ESTIMATION OF AGE FROM THE PUBIC SYMPHYSIS: DIGITAL IMAGING VERSUS TRADITIONAL OBSERVATION

A Thesis

Submitted to the Faculty of Graduates Studies
of the University of Manitoba
in fulfillment of the requirements for the degree of
Master of Arts
in

The Department of Anthropology

By
Myra Lynn Sitchon
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ESTIMATION OF AGE FROM THE PUBIC SYMPHYSIS: DIGITAL IMAGING VERSUS TRADITIONAL OBSERVATION

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ABSTRACT

A main challenge facing skeletal age determination is the inability to distinguish discernible aging features in older adults. This study addresses this issue with a threefold process involving age estimation from the pubic symphysis.

The first component consists of an evaluation of the Transition Analysis age estimation method (Boldsen and colleagues, 2002) in determining the age at death of 105 adults from the Grant collection. This aging technique applies a new statistical approach to calculate age at death from scores from the adult cranium and pelvis with *a priori* uniform or informative age distributions. The method predicted the ages at death of the older adults successfully with the assistance of broad age intervals to accommodate the increased variation expressed in the skeletal morphology with senescence.

The study progressed further with an examination of age at death determination from digital images of the pubic symphysis. Digital images offer the potential to develop an extensive skeletal database of an array of populations, as a means to analyze and control variations to produce precise age estimates for older adults. A comparison of 52 Suchey-Brooks scores assigned to digital images and actual bone revealed that age estimation is possible from the images but must be approached with caution. The subjective nature of scoring from digital photographs and actual bone demonstrates the limitations of the naked eye in identifying age related changes in certain skeletal features, especially where older adults are concerned.

The final component examines whether the application of image analysis techniques can identify discernible morphological changes related to increasing age from digital images of the pubic symphysis. Measures of image pixel brightness and pixel intensity data translated into line plots represent the range of elevations on a surface. Elevation data corresponded with different textures and relief exhibited in the various age-related stages of the symphyseal surface. Further, the plots delivered insightful information into age-related changes of the pubic symphysis unrecognized by the human eye. The results suggest that image analysis should not be overlooked as a useful tool to refine age estimation methodologies.

KEYWORDS: Age at death estimation, pubic symphysis, digital imaging

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INTRODUCTION

Age at death estimates are relied upon in a variety of osteological contexts like the identification of an unknown individual for forensic purposes (Konigsberg and Frankenberg, 1994; Angel, 1984). In order to determine the skeletal age of an unknown person, a forensic anthropologist will rely on their experience and literary information available on aging, growth, and development of particular populations (Ubelaker, 2000).

Skeletal aging techniques are also important for identifying the age at death of a series of individuals in order to reconstruct age distribution patterns or mortality structures. Palaeodemographers rely on these patterns to understand the mortality, fecundity, and the longevity of past populations (Angel, 1984). Further, age distribution patterns assist in the study of pathology (Bedford et al., 1993), disease processes (Aykroyd et al., 1999), and subsistence patterns (Konigsberg and Frankenberg, 1994).

This study focuses on adult age assessment using the pubic symphysis. Other skeletal indicators such as the auricular surface (Lovejoy et al. 1985b; Buckberry and Chamberlain, 2002) and cranial sutures (Masset, 1989) can also be used. However, the distinct morphological age-related changes of the pubic symphysis facilitate the use of this feature. As a result, this skeletal feature yields both high simplicity and accuracy compared to other methods (Pasquier et al., 1999).

Osteologists can approach skeletal age determination from the pubic symphysis by using a variety of established techniques, the most popular being the Suchey-Brooks cast comparison method (Suchey et al., 1986; Katz and Suchey, 1986; Brooks and Suchey, 1990). This widely utilized skeletal aging technique relies on the visual comparison of the pubic symphyseal surface of an unknown individual with that of visual aids and written descriptions outlining age-specific stages of characteristic morphological changes.

Another recently introduced age estimation technique that examines age-related morphological changes in the pubic symphysis is the Transition Analysis method (Boldsen et al., 2002). This method focuses on three anatomic features that are primarily used to assess age at death of an individual: the pubic symphysis, cranial sutures, and the iliac portion of the sacroiliac joint or more commonly referred to as the auricular surface. Each feature is dissected into several distinct components that are further categorized into age-specific transitional stages. For example, the dorsal rim of the pubic symphyseal surface can be described or "scored" as one of five distinct transitional stages (i.e. breakdown of rim). The "scores" are subsequently entered into an age estimation software program developed at the Anthropological Data Base Odense University (ADBOU) situated at the University of Southern Denmark. The program generates a maximum likelihood estimate (MLE), which is the most likely or probable age that an adult has died.

The age estimates derived from the Transition Analysis method are based on the idea that osteological features exhibit age-progressive developmental and degenerative morphological changes in a fixed manner. For instance, the pubic symphyseal surface exhibits clear and distinctive age-related changes such as the regular epiphyseal addition of bone (Meindl et al., 1985). Although the timing of these transitional changes may differ among individuals, they are essentially fixed in a single linear direction. By scoring them as stages that are set to occur at a specific chronological age interval, allows for inferences regarding the timing of transitions from one stage to the next.

This aging technique divides the symphyseal surface into various components (i.e. symphyseal texture, ventral symphyseal margin) like the McKern and Stewart (1957) method. Most pubic symphyseal aging methods combine the components and examine the metamorphosis of the pubic symphysis in its entirety such as the Suchey-Brooks (Suchey et al., 1986; Katz and Suchey, 1986; Brooks and Suchey, 1990) and Todd (1920; 1921) approaches.

The Transition Analysis method derives age estimates from multiple indicators. However, it can also determine skeletal age from a single indicator like the pubic symphysis if other skeletal structures are damaged or unavailable. This study involves the latter approach by focusing on the pubic symphysis to determine age at death

There are several objectives of this study involving the age-progressive metamorphosis of the pubic symphysis. The first objective involves an evaluation of the Suchey-Brooks cast system and the Transition Analysis aging methods in determining age at death of 105 adults from the Grant collection housed at the University of Toronto in the Department of Anthropology. Since there are no known published evaluations of the Transition Analysis technique, this study will involve an assessment of the age estimates derived from this method with those estimates provided by the Suchey-Brooks cast system.

The Suchey-Brooks and Transition Analysis methods require an osteologist to be in direct contact with a skeletal sample to determine age at death. However, the development of recent technology such as Internet, email, and digital imaging has introduced the concept of estimating skeletal age from remote images (Hutchison and Russell, 2001). Hutchinson and Russell (2001) have evaluated this idea through a comparison of auricular surface aging scores obtained through direct observation of the target sample with scores derived from digital, printed, slide, and scanned reproductions. The second objective of this study is to examine the application of remote or digital images in pubic symphyseal age estimation. This component involves the comparison of Suchey-Brooks scores assigned to 52 digital photographs of pubic symphyses from the Grant collection with the scores derived from direct observation of the sample.

The recent introduction of digital imaging technology leads to the third objective of this study: the potential application of digital image analysis software programs to assess age at death of an individual. In addition to being a visual representation of an object, a digital image can provide information regarding the elevation of the object's surface through the intensity or brightness of pixels (Russ, 1992). These pixel intensity values can be ascertained from digital images with image analysis computer programs. This concept was adopted into this study to determine if image analysis programs can identify various age-progressive relief and textural changes that occur in the pubic symphyseal surface from pixel intensity information.

In order to fulfill this objective, this study employs two widely utilized digital imaging programs: Adobe Photoshop, an image editing and enhancement application; and Scion Image, an image analysis program. Both programs offer applications such as pixel enhancements and measurement capabilities, which will be applied to acquire qualitative or quantitative information regarding the senescent changes of the pubic symphysis morphology.

In summary, the objectives are as follows:

i) Comparative assessment of accuracy of Transition Analysis and Suchey-Brooks methods for estimating age from the pubic symphyses of 105 adults from the Grant reference sample.

ii) Assessment of accuracy and reliability of assessing age-related morphological changes of the pubic symphysis from digital images versus direct observation of 52 individuals from the Grant collection.

iii) Assessment of the application of digital image techniques for quantifying age-related morphological changes from the Suchey-Brooks casts and the Grant collection pubic bones.

There are several expectations in this study. First, it is anticipated that the Transition Analysis technique will provide age estimates and intervals closer to the documented ages of the Grant collection than the Suchey-Brooks cast system. The component approach adopted by the Transition Analysis method is expected to capture the age-related senescent changes of the pubic symphysis better than the Suchey-Brooks method. As a result, it is anticipated that the documented ages of those individuals older than forty-five years of age will be closer to the estimates produced by the Transition Analysis technique than the Suchey-Brooks method.

Second, it is expected that a number of Suchey-Brooks scores derived from digital images of the pubic symphysis will match those scores obtained from direct observation of the Grant skeletal sample. The application of digital imaging functions like the magnification feature offered by Photoshop is expected to facilitate the determination of age at death from the images.

Finally, other imaging analysis applications such as microscopy and measures of pixel intensities are anticipated to deliver potential insight into the progression or transition of age-related features exhibited in the pubic symphysis. The image analysis programs are expected to present the results as qualitative, visual data, or quantitative values. The resulting data is expected to provide insightful information into the senescent morphological changes exhibited in the pubic bone that would normally be overlooked by the naked eye.

LITERATURE REVIEW

The skeletal system partakes in a systematic growth process that will eventually transform into a degenerative state once maturation has occurred (Maples, 1989). Noticeable morphological changes related to growth, development, and degeneration will occur in a variety of skeletal structures as an individual matures. The morphological changes that occur within a particular skeletal feature with increasing age are often referred to as "biological age markers" (Kemkes-Grottenthaler, 2002). Age at death is based on the assumption these "biological age markers" occur at a particular chronological age.

Osteologists have identified a variety of areas within the skeletal system that exhibit these age-related morphological changes such as the auricular surface, the sternal rib end, and cranial sutures. However, the most frequently utilized skeletal feature to indicate age at death is the pubic symphysis (Suchey and Katz, 1998). The pubic symphysis is one of the most popular anatomical features to establish the skeletal age of an adult individual in palaeodemographic and forensic contexts due to several factors (Buikstra and Ubelaker, 1994).

The first factor is based on the assumption that highly accurate age estimates are yielded from this skeletal feature in comparison to other age indicators (Suchey et al., 1986; Brooks and Suchey, 1990; Meindl et al., 1985; Klepinger et al., 1992). For instance, cranial suture closures provide highly inaccurate ages at death and are only utilized in conjunction with other aging methods or when other skeletal indicators are unavailable (Meindl and Lovejoy, 1985; 1989).

Another factor is that the pubic symphyseal age estimates are population-specific. There are recognizable differences between sexes and populations in the timing and transition of age-related changes exhibited in the pubic bone (Katz and Suchey, 1989; Suchey, 1979; Todd, 1920; Todd, 1921). For example, Katz and Suchey (1989) modified the Suchey-Brooks method with population specific age estimates and ranges upon the discovery of race differences in the rates of morphological change exhibited in the pubic bones of the reference collection. It is yet to be determined if population specific differences in the rates of age-related metamorphoses are inherent to other age indicators like the auricular surface and cranial sutures (Lovejoy et al., 1985b).

A third factor is related to the distinctive features exhibited in the pubic symphysis associated with growth and senescence. Like the auricular surface, this skeletal indicator exhibits regular, epiphyseal-like addition of bone throughout adulthood and degenerative changes like pitting (Meindl and Lovejoy, 1989). However, the auricular surface is often under utilized to determine age at death due to the difficulty in scoring age-related morphological changes compared to the pubic symphysis (Lovejoy et al. 1985b). In particular, the pubic bone exhibits unique textural and relief changes such as furrowing which simplify the scoring of age-related features.

The final factor is related to the early establishment of the pubic symphysis as a skeletal indicator of age at death. In particular, senescent morphological changes in the pubic bone were recognized in the early 1800's (McKern, 1956). This early discovery has led the pubic symphysis to receive the most attention of all of the skeletal features available for age estimation (Klepinger et al., 1992). In 1920, an English anatomist named T.W. Todd completed the first published research study outlining the age-related changes in exhibited in the pubic symphysis for skeletal aging purposes.

TODD

Todd examined individuals from the Case Western Reserve University skeletal collection to develop an age assessment technique based on the developmental and degenerative changes of the pubic symphysis. A thorough examination of the collection resulted in the creation of a ten-stage system based on key features of the pubic symphysis that exhibit age-progressive morphological changes from early to late adulthood. Todd's original study was based on 306 White males from a dissecting room sample of individuals obtained in Ohio in the early 1900's (Todd, 1920). The following year, the study was extended to a sample of 90 Black males from the Case Western Reserve University Collection or more commonly referred to as the Hamann-Todd collection, which is now housed at the Cleveland Museum of National History (Todd, 1921).

There are five key morphological features noted in Todd's age assessment technique that transform in appearance with increasing age: the symphyseal surface, the ventral rampart, the dorsal plateau, the superior and inferior extremities. These features are not examined as separate components but are combined into an ideal set of age-related traits known as a "stage" that are assigned to a specific age range.

There are several limitations associated with Todd's pubic symphyseal aging technique. First, there were indications that the ages of the Hamann-Todd collection were verified improperly. Many of the ages were listed as 35, 40, 45, 50, and 60 years of age implying that the documented ages were rounded off by a few years (Suchey et al., 1986).

Secondly, many of the adults from the Hamann-Todd collection fall within the older age ranges when the major developmental changes of the pubic symphysis are completed (Suchey et al., 1986). The extremely attenuated sample may contribute to the methods inclination to assign ages that are older than the documented ages of a skeletal sample (Brooks, 1955).

Todd's method is a foundation for many other pubic symphyseal aging methods and is regarded as one of the most highly reliable predictors of age at death (Brooks, 1955; Hanihara and Suzuki, 1978; Meindl et al., 1985; Suchey et al., 1986). Subsequent methodologies have modified Todd's system to address the issue of biased age estimates. These modifications are directed at narrowing or expanding the age intervals of Todd's method or condensing his ten-stage system (Kemkes-Grottenthaler, 2002; Meindl et al., 1985; Suchey et al., 1986).

BROOKS

In 1955, S.T. Brooks evaluated the accuracy of the Todd method and cranial suture techniques in determining the age at death of the Hamann-Todd collection and a prehistoric sample of 470 Californian Native Americans. In her study, Brooks discovered that a variety of individuals with particular ages exhibited pubic symphyseal traits that could not be scored with any of the stages outlined by the Todd system. The morphological traits that were not described by any of the Todd stages have yet to be characterized by any of the current pubic symphysis aging techniques (Suchey and Katz, 1998).

Brooks' initial examination of the Hamann-Todd collection found that the Todd system assigned age estimates with a thirty-percent success rate. In fact, the aging method provided age estimates that were older than the documented ages of adults who died in their third and fourth decade of life. This outcome was attributed to sampling issues outlined earlier in this chapter where many of the adults in the reference sample were older.

To address this issue, Brooks suggested that the age range for the Todd stages V-VIII (27-44 years) should be shifted to three years younger than those proposed in by Todd originally. Once the modifications were completed with the assistance of statistical applications, the modified technique produced accurate age estimates with a sixty-one percent success rate (Brooks, 1955). In her study, she also discovered that the correlations between estimated and documented ages were higher for males than females.

MCKERN, STEWART, AND GILBERT

McKern and Stewart (1957) developed their aging system in response to morphological variations exhibited in the symphyseal face outlined by Brooks (1955). They examined a skeletal sample of 349 American male casualties, most of whom were younger than thirty years of age.

This aging method incorporates a different strategy towards age estimation by dividing the pubic symphysis into three separate components: 1) the dorsal plateau, 2) the ventral rampart, and 3) the symphyseal rim. McKern and Stewart settled on these three discrete areas as they were found to exhibit the most distinctive age-related morphological features. This component approach enables the age determination of adults who possess morphological characteristics that cannot be described by the Todd (1920; 1921) stages.

Gilbert and McKern (1973) modified the McKern-Stewart method to accommodate the skeletal age determination of females. They examined a sample of 120 females of known ages, 80 of which with known parity and discovered that the morphology of females differed significantly from males. Further, those females who had given birth exhibited age-related traits that were characteristic of patterns found in older individuals.

This aging method was evaluated by Suchey (1979) and 23 professional osteologists on a sample of 11 females with unrevealed documented ages. The results were highly variable as only fifty-one percent of all age estimates assigned by the twenty-four osteologists predicted the documented ages of the study sample. The poor performance of the Gilbert-McKern method was attributed to difficulties in interpreting whether the symphyseal rim and ventral rampart were in the process of remodeling bone or erosion (Suchey 1979).

ACSADI and NEMESKERI

In 1970, Acsadi and Nemeskeri proposed a combined sex system of five pubic phases because of extensive European research conducted during the 1950s and 1960s. This system is derived from a reference sample of 105 individuals acquired from historic Hungarian cemeteries and includes 61 males and 44 females with ages ranging from 23 to 93 years (Nemeskeri et al., 1960; Acsadi and Nemeskeri, 1970).

There were a significantly limited number of younger individuals selected to represent the reference sample. Only thirteen females and twenty-seven males between the ages of twenty-three and fifty years were utilized in Acsadi and Nemeskeri's research.

In fact, there was only one female present whose documented age fell within the 23 to 30 year old age range category (Nemeskeri et al., 1960, Acsadi and Nemeskeri, 1970).

The phases outlined by Acsadi and Nemeskeri fail to describe the full age-related transition of morphological attribute that appear in the ventral rampart. In particular, this method overlooks the key morphological traits that occur in the ventral rampart of middle-aged adults, unlike previously developed methods such as the Todd (1920; 1921) and McKern-Stewart (McKern and Stewart, 1957) methods. The pubic phases only outline the metamorphoses of the ventral rampart related to bone remodeling in younger adults and erosion in older individuals (Brooks and Suchey, 1990).

HANIHARA AND SUZUKI

Hanihara and Suzuki (1978) explored the application of multiple regression analysis in age estimation from the pubic symphysis on a sample of seventy pubic bones acquired from the Anatomy Departments of the University of Tokyo and the Sapporo Medical College. They combine males and females in their research based on Todd's (1920) assumption that the sexes exhibited similar pubic symphyseal characteristics with increasing age. However, Hanihara and Suzuki suggest that the sexes should be examined as discrete groups in future studies due to the highly inaccurate age estimates assigned by the McKern-Stewart (McKern and Stewart, 1957) method to female pubic bones.

The reference sample suffers from an extremely attenuated age distribution ranging from 18 to 38 years. Hanihara and Suzuki selected young sample purposely with the premise that the pubic symphysis is extremely reliable in predicting the age at death of individuals between 20 and 40 years of age (Todd 1920; 1921).

Age estimates are derived from the examination of seven features of the pubic symphysis: horizontal ridges and furrows (X_1), pubic tubercle (X_2), lower end (X_3), dorsal margin (X_4), superior ossific nodule (X_5), ventral beveling (X_6), and symphyseal rim (X_7). Each feature is given a score of one through four based on stage descriptions outlined by Hanihara and Suzuki. Each score is entered subsequently into the following formula to provide an estimate of age: $Age = 10.14 + 1.40X_1 + 0.48X_2 + 2.11X_3 + 1.91X_4 - 0.27X_5 + 1.45X_6 + 0.14X_7$.

Meindl and colleagues (1985) have found the age estimation method introduced by Hanihara and Suzuki to be one of the most reliable methods in predicting the age at death of adults between twenty to forty years of age. However, the accuracy of the age estimates generated by this method is often is questioned since the stage descriptions for each feature pertain to both sexes. This approach is often criticized since it has been demonstrated that female pubic bone exhibit highly variable rates of age-progressive changes, which indicates that the sexes should be analyzed as discrete groups (Gilbert and McKern, 1973; Suchey et al., 1979).

MEINDL, LOVEJOY, MENSFORTH, AND WALKER

Meindl and colleagues (1985) tested the McKern-Stewart (McKern and Stewart, 1957), Gilbert-McKern (Gilbert and McKern, 1973), Hanihara-Suzuki (Hanihara and Suzuki, 1978), and Todd (1920; 1921) systems in a blind assessment of 96 adults from the Hamann-Todd collection. All of the aging techniques were highly susceptible to providing estimates that were significantly younger than the documented ages of older adults. This outcome may be attributed to the significant number of younger individuals present in the reference collections used to develop some of the methods tested in this study such as the McKern-Stewart and Hanihara-Suzuki techniques. The younger age estimates generated by the Todd system are thought to result from the narrow age intervals associated with most of stages, except for stage ten, which has an open ended interval of fifty-plus.

The most reliable aging technique from all of the methods tested in this study was the Todd system. The aging method's high success rate in predicting age at death is attributed to its use of a large reference collection with an extensive range of ages, unlike the other techniques tested in this study. Further, the success of the Todd system indicates that the sexes do not have to be analyzed as separate groups. The Todd stage descriptions were able to capture the range of variations exhibited in the morphology of the female and male pubic bones to provide accurate estimates of age at death. Modifications were made to the Todd system by Meindl and colleagues (1985) to eliminate the tendency of this method to under age individuals. A thorough analysis of the 10 stages in the Todd method revealed that some phases could be combined and summarized into five major biological phases. The proposed modified version of the Todd system consists of the following phases: Preepiphyseal (Todd stages I-V), Active epiphyseal (Todd stage VI), Immediate postepiphyseal (Todd stage VII), Maturing predegenerative (Todd stage VIII) and Degenerative (Todd stage IX-X).

This aging method was tested along with the McKern-Stewart and Gilbert-McKern techniques on a second sample consisting of 109 adults from the Hamann-Todd collection. The outcome of this second trial demonstrated that the number of biased age estimates was significantly reduced with the revised method. In particular, the age distribution constructed from the ages estimates of the revised Todd system resembled the actual age distribution of the target sample.

SUCHEY, BROOKS, AND KATZ

The Suchey-Brooks system (Suchey et al., 1986; Katz and Suchey, 1986; Brooks and Suchey, 1990) resulted from an effort to reduce the amount inter-observer error often associated with past age estimation techniques and to increase the accuracy of age estimates. The method is based on a sample of 1225 pubic bones acquired from autopsies conducted at the Department of the Coroner, County of Los Angeles from 1970 to 1977.

A thorough statistical examination of the sample revealed that the first three phases of the Todd age estimation method could be merged into one category. In addition, phases IV, and V and VII and VIII could be combined into a single phase. These modifications of the Todd system resulted in a six-phase system called the Suchey-Brooks method based on age related developmental and degenerative morphological changes in the pubic symphysis. The six phases outline the significant morphological changes of features set to occur at particular age ranges.

This technique estimates age at death by visually comparing features of an individual pubic bone to a set of six written descriptions and casts of age specific "phases". Each phase captures the developmental or degenerative morphological changes that are thought to occur in the pubic symphysis at a particular age interval.

An advantage of the Suchey-Brooks method over other age estimation methods is the availability of casts for comparative purposes. The representation of the age related changes associated with each phase through casts facilitates process of determining skeletal age of an unknown individual. Another advantage of this technique is that it is developed on a large multiracial reference sample whose age ranges vary from adolescence to the elderly. These factors have contributed to the popularity of the Suchey-Brooks method in estimating age at death in forensic contexts.

MILNER-BOLDSEN

Boldsen and colleagues (2002) have recently published a new method of adult age at death estimation called the Milner-Boldsen technique. This age estimation technique is also known as the Transition Analysis technique because it is based on the idea that various osteological features exhibit distinctive age related changes with the appearance of regular epiphyseal addition of bone. Although the timing of these transitional changes may differ among individuals, they occur in a fixed and linear direction. By identifying the age related morphological changes, an osteologist can make inferences about the sequence of transitions from one stage to the next.

Age estimates produced by this method are based on the age related transitions of morphological change exhibited in several distinct components of a particular skeletal structure. Inferences regarding age at death are determined through the combination of scores assigned to the components of one or more skeletal structures. The transition analysis method examines the morphological changes that occur in three skeletal structures: the iliac portion of the sacroiliac joint or the auricular surface, cranial sutures and the pubic symphysis.

The component approach adopted by this method allows for age at death estimates to be based on partial data from skeletal structures as might be found with partially preserved elements. For instance, post-mortem damage in the dorsal symphyseal margin or more commonly known as the dorsal rim prohibits any scoring of this area.

The Transition Analysis method will exclude this component from the analyses and it will generate an age at death estimate based on all of the other component scores provided. The ability to generate age estimates from partial data is thought to contribute to the superiority of this method to more common typecast approaches like the Suchey-Brooks method, which is based on grouping components into a specific category or "phase".

The Transition Analysis method has yet to be tested for its reliability and accuracy in obtaining age at death estimates in a target sample other than on the collections that Boldsen and colleagues (2002) have examined. A major focus of this study is to assess the reliability of the age at death estimates produced by the Transition Analysis technique in capturing the documented ages of adults from the Grant collection.

A persistent issue in skeletal age estimation is the high degree of bias present in age at death estimates. "Bias" in skeletal age estimation refers to the inclination of age estimates to be younger or older than the documented age of an adult (Meindl and Russell, 1998). Biased age estimates often results from the application of an aging method developed on a reference sample of a particular population affinity on a target sample of a completely different population affinity. They are commonly found when determining the skeletal age of an older individual. For example, Brooks (1955) found that Todd's (1920; 1921) system was inclined to provide estimates older than the documented ages of adults in the third and fourth decades of life. Iscan and colleagues (1992) found in their systematic comparison of aging techniques involving the pubic symphysis and sternal rib ends that Todd's method often assigned older adults to three stages younger than what they should have been assigned. An assessment of the multifactoral aging method on the Grant collection (Bedford et al., 1993) found that Meindl and colleagues (1985) modification of the Todd system generated age estimates that were younger than the documented ages listed for adults who were older than fifty years of age. Finally, an evaluation of the Suchey-Brooks cast system revealed that estimated ages were more inclined to deviate from documented ages with increasing chronological age (Klepinger et al., 1992).

Bocquet-Appel and Masset (1982) examined the effect of biased age estimates in age distributions of skeletal populations. Their study focused on a comparison of age at death profiles generated from the skeletal age estimates of a target sample and the documented ages of a reference population from which the skeletal aging method was originally developed. It was revealed that the distribution of the target sample reflected the age structure of the reference population rather than the sample of interest. Bocquet-Appel and Masset (1982) attributed the results to the regression of age on skeletal age indicators and maintained that age distribution reconstructions of skeletal populations were completely unattainable due to the flawed age estimates produced by skeletal age estimation.

The inclination towards regressing age on morphological changes of skeletal features represents a major issue associated with most pubic symphyseal aging methods (Bocquet-Appel and Masset, 1982; Konigsberg and Frankenberg, 1992; 1994). The regression of chronological age on to age indicator morphology implies that increasing chronological age occurs as a consequence of developmental and degenerative changes found in skeletal morphology. In actuality, the morphological changes of the skeleton should be perceived as a consequence of increasing chronological age as proven with biological studies of the human body. This concept of aging is difficult for osteologists to explore since study samples consist of deceased populations rather than living models. In an osteological context, evidence of the dynamic biological processes related to aging is ascertained from human skeletal morphology.

In order to understand the biological processes related to aging, osteologists rely on a "reference collection", a sample of skeletons with documented ages. The reference collection is utilized to develop macroscopic skeletal aging techniques beginning with the identification of a skeletal age indicator, a feature that exhibits key age-related morphological attributes like the development of a symphyseal rim. These attributes are isolated through the visual observation of physical changes that occur in a skeletal indicator like the pubic symphysis. Any distinct morphological changes that occur in the skeletal indicator are often correlated with a particular age interval and are organized into sequential categories like "phases" or "stages".

Macroscopic skeletal age estimation such as pubic symphyseal techniques, rely on these categories to assign age estimates to a target sample with unknown or undocumented ages. Skeletal age estimation involves the comparison of physical traits of a skeletal age indicator in the target sample with the established categories of age-related changes associated with a particular age interval. Age at death is determined once the characteristics exhibited in the age indicator of the target sample are assigned to a particular age category. The resulting age at death estimate is a value representing the probability that a person died at a particular age based on the evidence ascertained from the morphology of the individual's skeletal remains.

The aforementioned process of age determination appears to be simple and straightforward but also demonstrates a major flaw of most skeletal aging methods: the resulting age at death values of a target population is treated as being directly proportional to the ages-at-death of the reference collection. This approach in skeletal age determination implies that no variation occurs in the aging process of individuals from the target samples and reference collection and the rates of age-related morphological change are uniform across both populations. The manifestation of this particular situation is highly unlikely given the amount of variation that is known to exist in the rates of development and degeneration of bone across individual and populations. It is this false assumption that leads to the biased age estimates produced by most pubic symphyseal aging methods and results in the "age mimicry" of age distributions as found in Bocquet-Appel and Masset's (1982) study.

The proper determination of age at death where skeletal indicators are conditional on age requires the application of Bayes' Theorem (Bayes, 1763), a classic theorem in probability theory (Konigsberg and Frankenberg, 1994; Hoppa and Vaupel, 2002). The application of Bayesian statistics in age determination requires the probability distribution of the skeletal ages or the age distribution of the target sample (see Figures 2.1; 2.2). The age distribution (i.e., lifespan) of the target sample is a variable that represents the probability that an individual that was selected randomly from the sample of interest died at exactly age *x* (Konigsberg and Frankenberg, 1994; Hoppa and Vaupel, 2002; Boldsen et al. 2002). Without this variable, age estimates are based on the *a priori* assumption that skeletons in the target sample follow the same age at death distribution of the reference samples leading to biased estimates (Konigsberg and Frankenberg, 1994).

Bayes' Theorem in the determination of age at death

$$\Pr(a|c) = \frac{\Pr(c|a)\, f(a)}{\int_0^{\omega} \Pr(c|a)\, f(a)\, da}$$

or

$$\Pr(a|c) = \frac{\Pr(c|a)\, f(a)}{\Pr(c)}$$

FIGURE 2.1. Bayes Theorem applied in the determination of age at death (taken from Hoppa and Vaupel, 2002)

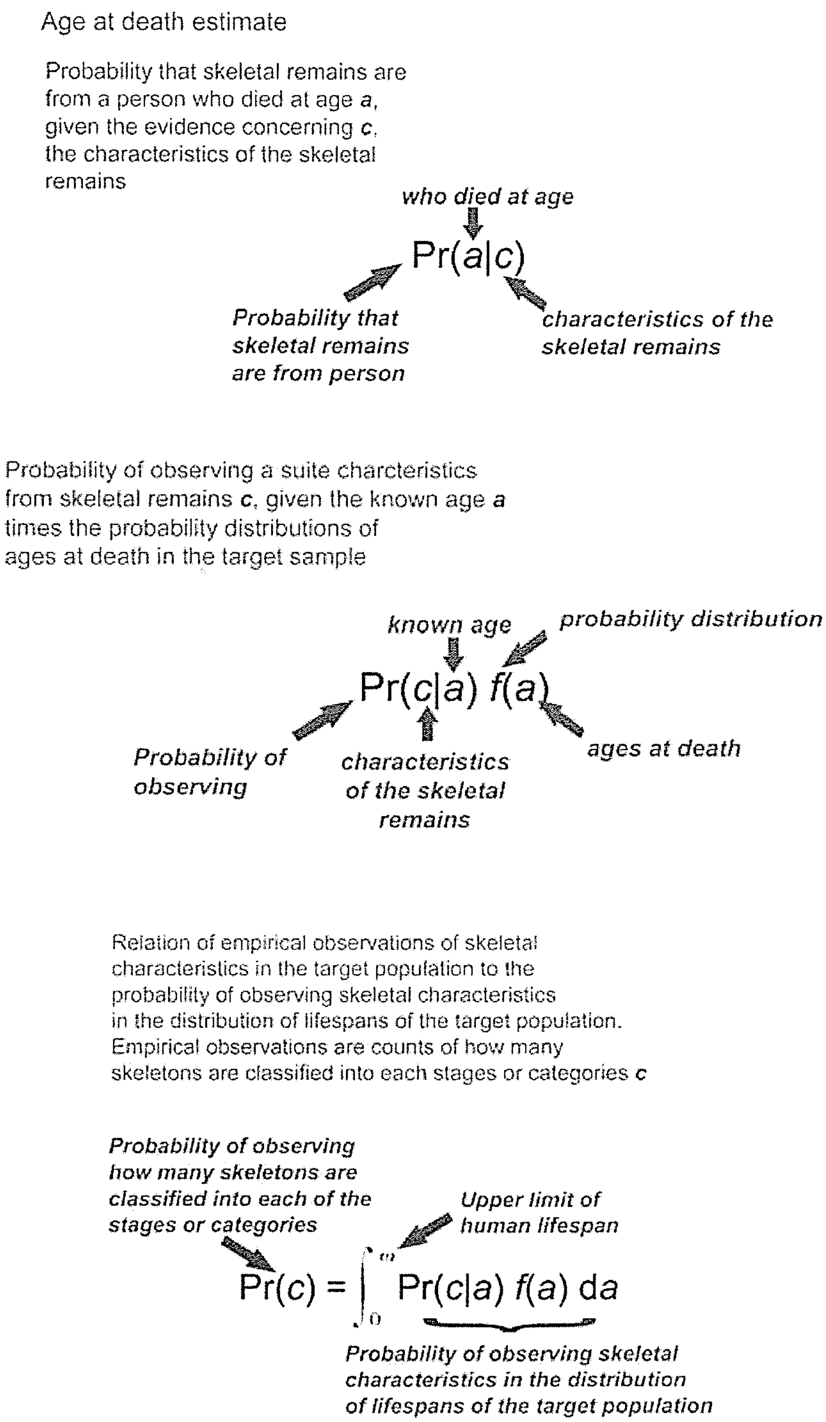

FIGURE 2.2. Explanation of the variables required by Bayes' Theorem to determine age at death. (Taken from Hoppa and Vaupel, 2002)

The fact that the age distribution of the sample of interest is required to determine skeletal age represents a fundamental paradox in age estimation, in such that age at death is required to generate age distributions. If this is the case, how is it possible to generate an age distribution of a target sample if the age at death is unknown? This paradox led Bocquet-Appel and Masset (1982) to believe that the reconstruction of age distributions from skeletal populations as practiced by palaeodemographers do not provide any significant information due to the shortcomings of skeletal age estimates.

