13
60	58.5	5	5	4	3	1	1	14
35	58.5	5	5	5	1	1	1	13
19	58.5	5	4	4	2	1	2	13
70	58.5	5	5	2	2	3	2	14
38	58.5	5	4	2	3	2	2	13
42	58.5	5	5	3	1	2	2	13
68	58.5	5	5	3	1	2	2	13
47	58.5	5	5	4	2	1	1	13
40	58.5	5	4	3	2	1	3	13
26	58.5	5	4	3	3	1	2	13
37	58.5	5	4	3	3	2	2	14
25	58.5	5	5	3	2	1	2	13
53	58.5	5	5	3	3	1	2	14
85	58.5	5	5	3	1	2	2	13
58	58.5	5	5	4	2	1	2	14
70	58.5	5	5	3	2	2	2	14
28	65.0	6	5	4	2	2	2	15
38	65.0	6	5	4	1	3	3	16
23	65.0	6	5	5	2	1	2	15
50	65.0	6	5	2	3	3	2	15
40	65.0	6	5	4	3	1	3	16
42	65.0	6	5	4	2	1	3	15
25	65.0	6	5	5	1	2	3	16

APPENDIX F

Table 28: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right female auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
45	73.0	7	5	4	3	3	2	17

APPENDIX G

Table 29: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left male auricular surfaces

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
16	17.5	1	1	1	1	1	2	6
16	17.5	1	2	1	1	1	1	6
16	17.5	1	1	1	2	1	1	6
18	29.5	2	2	1	1	1	3	8
16	29.5	2	4	1	1	1	1	8
21	29.5	2	1	2	2	1	1	7
21	29.5	2	3	1	1	1	1	7
24	29.5	2	2	3	1	1	1	8
67	29.5	2	2	3	1	1	1	8
52	29.5	2	1	2	1	1	2	7
30	29.5	2	2	2	1	1	1	7
23	29.5	2	4	1	1	1	1	8
21	29.5	2	3	2	1	1	1	8
23	29.5	2	3	2	1	1	1	8
33	29.5	2	1	2	2	1	1	7
21	29.5	2	2	2	1	1	2	8
46	40.5	3	4	2	1	1	1	9
70	40.5	3	2	3	2	1	2	10
60	40.5	3	4	2	2	1	1	10
19	40.5	3	4	2	1	1	1	9
18	40.5	3	2	3	1	1	2	9
23	40.5	3	4	2	1	1	1	9
26	40.5	3	2	2	2	1	2	9
54	40.5	3	2	3	2	1	1	9
56	40.5	3	4	1	2	1	1	9

APPENDIX G

Table 29: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left male auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
41	40.5	3	4	2	2	1	1	10
36	40.5	3	5	2	1	1	1	10
45	40.5	3	5	1	1	1	1	9
35	40.5	3	3	3	1	2	1	10
58	40.5	3	2	3	2	1	2	10
53	40.5	3	3	2	2	1	1	9
60	40.5	3	4	2	1	1	1	9
58	40.5	3	5	1	1	2	1	10
40	40.5	3	4	2	1	1	1	9
48	40.5	3	2	4	1	1	2	10
21	29.5	3	3	2	1	1	1	8
21	40.5	3	4	3	1	1	1	10
40	40.5	3	4	3	1	1	1	10
52	40.5	3	4	2	1	1	1	9
50	55.0	4	5	3	2	1	1	12
31	55.0	4	5	2	1	2	1	11
49	55.0	4	3	3	2	1	3	12
19	55.0	4	4	2	3	1	2	12
66	55.0	4	3	3	3	1	1	11
46	55.0	4	3	3	3	1	1	11
60	55.0	4	5	1	2	1	2	11
53	55.0	4	5	2	2	2	1	12
24	55.0	4	3	3	2	3	1	12
51	55.0	4	5	3	1	1	1	11
53	55.0	4	4	2	2	1	2	11

APPENDIX G

Table 29: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left male auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
51	55.0	4	3	3	2	1	2	11
30	55.0	4	4	3	2	1	2	12
60	55.0	4	4	3	3	1	1	12
52	55.0	4	3	3	3	1	1	11
49	55.0	4	4	2	2	1	2	11
45	55.0	4	4	2	2	2	1	11
79	55.0	4	4	3	2	1	2	12
52	55.0	4	3	3	2	2	1	11
35	55.0	4	4	3	3	1	1	12
59	55.0	4	4	3	2	1	2	12
62	60.0	4	4	3	3	1	1	12
70	55.0	4	4	3	1	1	3	12
70	55.0	4	5	3	1	1	1	11
55	55.0	4	5	3	2	1	1	12
25	55.0	4	4	5	1	1	1	12
48	55.0	4	5	4	1	1	1	12
47	55.0	4	2	5	1	1	2	11
48	55.0	4	2	3	2	2	3	12
56	55.0	4	3	4	2	1	1	11
30	55.0	4	4	3	1	1	2	11
34	55.0	4	2	5	2	1	2	12
40	55.0	4	4	3	2	1	1	11
56	55.0	4	5	3	1	1	2	12
81	55.0	4	5	3	1	1	2	12
24	58.5	5	4	3	2	2	2	13

APPENDIX G

Table 29: Data summarizing actual age, estimated age and phase as well as the scores for each feature for left male auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
49	58.5	5	4	4	2	2	1	13
46	58.5	5	5	3	2	2	2	14
36	58.5	5	4	3	3	2	2	14
38	58.5	5	4	3	2	2	2	13
55	58.5	5	5	3	1	1	3	13
62	58.5	5	5	4	1	2	2	14
30	58.5	5	5	4	2	2	1	14
30	58.5	5	5	5	1	1	2	14
52	58.5	5	5	4	2	1	2	14
52	58.5	5	4	4	3	1	2	14
50	58.5	5	4	4	2	1	2	13
65	58.5	5	5	4	3	1	1	14
40	58.5	5	4	4	2	1	2	13
49	58.5	5	4	3	2	1	3	13
60	58.5	5	4	3	2	2	2	13
46	58.5	5	5	4	2	2	1	14
55	58.5	5	5	4	1	2	2	14
67	65.0	6	5	3	2	3	3	16
50	60.0	6	5	5	1	1	3	15
53	65.0	6	5	4	2	2	3	16
51	65.0	6	5	4	3	1	2	15
46	65.0	6	5	4	2	1	3	15
60	72.5	7	5	4	3	3	2	17
50	72.5	7	5	5	3	2	3	18

APPENDIX H

Table 30: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right male auricular surfaces

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
16	17.5	1	1	1	1	1	1	5
16	17.5	1	2	1	1	1	1	6
16	17.5	1	1	1	1	2	1	6
70	29.5	2	1	2	2	1	2	8
18	29.5	2	2	1	1	1	2	7
16	29.5	2	4	1	1	1	1	8
21	29.5	2	1	2	2	1	2	8
21	29.5	2	3	1	1	1	1	7
24	29.5	2	2	2	1	1	1	7
41	29.5	2	3	2	1	1	1	8
52	29.5	2	1	2	2	1	2	8
30	29.5	2	2	2	1	1	2	8
23	29.5	2	3	2	1	1	1	8
21	29.5	2	2	2	2	1	1	8
23	29.5	2	2	2	2	1	1	8
21	29.5	2	3	2	1	1	1	8
33	29.5	2	1	2	1	1	2	7
21	29.5	2	2	2	1	1	2	8
19	40.5	3	3	2	2	1	2	10
46	40.5	3	5	2	1	1	1	10
60	40.5	3	4	3	1	1	1	10
19	40.5	3	5	1	1	1	1	9
18	40.5	3	2	3	1	1	2	9