This ideal of skeletal age estimation and the reconstruction of age distributions was contested by Konigsberg and Frankenberg (1992) who demonstrated that an estimate of the age distribution of the target sample is indeed recoverable. They proposed that skeletal age estimation adopt the "iterated age length key" model, a maximum likelihood estimation approach utilized in wildlife fisheries research. The "iterated age length key" is a two-step iterative method based on an expectation-maximization algorithm that results in maximum likelihood solutions. An analysis of an assortment of age indicators allowed Konigsberg and Frankenberg to demonstrate successfully how the principle of Maximum Likelihood Estimation can provide estimates of age distributions of the target sample and potentially eliminate or minimize the level of bias present in current age distributions. The Maximum Likelihood Estimation application generates an age at death distribution variable that is based on the probability of the skeletal ages of a group of individuals, which is determined from the skeletal age indicators of all skeletons in the sample (Konigsberg and Frankenberg, 1994).

Love and Muller (2002) have expanded on the principle of Maximum Likelihood methods introduced by Konigsberg and Frankenberg (1992; 1994) and employed the method to produce age at death estimates with minimal bias in a target population. This approach requires a large target sample size to estimate an age distribution variable based on the sample of interest. Unfortunately, an extensive target sample may not be available as demonstrated in archaeological and forensic contexts where there may be only one or a few individuals of interest (Boldsen et al., 2002).

Boldsen and colleagues (2002) address this issue by including prior information on age distributions of samples that are independent of the target sample to estimate age at death. This approach is an integral component of the Transition Analysis method established by Boldsen and colleagues (2002) to minimize the level of bias in age estimates produced by other skeletal aging methods. The age distribution of the target sample is represented by prior age distribution that is uniform or based on relevant documentary information that is independent of the sample of interest.

The Transition Analysis technique employs a uniform prior age distribution as Konigsberg and Frankenberg (1994) illustrated that the f(.) values will cancel out in Bayes theorem (Figure 2.1). This act eliminates the requirement of the age distribution variable of the target sample to estimate age at death. Although, the use of prior uniform or flat age distributions has been highly criticized (Di Bacco et al., 1999), there is adequate literature available that recommends incorporating uniform prior age distributions the determination of age at death (Konigsberg et al., 1998; Brown, 1993).

In addition to the application of a uniform age distribution, the Transition Analysis technique can base the statistical calculation of age at death on *a priori* archaeological and forensic age distributions. The ability to choose a forensic or an archaeological age distribution allows the determination of skeletal age to be based on a population that is relevant to the target sample. Boldsen and colleagues' (2002) method offers the choice of two types of age distributions models: an *archaeological* age at death distribution modeled after 17th century Danish rural parish records and a *forensic* age distribution model based on 1996 national homicide data from the United States. The estimation of age at death, however, does not have to be limited to the age distributions of the two populations incorporated into the Transition Analysis method. Boldsen and colleagues indicate that relevant information pertaining to different populations worldwide can be found easily and can serve as a general model to estimate age at death.

The selection of *a priori* age distributions reduces "age mimicry" bias since age estimates are based on an extensive population sample that is relevant to the sample of interest rather than a limited reference collection derived from a different population affinity. This bias is not fully eliminated since the Transition Analysis age estimates will still be biased towards the *a priori* mortality structure of a relevant population from a similar time period and/or geographic location.

Although, Boldsen and colleagues (2002) may have successfully minimized the level of bias that occurs in skeletal age estimation with the Transition Analysis approach, there is still a particular drawback associated with this method: the reliance on a qualitative approach to interpret age-related morphological changes observed in a skeletal age indicator to determine age at death.

The qualitative approach refers to the visual comparison of certain morphological features of a bone to a set of established age progressive stages of skeletal age markers developed from a reference sample of known age. This approach towards age determination is rather subjective, likening the methodology of age estimation to an art (Maples, 1989) and may influence the accuracy of predicting age at death.

The accuracy of age estimates varies among skeletal aging methods (Meindl and Russell, 1998) and it is often dependent on level of observer error present during the assignment of age at death estimates. Accuracy is dependent on an observer's ability to identify age-related morphological features, which is developed through substantial education and experience in aging techniques (Kemkes-Grottenthaler, 2002; Iscan et al., 1992; Angel, 1984). Further, an observer should have comprehensive knowledge of the biological processes of the skeletal system related to growth variations and adaptations (Loth and Iscan, 1989; Aykroyd et al, 1999). The degree of observer error in age estimation can be controlled by applying more than one method to determine age at death (Meindl and Russell, 1998).

However, education and experience do not fully eliminate the amount of subjectivity associated with current aging technique estimation. It is still possible for one observer to interpret features on the symphyseal surface that may remain unrecognizable by another. The subjective nature of skeletal age estimation implies that standardization is required to increase the accuracy of age estimates. However, this may be difficult to incorporate into skeletal aging methodology given the qualitative approach of current aging techniques. Aging methods incorporate standardization with the use of descriptive summaries and visual aides characterizing morphological traits that correlate with a specific age interval. Although, these aides may promote standardization and increase accuracy, age at death is still the product of subjective interpretations completed with the naked eye.

Current pubic symphyseal aging techniques that rely on macroscopic identification of skeletal traits often fail to identify key age-related morphological attributes in older adults. This is demonstrated with the narrow age at death intervals assigned to younger adults that broaden extensively with increasing age (Aykroyd et al., 1999; Ericksen, 1997). For example, the Suchey-Brooks techniques (Suchey et al., 1986; Katz and Suchey, 1986; Brooks and Suchey, 1990) will assign young adult females to a phase one classification that yields an age interval of 16.8 years to 22 years of age. The estimated age intervals will broaden for older adults who are often designated a higher score such as phase six where the age-interval is set at 47.6 to 72.4 years. Evidently, the phase six age interval contains five times the number of years present in the age interval designated for phase one. Additional age estimation like the Todd system (1920; 1921) assigns older adults with a stage ten designation to a broad and open-end category of "fifty-plus".

Although there is low number of biased age estimates generated by the Transition Analysis technique (Boldsen et al., 2002), there are broad age intervals produced for individuals older than fifty years of age. These extensive estimated age ranges are meant to accommodate the high degree of error associated with estimating age at death of older adults (Boldsen et al., 2002).

Hanihara and Suzuki (1978) deal with the difficulties of aging older adults by limiting their technique to determine age at death of adults between twenty to forty years. Adults older than forty are ignored since the authors maintain that it is difficult to ascertain age related changes in this age group due to increased variation in morphology.

The challenges facing current age estimation methodology stem from the underlying factor that the rates of skeletal development, remodeling, and degeneration are highly variable between individuals and populations (Buckberry and Chamberlain, 2002). The rates of biological processes related to aging are also known to differ within an individual where different estimates of chronological age can be derived from various biological age markers within a single skeleton.

A common misconception in age estimation is that all skeletal indicators exhibit similar rates of age-related morphological changes within a skeleton. This assumption is derived from the ideal that adult age at death estimation is analogous to the skeletal aging of a juvenile (Boldsen et al., 2002). Skeletal age indicators of sub-adult populations such as dental eruption and epiphyseal fusion demonstrate age-related developmental changes in a regular manner and can be correlated with documented age with minimal error (Boldsen et al., 2002). The same ideal cannot be applied to adults since age-related morphological changes are degenerative processes rather than developmental. Further, the pattern by which skeletal age indicators exhibit senescent morphological changes is highly variable and increases with senescence, particularly in the third decade of life (Harper and Crews, 2000; Meindl and Russell, 1998). As a result, it is harder to ascertain age at death from the skeletal remains of an older individual with a group of age estimation techniques (Ubelaker, 2000).

The rate by which skeletal indicators exhibit degenerative morphological changes related to senescence is related to a variety of factors like genetics, diet, physical activity, and disease (Angel, 1984; Buckberry and Chamberlain, 2002). These stress-inducing factors will influence the ageing process of collagen with respect to increased cross bonding, stiffness, and impermeability resulting in the increased variations associated with senescence (Angel, 1984).

For instance, Klepinger and colleagues (1992) maintain that severe trauma and lack of normal physical activity had delayed or advanced the rate of age-related morphological changes exhibited in the pubic symphyses of various individuals in their target sample. Further, daily activities like locomotion and the occasional circumstance of childbirth is known to affect pubic bone morphology (Iscan, 1992). Prior to establishing age at death it is, therefore, important to consider the condition of the biological age marker as the morphology may have been affected by factors like excessive functional use.

The variations in the rates of developmental and degenerative changes of the skeleton are significantly evident when individuals are analyzed collectively as a population (Aykroyd, 1997; Hoppa, 2000). A comparison of age at death estimates of groups from different biological affinities will often isolate populational differences in the remodeling and degenerative rates of bone.

Past studies (Todd, 1921; Gilbert and McKern, 1973; Gilbert, 1973) indicate that there are apparent differences in the morphology and maturational rates of males and females. Suchey and colleagues (Suchey et al., 1986; Katz and Suchey, 1986; Brooks and Suchey, 1990) address this concern by utilizing different cast models for males and females to compensate for the age related morphological differences exhibited in the pubic bones of the sexes. The authors indicate that female pubic bones will reflect age-related changes in an area between the ventral aspect of the symphyseal rim and the ventral arc, whereas males do not (Brooks and Suchey, 1990). Further, changes in the dorsal margin rim of the pubic bone in females are thought to be the related to pregnancy or other unknown factors and occur independently from senescence (Suchey et al., 1979; Brooks and Suchey, 1990). As a result, lipping of the dorsal symphyseal rim, a common feature utilized by the Suchey--Brooks method, is thought to be a highly unreliable indicator of age (Brooks and Suchey, 1990).

Other apparent populational differences in the age related metamorphosis of the pubic symphysis are recognized in the skeletal remains of adults with different population affinities. For example, Todd (1920; 1921) noted that African American males exhibited age related changes in the pubic symphysis that were more advanced in development and degeneration than the "White" American samples.

A multiracial sample of 704 adult males studied by Katz and Suchey (1989) demonstrated that there were differences in the patterning of age related changes exhibited in the pubic symphyses of American "White", African Americans, and Mexican populations. African Americans and Mexicans that exhibited advanced degenerative patterns of pubic symphyseal metamorphosis in relation to senescence were inclined to have lower ages than the "White" sample (Katz and Suchey, 1989). As a result, the age at death estimates and intervals corresponding with the various phases in the Suchey-Brooks method were modified to reflect the differences found in age-related patterns of Mexicans, African Americans, and American "Whites".

Sinha and Gupta (1995) found similar results in their study of 82 adult males from India. Age at death was determined through the application Todd's (1920; 1921) and McKern and Stewart's (1957) pubic symphyseal aging methods. The Indian sample exhibited differences in remodeling and degenerative aspects of the symphyseal rim, the dorsal plateau, and the ventral rampart relative to increasing age. The application of McKern and Stewart's (1957) component aging method demonstrated that remodeling of the dorsal margin occurs earlier in the Indian sample. Furthermore, the formation of the symphyseal rim begins early and reaches full completion at a later age in the target sample. The prolonged development of the symphyseal rim is thought to delay the completion of the ventral rampart in the pubic bones of the Indian males. Sinha and Gupta (1995) indicate these results were consistent with those found in Pal and Tamankar's (1983) study of pubic symphyses from an adult sample in India.

A common misconception in skeletal age estimation is that the skeletal indicators of populations from different periods will exhibit analogous rates of age related morphological change. This ideal arises from the uniformitarian assumption that the biological processes governing the senescent metamorphoses of skeletal aging indicators are the same for populations in past and present day contexts (Howell, 1976). As a result, aging methods developed from adults in a modern day context are often applied in the skeletal age determination of archaeological populations.

Saunders and colleagues (1992) examined the application of techniques derived from a modern context on an archaeological population. Their study applied the Suchey-Brooks method along with several other aging techniques on an archaeological sample derived from a 19th century Canadian pioneer cemetery collection with documented ages. From all of the aging techniques tested, the Suchey-Brooks method provided the least accurate age estimates and intervals for most of the age groups in the archaeological sample. A majority of the adults except for those in the youngest age categories was assigned significantly younger age estimates by the pubic symphyseal aging technique.

The inaccuracy of age estimates provided for adult in the target sample was attributed to the misapplication of a skeletal aging method derived from a modern day skeletal sample on a population from an archaeological context. In addition, the Suchey-Brooks method was criticized its failure to recognize discernible age-related morphological features in older populations as demonstrated with this study.

The inherent differences between past and present populations in the age-related patterns of pubic symphyseal metamorphosis were further tested by Hoppa (2000) who examined three samples with different population affinities. Adults from the reference collection used to develop the Suchey--Brooks technique were compared against a target sample derived from a 20th century forensic collection of similar composition (Klepinger et al., 1992) and a second target sample derived from a 18th to 19th century archaeological population with documented ages (Molleson et al., 1993). Hoppa (2000) observed differences in the timing of developmental and degenerative changes related to increasing chronological age between the reference and target samples. A significant observation in his study was that females in the target samples exhibited rates of morphological change that were statistically significantly different from the reference standard after thirty years of age.

The comparison of age estimates produced for groups of skeletons with different biological or population affinities allow osteologists to decipher the underlying factors that may contribute to the levels of variation observed in the patterning of age-related metamorphosis of skeletal indicators.

> .... The parameters of bone aging need not be considered merely as estimates of selective damage to the skeletal system, but should rather be regarded as a much broader reflection of the status of regulatory mechanisms monitoring the complex aging changes in the organism (Belkin et al., 1998:356).

There is an assortment of factors that direct the dynamics of age-progressive morphological change in the skeletal system such as environmental, behavioural, and biological or genetic variables. For instance, climate is an environmental factor that can regulate the rates of age-progressive changes in the skeletal system. Hand radiograms of more than 7,500 individuals residing in 31 different localities and belonging to 20 populational affinities were examined for the osseographic assessment of degenerative bone changes like demineralization of bone (Belkin et al., 1998). The radiograms were examined to determine if climate was a contributing factor in the onset of degenerative processes of the skeletal remains. The study revealed that temperature and humidity were key attributes that affected the degeneration of bone in various populations (Belkin et al., 1998). These climatic variables affect the thermoregulation of the human body and may subsequently alter the metabolic processes of the circulatory system (Hentschel and Turowki, 1988; Komarov et al., 1988; Bruce et al., 1991; Scarpace and Matheny, 1996).

Behavioral factors like the ingestion of drugs and nutritional additives are other contributing factors to the differences in aging patterns exhibited in various populations, especially those derived from a modern and archaeological context. For example, female oral contraceptives and vitamin additives in foods introduced in the modern era may have altered the progression of epiphyseal fusion in the adolescent skeletal system (Owings-Webb and Suchey, 1985). Further, substance abuse has been known to affect the demineralization rates in bone and may lead to inaccurate age at death estimates derived from histological aging techniques (Stout, 1998; Aykroyd et al., 1999) (See Table 2.1).

Drugs that affect the remodeling rates of bone
• Anticonvulsants
• Alcohol
• Estrogens
• Corticosteroids

TABLE 2.1. List of drugs that affect the remodeling rates of bone (taken from Stout, 1998).

Substance abuse and the modern medical health aides have resulted in the high degree of acculturation and variation in the health status of modern populations. Therefore, it is recommended that reference collections should be based on archaeological populations since the skeletal remains from these groups express greater stability and uniformity in environmental and genetic variations (Lovejoy et al., 1985).

Biological or genetic factors are other variables that affect the rate of developmental and degenerative aging processes exhibited in the pubic symphysis. The appearance of age-progressive changes in the pubic symphysis is known to differ between sexes because of the special hormonal influence of pregnancy and the trauma associated with childbirth (Putschar, 1976). For example, the resorption of bone reflected as pitting in the dorsal aspect of the pubic symphysis is more pronounced in adult females than males (Tague, 1988). In addition, the increased pitting of the female pubic symphysis is thought to be induced by the high level of estrogen required to stimulate the production of osteoclastic enzymes needed to relax the insertions of ligaments for obstetric purposes (Tague, 1988).

Evidently, the problems inherent to age estimation are related to variations in skeletal morphology exhibited in a variety of individuals and populations. These variations are the result of an assortment of intrinsic and extrinsic factors that govern the biological processes of the skeletal system related to growth and senescence. Although, it has been known for decades that the difficulties associated with age estimation are related to variations in the developmental and degenerative processes of the human skeleton. These issues have only been addressed recently with the realization that age at death estimates were flawed since past skeletal aging techniques had mistakenly regressed age on skeletal age indicators (Bocquet-Appel and Masset, 1982). Fortunately, skeletal age estimation methodology has overcome this particular limitation and progressed further with the inclusion of Maximum Likelihood estimation (Konigsberg and Frankenberg, 1992; 1994; 1997; Muller et al., 2001; Love and Mueller, 2002) and the development of new techniques like the Transition Analysis method (Boldsen et al., 2002) to estimate age at death.

Osteologists have accepted intrinsic and extrinsic factors will continually influence the rates of age-progressive changes, as they are an integral part of human growth and development. These factors should not dissuade osteologists into believing that skeletal aging is a wasted effort. The fact that patterns of discernible morphological traits that can be ascertained from skeletal remains with regularity implies strongly that aging systems can be developed and relied upon to determine age at death (Suchey et al., 1979).

The current limitations facing skeletal age estimation such as the issue of inaccuracy in age estimates of older adult can be addressed by refining the methodology to recognize discernible age-related morphological patterns in the skeletal indicators of older adults. In order to progress in this manner, osteologists should attempt to eliminate the level of subjective analyses in macroscopic aging techniques. In addition, increased standardization and quantitative measures should be incorporated into age estimation methodologies to identify discernible aging features that are better correlates of chronological age.

MATERIALS AND METHODS

Materials

1. The Grant Collection

The primary source of data for this study is the Grant skeletal collection. This collection consists of 202 individuals received by the University of Toronto's Anatomy Department for medical school purposes. The Anatomy Act and Revised Ontario Statutes of 1937, 1942, and 1946 enabled Dr. J.C.B. Grant and colleagues to collect unclaimed bodies of transients, migrant workers, or recent immigrants without related family from local hospitals and welfare institutions (Bedford et al., 1993). The department originally collected more than 202 individuals from 1928 to 1950. In 1948, however, any males whose age could not be accurately identified were discarded from the collection (Heathcote, unpublished manuscript).

Verification of age at death was determined with the assistance of vital statistic records, hospital records, or personal history provided by the actual individual prior to death. Detailed information such as name, sex, and cause of death is recorded for each individual in addition to age at death (Bedford et al., 1993).

The Grant collection is comprised mainly of males (n=175, 87%) that are over forty-five years of age (n=145, 72%). With respect to population affinity, the collection consists of individuals of "white", European descent with the exception of one person whose ancestry is described as "black". The population affinity of each individual was determined through the basis of surnames and the assistance of available records.

Various drawbacks limit the Grant collection from being a wholly adequate documented reference collection for research purposes. The main limitations are the lack of females represented in this sample (n=27, 13%) and the insufficient number of individuals less than forty-five years of age (n=55, 27%). These restrictions associated with the Grant collection can be potentially difficult to overcome during the selection of a study sample.

Other concerns are associated with the post-mortem preservation of the Grant collection. A thorough examination revealed that the collection contained innominates for 178 of 202 individuals (89%). All of the issues associated with the post mortem preservation of the pubic symphyses and the under representation of females and younger individuals were carefully addressed during the selection of a study sample.

2. The Transition Analysis method

A primary component of this study is to examine the accuracy of the Transition Analysis (Boldsen et al., 2002) ages at death. This method provides age estimates based on the examination of the pubic symphysis, the auricular surface, and cranial sutures. The features used in this aging approach were derived from descriptions of changes outlined in previous studies (e.g. McKern and Stewart, 1957; Lovejoy et al., 1985b) of the pelvis and the cranium. Estimates are derived from the examination of one or more of these skeletal features. This study will focus solely on the pubic symphysis, which is analyzed by the Transition Analysis method as five separate components: the symphyseal relief, symphyseal texture, the superior apex or also referred to as the cranial ossicle, the ventral symphyseal margin, and the dorsal symphyseal margin (Figure 3.1).

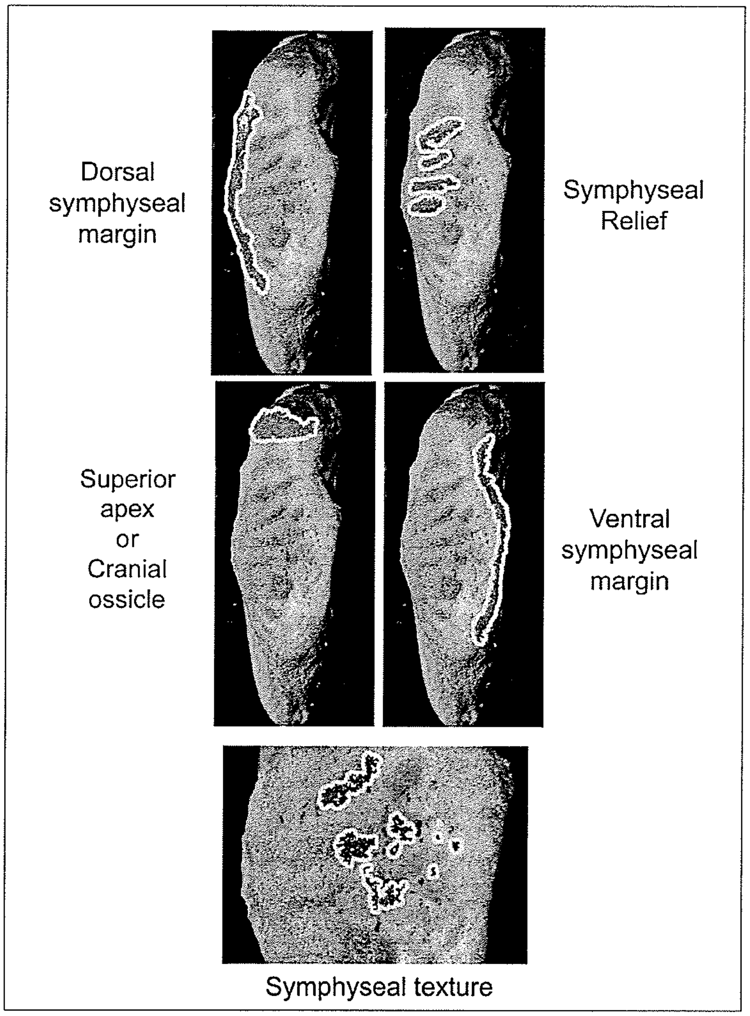

FIGURE 3.1. The various components of the pubic symphysis that are examined by the Transition Analysis to determine age at death. The areas that are of interest are outlined and darkened in this image.

Scores are assigned by identifying features exhibited in each component of the pubic bone to a set of component descriptions outlined by Boldsen and colleagues (2002). These pubic symphysis descriptions are derived from previous methods such as the McKern-Stewart method (McKern and Stewart, 1957) and Boldsen and colleagues (2002) extensive experience with several thousands of archaeological and modern skeletons from North America and Denmark. Each component score represents a stage outlining a set of morphological characteristics that appear at a particular age range.

These scores are entered subsequently into a computer program developed at the Anthropological Data Base Odense University (ADBOU) at the University of Southern Denmark (Figure 3.2). This program statistically combines component scores based on Maximum Likelihood Estimate (MLE) mathematical models (Konigsberg and Frankenberg, 1992; 1994; Love and Muller, 2002) to calculate the most probable skeletal age along with an associated ninety-five percent confidence interval.

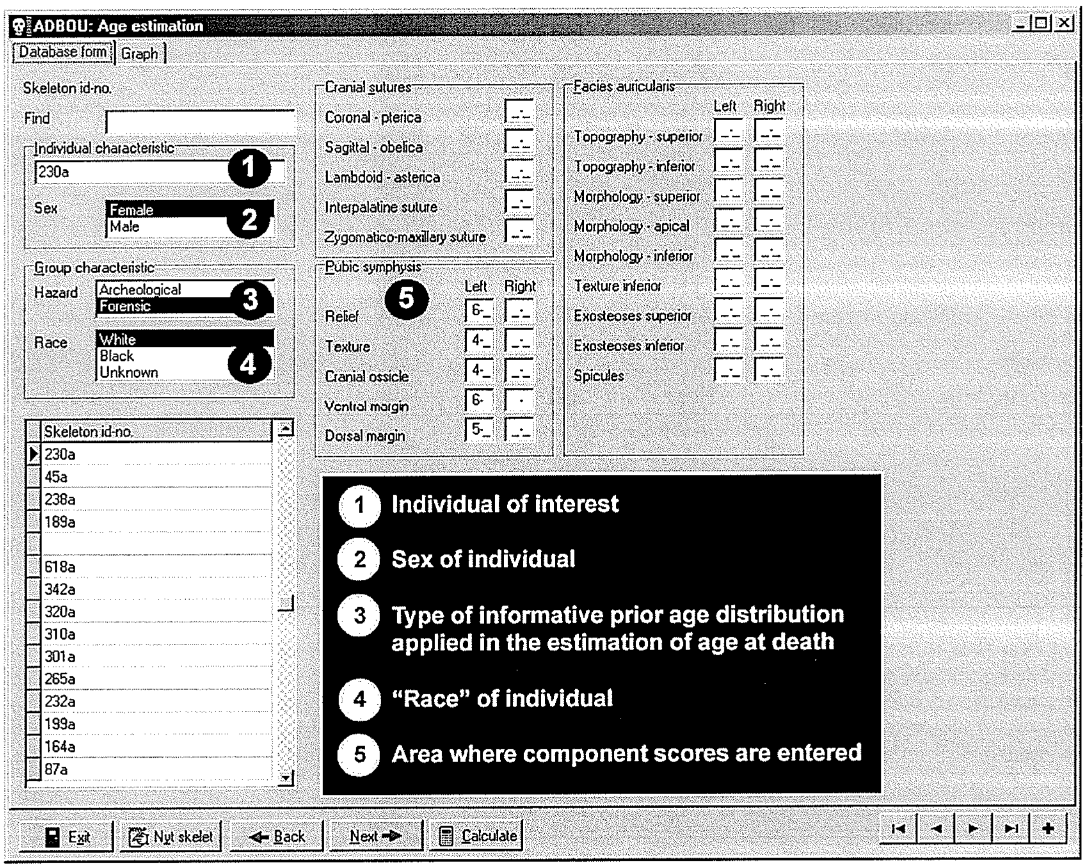

FIGURE 3.2. A screenshot of the database program created at ADBOU Southern Denmark University. Some features in the screenshot are outlined the black box in the image.

One advantage of the Transition Analysis method is that it accommodates two-stage designations if it is impossible to assign the characteristics to a single component stage (Figure 3.3). Previous methods such as the Suchey-Brooks (Suchey et al., 1986; Katz and Suchey, 1986; Brooks and Suchey, 1990) and Todd (1920; 1921) aging systems are often limited since they can only designate pubic bone traits to one stage, even if the characteristics correspond with two stage descriptions.

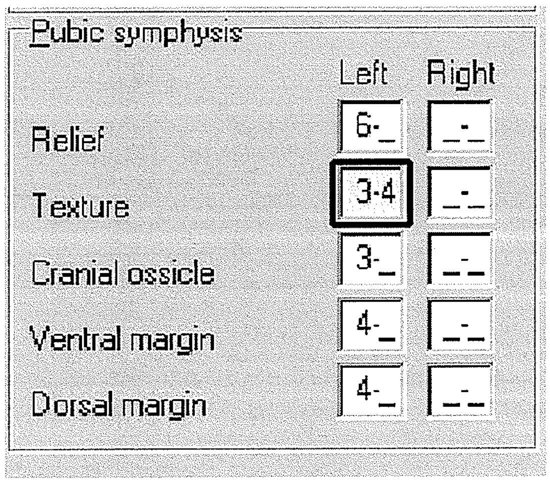

FIGURE 3.3. An example of a two-stage designation (outlined and highlighted) entered into the Transition Analysis software.

The results are displayed as numerical values reporting a Maximum Likelihood Estimate (MLE) of age at death with an associated ninety-five percent confidence interval. In addition, the software program generates a probability density curve plotting the MLE of skeletal age and the upper and lower limits of the confidence intervals. (Figure 3.4).

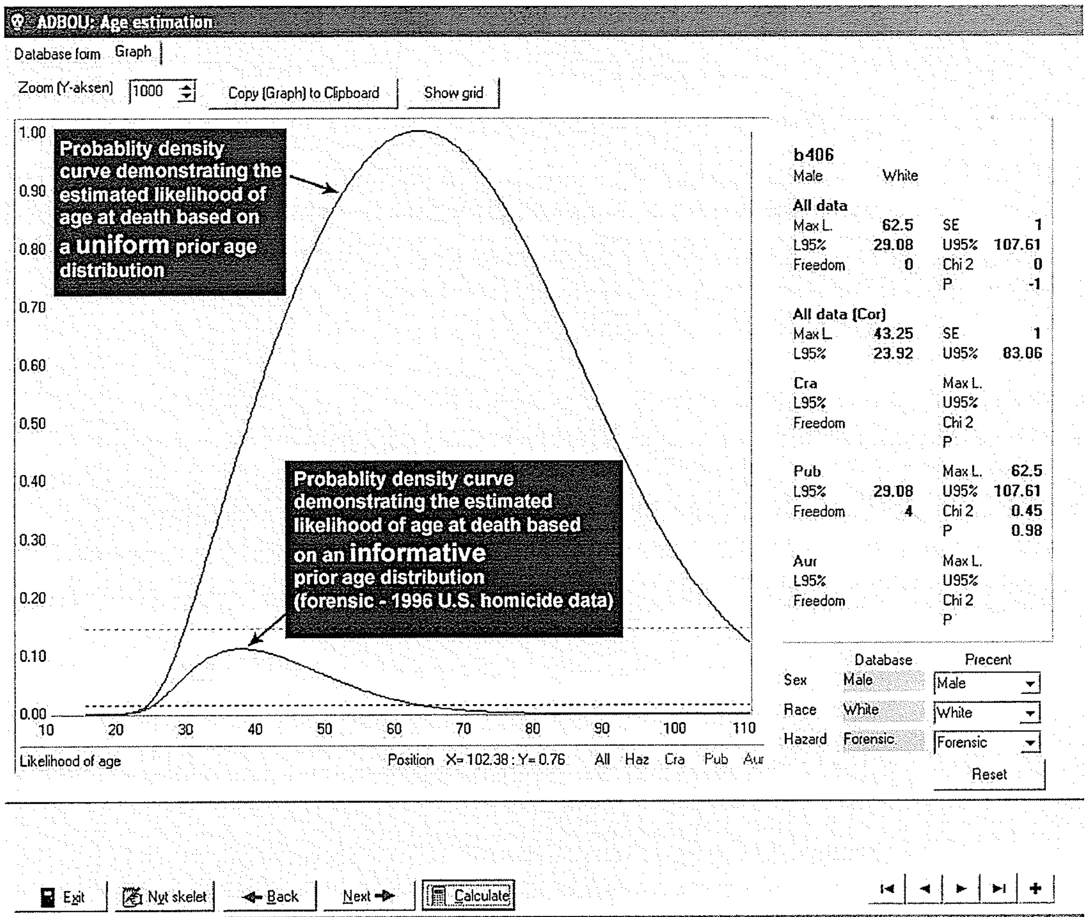

FIGURE 3.4. The numerical values of age estimates are presented in a graphical display by the Transition Analysis software program. An explanation of the graphical features generated by the program is outlined in the image.

The software program generates estimates of age at death for each feature scored and can be referred to as single indicator age estimates since they are based on the scores from one skeletal feature. The values representing single indicator age estimates are based on the statistical calculation of component scores with a uniform or flat age distributions using the Maximum Likelihood Estimate (MLE) model. This study focused on likelihood estimates presented in the "pub" or pubic symphysis region since it was the only skeletal feature examined in this study (Figure 3.5).