APPENDIX H

Table 30: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right male auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
23	40.5	3	4	2	1	1	1	9
26	40.5	3	2	2	2	1	2	9
38	40.5	3	4	2	2	1	1	10
54	40.5	3	2	3	2	1	1	9
56	40.5	3	4	1	1	1	2	9
36	40.5	3	4	2	1	1	1	9
51	40.5	3	4	3	1	1	1	10
53	40.5	3	3	2	2	1	1	9
45	40.5	3	5	1	2	1	1	10
35	40.5	3	3	3	1	1	1	9
58	40.5	3	2	3	1	2	1	9
53	40.5	3	3	2	2	1	1	9
60	40.5	3	4	1	1	1	2	9
58	40.5	3	5	1	1	1	2	10
40	40.5	3	3	3	1	1	1	9
48	40.5	3	3	4	1	1	1	10
21	40.5	3	3	4	1	1	1	10
40	40.5	3	3	3	1	1	1	9
52	40.5	3	4	2	1	1	2	10
50	55.0	4	5	2	2	1	1	11
66	55.0	4	4	2	3	1	1	11
46	55.0	4	3	4	3	1	1	12
60	55.0	4	5	1	2	1	2	11
53	55.0	4	5	2	2	2	1	12

APPENDIX H

Table 30: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right male auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
24	55.0	4	3	3	2	3	1	12
67	55.0	4	2	4	3	1	1	11
51	55.0	4	4	3	3	1	1	12
30	55.0	4	4	3	2	1	2	12
60	55.0	4	4	3	3	1	1	12
52	55.0	4	4	3	3	1	1	12
49	55.0	4	3	3	2	1	2	11
45	55.0	4	5	2	1	2	2	12
52	55.0	4	4	3	2	1	1	11
35	55.0	4	4	3	2	2	1	12
70	55.0	4	4	3	1	1	3	12
52	55.0	4	3	3	3	1	1	11
40	55.0	4	4	4	2	1	1	12
70	55.0	4	5	3	1	1	1	11
55	55.0	4	4	3	3	1	1	11
25	55.0	4	4	4	1	1	1	11
48	55.0	4	4	4	2	1	1	12
47	55.0	4	1	5	2	1	2	11
48	55.0	4	2	3	3	2	2	12
56	55.0	4	3	4	1	1	2	11
30	55.0	4	4	3	1	1	2	11
40	55.0	4	4	3	1	1	2	11
56	55.0	4	5	3	1	1	2	12
81	55.0	4	4	3	1	1	2	11

APPENDIX H

Table 30: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right male auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
24	58.5	5	4	4	2	1	2	13
31	58.5	5	5	4	2	2	1	14
49	58.5	5	5	3	2	1	3	14
49	58.5	5	4	4	2	2	1	13
46	58.5	5	5	3	1	2	2	13
36	58.5	5	4	3	3	1	2	13
55	58.5	5	5	4	1	1	3	14
62	58.5	5	4	4	2	2	2	14
30	58.5	5	5	5	1	1	2	14
79	58.5	5	5	3	2	1	2	13
59	58.5	5	5	3	2	1	2	13
52	58.5	5	5	4	2	1	2	14
50	58.5	5	5	4	2	1	1	13
65	58.5	5	5	3	2	1	2	13
49	58.5	5	5	3	2	1	3	14
60	58.5	5	4	3	2	2	2	13
46	58.5	5	5	4	3	1	1	14
55	58.5	5	5	5	1	1	2	14
34	58.5	5	4	4	2	2	2	14
30	65.0	6	5	5	2	2	1	15
67	65.0	6	4	4	2	3	2	15
50	65.0	6	5	4	1	2	3	15
62	65.0	6	4	3	3	2	2	14

APPENDIX H

Table 30: Data summarizing actual age, estimated age and phase as well as the scores for each feature for right male auricular surfaces (continued)

Actual Age	Estimated Age	Estimated Phase	Transverse Organization	Surface Texture	Microporosity	Macroporosity	Apical Changes	Composite Score
53	65.0	6	5	3	2	3	3	16
51	65.0	6	5	5	3	1	2	16
50	65.0	6	5	4	3	1	3	16
46	65.0	6	5	4	1	2	3	15
60	72.5	7	5	4	3	3	2	17