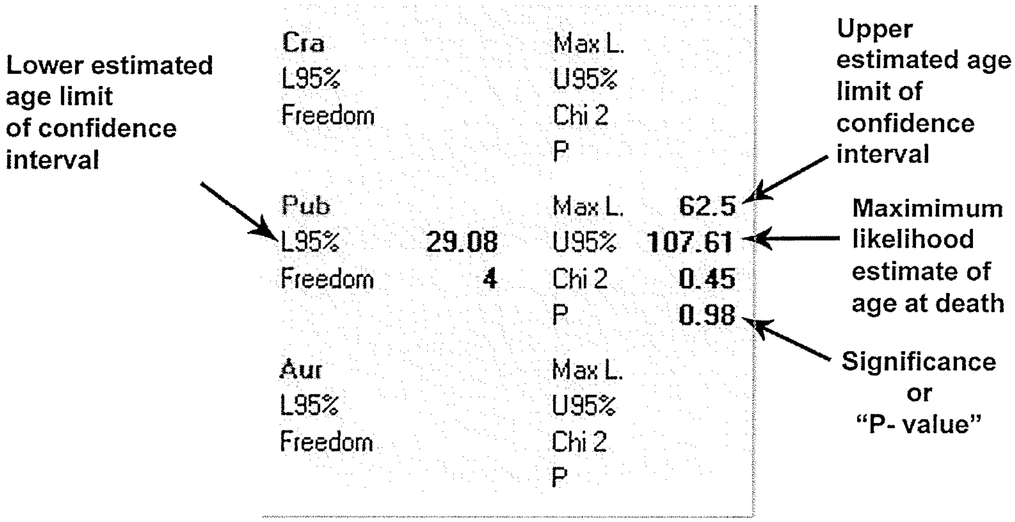

FIGURE 3.5.An example of the numerical values generated by the Transition Analysis Program representing the single indicator Maximum Likelihood Estimate (MLE) of age at death with associated confidence interval limits. The program generates estimates based on the component scores entered for each skeletal feature where in this case was the pubic symphysis.

If scores are recorded for two or more skeletal features, the scores are statistically combined to generate a likelihood estimate of age at death based on all features, which is presented, in the "all data" section (Figure 3.6). Like the single indicator estimates, skeletal age is assessed with the combination of all component scores with a uniform or flat age distribution using the MLE model. In this study, these values are equal to those estimates provided in the single indicator regions since there was only one feature examined in this study.

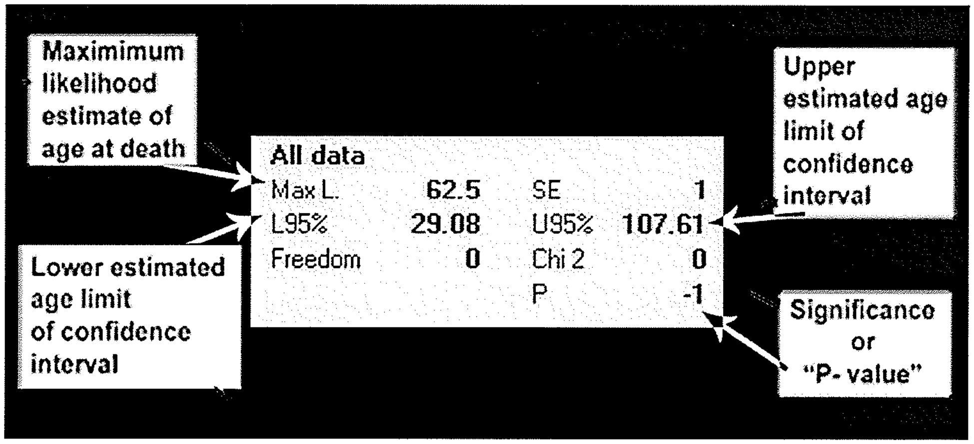

FIGURE 3.6. An example of the numerical values representing Maximum Likelihood Estimate (MLE) of age at death with associated confidence interval limits based on all of the features examined by the Transition Analysis method and a uniform or flat prior age distribution.

The program also generates likelihood skeletal age estimates derived from an archaeological or forensic informative prior age distributions. This study focused on applying a forensic age distribution generated from 1996 U.S. homicide data incorporated into the Transition Analysis software package. This age distribution was selected over the archaeological mortality structure since the Grant collection age distribution would most likely resemble the forensic population than a 17th century Danish sample. These estimates are presented in the "all data cor" region and can be referred to as final age estimates since they represent corrected values of estimated age based on an *a priori* age distribution (see Chapter 2 for a review) (Figure 3.7).

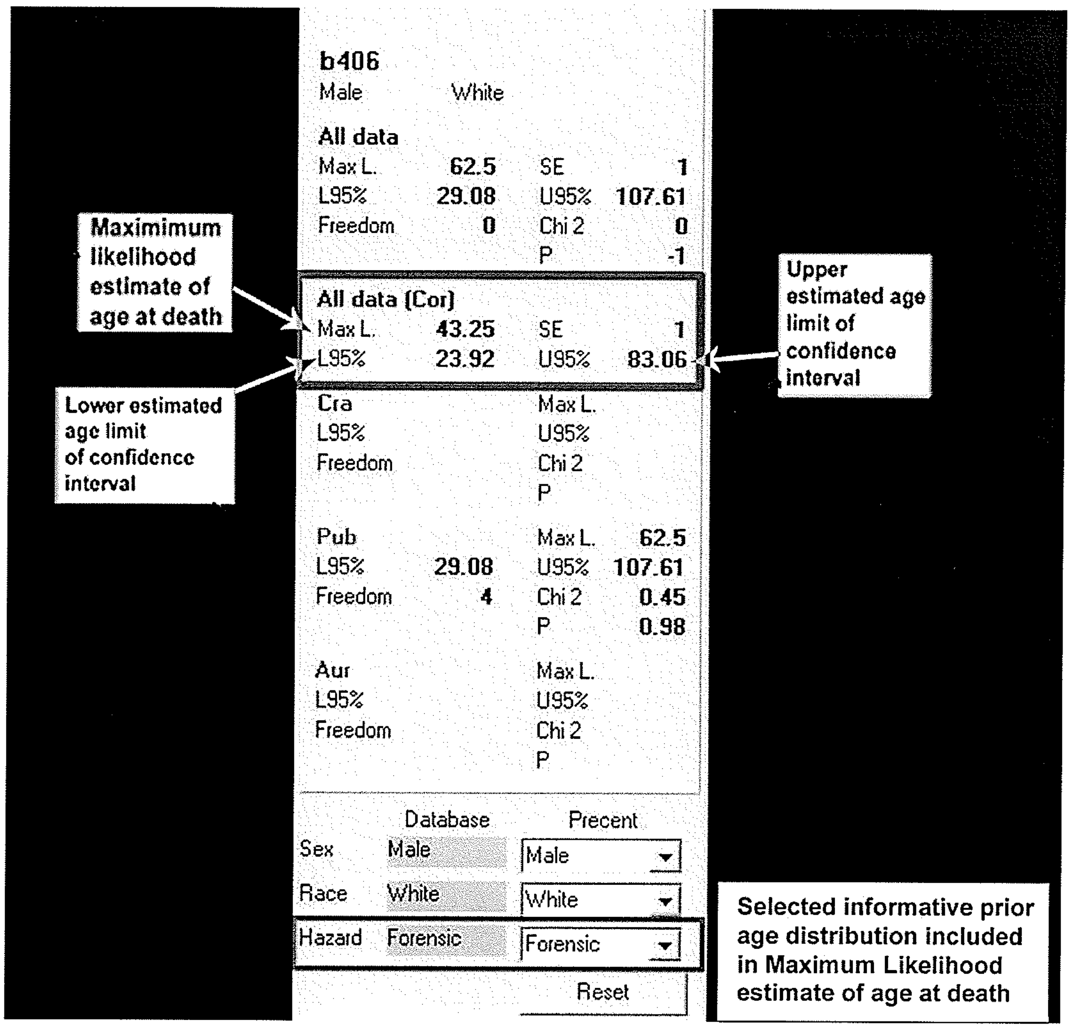

FIGURE 3.7. An example of the numerical values representing the final corrected Maximum Likelihood Estimate (MLE) of age at death with associated confidence interval limits based on an *a priori* archaeological or forensic sample. In this study, the informative prior age distribution was based on a forensic population as outlined in red.

3. The Suchey–Brooks method

Suchey, Katz, and Brooks (Suchey et al., 1986; Katz and Suchey, 1986; Brooks and Suchey, 1990) developed an age determination system that follows the same concept as Todd's (1920) method (see Chapter 2). Age related morphological changes that occur in the pubic symphysis are typified into a six-phase system. Each phase represents the morphological changes that are set to occur within a specific age interval. The Suchey-Brooks method consists of visually comparing pubic symphyseal features of an individual from the target sample to a set of published descriptions and casts for each phase.

The Suchey--Brooks cast system served three purposes in this study. Firstly, this method was applied to determine the age at death of individuals through direct observation of the Grant collection. The skeletal age estimates produced by the Suchey-Brooks method and the Transition Analysis technique were compared against the documented ages of the Grant collection to test the reliability of both methods in determining age at death.

Secondly, the Suchey--Brooks method was applied to determine age at death from the digital images of pubic bones of Grant collection study sample. In order to determine skeletal age from the digital images, this aging technique was employed in a manner similar to the determination of age at death through direct observation of the target sample. Age estimates derived from the application of the Suchey--Brooks method on digital images of the pubic symphysis were evaluated against those estimates acquired through direct observation. Age at death estimates were compared to determine if the information ascertained from digital images of the pubic symphysis is similar to the data yielded from directly observing the sample.

Finally, the Suchey--Brooks casts were utilized to determine if imaging techniques offered by image analysis software programs can capture age related morphological changes in the pubic symphysis in a quantitative form. The casts were used in this study to test the imaging techniques on a relatively standardized system with published descriptions. Digital imaging techniques were applied to the casts in an attempt to quantify the morphological changes associated with each phase. Various image analysis functions like the measurement of pixel intensities were explored to determine if quantitative analyses of age-related morphology of the pubic symphysis are possible using image analysis software.

4. Digital imaging

Digital images exist in two formats (Furness, 1997). The first type is a vector diagram, often associated with computer-generated animated images. The second relevant type in this study is the bitmap, a "photographic" image of a real object captured by a digital camera, or a copied image of a photograph recorded by a scanner. A bitmap is a two-dimensional image composed of "multiple points of variably luminous light" (Gilbert and Richards, 2000:239), more commonly known as pixels. Pixels control the appearance of the image because they contain information such as colour and resolution.

The term "resolution" pertains to the size of each pixel in a bitmap and is expressed in dots per inch (dpi). Augmenting the resolution results in an improved digital representation of the real object being "photographed". Resolution depends on the sensitivity of the digital image capture device, the availability of storage space, and the computer processor speed as the file size increases with improved resolution (Furness, 1997).

Various computer software programs may manipulate pixels to alter or enhance the appearance of a digital image. An imaging software program may apply one of two different methods to enhance an image: a manual pixel manipulation application or an algorithmic-based enhancement (Gilbert and Richards, 2000). Manual pixel manipulation refers to the input of additional features to enhance the appearance of an image. Reservation about the application of image enhancements are often associated with manual manipulation of pixels since functions like cutting or airbrushing results in a dramatic alteration of an image eliciting ideas of forgery. Algorithmic-based enhancements differ drastically from manual manipulation as they do not add data or alter features; instead, changes are subtle resulting in displaying unapparent features (Gilbert and Richards, 2000). The underlying mechanism behind this technique is based on adjusting pixel values in mathematical accordance with neighbouring pixels. This process is found more commonly in medical and scientific studies and will be applied in this study.

Images of the symphyseal surface were captured using an Olympus C3030 Zoom digital camera. This camera has a 1/1.8" CCD and 3,340,000 pixels resolution for image capture in an uncompressed TIFF format at 2048 x 1536 pixels. It uses a digital iESP metering system and TTL system is auto focus and contrast detection system. The camera has an asperical glass lens with 2x optical zoom. Pictures were taken at F11.0 under controlled lighting conditions.

There are a variety of computer software programs available for digital imaging enhancements including Adobe Photoshop and Corel Photo Paint. These programs offer a wide array of enhancement possibilities from airbrushing to focusing an image. The two programs utilized in this study were: Adobe Photoshop 6.0, an image creation, and editing program and Scion Image, an image acquisition and analysis program.

Adobe Photoshop was primarily applied in this program for visual and corrective enhancements to prepare the image for analysis. This program offers a variety of methods to improve the quality of an image through manual pixel manipulation and algorithmic based filters. The Photoshop program served two purposes in this study: to open digital images to determine age at death and to apply algorithmic filters like colour, brightness, and focus adjustment to the digital image prior to the application of image analysis techniques.

Two algorithmic filters were employed in this study to prepare the image for analysis. The first filter applied to the images was the "Auto Levels" command. This function is considered a quick correction function that increases the contrast of an image to the standards by which the Photoshop program considers the most ideal brightness values (McClelland, 2001). The program attempts to adjust the brightness values of the image closest to what the naked eye views the object in a real life situation. The "Auto Levels" function is applied by choosing Image ⇒ Adjust ⇒ Auto Levels.

The second algorithmic filter is the "Curves" command. This feature enables the subtle adjustment of brightness levels to a personal preference. The "Curves" adjustment allows the user to adjust the brightness values of the image beyond the assistance of the "Auto Levels" command. The purpose of applying this filter is to highlight the definitions of the pubic symphyseal surface that may be too dark or too light to view in the image even after the application of the "Auto Levels" function. The "Curves" command is selected by choosing Image ⇒ Adjust ⇒ Curves.

This function produces a Curves dialog box (Figure 2.8) illustrating a brightness curve plot in a graph format. The colours on the graph proceed from black on the left to white on the right and brightness and higher values are meant to represent lighter colours. Darker values are adjusted in a subtle manner by clicking on the bottom left hand corner where the plot begins on the graph and placing the start point on any selected area of the graph. A preview of the brightness adjustment is illustrated in the digital image. The same method is applied for adjusting lighter pixel values by selecting the end point of the graph on the upper right hand corner and placing it on any area of the graph.

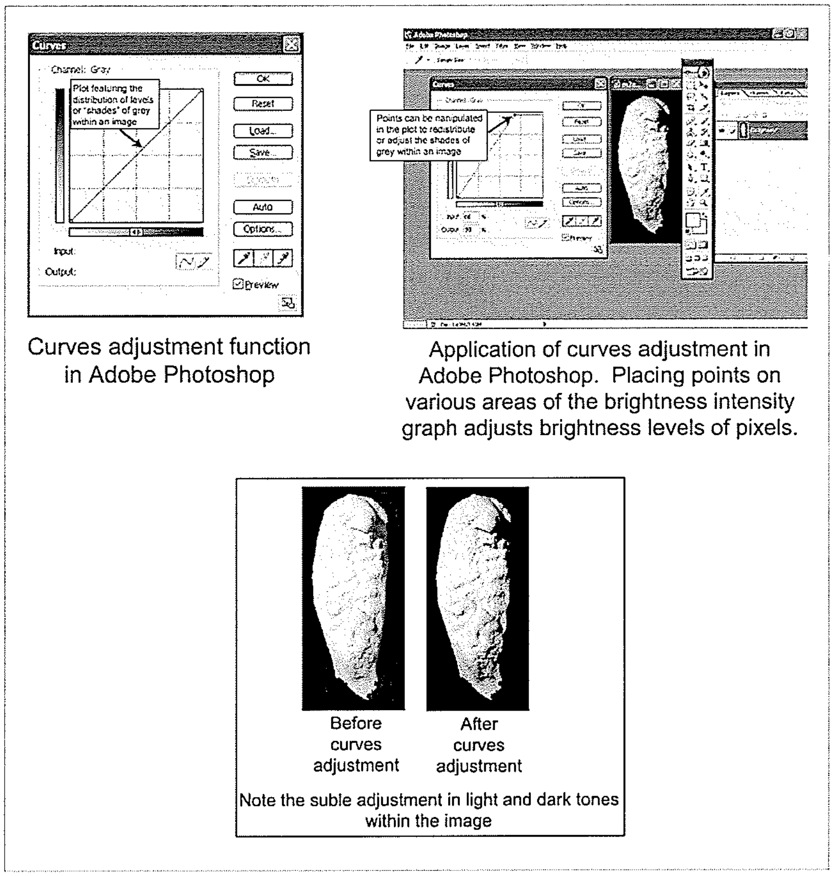

FIGURE 3.8. Application of the curves adjustment function offered by Adobe Photoshop to adjust brightness levels within an image.

The second program, Scion Image, offered by Scion Corporation as a freeware program (www.scioncorp.com) was utilized to perform analytical functions to measure pixel brightness and intensity. Scion Image offers a wide array of functions ranging from enhancement to measuring features within an image. Although Scion Image does offer a set of image enhancement filters that are algorithmic based, it does not offer the full range of enhancement functions that are available in Adobe Photoshop. The Scion Image program is better suited for analytical investigations on images such as performing measurements within an image as completed in this study.

Methods

1. Initial setup

There are many sampling issues associated with the Grant collection such as the number of individuals over the age of 45 and an excessive number of males. In addition, it is impossible to examine the pubic symphyses of all 202 individuals in the collection due to poor preservation of the pubic symphysis or the absence of an innominate.

The initial sample was selected based on adequate preservation of the pubic symphysis such as lack of post-mortem damage and whether an innominate was indeed present with the individual. Once the initial sample selection was completed, individuals were separated into two groups by sex. Unfortunately, the issue of over representation of males within the Grant collection was difficult to overcome. In addition, the poor condition of the pubic symphyseal surface limited the number of female individuals available for study. In total, 90 males and 15 females (n=105, 52% of the collection) possessed pubic symphyses in excellent condition for analysis.

Following the separation of individuals by sex, the sample was further defined by documented age at death. All recorded ages were entered into an Excel spreadsheet, grouped, and then sorted on the basis of increasing age. The ages were then divided into the following age ranges or more commonly referred to as "decades of life": 18-29, 30-39, 40-49, 50-59, 60-69, 70-79, and 80 plus. Separating each adult into groups based on documented age assisted in the evaluation of aging methods by demonstrating their performance in each age category. Each case number identifier remained hidden in the spreadsheet to eliminate any biases during the assignment of Transition Analysis and Suchey-Brooks scores. Unfortunately, it was difficult to overcome the under representation of younger adults in the selection process as demonstrated in the final sample of 5 individuals chosen to represent the 18 to 29 year old age group. The final sample size for this study is presented in Table 3.1.

AGE GROUP	SAMPLE SIZE MALES (n)	SAMPLE SIZE FEMALES (n)	TOTAL SAMPLE SIZE (n)
18-29	3	2	5
30-39	15	1	16
40-49	15	1	16
50-59	15	0	15
60-69	14	5	20
70-79	14	4	18
80+	13	2	15
Total	**90**	**15**	**105**

TABLE 3.1.Table outlining the final sample selected for this study.

2. Application of age estimation techniques

Once the selection of the study sample was completed, each individual was placed randomly on a surface for analysis. The study sample was separated into two areas according to sex and no distinctions were made according to documented age. Innominates were selected in a random manner and each component of the pubic symphysis was scored according to the descriptions outlined by the Transition Analysis method (Boldsen et al., 2002). A temporary marker such as a Post-It note was placed on the innominate to indicate that Transition Analysis scores had been assigned for that particular individual.

Once all of the scoring was completed with the Transition Analysis method, each innominate was randomly selected and scored against the written descriptions and cast replicas of the different phases outlined by the Suchey-Brooks method (Suchey et al., 1986; Katz and Suchey, 1986; Brooks and Suchey, 1990). After designating a Suchey-

Brooks score, the Post-It note was removed from the innominate to indicate that the pubic bone was assigned to a particular phase.

3. Analysis of traditional age estimation techniques

All Transition Analysis component scores were entered into the ADBOU age estimation software to calculate likelihood estimates of age at death. The Suchey–Brooks scores were also translated into age estimates using the standard summary statistics provided by Suchey and Katz (1998). The resulting ages at death were then evaluated against the documented ages with the assistance of statistical applications and comparative graphs.

The study focused on a comparison of age estimates and intervals provided by the Suchey-Brooks technique and the Transition Analysis method. Instead of focusing on one age estimate provided by the Transition Analysis method, the estimated ages at death and confidence intervals presented in the "All data cor" and the "Pub" region were evaluated to examine the accuracy of age estimates derived from uniform prior and informative prior age distributions. For the purposes of this study, the values presented in the "Pub" region were referred to as the single indicator estimates and those estimated values presented in the "All data cor" section were known as the final age estimates.

In addition to evaluating the age estimation methods on the basis of age estimates and intervals, this study examined the distribution and assignment of Transition Analysis component scores and Suchey-Brooks phases. This examination of age estimation scores involved a detailed analysis of the distribution of scores in each "decade of life".

4. Capture and preparation of digital images

After all age estimates were completed, images of the pubic symphyseal surface of each individual were captured through digital photography. In addition, all of the Suchey--Brooks casts for both males and females were photographed for comparative purposes. Controlled lighting and background conditions were maintained during photography with the assistance of tungsten lighting, gel light diffusers, and black velvet skirting. The lighting source for this study consisted of a Calumet Travellite 250 and was used in conjunction with a light diffuser to eliminate unwanted shadows. Regular halogen lighting was unsuitable for this study because this type of lighting is known to cast a yellowish tinge on to a bone's surface and may inhibit the differentiation of the symphyseal surface from the rest of the innominate.

Controlled background conditions consisted of black velvet skirting placed around the pubic symphysis. This type of fabric allows the camera to focus exclusively on the pubic symphysis from the rest of the innominate and accentuates the natural definitions of the symphyseal surface. In addition, black velvet absorbs the reflective light and eliminates unwanted shadows on various features of the pubic symphysis.

All images were saved in an uncompressed TIFF (Tagged Image File Format) format at 2048 X 1536 pixels. TIFF images were used in this study rather than the conventional JPEG (Joint Photographic Experts Group) format. JPEG is considered to be the most efficient means of storing an image as it compresses information to save disk space.-As a result, the quality of the image is sacrificed to conserve space on disk or in the hard drive of the computer (McClelland, 2001). JPEG recompresses the pixel information in an image the instance it is saved onto disk resulting in a loss of image quality. When images are continually saved and reopened, there is continual damage inflicted on the quality of the image due to the compression of information.

In order to maintain image quality at an optimum level, all images were saved in the TIFF format. This type of format does not possess the same compression schemes that are associated with the JPEG format to affect pixel information.

5. Age at death estimation from digital images of the pubic symphysis

Three months following the initial examination and scoring of adults from the Grant collection, age at death was assessed from the digital images of the pubic symphyses. Only one traditional method of age estimation was applied in this study to determine if age at death could be derived from digital images of the pubic bone. The Suchey--Brooks method was selected over the Transition Analysis technique because it appeared that casts would facilitate the procedure of estimating skeletal age through the provision of visual aids in addition to written descriptions. A second trial of age at death determination with the Suchey-Brooks method was completed from the digital images once three months had passed after the first trial. The Suchey-Brooks scores from both trials were then evaluated against those scores obtained from direct observation of the pubic bones to test the reliability of age estimation from digital images.

6. Digital imaging software applications for age estimation purposes

This component focused primarily on the digital images of the Suchey-Brooks casts to determine if age related morphological changes from a relatively standardized system (Suchey et al., 1988) could be identified with image analysis software programs. The descriptions featuring notable age related traits of several phases outlined by Suchey and Katz (1988) provide a reference point to compare the visual or numerical output of data generated by the imaging software. Once it was determined that morphological changes can be identified the Suchey-Brooks casts with image analysis applications, then the same techniques were applied to the images of pubic bones from the Grant collection.

The first step was to open the images of the Suchey--Brooks casts in Photoshop 6.01 to adjust the colour and tonal features of the digital images. Images were transformed into Greyscale format from RBG (RedBlueGreen) colour format in Photoshop by selecting Edit ⇒ Adjust ⇒ Greyscale. It is essential that this colour transformation occurred since pixel brightness or intensity was the variable of interest rather than the quantity or amount of different hues present within an image.

Next, the "Auto-levels" function available in Photoshop was applied to balance the range of light and dark grey tonal values. This function adjusts the image so that the tones of the image will appear similar to what is uncovered by the naked eye when viewing the actual specimen. In addition, the "curves" function was applied to enhance the grey tonal values further in a subtle manner. Both of these algorithmic-based enhancements assist in the exploitation of visual features of the symphyseal surface by increasing the tonal values within the images for image analysis.

The final step was to apply the line plot function offered by the Scion Image program. This feature allows the user to measure the pixel brightness or intensity of a selected area within an image. Line plots generated by the program illustrate the grey intensity values within a selection of pixels. The purpose of employing line plots in this study is derived from Russ (1992) who implies that within a two-dimensional image, pixel brightness can be proportional to depth of elevation that can be measured by particular image analysis software programs. Therefore, when applying an imaging technique that measures pixel intensity within a selection of a two-dimensional image of an object's surface, the resulting data presented as a line plot will resemble a cross section of the object being photographed. If this concept is true, then this particular imaging technique has the potential to obtain an idea of the relief and textures of the pubic symphyseal surface. In this study, the term "relief" refers to the elevation of a surface and can be described with terms such as billowing, plateau, and recession. The term "texture" describes the textural features associated with the pubic symphyseal surface as summarized with terms such as smoothness, porosity, and pitting.

The line plot function is applied to the digital image in Scion Image by placing a single line or rectangle on a selected area of the pubic symphysis. Once the area to be analyzed is selected then the line plot function is applied by choosing Analyze ⇒ Plot profile.

A single line selection generates a line plot illustrating the measurement of each pixel's brightness or intensity along the selected line. A rectangular selection generates a "row average plot" where the width of the plot is equal to the height of the selection. Each value in a plot generated from a rectangular selection is an average of pixel intensities along its corresponding row.

The line plots generated by Scion Image record the gray intensity value out of a possible 256 where 0 is included as a value in the 255 listed on the y-axis. The x-axis represents the intensity or brightness of pixels across a certain selection. High intensity values are proportional to grey levels closer to white and are represented in points in the upper extremities of the plot. Lower intensity values are grey levels closer to black and are represented as points in the lower extremities of the line plot.

Once all of the steps summarized in Table 3.2 were completed, the results were examined to evaluate each approach in the different research components of this study. The scope of this project, however, was not limited to an evaluation of all of the techniques applied in this analysis. An important aspect of this project was to determine if the different skeletal aging strategies and technological approaches address the current issues facing skeletal age estimation outlined in chapter two. The results of this study are expected provide insightful information into how the varied approaches offer significant contributions in resolving the problems related to the determination of age at death from skeletal samples.

STEPS	Procedures	
1	Selection of study sample from grant collection	105 individuals selected
2	Application of Age estimation techniques	Obtain age estimates from Transition Analysis techniques and Suchey Brooks method
3	Capture and preparation of digital images	Capture images of Suchey Brooks casts and grant collection individuals
4	Analysis of traditional age estimation techniques	Examine age estimates with standard summary statistics and graphs offered by SPSS
5	Digital imaging software applications for age estimation purposes	Adjust images for analysis through the application of various functions offered by imaging software
		Attempt to recognize age related patterns in morphology of the pubic symphysis with image analysis software
6	Estimating age at death from digital images of the pubic symphysis	Estimate age at death from digital images of the pubic symphysis with the application of the Suchey Brooks method. The examinations of the digital images were completed after a three month and a six-month interval had surpassed after the initial analysis of the actual sample.

TABLE 3.2. Summary of the steps completed for each component of this study.

Results

Transition Analysis method

As previously mentioned, this study focuses on Transition Analysis (Boldsen et al. 2002) scores assigned to components of the pubic symphysis. Each individual was assigned to one of several "decades of life" beginning with the 18 to 29 year old age category. This group consisted of five adults including three males and two females (5% of study sample total). The small sample size is attributed to a sampling issue related to the extremely limited number of adults less than 45 years of age available for study in the Grant collection (Bedford et al., 1993).

In this age group, all of the Transition Analysis estimated age intervals captured the documented ages of the sample (Figure 4.1; 4.2). The Suchey-Brooks method produced one age inaccurate age interval that was younger than the documented age of a twenty-nine year old male. The upper and lower estimated age intervals for both methods are derived from a 95% confidence interval or two standard deviations from the age estimate. The average numbers of years within these age intervals produced by both methods for this age group are provided in Tables 4.1 and 4.2. The Transition Analysis method generated the narrowest age intervals based on an average of upper and lower 95% confidence interval limits of the age estimate for both males and females.

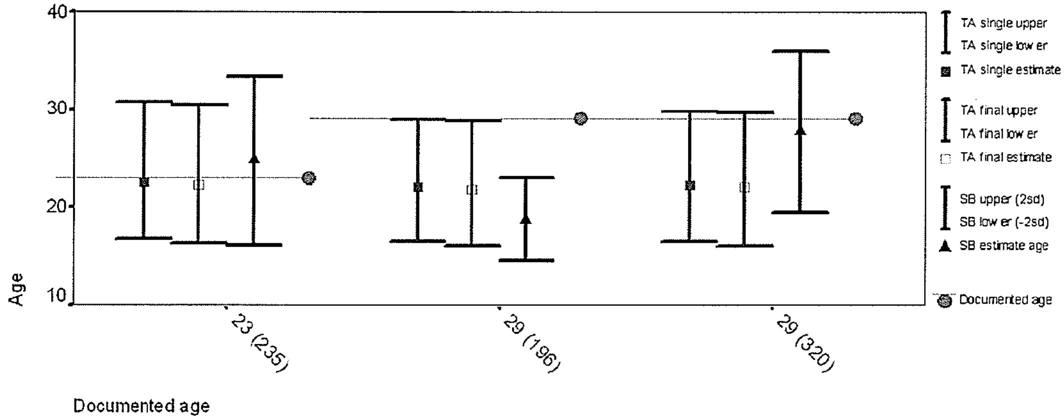

FIGURE 4.1. Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for males with documented ages ranging from 18 to 29 years. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

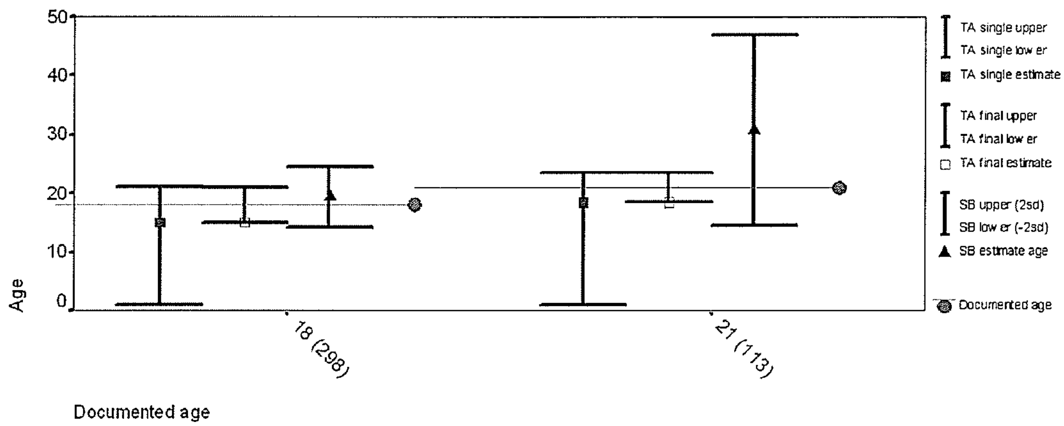

FIGURE 4.2. Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for females with documented ages ranging from 18 to 29 years. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual .(Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

		Mean
Pair 1	TA single upper - TA single lower	13.1267
Pair 2	TA final upper - TA final lower	13.5000
Pair 3	SB upper (2sd) - SB lower (-2sd)	14.0000

TABLE 4.1. The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for males in the 18 to 29 year old group.

		Mean
Pair 1	TA single upper - TA single lower	21.4300
Pair 2	TA final upper - TA final lower	5.5450
Pair 3	SB upper (2sd) - SB lower (-2sd)	21.4000

TABLE 4.2. The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for females in the 18 to 29 year old group.

The Suchey-Brooks method produced the lowest mean difference between age estimates and documented ages of males in this age group at 3.23 years (Table 4.3). However, both age estimates produced by the Transition Analysis method were on average closer to the documented ages of the females in this sample (Table 4.4). Further, most of the Transition Analysis age estimates (80%) were within a seven- year range of the documented ages of the overall sample in this age group compared to the Suchey-Brooks method (60%) (Table 4.5).

		Mean	N
Pair 1	Documented age	27.0000	3
	TA single estimate	22.2500	3
Pair 2	Documented age	27.0000	3
	TA final estimate	22.0000	3
Pair 3	Documented age	27.0000	3
	SB estimate age	23.7667	3

		Paired Differences			t	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean		
Pair 1	Documented age - TA single estimate	4.7500	3.68273	2.12623	2.234	.155
Pair 2	Documented age - TA final estimate	5.0000	3.68273	2.12623	2.352	.143
Pair 3	Documented age – SB estimate age	3.2333	6.22923	3.59645	.899	.464

TABLE 4.3 Results of paired sample statistics representing the mean differences in years between the age estimates produced by the Transition analysis and Suchey-Brooks age estimation techniques and documented ages of males in the 18 to 29 year old age category.

		Mean	N
Pair 1	Documented age	19.50	2
	TA single estimate	16.7500	2
Pair 2	Documented age	19.50	2
	TA final estimate	16.7500	2
Pair 3	Documented age	19.50	2
	SB estimate age	25.0500	

		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1	Documented age - TA single estimate	2.7500	.35355	.25000	11.000	1	.058
Pair 2	Documented age - TA final estimate	2.7500	.35355	.25000	11.000	1	.058
Pair 3	Documented age - SB estimate age	-5.5500	5.86899	4.15000	-1.337	1	.409

TABLE 4.4 Results of paired sample statistics representing the mean differences in years between the age estimates produced by the Transition analysis and Suchey-Brooks age estimation techniques and documented ages of females in the 18 to 29 year old age category.

	Case ID	Documented age	TA single estimate	Doc - single	TA final estimate	Doc - final	SB estimate age	Doc- SB
Males n=3	235	23	22.5	0.5	22.25	0.75	24.8	-1.8
	196	29	22	7	21.75	7.25	18.8	10.2
	320	29	22.25	6.75	22	7	27.7	1.3
Females n = 2	298	18	15	3	15	3	19.4	-1.4
	113	21	18.5	2.5	18.5	2.5	30.7	-9.7

TABLE 4.5. The differences in years between the estimated ages at death and the documented ages at death for adults in the 18 to 29 year old age category. Values with a difference of more than seven years from the documented age are highlighted in black.

The distribution of Transition Analysis component scores is provided in Table 4.6. As expected, most of the individuals in the age category were assigned low scores ranging from 1 to 3. Similar results were demonstrated with the Suchey-Brooks method where a majority of adults was assigned to phases I, II, or III (Table 4.7).

Component scores distributed to indivdiuals in sample

18-29		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR				1		2								
n = 3	ST			1	1		1								
	SA		2		1										
	V				1	1	1								
	D				1		2								
Females	SR		1		1										
n = 2	ST		2												
	SA	1			1										
	V		1			1									
	D		2												

Percentage of component scores distributed in sample

18-29		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR	0%	0%	0%	33%	0%	67%	0%	0%	0%	0%	0%	0%		
n = 3	ST	0%	0%	33%	33%	0%	33%	0%	0%						
	SA	0%	67%	0%	33%	0%	0%	0%	0%						
	V	0%	0%	0%	33%	33%	33%	0%	0%	0%	0%	0%	0%	0%	0%
	D	0%	0%	0%	33%	0%	67%	0%	0%	0%	0%				
Females	SR	0%	50%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%		
n = 2	ST	0%	100%	0%	0%	0%	0%	0%	0%						
	SA	50%	0%	0%	50%	0%	0%	0%	0%						
	V	0%	50%	0%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	D	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%				

TABLE 4.6. Distribution and percentage of Transition Analysis component scores assigned to adults in the 18 to 29 year old age group. (SR, Symphyseal relief; ST, Symphyseal texture; SA, Superior apex; V, Ventral symphyseal margin; D, Dorsal symphyseal margin).

Individuals assigned to a particular Suchey-Brooks phase in sample

18-29	1	2	3	4	5	6
Males (n=3)	1	1	1			
Females (n=2)	1		1			

Percentage of individuals assigned to a particular Suchey-Brooks phase

18-29	1	2	3	4	5	6
Males (n=3)	33%	33%	33%	0%	0%	0%
Females (n=2)	50%	0%	50%	0%	0%	0%

TABLE 4.7. Distribution and percentage of individuals assigned to various phases of the Suchey-Brooks method.

The second age category consisted of fifteen males and one female (15% of study sample total) ranging from 30 to 39 years of age from the Grant collection. Both methods performed equally in producing one inaccurate age estimate that was slightly younger for a male adult with a documented age thirty-seven years (Figures 4.3 and 4.4). The Suchey-Brooks method produced the narrowest age intervals based on two standard deviations for males with an average of thirty years (Table 4.8). The Transition Analysis method generated the narrowest age interval for the single female in this age group as indicated in Table 4.9.

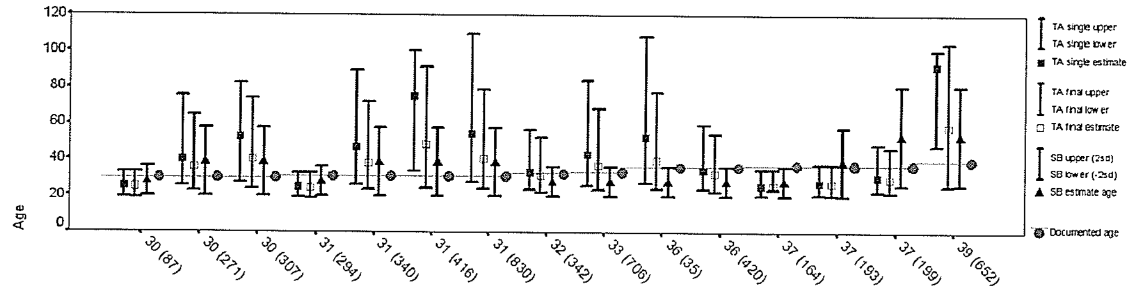

FIGURE 4.3. Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for males with documented ages ranging from 30 to 39 years. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

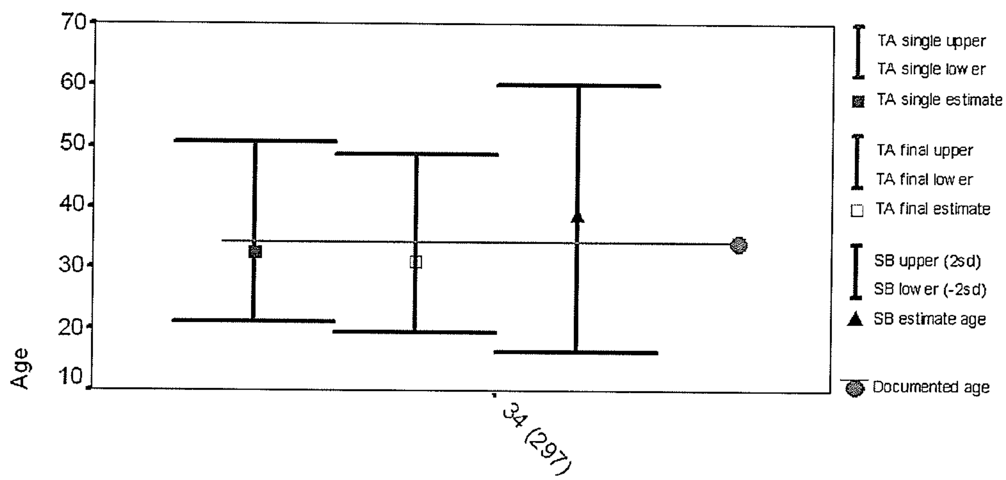

FIGURE 4.4. Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for a female whose documented age falls within 30 to 39 years. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

		Mean
Pair 1	TA single upper - TA single lower	44.0407
Pair 2	TA final upper - TA final lower	38.8233
Pair 3	SB upper (2sd) - SB lower (-2sd)	30.0000

TABLE 4.8. The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for males in the 30 to 39 year old group.

		Difference
Pair 1	TA single upper – TA single lower	29.3600
Pair 2	TA final upper - TA final lower	29.0600
Pair 3	SB upper (2sd) - SB lower (-2sd)	43.6000

TABLE 4.9. The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for the single female falling in the 30 to 39 year old group.

In addition, the Transition Analysis method produced the lowest difference of years between estimated age at death and the documented age of the single female in this age group. For males, however, the average lowest difference of years between documented age and estimated ages was found with the Suchey-Brooks method (Table 4.10).

		Mean	N
Pair 1	Documented age	33.40	15
	TA single estimate	43.6667	15
Pair 2	Documented age	33.40	15
	TA final estimate	35.4167	15
Pair 3	Documented age	33.40	15
	SB estimate age	35.3400	15

		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1	Documented age - TA single estimate	-10.2667	19.28347	4.97897	-2.062	14	.058
Pair 2	Documented age - TA final estimate	-2.0167	9.67668	2.49851	-.807	14	.433
Pair 3	Documented age – SB estimate age	-1.9400	8.38347	2.16460	-.896	14	.385

TABLE 4.10 Results of paired sample statistics representing the mean differences in years between the age estimates produced by the Transition analysis and Suchey-Brooks age estimation techniques and documented ages of males in the 30 to 39 year old age category.

Most of the Suchey-Brooks age estimates were not within a seven-year range of the documented ages of the overall sample (62.5% of age estimates differed more than seven years from documented age). The Transition Analysis produced the most age estimates that were within seven years of the recorded ages of the adults in this sample (50% within seven year range) (Table 4.11).

	Case ID	Documented age	TA single estimate	Doc - single	TA final estimate	Doc - final	SB estimate age	Doc- SB
Males	87	30	25	5	24.75	5.25	27.7	2.3
n = 15	271	30	40.25	-10.25	35.5	-5.5	38.4	-8.4
	307	30	52.25	-22.25	40.25	-10.25	38.4	-8.4
	294	31	24.75	6.25	24.25	6.75	27.7	3.3
	340	31	46.75	-15.75	38	-7	38.4	-7.4
	416	31	74.5	-43.5	48.25	-17.25	38.4	-7.4
	830	31	54.25	-23.25	40.75	-9.75	38.4	-7.4
	342	32	33	-1	31.25	0.75	27.7	4.3
	706	33	42.75	-9.75	36.75	-3.75	27.7	5.3
	35	36	52.25	-16.25	39.5	-3.5	27.7	8.3
	420	36	34	2	32	4	27.7	8.3
	164	37	25.75	11.25	25.5	11.5	27.7	9.3
	193	37	27	10	26.5	10.5	38.4	-1.4
	199	37	30.5	6.5	29.5	7.5	52.9	-15.9
	652	39	92	-53	58.5	-19.5	52.9	-13.9
Female (n=1)	297	34	32.5	1.5	31	3	38.2	-4.2

TABLE 4.11. The differences in years between the estimated ages at death and the documented ages at death for adults in the 18 to 29 year old age category. Values with a difference of more than seven years from the documented age are highlighted in black.

A majority of the adults in this age group were assigned component scores of either 3 or 4 (Table 4.12). However, 47% of males in this age category were assigned a symphyseal relief component score of 6, which describes an irregular symphyseal surface (Boldsen et al., 2002). Normally, it is assumed that this higher score is designated to adults older than those in this age category. The Suchey-Brooks method did fulfill an expected outcome for this age group where a majority of individuals were assigned to phases III (males = 47%) or IV (males = 40% and females 100%) (Table 4.13).

Component scores distributed to indivdiuals in sample

30 - 39		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR						1		2		4	1	7		
n = 16	ST				1	1	3	2	8						
	SA				4		9		2						
	V						5		4		4		2		
	D				3		5	2	5						
Females	SR											1			
n = 1	ST							1							
	SA	1													
	V	1													
	D						1								

Percentage of component scores distributed in sample

30 - 39		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR	0%	0%	0%	0%	0%	7%	0%	13%	0%	27%	7%	47%		
n = 15	ST	0%	0%	0%	7%	7%	20%	13%	53%						
	SA	0%	0%	0%	27%	0%	60%	0%	13%						
	V	0%	0%	0%	0%	0%	33%	0%	27%	0%	27%	0%	13%	0%	0%
	D	0%	0%	0%	20%	0%	33%	13%	33%	0%	0%				
Females	SR	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%		
n = 1	ST	0%	0%	0%	0%	0%	0%	100%	0%						
	SA	100%	0%	0%	0%	0%	0%	0%	0%						
	V	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	D	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%				

TABLE 4.12. Distribution and percentage of Transition Analysis component scores assigned to adults in the 30 to 39 year old age group. (SR, Symphyseal relief; ST, Symphyseal texture; SA, Superior apex; V, Ventral symphyseal margin; D, Dorsal symphyseal margin).

Individuals assigned to a particular Suchey-Brooks phase in sample

30 - 39	1	2	3	4	5	6
Males (n = 15)			7	6	2	
Females (n =1)				1		

Percentage of individuals assigned to a particular Suchey-Brooks phase

30 - 39	1	2	3	4	5	6
Males (n = 15)	0%	0%	47%	40%	13%	0%
Females (n =1)	0%	0%	0%	100%	0%	0%

TABLE 4.13. Distribution and percentage of individuals assigned to various phases of the Suchey-Brooks method.

The next age group included a set of fifteen males and one female (15% of study sample total) from the Grant collection whose documented ages ranged from 40 to 49 years. The Transition Analysis method provided the most age intervals that captured the documented ages of the overall sample (Figures 4.5 and 4.6.). Only three Transition Analysis final age intervals were found to be younger than the documented ages of the males in this sample. However, the narrowest age intervals for males and females were generated by the Suchey-Brooks method (Tables 4.14 and 4.15).

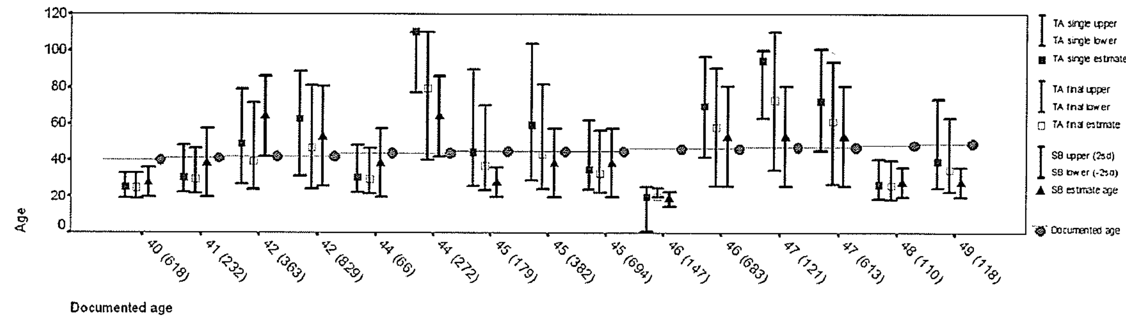

FIGURE 4.5. Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for males with documented ages ranging from 40 to 49 years. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

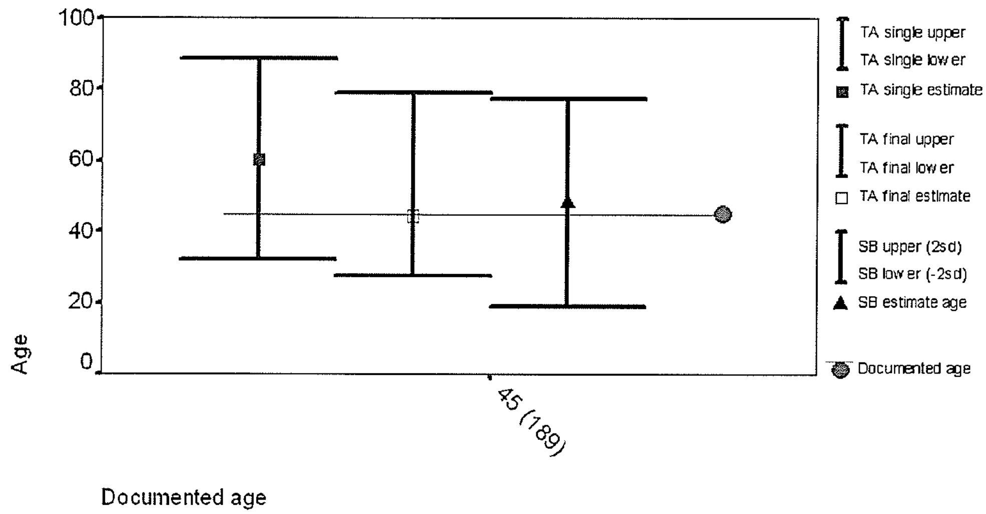

FIGURE 4.6. Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for a female whose documented age falls within 40 to 49 years. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

		Mean
Pair 1	TA single upper – TA single lower	41.7033
Pair 2	TA final upper - TA final lower	43.3487
Pair 3	SB upper (2sd) – SB lower (-2sd)	35.4400

TABLE 4.14. The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for males in the 40 to 49 year old group.

		Difference
Pair 1	TA single upper - TA single lower	56.1471
Pair 2	TA final upper - TA final lower	52.8850
Pair 3	SB upper (2sd) - SB lower (-2sd)	41.6286

TABLE 4.15. The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for the single female falling in the 40 to 49 year old group.

The Transition Analysis final estimates resulted in the lowest mean difference of years between age estimates and documented ages of males and females in this group (Table 4.16). However, the Suchey-Brooks method produced the least number of age estimates that differed more than seven years from the documented ages of the overall sample (Table 4.17).

		Mean	N
Pair 1	Documented age	44.73	15
	TA single estimate	51.2167	15
Pair 2	Documented age	44.73	15
	TA final estimate	44.4220	15
Pair 3	Documented age	44.73	15
	SB estimate age	41.5200	15

		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1	Documented age - TA single estimate	-6.4833	26.34447	6.80211	-.953	14	.357
Pair 2	Documented age - TA final estimate	.3113	19.53896	5.04494	.062	14	.952
Pair 3	Documented age - SB estimate age	3.2133	14.99190	3.87089	.830	14	.420

TABLE 4.16 Results of paired sample statistics representing the mean differences in years between the age estimates produced by the Transition analysis and Suchey-Brooks age estimation techniques and documented ages of males in the 40 to 49 year old age category.

	Case ID	Documented age	TA single estimate	Doc - single	TA final estimate	Doc - final	SB estimate age	Doc- SB
Males n=3	618	40	25	15	24.75	15.25	27.7	12.3
	232	41	30.5	10.5	29.5	11.5	38.4	2.6
	363	42	49	-7	71.33	-29.33	64	-22
	829	42	62.75	-20.75	46.5	-4.5	52.9	-10.9
	66	44	30.5	13.5	29.5	14.5	38.4	5.6
	272	44	110	-66	79.5	-35.5	64	-20
	179	45	44.25	0.75	37	8	27.7	17.3
	382	45	59.5	-14.5	43	2	38.4	6.6
	694	45	35.25	9.75	32.75	12.25	38.4	6.6
	147	46	19.5	26.5	19.5	26.5	18.8	27.2
	683	46	69.75	-23.75	58	-12	52.9	-6.9
	121	47	94.25	-47.25	73	-26	52.9	-5.9
	613	47	72.25	-25.25	61.25	-14.25	52.9	-5.9
	110	48	26.75	21.25	26	22	27.7	20.3
	118	49	39	10	34.75	14.25	27.7	21.3
Females (n=1)	189	45	60.25	-15.25	44.5	0.5	48.1	-3.1

TABLE 4.17. The differences in years between the estimated ages at death and the documented ages at death for adults in the 40 to 49 year old age category. Values with a difference of more than seven years from the documented age are highlighted in black.

As for the distribution of Transition Analysis component scores in this age category, most of the individuals were assigned scores ranging from 4 to 5 (Table 4.18). Most of the individuals in this age group were also assigned to the Suchey-Brooks phases III to V (Table 4.19).

Component scores distributed to indivdiuals in sample

40 - 49		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR				1		1		1		6	1	5		
n = 15	ST		1		3	2	2	2	5						
	SA				3		5		7						
	V	1			1		2		2		3		4		2
	D				2		3	2	6		2				
Females	SR										1				
n = 1	ST							1							
	SA								1						
	V												1		
	D									1					

Percentage of component scores distributed in sample

40 - 49		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR	0%	0%	0%	7%	0%	7%	0%	7%	0%	40%	7%	33%		
n = 15	ST	0%	7%	0%	20%	13%	13%	13%	33%						
	SA	0%	0%	0%	20%	0%	33%	0%	47%						
	V	7%	0%	0%	7%	0%	13%	0%	13%	0%	20%	0%	27%	0%	13%
	D	0%	0%	0%	13%	0%	20%	13%	40%	0%	13%				
Females	SR	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%		
n = 1	ST	0%	0%	0%	0%	0%	0%	100%	0%						
	SA	0%	0%	0%	0%	0%	0%	0%	100%						
	V	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%
	D	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%				

TABLE 4.18 Distribution and percentage of Transition Analysis component scores assigned to adults in the 40 to 49 year old age group. (SR, Symphyseal relief; ST, Symphyseal texture; SA, Superior apex; V, Ventral symphyseal margin; D, Dorsal symphyseal margin).

Individuals assigned to a particular Suchey-Brooks phase in sample

40 - 49	1	2	3	4	5	6
Males (n=15)	1		4	4	4	2
Females (n=1)					1	

Percentage of individuals assigned to a particular Suchey-Brooks phase

40 - 49	1	2	3	4	5	6
Males (n=15)	7%	0%	27%	27%	27%	13%
Females (n=1)	0%	0%	0%	0%	100%	0%

TABLE 4.19 Distribution and percentage of individuals assigned to various phases of the Suchey-Brooks method.

The fourth age group in this study consisted of fifteen males (14% of study sample total) with documented ages ranging from 50 to 59 years. The Suchey-Brooks method performed better than the Transition Analysis method by yielding estimated age intervals that captured all of the documented ages in this sample (Figure 4.7). Further, this method provided the narrowest age intervals with an average of 43.47 years (Table 4.20).

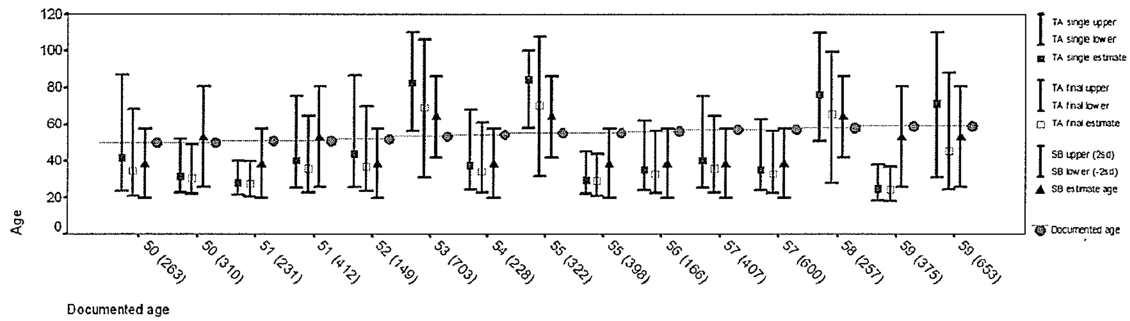

FIGURE 4.7 Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for males with documented ages ranging from 50 to 59 years. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

		Mean
Pair 1	TA single upper - TA single lower	44.5033
Pair 2	TA final upper - TA final lower	43.7800
Pair 3	SB upper (2sd) - SB lower (-2sd)	43.4667

TABLE 4.20 The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for males in the 50 to 59 year old group.

In addition, the Suchey-Brooks method produced the lowest mean difference of years between estimated age and the documented ages of males in this group (Table 4.21). Most of these age estimates were within a seven-year range of the ages at death recorded for this sample. Six (40%) Suchey-Brooks age estimates were within seven years of the ages recorded for this age category, whereas the Transition Analysis method produced fifteen (100%) single indicator and final age estimates that differed more than seven years from the documented ages in this sample (Table 4.22).

		Mean	N
Pair 1	Documented age	54.47	15
	TA single estimate	46.7167	15
Pair 2	Documented age	54.47	15
	TA final estimate	40.2167	15
Pair 3	Documented age	54.47	15
	SB estimate age	47.3867	15

		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1	Documented age - TA single estimate	7.7500	20.10597	5.19134	1.493	14	.158
Pair 2	Documented age - TA final estimate	14.2500	15.14041	3.90924	3.645	14	.003
Pair 3	Documented age - SB estimate age	7.0800	10.59455	2.73550	2.588	14	.021

TABLE 4.21 Results of paired sample statistics representing the mean differences in years between the age estimates produced by the Transition analysis and Suchey-Brooks age estimation techniques and documented ages of males in the 50 to 59 year old age category.

	Case ID	Documented age	TA single estimate	Doc - single	TA final estimate	Doc - final	SB estimate age	Doc- SB
Males	263	50	41.75	8.25	34.75	15.25	38.4	11.6
n = 15	310	50	31.75	18.25	30.25	19.75	52.9	-2.9
	231	51	28	23	27.5	23.5	38.4	12.6
	412	51	40.25	10.75	35.5	15.5	52.9	-1.9
	149	52	43.75	8.25	37	15	38.4	13.6
	703	53	82	-29	69.25	-16.25	64	-11
	228	54	37.25	16.75	34	20	38.4	15.6
	322	55	84.25	-29.25	70	-15	64	-9
	398	55	29.5	25.5	28.75	26.25	38.4	16.6
	166	56	35.25	20.75	32.75	23.25	38.4	17.6
	407	57	40.25	16.75	35.5	21.5	38.4	18.6
	600	57	35.25	21.75	32.75	24.25	38.4	18.6
	257	58	76	-18	65.5	-7.5	64	-6
	375	59	24.75	34.25	24.25	34.75	52.9	6.1
	653	59	70.75	-11.75	45.5	13.5	52.9	6.1

TABLE 4.22 The differences in years between the estimated ages at death and the documented ages at death for adults in the 50 to 59 year old age category. Values with a difference of more than seven years from the documented age are highlighted in black.

The distribution of Transition Analysis component scores is illustrated in Table 4.23. A majority of individuals in this sample were assigned scores ranging from 3 to 5 for all of the components examined. The Suchey-Brooks method often assigned adults in this age category to phase IV as demonstrated in Table 4.24.

Component scores distributed to indivdiuals in sample

50-59		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR								4		9		2		
n = 15	ST		1		5		5	1	3						
	SA			1	2		9	1	2						
	V	1				1	1		1		7		1		3
	D						5		8	1	1				

Percentage of component scores distributed in sample

50-59		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR	0%	0%	0%	0%	0%	0%	0%	27%	0%	60%	0%	13%		
n = 15	ST	0%	7%	0%	33%	0%	33%	7%	20%						
	SA	0%	0%	7%	13%	0%	60%	7%	13%						
	V	7%	0%	0%	0%	7%	7%	0%	7%	0%	47%	0%	7%	0%	20%
	D	0%	0%	0%	0%	0%	33%	0%	53%	7%	7%				

TABLE 4.23 Distribution and percentage of Transition Analysis component scores assigned to adults in the 50 to 59 year old age group. (SR, Symphyseal relief; ST, Symphyseal texture; SA, Superior apex; V, Ventral symphyseal margin; D, Dorsal symphyseal margin).

Individuals assigned to a particular Suchey-Brooks phase in sample

50-59	1	2	3	4	5	6
Males (n=15)				8	4	3

Percentage of individuals assigned to a particular Suchey-Brooks phase

50-59	1	2	3	4	5	6
Males (n=15)	0%	0%	0%	53%	27%	20%

TABLE 4.24 Distribution and percentage of individuals assigned to various phases of the Suchey-Brooks method.

The fifth age category included fifteen males and five females (19% of study sample total) adults from the Grant collection with documented ages of 60 to 69 years. The Transition Analysis method was the best performer by producing the most age intervals that captured the documented ages of the males in this sample. Twelve (80%) single indicator estimated age intervals predicted the documented ages of adults in this sample. In comparison, the Suchey-Brooks method produced six (40%) estimated age intervals (Figure 4.8). Both methods performed equally by presenting two (40%) estimated age intervals that predicted the documented ages of the females in this sample. The Suchey-Brooks method provided the narrowest age intervals for males based on an average width of two standard deviations (Table 4.25). However, the final age intervals generated by the Transition Analysis method were narrowest for the females in this group (Table 4.26).

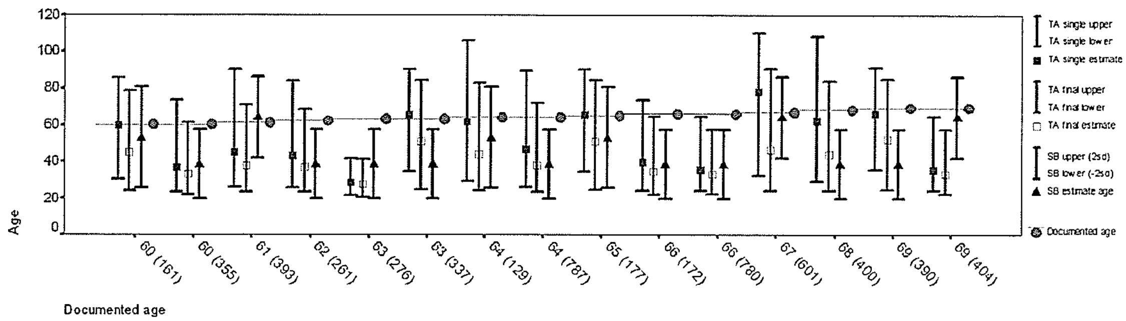

FIGURE 4.8 Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for males with documented ages ranging from 60 to 69 years. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

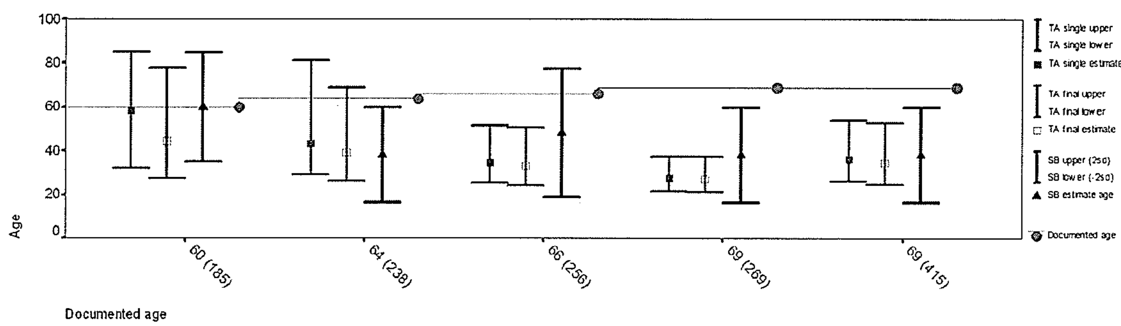

FIGURE 4.9 Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for females with documented ages ranging from 60 to 69 years. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

		Mean
Pair 1	TA single upper - TA single lower	56.0260
Pair 2	TA final upper - TA final lower	48.6653
Pair 3	SB upper (2sd) - SB lower (-2sd)	42.3200

TABLE 4.25 The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for males in the 60 to 69 year old group.

		Mean
Pair 1	TA single upper - TA single lower	35.0000
Pair 2	TA final upper - TA final lower	32.5520
Pair 3	SB upper (2sd) - SB lower (-2sd)	47.7600

TABLE 4.26 The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for females in the 60 to 69 year old group.

In relation to age estimates, the Transition Analysis single estimates were on average closer to the documented ages of the males in this sample compared to the Suchey-Brooks method (Table 4.27). In contrast, the Suchey-Brooks method possessed the lowest mean difference of years between estimated age and documented ages of females in this age group (Table 4.28). At least seven (35%) of the single indicator age estimates produced by the Transition Analysis method were within seven years of the documented ages of the overall sample compared to the Suchey-Brooks method which only possessed five (25%) age estimates (Table 4.29).

		Mean	N
Pair 1	Documented age	64.47	15
	TA single estimate	51.2167	15
Pair 2	Documented age	64.47	15
	TA final estimate	40.4667	15
Pair 3	Documented age	64.47	15
	SB estimate age	46.4200	15

		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1	Documented age - TA single estimate	13.2500	14.47196	3.73664	3.546	14	.003
Pair 2	Documented age - TA final estimate	24.0000	7.63509	1.97137	12.174	14	.000
Pair 3	Documented age - SB estimate age	18.0467	11.02930	2.84775	6.337	14	.000

TABLE 4.27 Results of paired sample statistics representing the mean differences in years between the age estimates produced by the Transition analysis and Suchey-Brooks age estimation techniques and documented ages of males in the 60 to 69 year old age category.

		Mean	N
Pair 1	Documented age	65.60	5
	TA single estimate	40.0000	5
Pair 2	Documented age	65.60	5
	TA final estimate	35.7500	5
Pair 3	Documented age	65.60	5
	SB estimate age	44.5400	5

		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1	Documented age - TA single estimate	25.6000	15.32013	6.85137	3.736	4	.020
Pair 2	Documented age - TA final estimate	29.8500	9.92724	4.43959	6.724	4	.003
Pair 3	Documented age - SB estimate age	21.0600	12.90070	5.76937	3.650	4	.022

TABLE 4.28 Results of paired sample statistics representing the mean differences in years between the age estimates produced by the Transition analysis and Suchey-Brooks age estimation techniques and documented ages of females in the 60 to 69 year old age category.

	Case ID	Documented age	TA single estimate	Doc - single	TA final estimate	Doc - final	SB estimate age	Doc- SB
Males	161	60	59.75	0.25	45	15	52.9	7.1
n = 15	355	60	36.75	23.25	33.25	26.75	38.4	21.6
	393	61	45	16	37.5	23.5	64	-3
	261	62	42.75	19.25	36.75	25.25	38.4	23.6
	276	63	28.5	34.5	27.75	35.25	38.4	24.6
	337	63	65.25	-2.25	51	12	38.4	24.6
	129	64	61.5	2.5	43.75	20.25	52.9	11.1
	787	64	46.75	17.25	38	26	38.4	25.6
	177	65	65.25	-0.25	51	14	52.9	12.1
	172	66	39.75	26.25	34.75	31.25	38.4	27.6
	780	66	35.5	30.5	33	33	38.4	27.6
	601	67	77.75	-10.75	46.25	20.75	64	3
	400	68	62.25	5.75	44	24	38.4	29.6
	390	69	66	3	52	17	38.4	30.6
	404	69	35.5	33.5	33	36	64	5
Females	185	60	58.5	1.5	44.25	15.75	60	0
n = 5	238	64	43.25	20.75	39.25	24.75	38.2	25.8
	256	66	34.5	31.5	33.25	32.75	48.1	17.9
	269	69	27.75	41.25	27.25	41.75	38.2	30.8
	415	69	36	33	34.75	34.25	38.2	30.8

TABLE 4.29 The differences in years between the estimated ages at death and the documented ages at death for adults in the 60 to 69 year old age category. Values with a difference of more than seven years from the documented age are highlighted in black.

The Transition Analysis age estimates and intervals for this age group were based on component scores ranging from 4 to 6 as demonstrated in Table 4.30. Many of the adults in this group were assigned to the Suchey-Brooks phase IV as demonstrated in Table 4.31.

Component scores distributed to indivdiuals in sample

60 - 69		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR									1	5	3	6		
n = 15	ST				5		4	2	4						
	SA	1	1		1		4	8							
	V								3		7		5		
	D						5	2	8						
Females	SR								1		2		2		
n = 5	ST						3	1	1						
	SA						2		3						
	V								2		1		2		
	D				1		1		3						

Percentage of component scores distributed in sample

60 - 69		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR	0%	0%	0%	0%	0%	0%	0%	0%	7%	33%	20%	40%		
n = 15	ST	0%	0%	0%	33%	0%	27%	13%	27%						
	SA	7%	7%	0%	7%	0%	27%	53%	0%						
	V	0%	0%	0%	0%	0%	0%	0%	20%	0%	47%	0%	33%	0%	0%
	D	0%	0%	0%	0%	0%	33%	13%	53%	0%	0%				
Females	SR	0%	0%	0%	0%	0%	0%	0%	20%	0%	40%	0%	40%		
n = 5	ST	0%	0%	0%	0%	0%	60%	20%	20%						
	SA	0%	0%	0%	0%	0%	40%	0%	60%						
	V	0%	0%	0%	0%	0%	0%	0%	40%	0%	20%	0%	40%	0%	0%
	D	0%	0%	0%	20%	0%	20%	0%	60%	0%	0%				

TABLE 4.30 Distribution and percentage of Transition Analysis component scores assigned to adults in the 60 to 69 year old age group. (SR, Symphyseal relief; ST, Symphyseal texture; SA, Superior apex; V, Ventral symphyseal margin; D, Dorsal symphyseal margin).

Individuals assigned to a particular Suchey-Brooks phase in sample

60 - 69	1	2	3	4	5	6
Males (n=15)				9	3	3
Females (n=5)				3	1	1

Percentage of individuals assigned to a particular Suchey-Brooks phase

60 - 69	1	2	3	4	5	6
Males (n=15)	0%	0%	0%	60%	20%	20%
Females (n=5)	0%	0%	0%	60%	20%	20%

TABLE 4.31 Distribution and percentage of individuals assigned to various phases of the Suchey-Brooks method.

The next age group that was analyzed consisted of fourteen males and four females (17% of study sample total) whose documented ages ranged from 70 to 79 years. The Transition Analysis produced the most age intervals that correlated with the ages at death recorded for this older sample. Ten (71%) Transition Analysis single indicator age intervals predicted the documented ages of the males (Figure 4.10). Further, three (75%) single indicator and final age Transition Analysis intervals captured the ages recorded for females in this group (Figure 4.11). The Transition Analysis age intervals generated for males were rather broad in comparison to the Suchey-Brooks estimated intervals (Table 4.32). However, the Transition Analysis method did produce the narrowest age based on the upper and lower limits of 95% confidence intervals of the single age estimates for females in this group as indicated in Table 4.33.

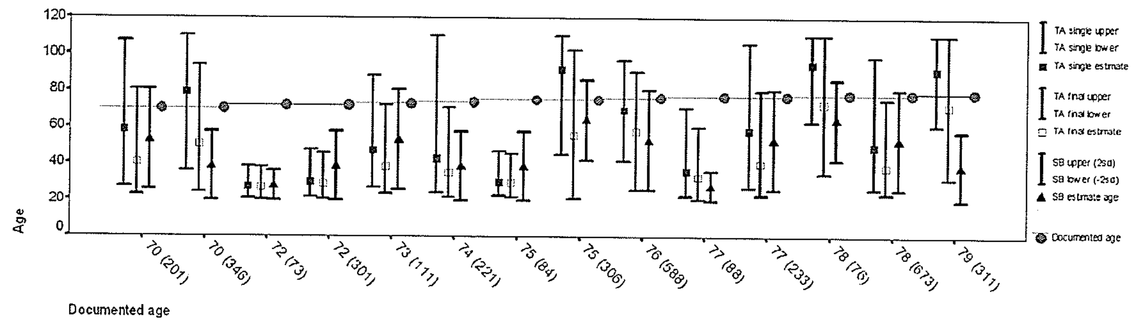

FIGURE 4.10 Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for males with documented ages ranging from 70 to 79 years. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

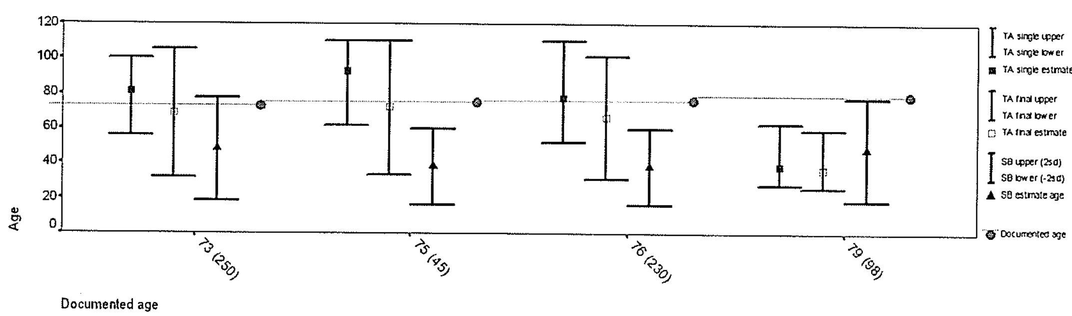

FIGURE 4.11 Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for females with documented ages ranging from 70 to 79 years. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

		Mean
Pair 1	TA single upper - TA single lower	56.1471
Pair 2	TA final upper - TA final lower	52.8850
Pair 3	SB upper (2sd) - SB lower (-2sd)	41.6286

TABLE 4.32 The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for males in the 70 to 79 year old group.

		Mean
Pair 1	TA single upper - TA single lower	46.4850
Pair 2	TA final upper - TA final lower	63.3250
Pair 3	SB upper (2sd) - SB lower (-2sd)	51.0000

TABLE 4.33 The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for females in the 70 to 79 year old group.

Further, the Transition Analysis single indicator age estimates presented the lowest mean difference of years between estimated age and the documented ages of males and females in this age group (Tables 4.34;4.35).Only three (21%) of Transition Analysis age estimates ranged within a seven years of the documented ages of the overall group (Table 4.36). Yet, this method did perform better than the Suchey-Brooks method, which did not provide any estimates within seven years of the ages recorded for the sample.

		Mean	N
Pair 1	Documented age	74.71	14
	TA single estimate	57.4643	14
Pair 2	Documented age	74.71	14
	TA final estimate	44.1786	14
Pair 3	Documented age	74.71	14
	SB estimate age	45.7071	14

		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1	Documented age - TA single estimate	17.2500	23.36212	6.24379	2.763	13	.016
Pair 2	Documented age - TA final estimate	30.5357	14.17265	3.78780	8.062	13	.000
Pair 3	Documented age - SB estimate age	29.0071	11.61507	3.10426	9.344	13	.000

TABLE 4.34 Results of paired sample statistics representing the mean differences in years between the age estimates produced by the Transition analysis and Suchey-Brooks age estimation techniques and documented ages of males in the 70 to 79 year old age category.

		Mean	N
Pair 1	Documented age	75.75	4
	TA single estimate	72.3750	4
Pair 2	Documented age	75.75	4
	TA final estimate	60.8750	4
Pair 3	Documented age	75.75	4
	SB estimate age	43.1500	4

		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1	Documented age - TA single estimate	3.3750	25.57709	12.78854	.264	3	.809
Pair 2	Documented age - TA final estimate	14.8750	18.65532	9.32766	1.595	3	.209
Pair 3	Documented age - SB estimate age	32.6000	5.96825	2.98412	10.924	3	.002

TABLE 4.35 Results of paired sample statistics representing the mean differences in years between the age estimates produced by the Transition analysis and Suchey-Brooks age estimation techniques and documented ages of females in the 70 to 79 year old age category.

	Case ID	Documented age	TA single estimate	Doc - single	TA final estimate	Doc - final	SB estimate age	Doc- SB
Males n = 14	201	70	58.25	11.75	80.23	-10.23	52.9	17.1
	346	70	78.75	-8.75	50.5	19.5	38.4	31.6
	73	72	27.25	44.75	26.75	45.25	27.7	44.3
	301	72	29.75	42.25	28.5	43.5	38.4	33.6
	111	73	47.25	25.75	38.5	34.5	52.9	20.1
	221	74	42.5	31.5	35	39	38.4	35.6
	84	75	30	45	29.25	45.75	38.4	36.6
	306	75	91.75	-16.75	55.75	19.25	64	11
	588	76	69.75	6.25	58	18	52.9	23.1
	88	77	36	41	32.5	44.5	27.7	49.3
	233	77	58.25	18.75	40	37	52.9	24.1
	76	78	94.25	-16.25	73	5	64	14
	673	78	49.5	28.5	38.5	39.5	52.9	25.1
	311	79	91.25	-12.25	71.5	7.5	38.4	40.6
Females n = 4	250	73	81.25	-8.25	68.5	4.5	48.1	24.9
	45	75	92.25	-17.25	72.25	2.75	38.2	36.8
	230	76	77.5	-1.5	66.25	9.75	38.2	37.8
	98	79	38.5	40.5	36.5	42.5	48.1	30.9

TABLE 4.36 The differences in years between the estimated ages at death and the documented ages at death for adults in the 70 to 79 year old age category. Values with a difference of more than seven years from the documented age are highlighted in black.

As expected, many of the adults in this age category were assigned higher Transition Analysis component scores. Many of the scores ranged from 4 to 7 as demonstrated in Table 4.37. Similar expectations were also obtained with the Suchey-Brooks scores where a majority of adults was assigned to phase IV or V (Table 4.38).

Component scores distributed to indivdiuals in sample

70 - 79		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR								2		3	3	6		
n = 14	ST				2		3		4						
	SA	5			1		4		4						
	V	2					3		3		3		1		2
	D	1					3		8	2					
Females		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
n = 4	SR										3		1		
	ST						3		1						
	SA	1					1		2						
	V										1		1		2
	D								1		3				

Percentage of component scores distributed in sample

70 - 79		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR	0%	0%	0%	0%	0%	0%	0%	14%	0%	21%	21%	43%		
n = 14	ST	0%	0%	0%	14%	0%	21%	0%	29%						
	SA	36%	0%	0%	7%	0%	29%	0%	29%						
	V	14%	0%	0%	0%	0%	21%	0%	21%	0%	21%	0%	7%	0%	14%
	D	7%	0%	0%	0%	0%	21%	0%	57%	14%	0%				
Females		N/A	100%	120%	200%	230%	300%	340%	400%	450%	500%	560%	600%	670%	700%
n = 4	SR	0%	0%	0%	0%	0%	0%	0%	0%	0%	75%	0%	25%		
	ST	0%	0%	0%	0%	0%	75%	0%	25%						
	SA	25%	0%	0%	0%	0%	25%	0%	50%						
	V	0%	0%	0%	0%	0%	0%	0%	0%	0%	25%	0%	25%	0%	50%
	D	0%	0%	0%	0%	0%	0%	0%	25%	0%	75%				

TABLE 4.37 Distribution and percentage of Transition Analysis component scores assigned to adults in the 70 to 79 year old age group. (SR, Symphyseal relief; ST, Symphyseal texture; SA, Superior apex; V, Ventral symphyseal margin; D, Dorsal symphyseal margin).

Individuals assigned to a particular Suchey-Brooks phase in sample

70 - 79	1	2	3	4	5	6
Males (n=14)			2	5	4	2
Females (n=4)				2	2	

Percentage of individuals assigned to a particular Suchey-Brooks phase

70 - 79	1	2	3	4	5	6
Males (n=14)	0%	0%	14%	36%	29%	14%
Females (n=4)	0%	0%	0%	50%	50%	0%

TABLE 4.38 Distribution and percentage of individuals assigned to various phases of the Suchey-Brooks method.

The final age group analyzed in this study consisted of thirteen males and two females (14% of study sample total) from the Grant collection with the recorded ages of 80 or older. The Transition Analysis performed better than the Suchey-Brooks technique in this age group where nine (69%) of the single indicator age intervals for males predicted the documented ages of males in this group (Figure 4.12). This method also provided one single indicator and final age interval estimate that captured the documented age of a female in this sample, whereas the Suchey-Brooks technique provided none (Figure 4.13). The Transition Analysis age intervals produced for males were broad compared to those generated by the Suchey-Brooks method (Table 4.39). However, the Transition Analysis single indicator age intervals were the narrowest for females in this age group (Table 4.40).

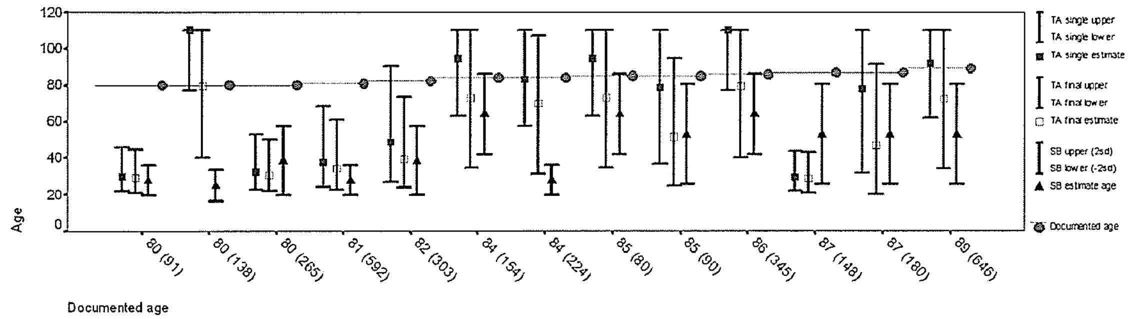

FIGURE 4.12 Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for males with documented ages ranging from 80 and older. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

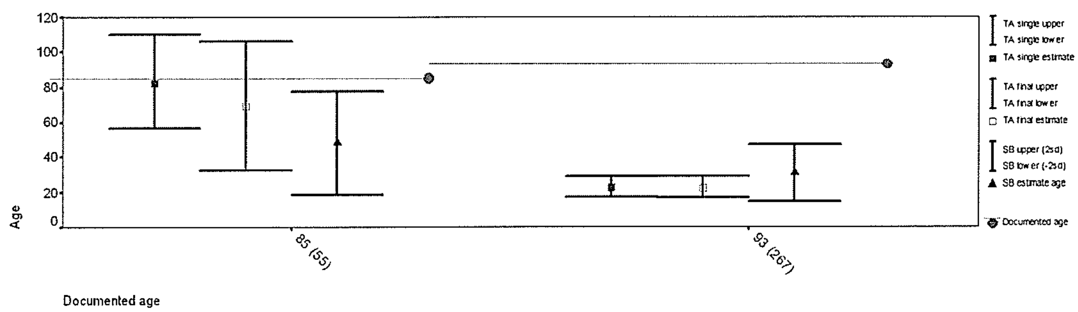

FIGURE 4.13 Plot of the estimated ages at death and intervals produced by the Transition Analysis and Suchey-Brooks method for females with documented ages ranging from 80 years and older. The horizontal axis represents the documented age of each individual and the value in parentheses represents the case identification number of an individual from the collection. A right line is drawn from the documented age value to indicate if the estimated age intervals predicted the documented age of an individual. (Full squares, Transition Analysis single indicator age estimates; Open squares, Transition Analysis final age estimate; Full triangles, Suchey-Brooks age estimates; Full circles, documented age)

		Mean
Pair 1	TA single upper - TA single lower	45.6746
Pair 2	TA final upper - TA final lower	57.1631
Pair 3	SB upper (2sd) - SB lower (-2sd)	37.9077

TABLE 4.39 The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for males that were 80 years of age and older.

		Mean
Pair 1	TA single upper - TA single lower	32.3450
Pair 2	TA final upper - TA final lower	42.6900
Pair 3	SB upper (2sd) - SB lower (-2sd)	45.4000

TABLE 4.40 The mean number of years present in the estimated age intervals generated by the Transition Analysis and Suchey-Brooks aging techniques for females 80 years of age and older.

The Transition Analysis method also produced the lowest mean age difference between age at death estimates and documented ages of the overall sample (Tables 4.41 and 4.42). Further, this method produced the most age estimates that were within seven years of the documented ages for this age range. Four (27%) single age estimates were within seven years of the recorded ages, whereas the Suchey-Brooks method, which produced none (Table 4.43).

		Mean	N
Pair 1	Documented age	83.85	13
	TA single estimate	70.5000	13
Pair 2	Documented age	83.85	13
	TA final estimate	54.2885	13
Pair 3	Documented age	83.85	13
	SB estimate age	45.2538	13

		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1	Documented age - TA single estimate	13.3462	29.84588	8.27776	1.612	12	.133
Pair 2	Documented age - TA final estimate	29.5577	19.94606	5.53204	5.343	12	.000
Pair 3	Documented age - SB estimate age	38.5923	13.06047	3.62232	10.654	12	.000

TABLE 4.41 Results of paired sample statistics representing the mean differences in years between the age estimates produced by the Transition analysis and Suchey-Brooks age estimation techniques and documented ages of males 80 years of age and older.

		Mean	N
Pair 1	Documented age	89.0000	2
	TA single estimate	52.2500	2
Pair 2	Documented age	89.0000	2
	TA final estimate	45.5000	2
Pair 3	Documented age	89.0000	2
	SB estimate age	39.4000	2

		Paired Differences			t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean			
Pair 1	Documented age - TA single estimate	36.7500	48.08326	34.00000	1.081	1	.475
Pair 2	Documented age - TA final estimate	43.5000	38.89087	27.50000	1.582	1	.359
Pair 3	Documented age - SB estimate age	49.6000	17.96051	12.70000	3.906	1	.160

TABLE 4.42 Results of paired sample statistics representing the mean differences in years between the age estimates produced by the Transition analysis and Suchey-Brooks age estimation techniques and documented ages of females 80 years of age and older.

	Case ID	Documented age	TA single estimate	Doc - single	TA final estimate	Doc - final	SB estimate age	Doc- SB
Males	91	80	29.75	50.25	28.75	51.25	27.7	52.3
n = 13	138	80	110	-30	79.5	0.5	24.8	55.2
	265	80	32	48	30.5	49.5	38.4	41.6
	592	81	37.25	43.75	34	47	27.7	53.3
	303	82	48.5	33.5	39	43	38.4	43.6
	154	84	94.25	-10.25	73	11	64	20
	224	84	83	1	69.75	14.25	27.7	56.3
	80	85	94.25	-9.25	73	12	64	21
	90	85	78.5	6.5	51.5	33.5	52.9	32.1
	345	86	110	-24	79.5	6.5	64	22
	148	87	29.25	57.75	28.25	58.75	52.9	34.1
	180	87	77.75	9.25	46.5	40.5	52.9	34.1
	646	89	92	-3	72.5	16.5	52.9	36.1
Females	55	85	82.25	2.75	69	16	48.1	36.9
n = 2	267	93	22.25	70.75	22	71	30.7	62.3

TABLE 4.43 The differences in years between the estimated ages at death and the documented ages at death for adults in the 80 years of age and older age category. Values with a difference of more than seven years from the documented age are highlighted in black.

These age intervals and estimates generated by the Transition Analysis method were based on the assignment of component scores ranging from 4 to 7 to several individuals in this age group (Table 4.44). Many of the adults were also assigned to the Suchey-Brooks phase V in the determination of age at death (Table 4.45).

Component scores distributed to indivdiuals in sample

80 +		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR								2		5		6		
n = 13	ST				4		1	2	6						
	SA	1			1		2		9						
	V	1					1			2	1		1	1	6
	D					1	2	1	4	2	3				
Females		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
n = 2	SR						1						1		
	ST				1				1						
	SA	1					1								
	V				1										1
	D				1				1						

Percentage of component scores distributed in sample

80 +		N/A	1	1.2	2	2.3	3	3.4	4	4.5	5	5.6	6	6.7	7
Males	SR	0%	0%	0%	0%	0%	0%	0%	15%	0%	38%	0%	46%		
n = 13	ST	0%	0%	0%	31%	0%	8%	15%	46%						
	SA	8%	0%	0%	8%	0%	15%	0%	69%						
	V	8%	0%	0%	0%	0%	8%	0%	0%	15%	8%	0%	8%	8%	46%
	D	0%	0%	0%	0%	8%	15%	8%	31%	15%	23%				
Females		N/A	100%	120%	200%	230%	300%	340%	400%	450%	500%	560%	600%	670%	700%
n = 2	SR	0%	0%	0%	0%	0%	50%	0%	0%	0%	0%	0%	50%		
	ST	0%	0%	0%	50%	0%	0%	0%	50%						
	SA	50%	0%	0%	0%	0%	50%	0%	0%						
	V	0%	0%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%
	D	0%	0%	0%	50%	0%	0%	0%	50%	0%	0%				

TABLE 4.44 Distribution and percentage of Transition Analysis component scores assigned to adults in the 80 years and older age group. (SR, Symphyseal relief; ST, Symphyseal texture; SA, Superior apex; V, Ventral symphyseal margin; D, Dorsal symphyseal margin).

Individuals assigned to a particular Suchey-Brooks phase in sample

80 +	1	2	3	4	5	6
Males (n=13)		1	3	2	4	3
Females (n=2)			1		1	

Percentage of individuals assigned to a particular Suchey-Brooks phase

80 +	1	2	3	4	5	6
Males (n=13)	0%	8%	23%	15%	31%	23%
Females (n=2)	0%	0%	50%	0%	50%	0%

TABLE 4.45 Distribution and percentage of individuals assigned to various phases of the Suchey-Brooks method.

Web based observations

The second component of the study involved an examination of acquiring age at death estimates from digital images of the pubic symphysis. The Suchey-Brooks scores were not translated into age at death estimates and intervals. Instead, they were compared to the scores obtained through direct observation of the Grant collection.

This approach follows that of Hutchinson and Russell's study, which compares the scores acquired through direct observation of the target sample with those assigned to digital images viewed on the monitor, digital printouts, and slide images of the auricular surface. Hutchinson and Russell (2001) assumed that age estimates obtained through direct observation of the sample were the most accurate estimations of chronological age. In order to test the reliability of age estimates acquired from digital and slide representations, they compared the estimates of age at death from the images with those rendered from the actual bones. None of the age estimates determined from the digital and visual representations were tested against the documented ages of the target sample for accuracy. The procedures presented by Hutchinson and Russell (2001) were adopted in this study to determine if age related metamorphoses of the pubic symphysis can be ascertained from digital images in a manner comparable to direct observation.

The study began with a random selection of digital images of the pubic symphyses from several adults in the Grant collection. The selection process resulted in a sample size of fifty-two individuals including thirty-eight (73%) males and fourteen (27%) females. All of the images were viewed on a 17-inch monitor in a colour format and compared with the Suchey-Brooks casts and phase descriptions in order to determine age at death.

In trial one, twenty-eight scores (52%) matched the scores obtained through direct observation of the sample (Figure 4.14). Fourteen (27%) individuals were assigned to phases younger than those derived from direct observation while there were ten (19%) adults assigned ages at death older than those obtained through direct observation. One (2%) adult was assigned a score four phases older than the score assigned during direct contact with the actual pubic bone. The mean difference between scores assigned to the digital images and those assigned to the actual pubic bones is 0.15. These scores assigned in trial one to digital images of the pubic symphysis were not statistically significant from the scores assigned during direct observation of the Grant collection as demonstrated with value of 0.252 (Figure 4.15)

In trial two, there were thirty-one (60%) scores assigned to the digital images that matched those scores assigned to the actual pubic bones (Figure 4.14). Twelve adults (23%) were assigned to phases younger than the original scores assigned through direct observation of the target sample. Nine (17%) individuals were allocated to phases older than those assigned during direct contact with the sample. The mean difference between scores assigned to the digital images in trial two and those scores assigned to the actual pubic bones stands at a slightly lower value of 0.13 (Figure 4.15). Trial two demonstrated similar results to trial one where the scores assigned to the digital images of the pubic bones were not statistically significant from those scores obtained through direct observation of the target sample (Figure 4.15).

The scores were examined further with the application of the Kendall's W coefficient of concordance test to measure the agreement between he scores obtained from both trials and those derived from direct observation of the sample. The high Kendall's W values indicated in Figure 4.16 for both trials denote that there are strong associations between scoring from digital images of the pubic symphysis and from actual bone.

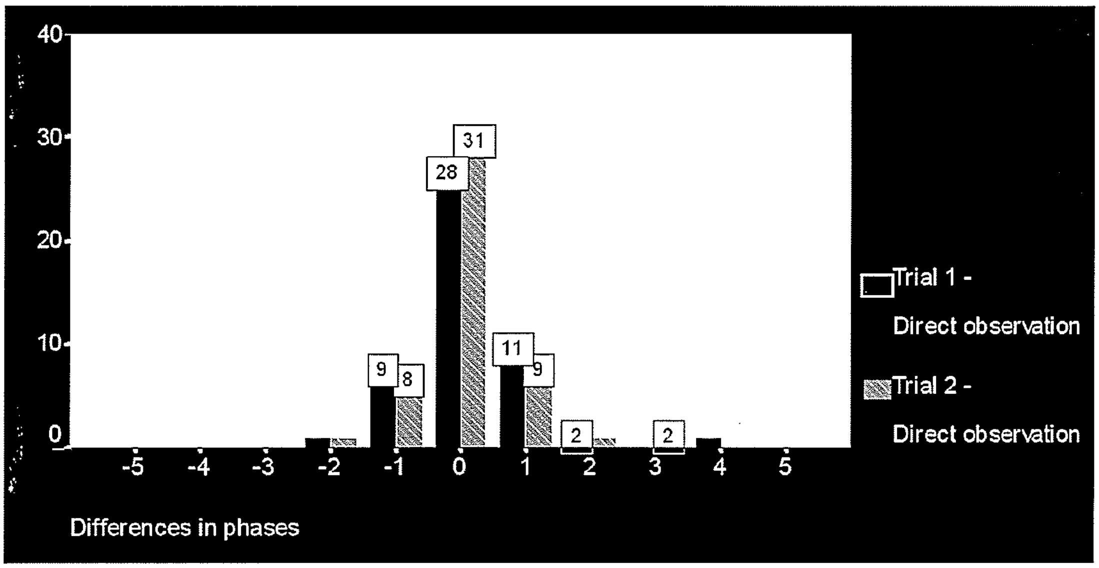

FIGURE 4.14. Differences between scores assigned to digital images of the pubic symphysis and to actual pubic bones in both trials.

		Paired Differences					
		Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Pair 1	Traditional scores - Trial 1 score	.15	.958	.133	1.158	51	.252
Pair 2	Traditional scores - Trial 2 score	.13	.908	.126	1.069	51	.290
Pair 3	Trial 1 score - Trial 2 score	-.02	1.019	.141	-.136	51	.892

FIGURE 4.15. Mean differences between scores assigned to digital images of the pubic symphysis and to actual pubic bones in both trials.

Traditional & Trial 1

Kendall's W Test

Test Statistics

N	2
Kendall's W[a]	.766
Chi-Square	78.112
df	51
Asymp. Sig.	.009

a. Kendall's Coefficient of Concordance

Traditional & Trial 2

Kendall's W Test

Test Statistics

N	2
Kendall's W[a]	.751
Chi-Square	76.573
df	51
Asymp. Sig.	.012

a. Kendall's Coefficient of Concordance

FIGURE 4.16 Kendall's W coefficient of concordance results indicating the agreement of scores obtained both trials and those derived from direct observation.

Digital imaging applications

The final component of the study concentrated on the application of digital imaging techniques in deciphering age related changes of the pubic symphysis. This examination was approached with the application of the line plot function offered by the Scion Image computer software program onto digital images of the Suchey-Brooks casts and pubic symphyses from the Grant collection. This function measures the pixel intensities across an area of interest within a digital image.

The analysis focused on the Suchey-Brooks system in order to test the application of digital imaging techniques on a group of casts known to exhibit age specific morphological features. The study was initiated with the placement of several line and rectangular selections across three particular areas of the pubic symphyseal surface known to exhibit age-related morphological changes: the dorsal plateau, the ventral rampart and the dorsal margin. The primary focus of this study was to determine if the senescent morphological changes exhibited in the symphyseal relief and texture of these three areas can be detected by the imaging program. Several line and rectangular selections at varying widths and lengths were tested across these areas to examine the quality of pixel intensity information gathered against the morphological changes exhibited in the pubic symphyseal areas of interest (Figure 4.17).

A single line selection across any surface of the symphyseal surface produced line plots that contained many sharp peaks and jagged edges (Figure 4.18). The features exhibited in the line plot represent the pixel intensities across a single row of pixels. The line plots generated from a single line selection did not provide any significant insight into the relief and texture of the symphyseal surface.

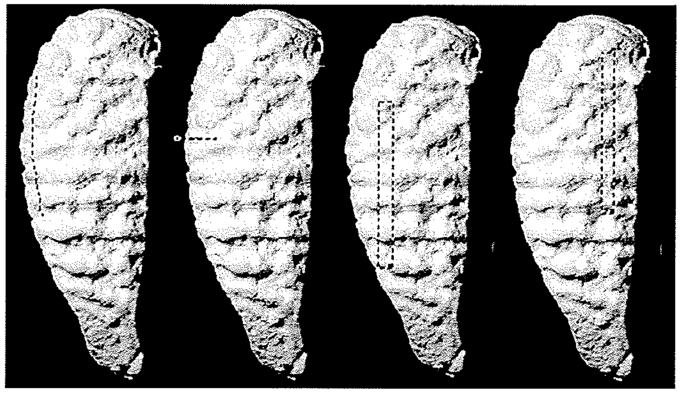

FIGURE 4.17. Example of rectangular and line selections drawn across several areas of the pubic symphysis

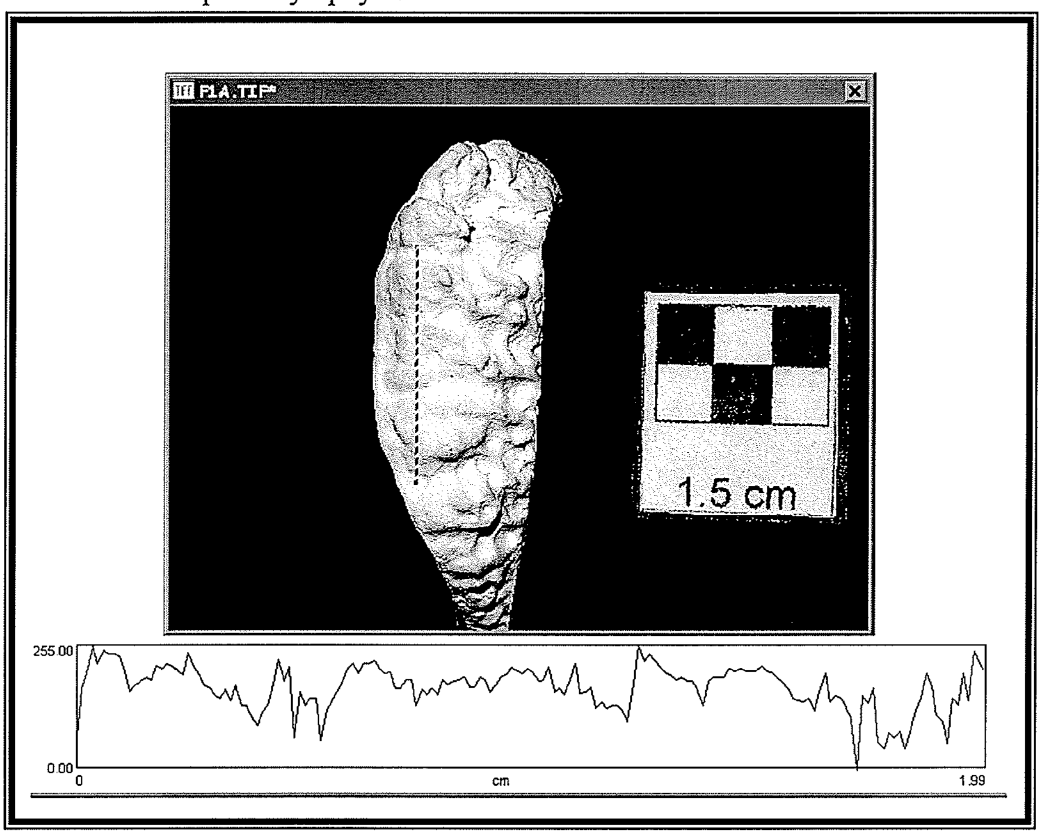

FIGURE 4.18. Single line selection placed on the dorsal symphyseal surface of female Ia cast with accompanying line plot generated by Scion Image.

It was discovered that a rectangular selection produced the most suitable type of line plot for this study as it generates a "row average plot" (Figure 4.19). This type of plot represents an area where the width of the selection is equal to its height. As a result, each value is the average of pixel intensities across a corresponding row. The rectangular selection smoothes the jagged edges found in a single line selection plot by averaging the pixel intensities across a row.

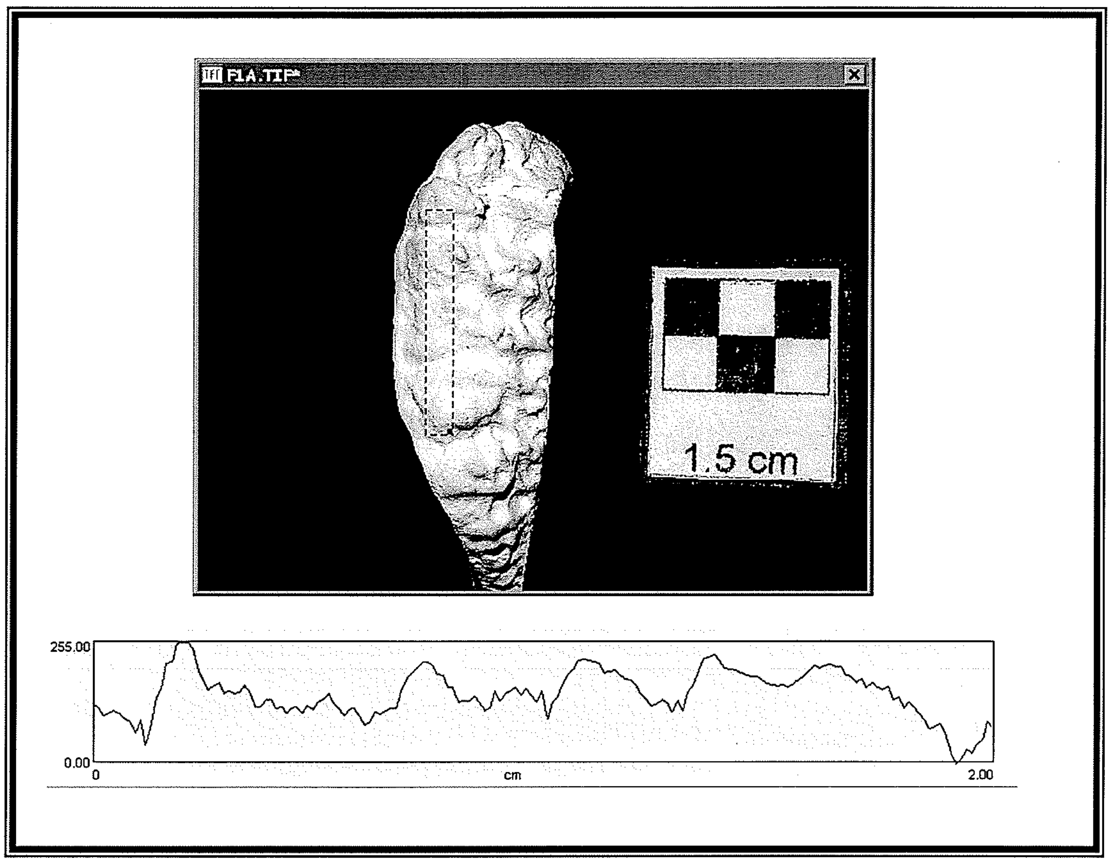

FIGURE 4.19. Rectangular selection placed on the dorsal symphyseal surface of female Ia cast with accompanying line plot generated by Scion Image.

Varieties of areas across the surface of the pubic symphysis were tested including the changes in the upper and lower extremities of the surface and the development of the ventral rampart and the dorsal surface. The line plots generated from Scion Image were compared against the images of the symphyseal surface for each phase and the written descriptions of age-related changes of the pubic symphysis provided by Suchey and Katz (1998) and Boldsen and colleagues (2002). It was discovered that the line plots generated from rectangular selections along the dorsal area resembled cross sections capturing the age related changes outlined by the two techniques (Figure 4.20; 4.21; 4.22; 4.23). The surrounding areas line plots were darkened to demonstrate how these plots resemble the cross sectional profiles of the pubic symphysis (Figure 4.24).

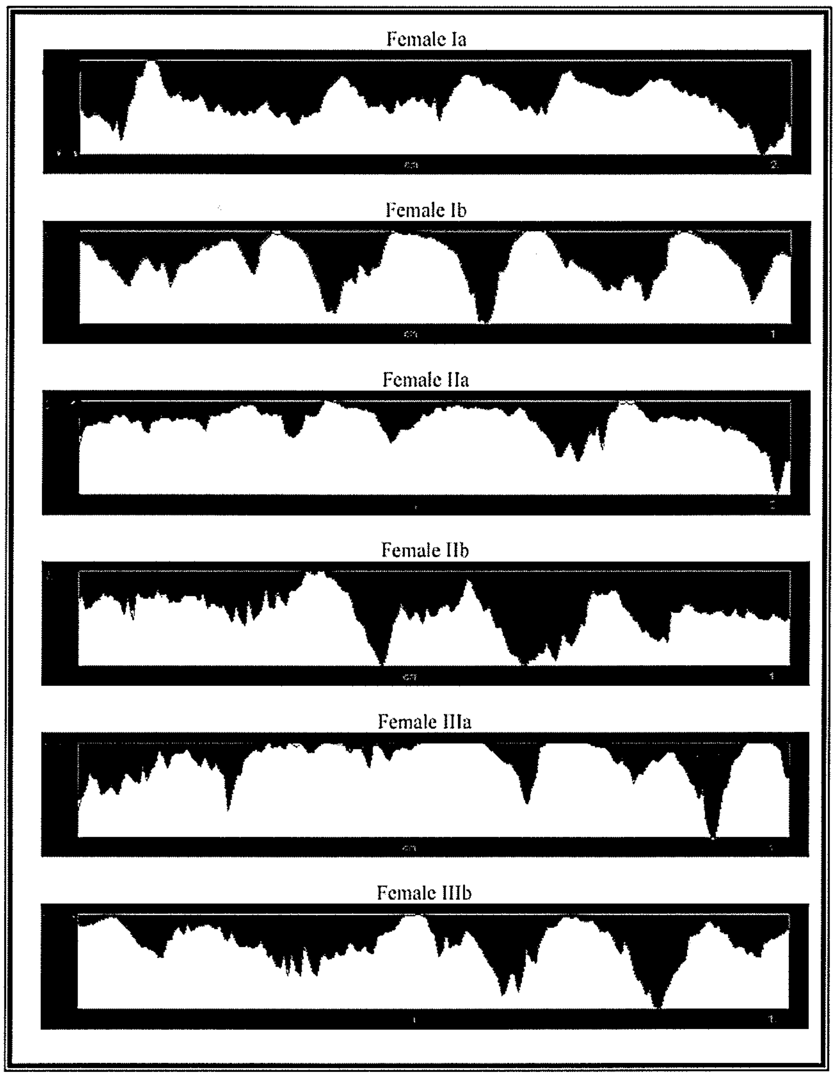

FIGURE 4.20. Collection of the line plots generated by Scion Image of the rectangular selections placed on the dorsal symphyseal surface of female casts I, II, and III (early and late phases).

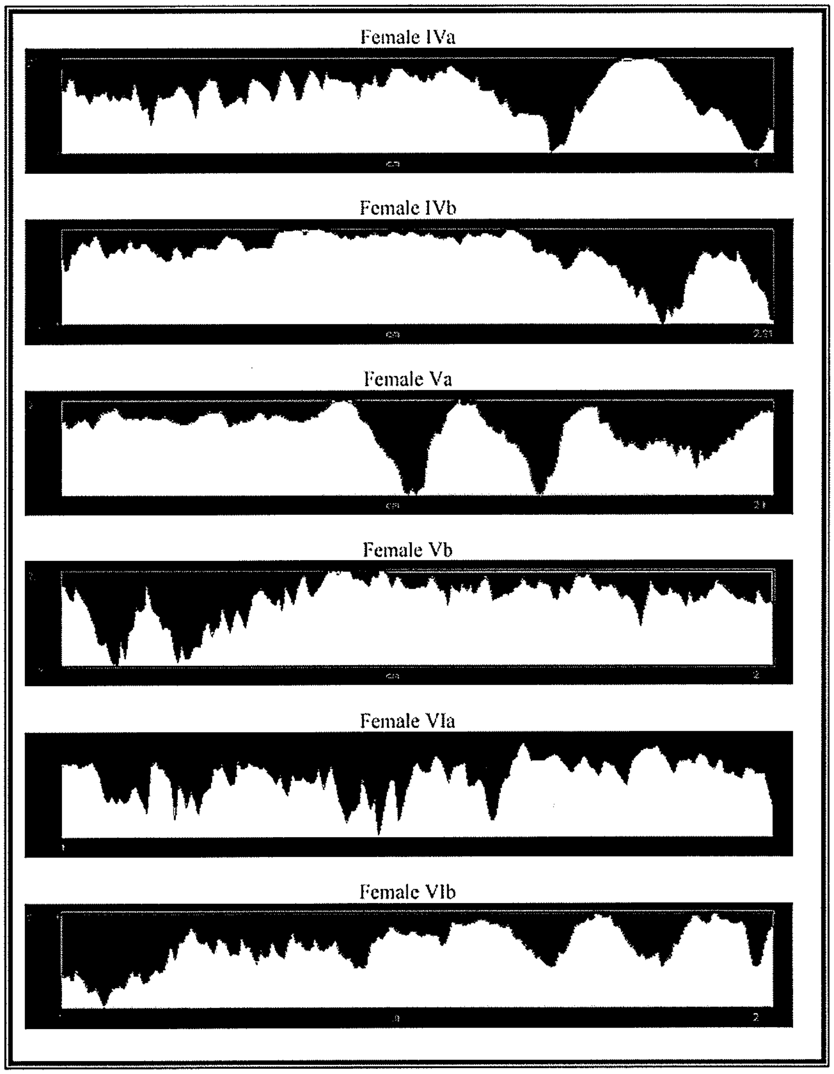

FIGURE 4.21. Collection of the line plots generated by Scion Image of the rectangular selections placed on the dorsal symphyseal surface of female casts IV, V, and VI (early and late phases).

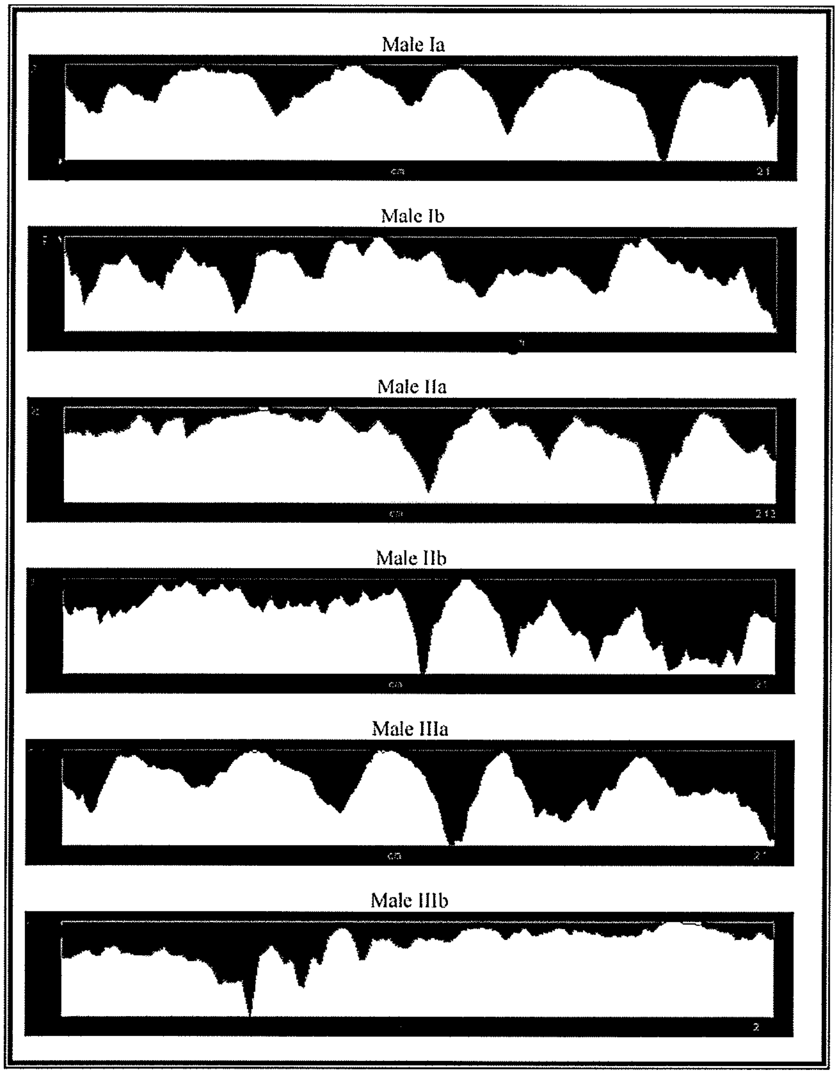

FIGURE 4.22. Collection of the line plots generated by Scion Image of the rectangular selections placed on the dorsal symphyseal surface of male casts I, II, and III (early and late phases).

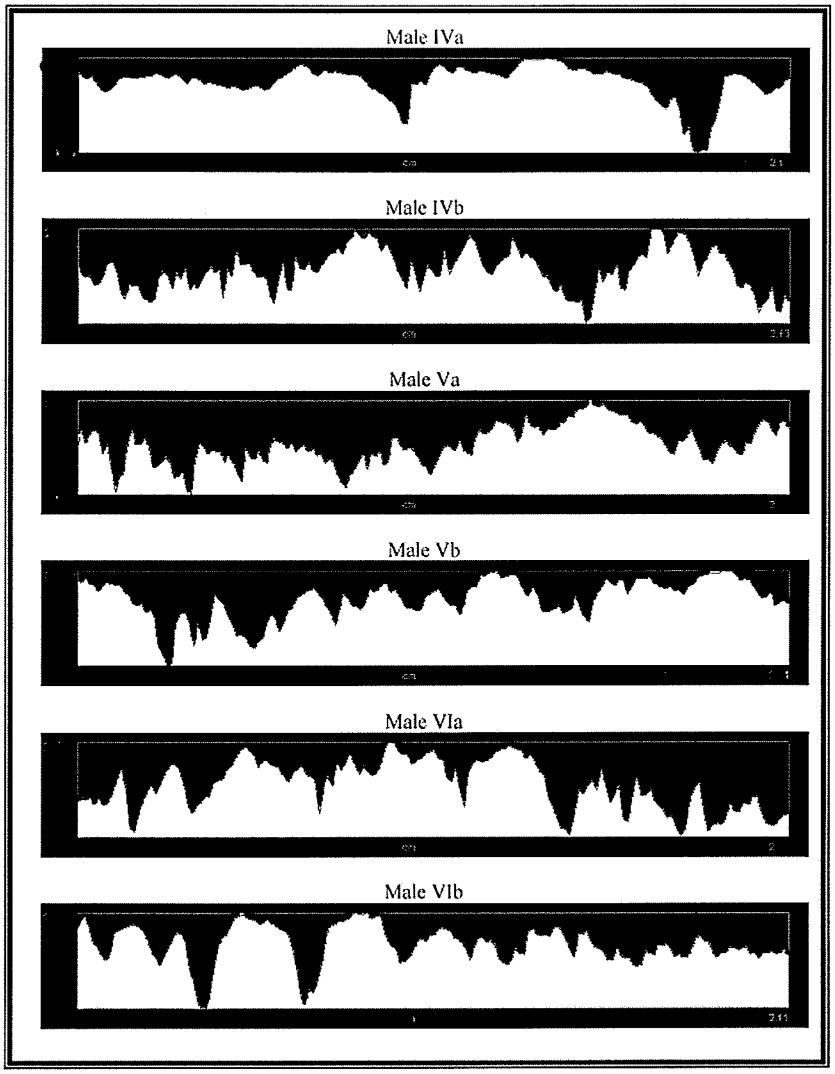

FIGURE 4.23. Collection of the line plots generated by Scion Image of the rectangular selections placed on the dorsal symphyseal surface of male casts IV, V, and VI (early and late phases).

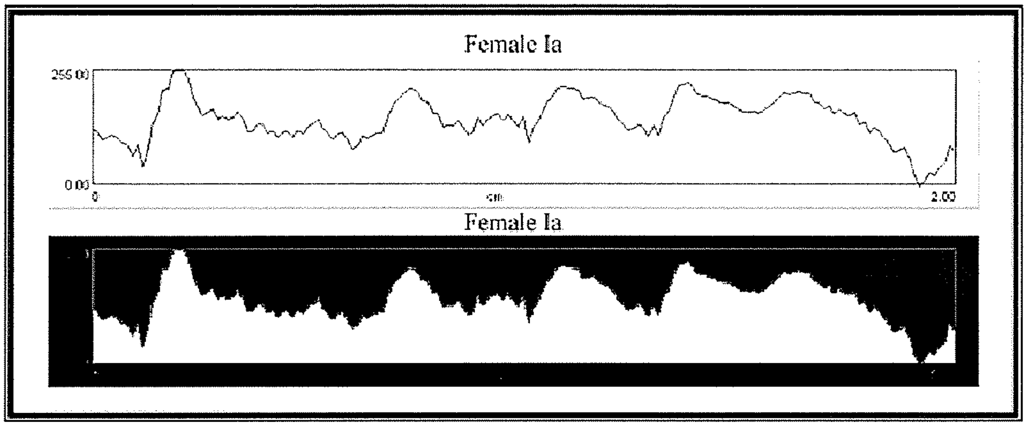

FIGURE 4.24. Example of darkened surrounding area of line plot emphasize the cross sectional pattern of the pubic symphyseal surface demonstrated in the plot

MALES AND FEMALES

Males and females exhibited similarities in line patterning throughout most of the line plots generated for each phase. For instance, Figure 4.25 demonstrates the similarities in the early and late phases in line plot patterning. These plots demonstrate general similarities in the layout of peaks and troughs exhibited throughout plot. The only apparent difference between males and females in line plot patterning was in phases four and five. The prevalence of sharp peaks in the line plots do not occur in females until phaseVb, whereas males display the sharp peaks and irregularities in line patterning as early as phase IVb (Figure 4.26). The line plot patterning in these phases may suggest that there are differences present in the manner that males and females exhibit senescent morphological changes of the pubic symphysis. The patterns suggest that the dorsal symphyseal surfaces may undergo changes in porosity and coarseness earlier than in females. For the most of this study, the descriptions of the line plots for the males and females can be summarized together due to the similarities in patterning throughout the phases of the Suchey-Brooks method.

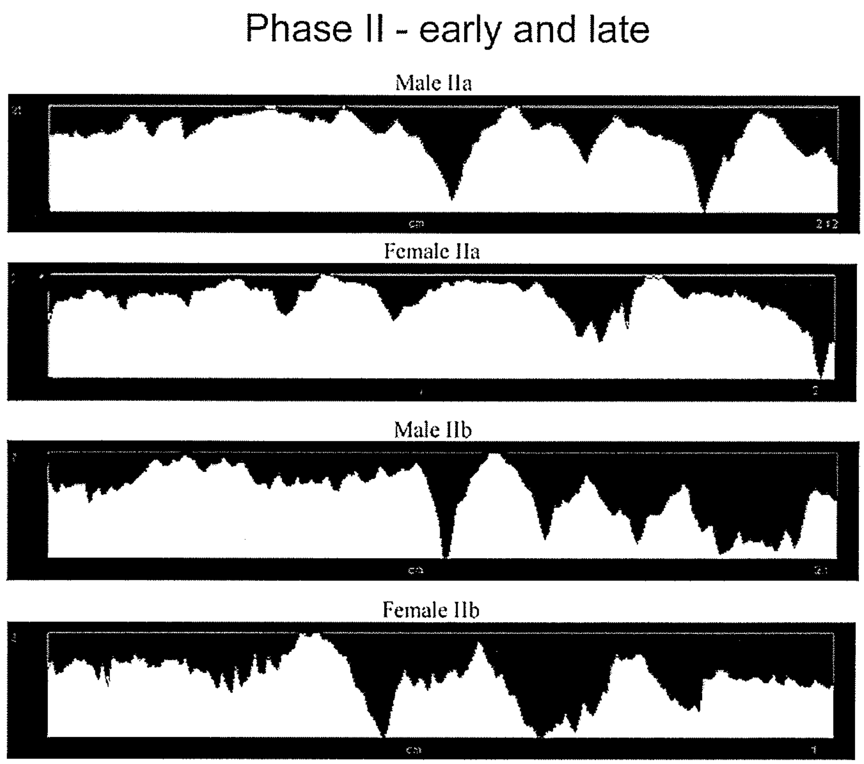

FIGURE 4.25. Comparison of the line plots generated for male II and female II to illustrate the similarities exhibited in line plot patterning of both phases.

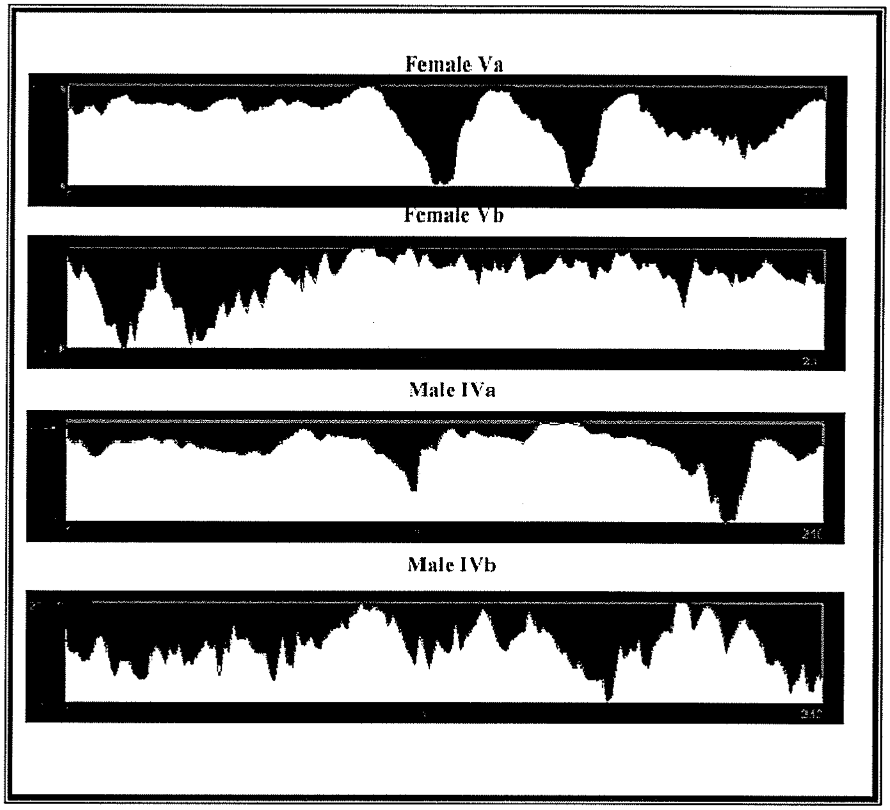

FIGURE 4.26. Comparison of line plots generated for female casts Va, Vb and for male casts IVa and IVb. Note the how changes in line plot patterning occur in an earlier phase for males.

The line plots generated by Scion Image for each phase were assessed in accordance with the images of the dorsal selections and written descriptions of age-related changes of the symphyseal surface provided by Suchey and Katz (1998) and those reported by Boldsen and colleagues' (2002) Transition Analysis method. The results obtained for each phase are reviewed below and are further summarized in Table 4.16.

Phase 1

In phase one, deeply curved line patterns expressing pixel intensities found in both extremes of the greyscale are distributed throughout the plot in a repetitive manner (Figure 4.27). When compared to the known descriptions of the symphyseal surface for phase one in outlined by Suchey and Katz (1998), repetitive patterns of values located in the upper and lower extremities in an undulating fashion resemble the deep billows and furrows associated with this phase. The short rounded curves present throughout the plot are indicative of the rounded and smooth grained texture associated with phase one.

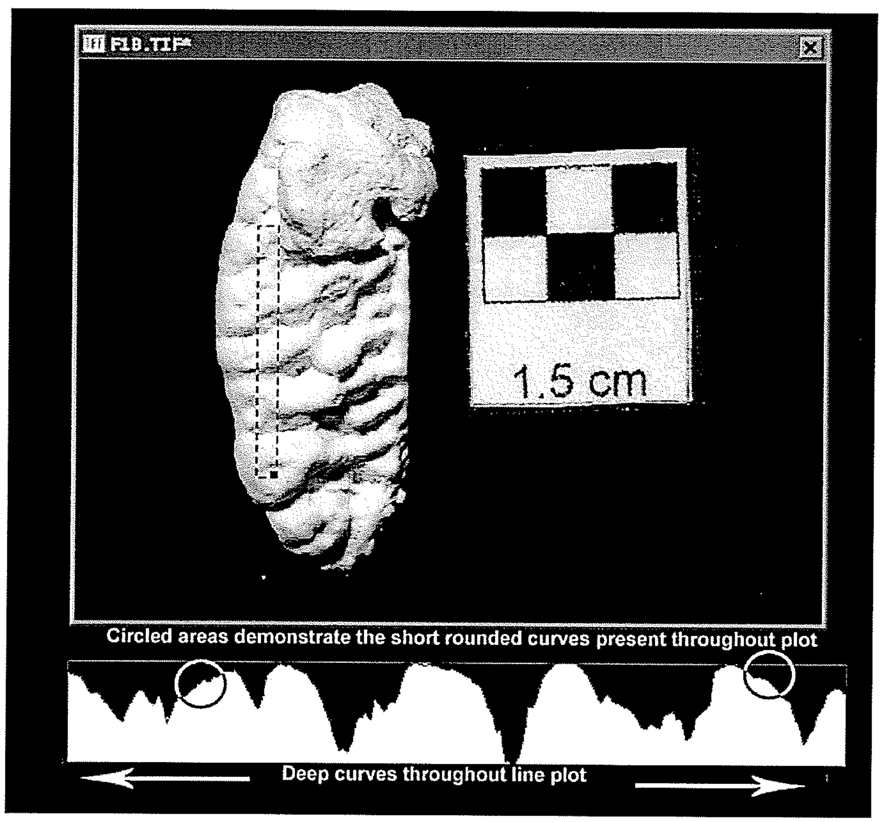

FIGURE 4.27. Line plot generated from rectangle selection placed on dorsal surface of female Ia with accompanying descriptions related to the relief and texture of the symphyseal surface. Circles outline textural patterns exhibited in line plot.

Phase 2

In phase two, the deeply curved peaks start to plateau in the first half of the line plot with the appearance of shallow peaks and troughs present in the remaining half of the plot. These features of the line plot resemble the transition of the symphyseal surface from deep billows to shallow ones with the commencement of a developing plateau (Figure 4.28). There are short rounded peaks scattered throughout the plot combined with short sharps peaks. These features represent the smooth grained texture of the surface transforming into fine-grained microporous features.

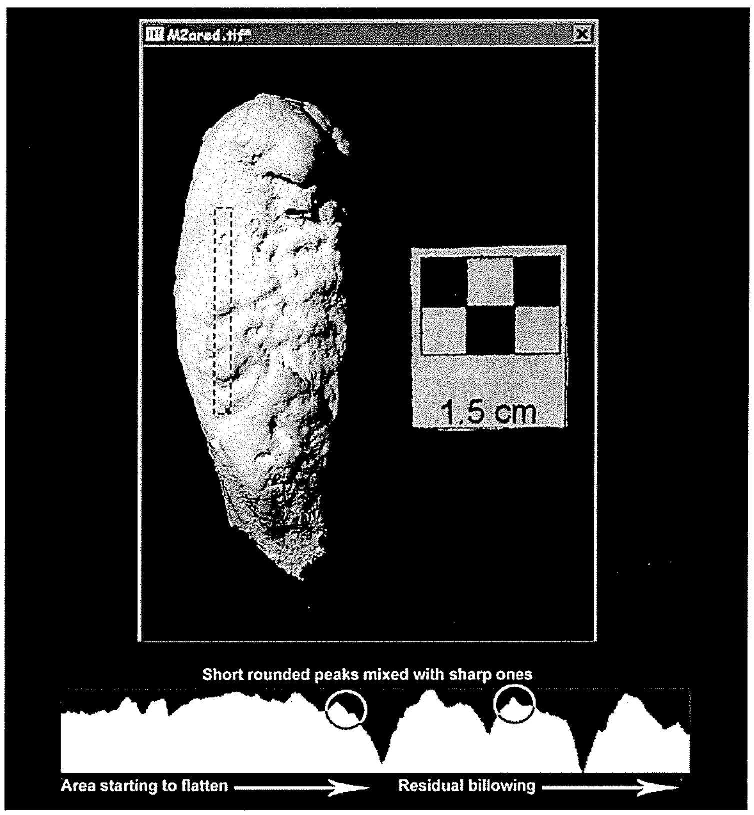

FIGURE 4.28. Line plot generated from rectangle selection placed on dorsal surface of male IIa with accompanying descriptions related to the relief and texture of the symphyseal surface. Circles outline textural patterns exhibited in line plot.

Phase 3

In phase three, approximately two-thirds of the line plot plateaus in the upper region of the grey level intensity scale. In addition, there is a slight recession present in the plateau (Figure 4.29). The latter one-third of the plot exhibits shallow rounded peaks and troughs. The line patterning of phase 3 casts resembles the residual billowing associated with this phase with the development of the dorsal area into a flat plateau. Often the plateau may exhibit a slight recession of the area. The proportion of short sharp peaks increases throughout the plot with some peaks fluctuating into deep jagged peaks. The increase in sharp jagged peaks may be indicative of an increase in macroporosity.

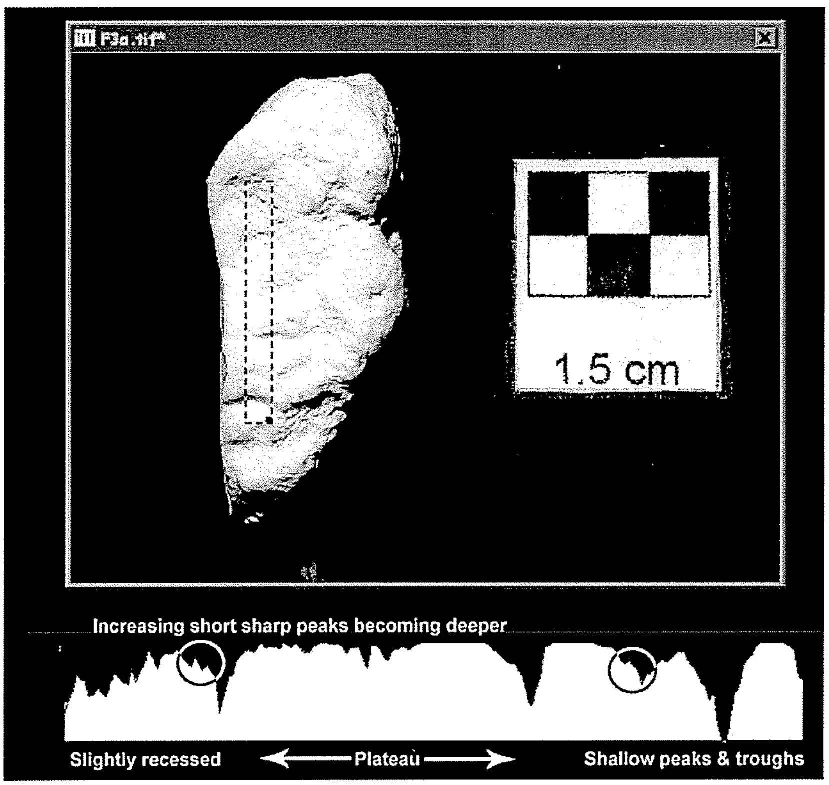

FIGURE 4.29. Line plot generated from rectangle selection placed on dorsal surface of female IIIa with accompanying descriptions related to the relief and texture of the symphyseal surface. Circles outline textural patterns exhibited in line plot.

Phase 4

A considerable portion of the pixel intensity values in the line plots for phase four remain in the upper region of the intensity scale. There is still a small area of the line plot that possesses small peaks and troughs (Figure 4.30). The distribution of pixel intensities in this phase represents the flattening and recession of the dorsal plateau. In addition, there are a few residual billows present in the latter one-third of surface. In this phase, there are still short sharp peaks mixed with jagged deep edges as found in the previous phase. This feature suggests that there is no change in texture, only that there is a continual increase in macroporosity present in the surface.

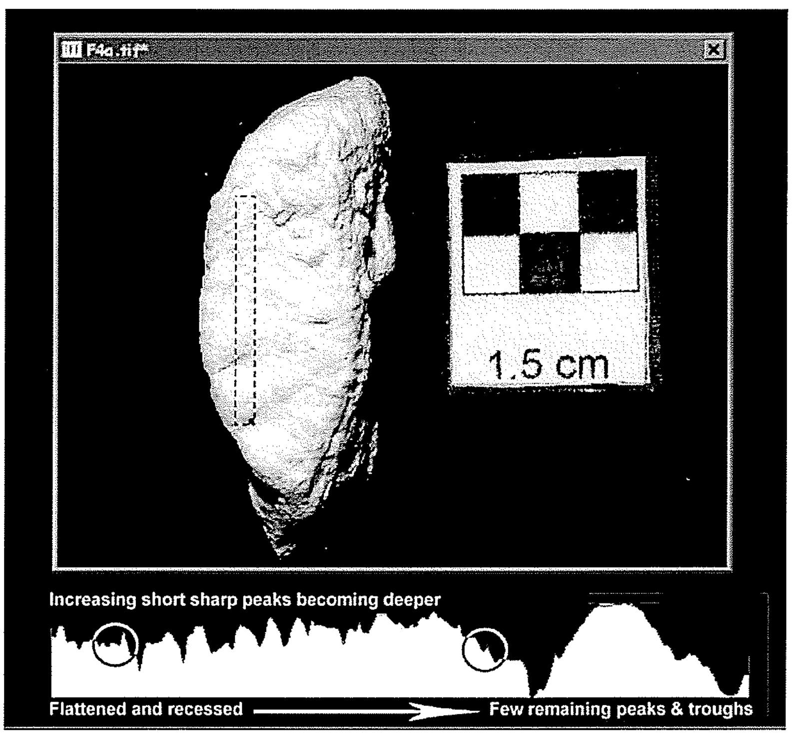

FIGURE 4.30. Line plot generated from rectangle selection placed on dorsal surface of female IVa with accompanying descriptions related to the relief and texture of the symphyseal surface. Circles outline textural patterns exhibited in line plot.

Phase 5

Phase five exhibits intensity values that begin to drop from the upper extremities of the scale to the lower region of the plot. There is also the presence of irregular deep and shallow peaks and troughs distributed throughout the plot (Figure 4.31). The line patterning in this plot illustrates the depression of the symphyseal face associated with this phase. Furthermore, there are numerous short and deep sharp peaks prevalent throughout the plot. These characteristics of the plot are indicative of an irregular texture of the surface with increasing coarseness, spitting, and macroporosity.

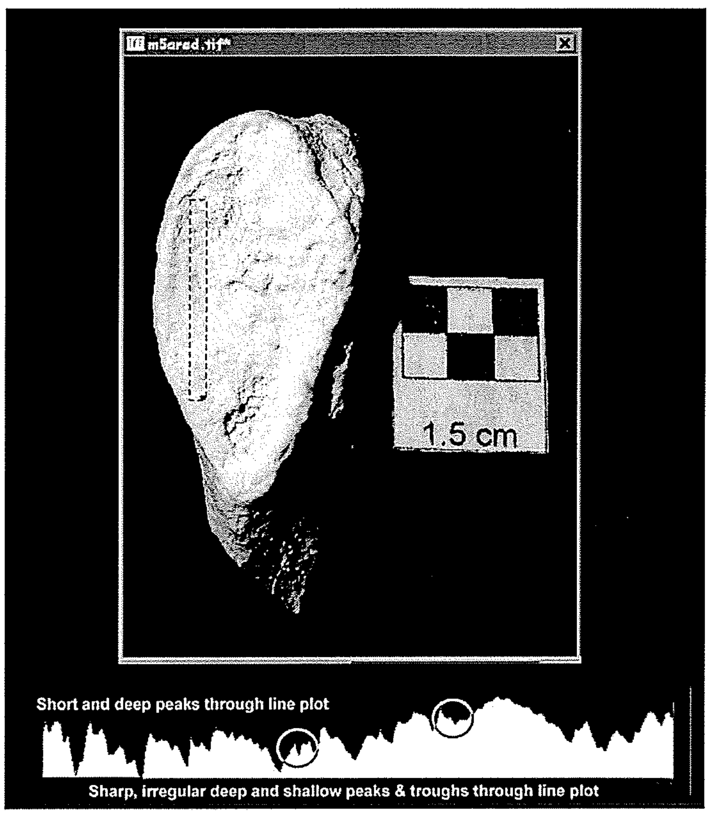

FIGURE 4.31. Line plot generated from rectangle selection placed on dorsal surface of male Va with accompanying descriptions related to the relief and texture of the surface. Circles outline textural patterns exhibited in line plot.

Phase 6

The line pattering in phase six exhibits sharp, irregular peaks present throughout the plot. These peaks are also intermixed with deep troughs that are also present throughout the plot (Figure 4.32). The distribution of intensity values in the line plots for this phase are suggestive of an irregular surface filled with macroporosity, pitting, and small sharp extoses often associated with this phase.

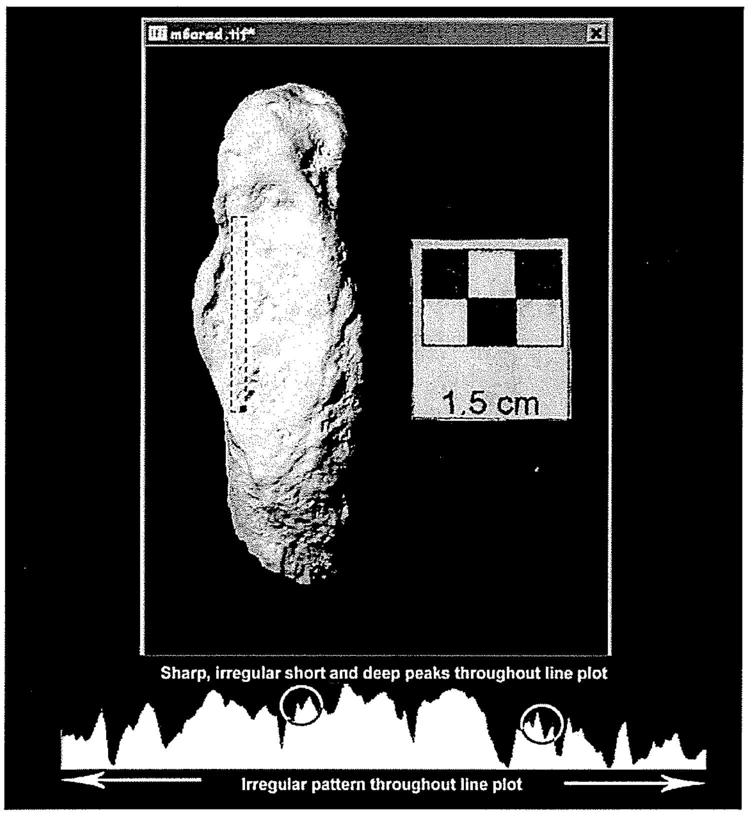

FIGURE 4.32. Line plot generated from rectangle selection placed on dorsal surface of maleVIa with accompanying descriptions related to the relief and texture of the surface. Circles outline textural patterns exhibited in line plot.

PHASE	RELIEF AND TEXTURE	LINE DESCRIPTION	DESCRIPTION FROM PUBLISHED MATERIAL
PHASE 1	**Relief**	Deeply curved peaks and troughs	Billowing ridges and furrows
	Texture	Smooth, occasional, short rounded curves	No porosity or pitting (smooth grained)
PHASE 2	**Relief**	Deeply curve peaks begin to plateau	Shows some ridge development, start of plateau
	Texture	Short, rounded curves mixed with short sharp peaks	Smooth with some fine grain (microporosity)
PHASE 3	**Relief**	2/3 of plot plateaus, remainder 1/3 shallow peaks and troughs	Remnants of furrows, plateau present
	Texture	Prevalence in short, sharp peaks	Fine grain, increase in microporosity
PHASE 4	**Relief**	Plateau present with visible recession	Remnants of furrows, plateau present, rim development on dorsal surface
	Texture	No difference from phase 3	Fine grain, microporous
PHASE 5	**Relief**	Plateau disappears, increase in sharp, irregular peaks and troughs	Depression of face
	Texture	Sharp peaks prevalent throughout plot	Increase in pitting and porosity (macroporosity)
PHASE 6	**Relief**	Irregular throughout with very sharp peaks	Disfigurement of face
	Texture	Sharp peaks, short and deep prevalent throughout plot	Pitting and porosity throughout, coarse macroporosity

TABLE 4.46. Summary of published descriptions of age-related changes in the symphyseal surface with associated descriptions of line patterning exhibited in the line plots generated from each phase.

GRANT COLLECTION

This study followed the success of identifying age-related patterns from the Suchey-Brooks casts with the application of digital imaging techniques on images of the pubic symphyses of several individuals from the Grant collection. This preliminary analysis consisted of a small sample of fourteen males. The selection process consisted of a random draw of two individuals from each of the age groups outlined earlier in this chapter.

Each of the digital images of the pubic bones from the Grant collection were prepared in the same manner as the digital images of the Suchey-Brooks casts for analysis. The images were opened in the Scion Image program to apply the line plot function to measure the pixel intensities within a rectangular selection drawn across the dorsal plateau of the symphysis. The resulting line plots were examined to identify any discernible patterns similar to those found in the Suchey-Brooks cast images (Figures 4.33; 4.34 and 4.35).

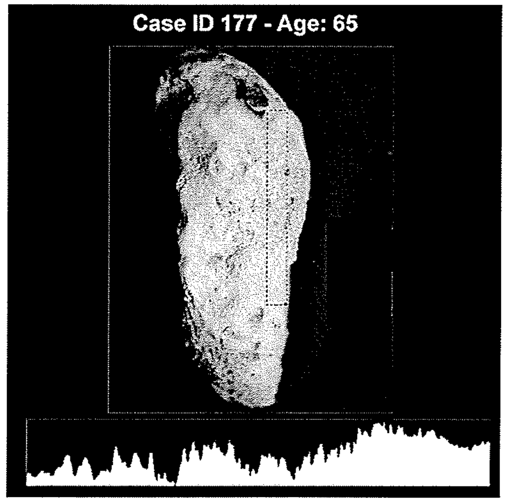

FIGURE 4.33. Example of a rectangular selection drawn across the dorsal area of the pubic bone from the Grant collection

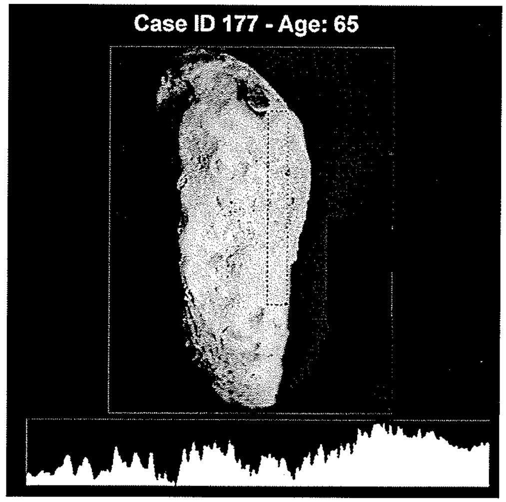

FIGURE 4.33. Example of a rectangular selection drawn across the dorsal area of the pubic bone from the Grant collection

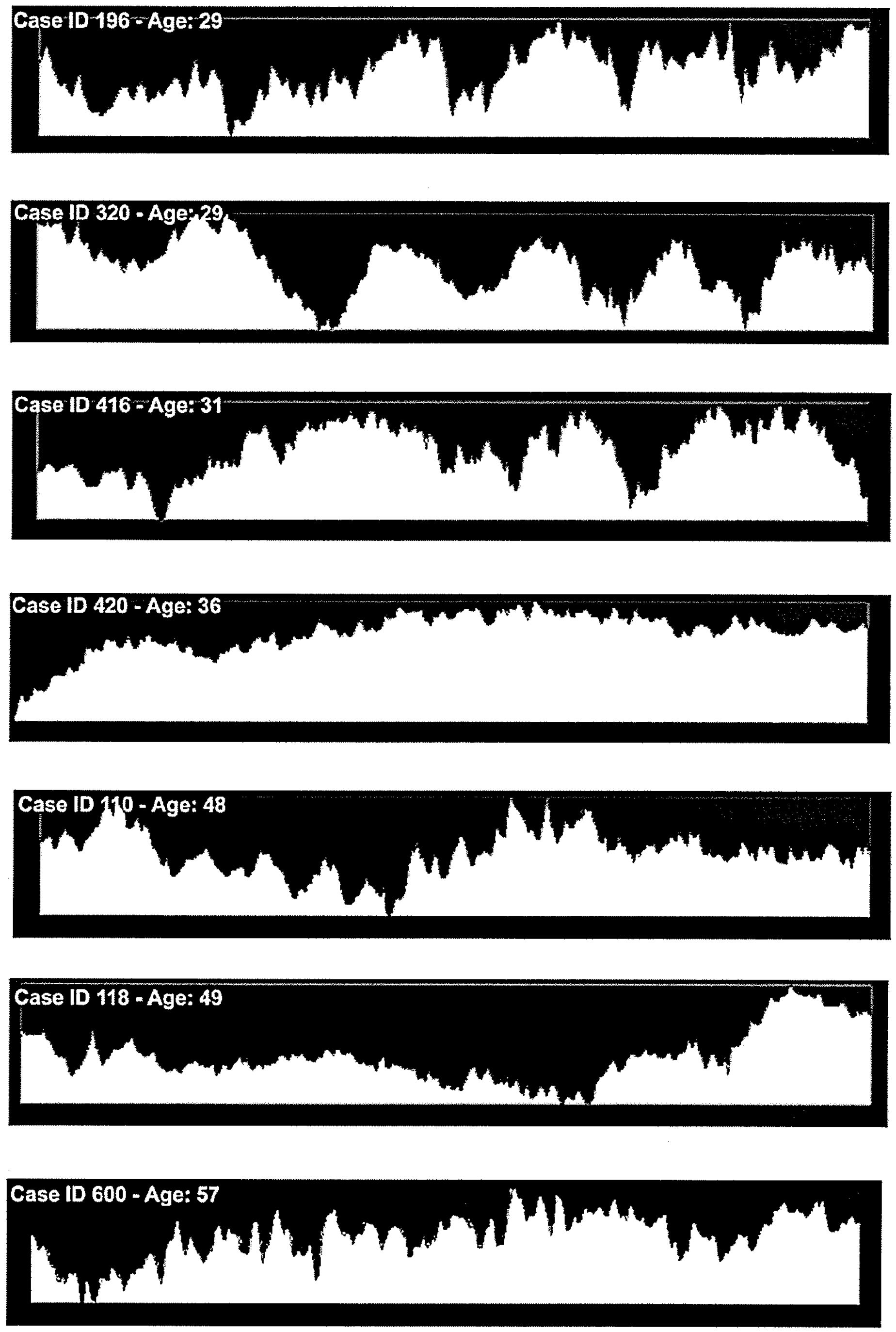

FIGURE 4.34. Line plots generated from rectangular selections placed on the dorsal area of the pubic bones from seven individuals from the Grant collection. The documented ages in this group range from 29 to 57 years.

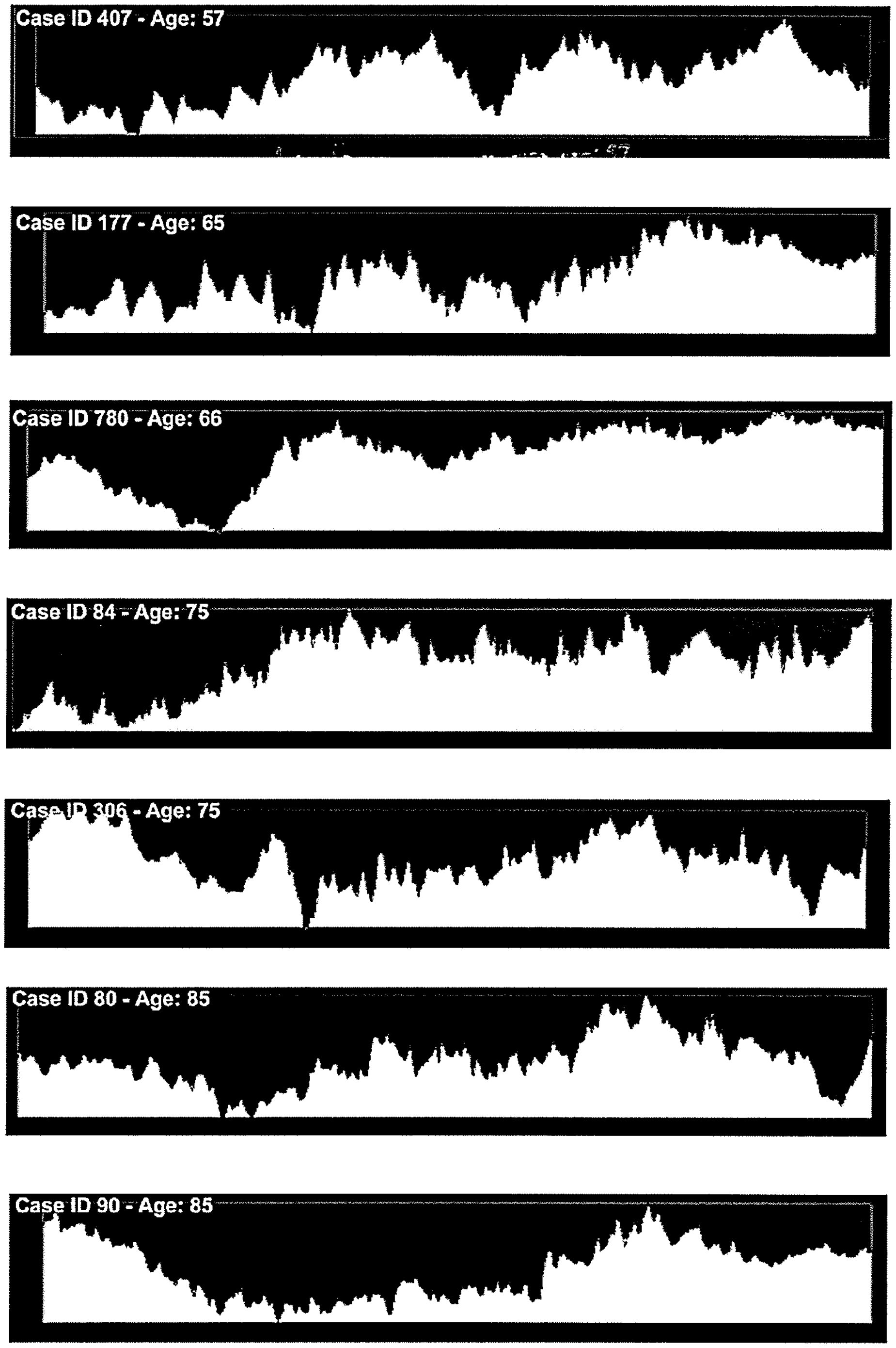

FIGURE 4.35. Line plots generated from rectangular selections placed on the dorsal area of the pubic bones from seven individuals from the Grant collection. The documented ages in this group range from 57 to 89 years.

Unfortunately, the line plots generated from the Grant collection did not exhibit smooth transitional patterns with increasing age as found with the Suchey-Brooks casts. The line plots exhibited a rather "jagged" appearance compared to the plots generated from the Suchey-Brooks casts (Figure 4.36).

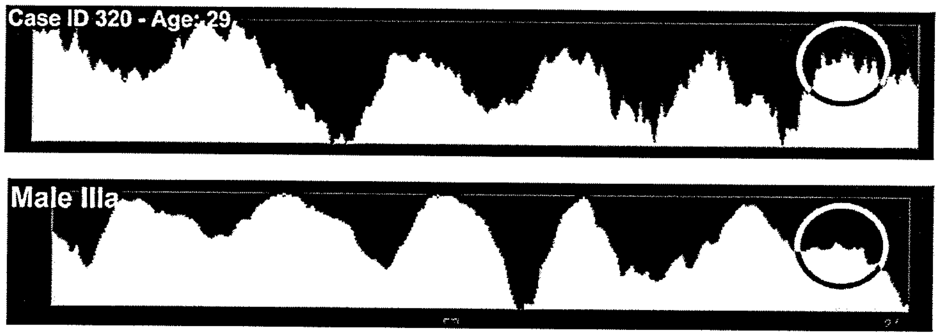

FIGURE 4.36. Comparison between the line plot generated from a pubic bone from the Grant collection compared to a plot obtained from the male phase IIIa cast. Note the "jagged" appearance of the line plot from the target sample.

It was difficult to discern any distinguishable patterns related to the texture of the symphyseal surface from the line plots generated from the Grant collection pubic bones. The line plots from the study sample were fairly distorted in such a way that it was difficult to ascertain any "short, smooth curves" or "short, sharp peaks" as found with the Suchey-Brooks casts. However, the line plots did provide insight into the relief of the symphyseal surface as demonstrated in Figure 4.37.

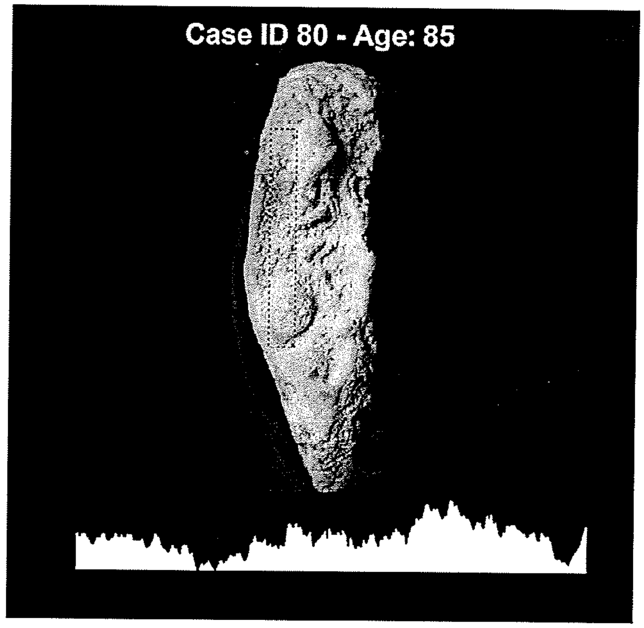

FIGURE 4.37. Example of a line plot generated from the pubic bone of an eighty-five year old individual from the Grant collection. Note the depression of the symphyseal face in the image is characterized by the line plot profile.

It was expected that the line plots generated from the rectangular selections on the dorsal area of pubic bones from the Grant collection would follow the same patterns exhibited in the line plots from the Suchey-Brooks casts. For instance, the digital image of the pubic bone of an adult with a documented age of 29 was expected to display line plot features similar to those found in the Suchey-Brooks phases II to IV.

This expectation was somewhat fulfilled where the line plots generated from the Grant collection and the Suchey-Brooks casts revealed similarities in patterning related to relief and sometimes texture of the surface. For instance, the line plot generated from the pubic bone of an adult with a documented age of 29 years old was compared against the plots from the Suchey-Brooks phases to determine if there was any similarities present in the line plot features. The comparison revealed that the line plot from the target sample displayed characteristics that resembled some features found in the line plot for male phase VIb (Figures 4.38 and 4.39). The line plot obtained from the Grant collection exhibited characteristics that would indicate a plateau with visible recession with remnants of furrows as displayed in the latter one-third of the plot. The line plot patterning from this individual was thought to resemble the Suchey-Brooks phase IVb rather than phase Va due to the prevalence of furrows remaining in latter one-third of plot. Furthermore, the sharp peaks distributed throughout the plot may be indicative of an increase in microporosity. This characteristic was outlined earlier in this chapter where changes in microporosity are textural changes associated with Suchey-Brooks phases III and IV.

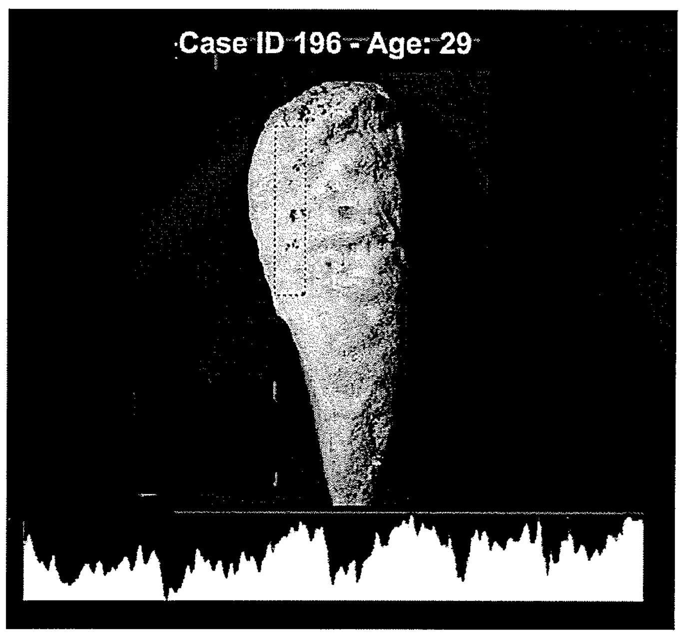

FIGURE 4.38. Line plot generated from a rectangular selection placed on the dorsal area of the pubic bone from a twenty-nine year old male from the Grant collection (Case identification number 196).

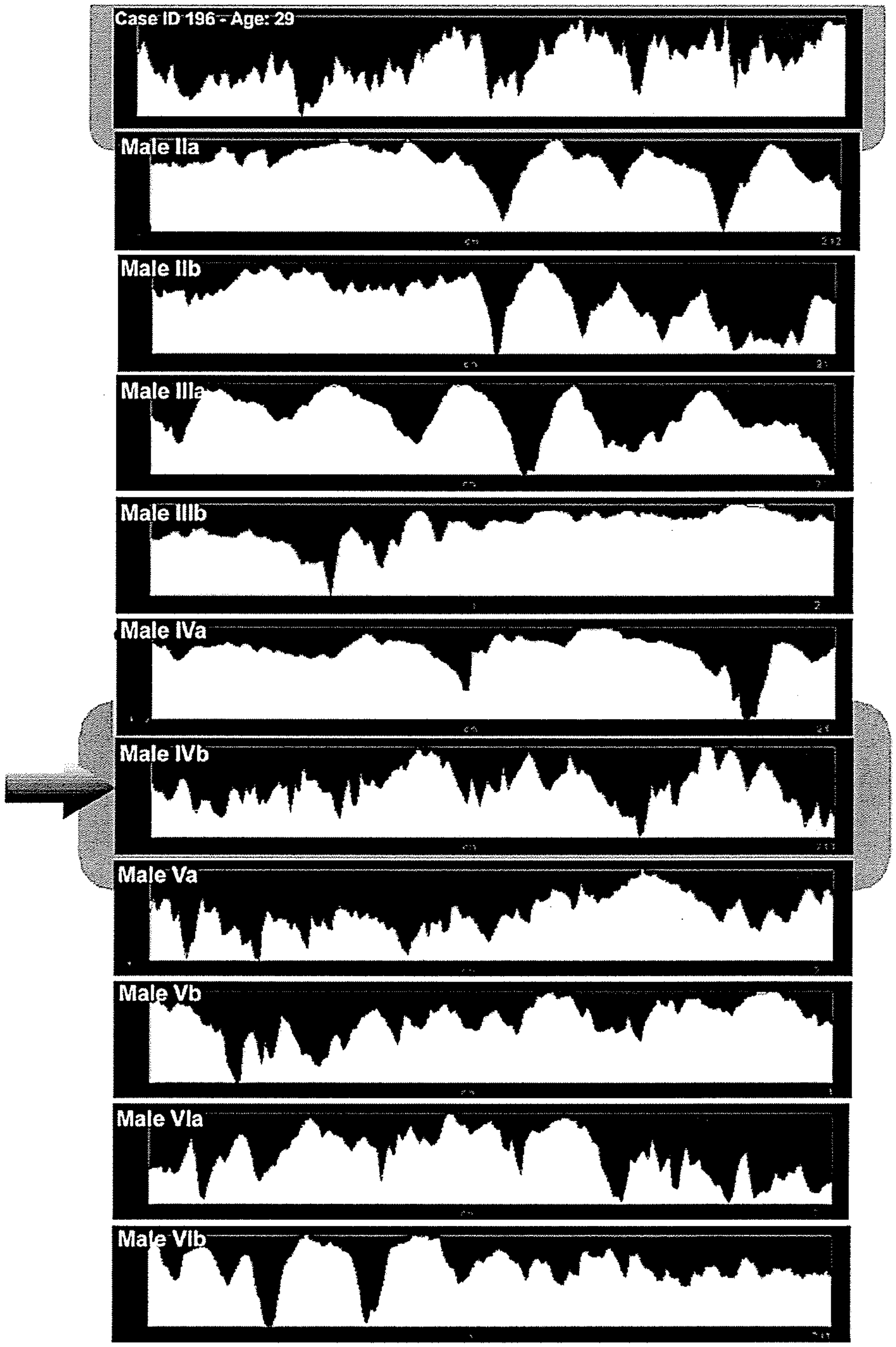

FIGURE 4.39. Comparison of a line plot generated from the pubic bone of a twenty-nine year old individual (Case identification number 196 from the Grant collection) with the Suchey-Brooks phases. The line plots that exhibit similarities to the plot from the Grant collection are identified with arrows and highlighted in grey.

Another individual with a documented age of 29 also displayed line plot characteristics that were similar to the plots generated from the Suchey-Brooks casts (Figures 4.40 and 4.41). Unfortunately, the line plot generated from an image of the pubic bone from this individual did not display any significant information regarding the symphyseal texture of the surface. However, the characteristics of the plot provided general insight into the relief of the symphyseal surface of the pubic bone. The line plot exhibited features that were characteristic of phases II and III of the Suchey-Brooks method. The deeply curved peaks of this line plot from the target sample appear to transform into a plateau. There are also some shallow peaks and troughs in the latter one-third of the plot indicating the remnants of furrows present on the symphyseal surface.

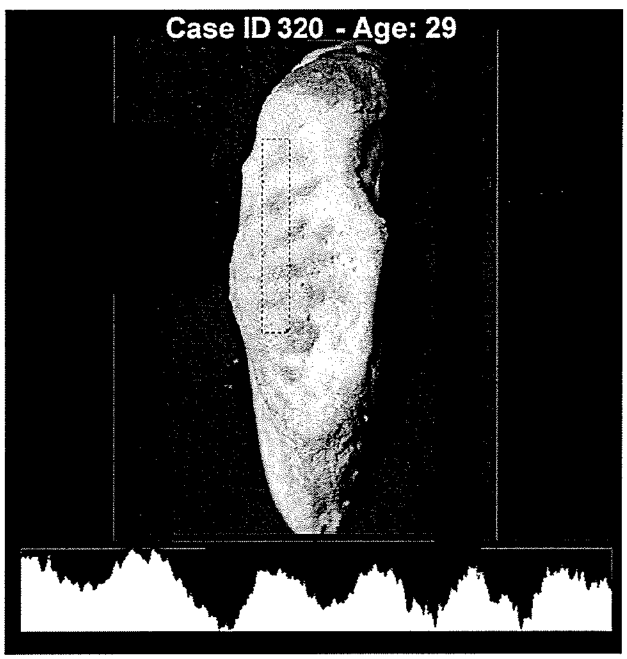

FIGURE 4.40. Line plot generated from a rectangular selection placed on the dorsal area of the pubic bone from a twenty-nine year old male from the Grant collection (Case identification number 320).

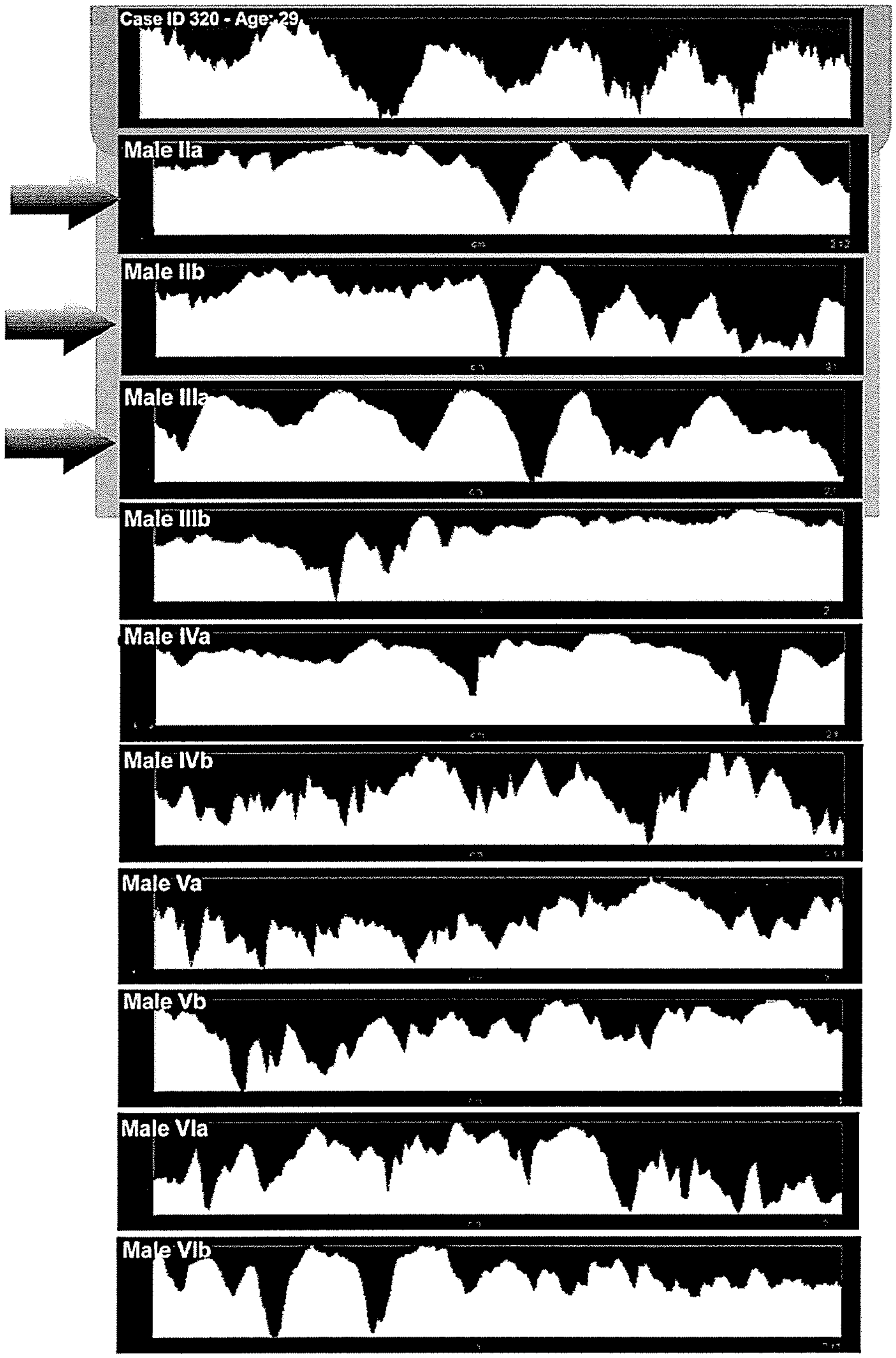

FIGURE 4.41. Comparison of a line plot generated from the pubic bone of a twenty-nine year old individual (Case identification number 196 from the Grant collection) with the Suchey-Brooks phases. The line plots that exhibit similarities to the plot from the Grant collection are identified with arrows and highlighted in grey.

The final example demonstrates the similarities found between the line plot of an individual with a documented age of 57 years and the line plots from the Suchey-Brooks phases IVb, Va, and Vb (Figures 4.42 and 4.43). The line plot produced from the Grant collection sample exhibits textural characteristics similar to phases IVb, Va, and Vb where there are sharp peaks prevalent throughout the plot indicating an increase in pitting and porosity. Furthermore, the line plot exhibits characteristics similar to those found in Suchey-Brooks phase V where the plateau disappears amid an increase of sharp, irregular peaks and troughs. The line plot features characterize the development of a depression of the symphyseal face resulting in the disappearance of the dorsal plateau.

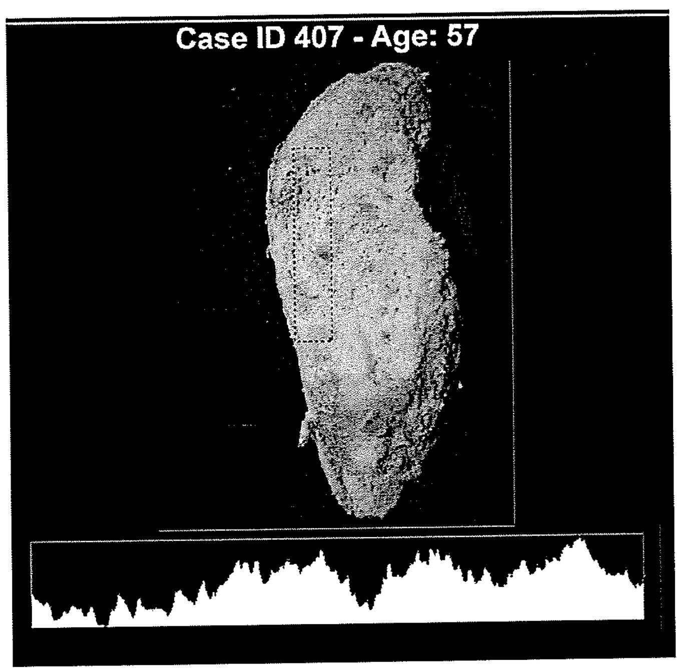

FIGURE 4.42. Line plot generated from a rectangular selection placed on the dorsal area of the pubic bone from a fifty-seven year old male from the Grant collection (Case identification number 407).

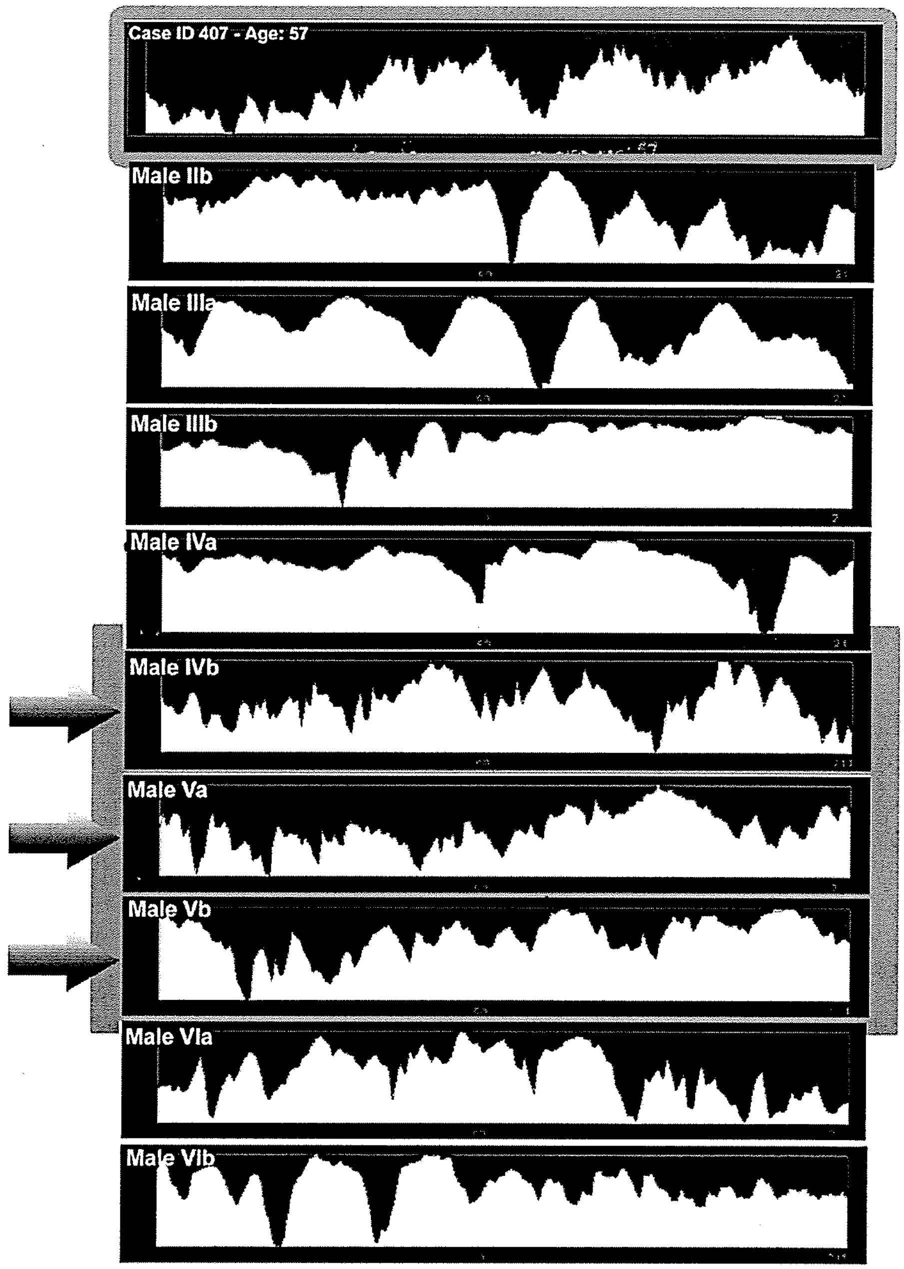

FIGURE 4.43. Comparison of a line plot generated from the pubic bone of a fifty-seven year old individual (Case identification number 407 from the Grant collection) with the Suchey-Brooks phases. The line plots that exhibit similarities to the plot from the Grant collection are identified with arrows and highlighted in grey.

DISCUSSION

Current age estimation methodologies are developed from skeletal changes observed in a reference collection of known or documented age. In this process, there are often difficulties in identifying a suite of age-related morphological features in a skeletal indicator that are characteristic of an older individual. This is due to the influence of behavioural, genetic, and environmental factors causing an increased variation in rates of morphological change of skeletal indicators as an individual ages. As a result, there are often poor correlations between the skeletal aging indicators of older adults and age. Further, most methods will accommodate for the wide margin of errors by reporting ages at death of older individuals as broad or open ended age intervals (Todd 1920;1921; Suchey et al., 1986.)

Reporting the age at death of older adults in this manner is problematic in the reconstruction of age distributions of past populations. The resulting age distributions that are recreated from age estimates of archaeological populations will often contain few individuals that are over fifty years of age. As a result, it is implied that past populations had a low life expectancy and most adults died by the age of fifty (Meindl and Russell, 1998; Van Gerven and Armelago, 1983). It is, however, not unreasonable to doubt that adults from archaeological populations lived well into old age (Jackes, 2000). For instance, it has been maintained the life spans of archaeological populations born before 100 B.C. were similar to those of populations that lived prior to fifty years ago (Montagu, 1994).

The problems associated with the age determination of older adults stem from the underlying factor that estimates of current aging methods are indirectly affected by the mortality structures of reference populations. As outlined in Chapter 2, this feature results from the regression of age on the skeletal indicator of a reference collection. As a result, an age distribution of a target sample created from the age estimates will have a similar structure as the reference collection, an incidence that is often referred to as "age mimicry" bias (Bocquet-Appel and Masset, 1982).

Boldsen and colleagues (2002) have addressed this issue by creating the Transition Analysis method, which includes estimation of most probable age at death from the observed stages, using either a uniform or informative prior mortality structures from archaeological or forensic populations. The evaluation presented here of this method, demonstrates that the Transition Analysis method significantly reduces the effect of "age mimicry" and produces successful estimates of age at death for adults older than sixty years of age.

Overall, the Transition Analysis aging method outperformed the Suchey-Brooks technique by delivering consistent and accurate age estimates for most of the age groups in this study. In particular, the method generated less biased age intervals and more age estimates that were within seven years of the documented ages of the target samples.

There were slight inconsistencies in the age estimates of a few age groups such as males in the 50 to 59 year old age group. This is the only age category where the Suchey-Brooks method predicted the ages at death of the sample more successfully than the Transition Analysis method. For instance, none of the Transition Analysis age estimates where within seven years of the documented ages of the individuals in this category. In fact, a majority of estimates for the 50 to 59 year old groups were significantly younger than the documented ages of the adults in this age group.

This discrepancy may be attributed to the assignment of superior apex component scores to adults within these age ranges. Nine males from a total of sixteen (60%) were given superior apex scores of 3, which characterize the *late protuberance* stage. However, numerous adults from the contiguous age groups of 40 to 49 years old (8 from a total of 16; 50%) and 60 to 69 years old (11 from a total of 20; 55%) were assigned a component score of 4 characterizing a later stage where the superior apex protuberance is fully *integrated* with the symphyseal face. Thus, it is implied that the lower superior apex scores have contributed to the younger age estimates present in the 50 to 59 year old group. This outcome suggests that the stage descriptions for the superior apex inaccurately describe the possible normal range of human variation of changes occurring in the pubic bones of middle-aged adults. Another explanation may be that the Grant collection exhibits unique pubic symphyseal morphological changes that deviate from the superior apex descriptions.

Other inconsistencies exist in the distribution of symphyseal relief component scores assigned to adults in the 30 to 39 year old age category. Seven males out of fifteen (47%) were assigned a symphyseal relief score of 6 characterizing an *irregular* surface. This high score is often assigned to older adults. Although these scores did not have a significant impact on the age estimates, the results suggest that the pubic bones in this age group may display characteristics associated with advanced senescence.

Breaking down the pubic symphysis into separate components enables the examination of the distribution of the scores across the target sample. This is a useful feature of the Transition Analysis method because it helps determine what features may cause age estimates to be older or younger than the documented ages. More importantly, the single component approach in age estimation is more advantageous than combining components into typecast set or "phase" because it acknowledges that different features within the pubic bone display variations in the rates of senescent morphological change. These variations are harder to ascertain with a typecast approach like the Suchey-Brooks method because the "phase" categories are highly descriptive (Kemkes-Grottenhaler, 2002).

The single component approach also simplified the assignment of scores to estimate age at death from the Grant sample. The Transition Analysis method was easier to apply than the Suchey-Brooks method because it was easier to examine the changes in each component than in the entirety of the pubic bone. An element that would improve the Transition Analysis scoring process is to include visual aides like casts or illustrations to supplement the written descriptions outlined for the various stages of each component.

There were other interesting trends that appeared in this evaluation of the Transition Analysis method regarding the accuracy of single indicator ("Pub" estimates) and final (All "cor" estimates) ages at death. It was expected that both Transition Analysis method estimates would perform similarly in determining skeletal age. However, final estimates and intervals were closer to the documented ages of adults within the range of eighteen to sixty years while single indicator estimates and intervals were better predictors for those adults older than sixty years.

This discrepancy may be attributed to the uniform or informative prior mortality structures applied in the Transition Analysis technique. To review, single indicator age estimates are based on the component scores derived from the pubic symphysis and employ a uniform prior age distribution in the calculation of age at death (see Chapter 2). Final age estimates are also based on pubic symphyseal component scores. However, these age estimates utilize informative prior age distributions based on an archaeological sample (i.e. 17th century Danish cemetery collection) or a forensic population (i.e. 1996 United States national homicide data). The inaccuracy of the final age estimates and intervals in this study suggests that it may be inappropriate to determine the ages at death of the current target sample established during the early 20th century with a mortality structure derived from a contemporary American population.

In addition, a "forensic" population based on homicide data bases age estimates on a population with probable low income whose skeletal morphology was more than likely influenced by behavioural and environmental variables that are highly dissimilar to those affecting the Grant collection. For instance, deceased individuals represented in homicide data are assumed to be more highly susceptible to substance abuse of illegal narcotics. Mortality structures based on homicide statistics may be inapplicable to adults from the Grant collection since they were probably not subjected to similar types of substance abuse.

Evidently, behavioural factors like substance abuse and the introduction of modern medical health aides can contribute to the varying rates of age-related metamorphoses exhibited the pubic symphyses of past and present populations (Owings-

Webb and Suchey 1985; Stout, 1998; Aykroyd et al., 1999, Lovejoy et al., 1985). Further, these variations in the pubic bone increase substantially in older populations (Angel, 1984; Meindl and Russell, 1998). These results suggest that relevant *a priori* mortality structures are required to yield Transition Analysis age estimates that are closer to the documented ages of the current sample of interest. Such informative prior age distributions relevant to the Grant collection may be established from Canadian census data or from parish records of cemetery populations across Southern Ontario from the early 20th century.

The fact that older adults exhibit variations in the rates of senescent morphological changes is not overlooked by Boldsen and colleagues (2002). For instance, the Transition Analysis method will produce broad estimated age intervals to account for the variation demonstrated in the skeletal features of older adults. As demonstrated in this study, these age ranges broaden with increasing age compared to the ranges generated by the Suchey-Brooks method.

These extensive age range estimates for older adults may be construed by some osteologists as a major limitation of the Transition Analysis method. However, these estimates reflect that aging is a dynamic progression. Unlike other methods, that view senescence as static process by reporting age at death estimates for older adults as open-ended terminal intervals of fifty years old and older (i.e. Todd 1920; 1921) or as severely constrained and fixed ranges such as 47.6 to 72.4 years (i.e. Suchey-Brooks method - phase 6 female).

In this study, an interesting observation related to both males and females older than sixty years of age is that in some cases both aging methods produced similar age estimates and intervals that were significantly younger than the documented ages (Figure 5.1). Many of these cases were assigned low component scores ranging from 2 to 4 by the Transition Analysis method for the symphyseal texture, superior apex and the dorsal symphyseal margin and low Suchey-Brooks scores of III or IV (Table 5.1).

These scores result from difficulties in interpreting whether the pubic symphysis was in the process of development or degeneration. This interpretive problem has been expressed with other methods like the Gilbert-McKern system where many osteologists experienced troubles in deciding if the ventral rampart and the symphyseal rim were in the process of developing or eroding (Suchey, 1979). Suchey and Brooks also encountered these problems with the ventral rampart during the development of their skeletal aging technique (Suchey and Katz, 1998). The age distribution of the reference sample utilized to develop phase 3 demonstrated outlying cases of adults in their sixties due to errors in interpreting the changes in the ventral rampart as developmental instead of erosion. It is suspected that similar interpretive errors were encountered in this study and during the development of the Transition Analysis descriptions for the dorsal symphyseal margin and symphyseal texture components.

The resulting scores may be attributed to the increasing range of variation exhibited in the pubic morphology of older adults with senescence. The skeletal morphology of the Grant collection may exhibit a range of variation that is inadequately described or captured by current aging methods. This is the most likely explanation given that most age estimation methods exhibit difficulties in aging older adults (Brooks, 1955; Iscan et al., 1992; Klepinger et al., 1992).

Perhaps the problems encountered with the Transition Analysis and Suchey-Brooks method, such as the inaccurate age estimates and the broad age intervals, may be a strong indication that the pubic symphysis is not a robust indicator of age at death in older adults. Although this conclusion may hold some truth, it is unreasonable to accept the finality of this explanation until the robustness of the pubic bone as an age indicator is examined on a completely diverse reference sample of skeletons.

Most pubic symphyseal aging techniques developed to date have resulted from an examination of select reference collections like the Hamann-Todd sample, which represent a small proportion of populations in the world. This approach stems from the assumption that the biological relationship between skeletal age indicators and chronological age is constant across populations (Schmitt et al., 2002). In reality, diverse populations exhibit a wide range of variation due to a variety of behavioural, environmental, and genetic factors (see Chapter 2). Unfortunately, most reference collections with a sample size often limited to a hundred adults cannot accommodate for the range of variability exhibited across an array of populations as would a large and diverse reference collection of skeletons.

In fact, implementing a large reference sample into the development of an age estimation technique allows for a thorough examination of morphological variation related to aging exhibited in an individual and across populations. More importantly, a diversified skeletal collection promotes the development of new age estimation methodologies that can control for the degree of variation present in the morphology of skeletal indicators that result from behavioural , environmental, and genetic factors outlined in chapter 2 (Hoppa and Sitchon, 2002).

It is almost impossible to create this kind of a reference sample since it involves accessing a wide array of skeletal collections available worldwide. In order to access these collections requires permission from the institution housing the skeletal remains, financial support for travel, and an indefinite amount time to conduct thorough analyses. Furthermore, the development of such a reference populations requires an analysis of archaeological populations. However, access to such groups can be problematic with the development of recent legislation governing the repatriation of human skeletal remains. For instance, the Native American Graves Protection and Repatriation Act (NAGPRA) in the United States required various federal institutions or agencies, e.g. museums, that house skeletal remains to complete detailed inventories by November 1995 to determine proper repatriation of their collections (Bray, 1996; Watkins, 2000). Further, any future analyses of the archaeological sample are prohibited once the skeletal remains are reburied.

Issues related to accessibility skeletal samples available worldwide may be addressed with the recent technological developments in image processing to a digital format. Digital images have facilitated the rapid transmission of photographic information over long distances via Internet based networks. In addition, digital images have increased the efficiency of storing visual information into user-friendly databases. The ability to store photographs into a viable and compact format offers new possibilities in skeletal age estimation. For instance, images of skeletal features may be shared and stored in a digital form resulting in an efficient and economical alternative to 35mm photography. Furthermore, the availability of digital images enables osteologists to gain unlimited access to collections with relative ease and by eliminating time restrictions and financial burdens.

More importantly, the introduction of digital or scanned photographs of skeletal features encourages the development of a comprehensive database of skeletal features. For instance, a collection of images of skeletal age indicators with known age-progressive traits can established themselves as a comparative collection that is virtually accessible from any location via the Internet, email, or through software programs. The development of an electronic osteological database addresses the issues of variation associated with current age estimation methodology. By building the representation of samples through a comprehensive visual database allows osteologists to explore the variations present in the age-related metamorphoses of skeletal indicators across several populations (Hoppa and Sitchon, 2002). Further, access to such a database promotes the development of age estimation methodologies that can control for variations and be applicable to an assortment of populations or modeled to suit a specific target sample.

The second component of this study examined the potential use of digital images of the pubic symphysis for comparative analyses to determine age at death. Past studies such as Hutchinson and Russell (2001) have explored the reliability of estimating age at death from remote images of the auricular surface. Their study assigned age at death estimates to images of the auricular surface in a digital and slide format. They concluded that images from the auricular surface do not provide significant information into age at death compared to actual bone.

Similar procedures with slight modifications were adopted in this study and resulted in interesting observations related to age estimation from digital images of the pubic symphysis. The magnification or "zoom" function offered by various computer software applications facilitated the process of determining age at death the images. For example, features that were unrecognizable to the naked eye could be magnified for further inspection. A main concern of magnification with imaging programs is that the photograph may appear pixilated or distorted. Hutchinson and Russell (2001) address this concern by suggesting that the slide projector images offer better resolution for magnification purposes than digital images. However, they overlook that the resolution of digital images can be controlled by the digital camera or scanner. Scanning or capturing digital photographs at a high resolution (i.e. 1600 X 1800 pixels) will eliminate or reduce the amount of distortion exhibited in the image during magnification (for a review on resolution see chapter 2).

Distortions may also be eliminated by saving images as a Tagged Image File Format (TIFF). This format does not affect the quality of the images since there are no compression schemes to affect pixel information, unlike photographs saved in a Joint Photographic Experts Group (JPEG) format that uses compression schemes to reduce the information contained within an image to save disk space. A JPEG format recompresses the pixel information every time it is saved on to disk, resulting in a loss of image quality. Continual opening and saving of JPEG images destroys pixels and affects the quality of an image (to review see chapter 2).

The results of this research imply that it is possible to obtain age estimates from digital images that are accurate and correlate strongly with those obtained through direct or traditional observation of the Grant pubic bones. A Kendall's W coefficient of concordance value of 0.766 for trial one and traditional scores and a value of 0.751 for trial two and traditional scores imply that there significant agreement between osteological assessment of aging criteria from digital images and direct observation – greater than random change alone ($p<0.05$).

However, given that only 28 (54%) scores in the first trial and 31 (60%) scores in the second trial matched the scores obtained from direct observation suggests that there is a certain degree of error in scores obtained from digital images of the pubic symphysis. Furthermore, the results imply that age estimation from the digital photographs is not foolproof and should be approached with caution.

Unfortunately, these low success rates did not meet the expectations outlined for this component in chapter one. It was expected that more age estimates from the digital images of the pubic symphyses would be equal to those obtained from direct observation of the study sample. This outcome can be attributed to several causes, the first being an increase in observer experience in determining age at death from the pubic symphyses. This can be demonstrated by the fact that there was a slight increase of three estimates in trial two that matched with those derived from the actual pubic bones.

Most of the erroneous age estimates, however, result from interpretive errors. As outlined earlier in this chapter, it is often difficult for osteologists to decipher from actual bone if the age-related changes exhibited in the pubic symphysis are developmental or degenerative. Similar problems exist in the age estimation from two-dimensional images where identifying developmental or degenerative changes of bone from digital images can be an even more difficult task to complete. For instance, many of the pubic symphyses that were assigned a score of 6 during direct observation were assigned lower scores in their digital image format.

However, a majority of the interpretive errors related to the development and degeneration of the ventral rampart and the dorsal margin. A majority of individuals whose age estimates were derived from the digital images were assigned to a score of either 3, 4, 5, or 6. These phases describe changes that are associated with build up or breakdown of bone in these regions. A close examination of the digital images of pubic bones assigned erroneous scores revealed that it was difficult to determine if the lipping of the dorsal area was slight, moderate, or non-existent from the photograph. Furthermore, it was harder to ascertain if the there were fusing ossific nodules developing on the ventral rampart or if this region was in the process of irregular erosion. These interpretive errors imply that the naked eye possesses inherent difficulties in identifying three-dimensional features from two-dimensional images.

To examine this issue, this research addressed whether digital image application can offer potential insight into three-dimensional features from digital images that are unrecognizable by the human eye. This component of the study demonstrated that it is possible to ascertain age-related morphological features with the imaging software program. The Scion Image program delivered significant results in the form of qualitative cross-sectional line plot patterns from the dorsal area of the Suchey-Brooks casts and the Grant collection pubic bones. The generated line plots from both samples exhibited characteristics that correlated with the published descriptions by Suchey and Katz (1998) and Boldsen and colleagues (2002) outlining the distinctive age-progressive traits found in the pubic symphysis.

The plots were able to provide insightful information into the senescent textural and relief changes exhibited in the Suchey-Brooks casts. However, the line plots obtained from the Grant collection pubic bones displayed age progressive features related to the relief not texture of the surface. Most of the line plots generated from the pubic symphyses from the Grant sample exhibited "jagged edges" prohibiting any identification of textural features from the plot.

The "jagged edges" in the plot are attributed the varying colours present in the image of the Grant pubic bones. Since the images were transformed into a greyscale format, the different colours were translated into high contrasted grey levels producing unsightly noise or "jagged edges" throughout the line plots. This factor was not an issue with the Suchey-Brooks casts as they were all uniform in colour. Unfortunately, due to poor preservation or inadequate maceration techniques, the Grant collection pubic bones varied in colour and some had retained small bits of dried tissue. Further, some of the pubic bones were lacquered for preservation purposes, which produced a shiny, reflective symphyseal surface. These issues may be addressed with a thin application of a non-reflective powder or by adjusting the greyscale levels with an image program like Photoshop to adjust the colour of the images prior to analyses. However, this procedure can only be completed up to a certain threshold before the integrity of the digital image as an actual representation of the object is compromised. The colour adjustment process was tested on the Grant collection pubic symphyses but it did not work for all of the images.

The most significant outcome of this study is that the digital image programs were able to provide insightful information into the transition of textural and relief changes exhibited in the pubic symphysis that were unrecognizable by the naked eye. For instance, it was revealed that the line plots generated from the Suchey-Brooks casts exhibited differences in the transition of age-related features exhibited in males and female pubic bones. The sharp peaks in the plots were correlated with an irregular texture consisting of coarse, pitting and macroporosity of the symphyseal surface. These sharp peaks begin to appear in phase IVb whereas females do not exhibit this feature until phase Vb. This outcome implies that the dorsal symphyseal surface in males may exhibit changes in porosity and coarseness sooner than females.

This assessment of digital images analyses on the Suchey-Brooks casts and the Grant collection pubic bones suggests that qualitative cross sectional patterning of age-progressive changes may be discerned through this type of computer application. By completing this objective, this component of the study strongly implies that digital image applications are indeed useful for skeletal aging purposes. For instance, digital images analyses may identify age progressive changes in other skeletal features that remain unrecognizable to the human eye and result in the identification of new skeletal indicators of age within the skeletal system.

More importantly, computer assisted analyses like digital image applications promote the increased standardization in age estimation methodologies with quantitative analyses. A feature that is often difficult to incorporate into subjective, macroscopic skeletal aging approaches. This feature benefits the observer by improving efficiency, decreasing visual fatigue, and the general reduction of human error when estimating age at death. These factors and the results from this study are strong indications that the application of this innovative technology should recognized in skeletal age estimation.

CONCLUSIONS

This study demonstrates that the pubic symphysis should not be overlooked as an adequate indicator of age at death of older individuals. The results from the Transition Analysis evaluation illustrate that age at death of adults older than sixty years of age can be determined with a high degree of success. Further, this method illustrates the importance of using a prior mortality structure based on a uniform or an informative prior age distribution instead of one that is derived form the reference collection. The results imply that the use of a mortality structure that is independent of the skeletal reference samples may have contributed to the significant proportion accurate age estimates obtained for the older adults in the Grant collection.

The Transition Analysis method captured the documented ages of older adults with the use of broad estimated age intervals. This feature demonstrates an inherent problem in age estimation where most current techniques generate broad age intervals to accommodate the increased variability found in the in the rates of senescent morphological changes exhibited the skeletal age indicators of older adults. To control for the variation exhibited in the morphology of skeletal indicators requires an examination of a completely diversified skeletal sample from a wide array of populations. This would involve building a large database based on information obtained from an assortment of reference skeletal collections and could potentially be fulfilled with the recent technological advances in digital photography and internet-based networks. It is the notion of a virtual database of skeletons that initiated the second objective of this study involving the determination of age at death from digital images of the pubic symphysis.

The results from this component demonstrated that age estimation is possible from the digital images as suggested with the significant agreement between the scores assessed from digital images and those determined from direct observation of the pubic bones. However, no more than 60 percent of the Suchey-Brooks scores derived from both trials matched those determined through direct observation of the sample. Therefore, it is suggested that age estimation from digital images possesses a certain degree of error and it must be approached with caution.

The mismatched scores are attributed to interpretive errors in identifying whether the pubic bone exhibited changes related to development or degeneration. These errors imply that it may be difficult to identifying three-dimensional changes from two-dimensional images with the human eye alone. To address this issue, this study used digital image analysis functions to identify morphological characteristics of the pubic bone that may be overlooked by the naked eye. This study focused on the application of line plot functions offered by the Scion Image software program to measure the brightness or "intensities" of pixels distributed throughout a digital image of a Grant pubic bone or Suchey-Brooks cast. The resulting line plots provided insightful information into the textural and relief changes related to senescence exhibited in the Suchey-Brooks casts. However, the plots obtained from the Grant sample provided information regarding the relief changes exhibited in the pubic bones. Textural changes could not be ascertained from the images of the Grant pubic bones due to noise or highly contrasted grey intensity values distributed throughout the digital image.

A future direction of this study to resolve the contrasting grey intensity values is to incorporate optical calibration into the preparation of the digital images. Optical calibration is a feature offered by image analysis programs that calibrates the intensity values across images into a standard optical density curve. By default, software programs will express intensity values such as those found within the line plots as actual pixel values contained within an image, assuming these levels are between 0 and 255. However, due to interferences like contrast in background lighting, these values are often not true visual representations of the subject in reality. Therefore, it is important to calibrate the "black" and incident light values for the images. A "black" value is the level by which a camera captures images in pitch-black darkness. Incident light represents the values of the area between the camera lens and the subject's light source.

The application of optical calibration promotes standardization during image capture and analyses. For instance, optical calibration controls for the variation exhibited in the pixel intensities across digital images of pubic bones from different individuals. More important, optical calibration allows pixel intensities to be justified as a true value as seen by the human eye rather than as a value assigned by the camera. This feature also enables pixel intensities to be expressed in numerical terms and is beneficial since it allows for quantitative analyses of age-related changes among different images of pubic bones or Suchey-Brooks casts.

By focusing on the translation of pixel intensity data into numerical terms may result in a refinement of age estimation methodology by replacing subjective analyses with quantitative approaches. For instance, numerical data allows for statistical applications like spatial analysis to identify the frequency of pitting or depth, slope, and elevation of ridges within a certain area of the pubic symphyseal surface. Further, the assistance of computer technology to conduct such quantitative approaches promotes the standardization of age estimation methodology by making comparisons of morphological changes exhibited in skeletal features in a systematic and automated manner. More importantly, quantitative analyses conducted with the assistance of computer technology may identify other potential skeletal age indicators unseen by the naked eye.

It is expected that the computer-assisted analyses will assist in the refinement of age estimation by improving the accuracy of age estimates, especially where older adults are concerned. In the end, these refinements will lead to more accurate identifications of unknown individuals for forensic purposes. On a much wider scale, the improved age estimates results in reconstructions of mortality structures in palaeodemographic contexts that are close representations of age distributions of archaeological populations. Improved age distribution reconstructions will lead to an improved understanding of the longevity, health, and fecundity of a series of individuals from the past.

APPENDIX I

Case ID	Side	Age	Symphyseal Relief score	Symphyseal Texture score	Superior Apex score	Ventral Symphyseal Margin score	Dorsal Symphyseal Margin score
235	R	23	3	3	2	2.3	3
196	L	29	3	2	1	2	3
320	L	29	2	1.2	1	3	2
87	L	30	4	2.3	2	3	2
271	R	30	5	3	3	5	4
307	R	30	5.6	3.4	3	6	4
294	L	31	3	2	2	6	2
340	L	31	5	3	3	4	4
416	R	31	6	4	3	4	4
830	R	31	6	4	4	5	3
342	R	32	6	4	3	3	3
706	R	33	6	4	3	5	3
35	R	36	6	4	3	4	3
420	L	36	4	3	3	5	3.4
164	R	37	6	4	2	3	2
193	R	37	5	4	2	3	3
199	L	37	5	3.4	3	3	3.4
652	L	39	6	4	4	4	4
618	R	40	4	3.4	2	3	2
232	R	41	5	2.3	3	3	3.4
363	R	42	5	3	3	6	4
829	R	42	5.6	3	4	6	4
66	L	44	6	3.4	2	4	4
272	R	44	6	4	4	7	5
179	R	45	5	2	4	4	3
382	R	45	5	4	4	5	4
694	R	45	5	2	3	5	3
147	L	46	2	1	2	2	2
683	R	46	6	4	4	6	4
121	R	47	6	4	4	7	4
613	L	47	6	4	3	6	5
110	R	48	3	2	3	NA	3
118	L	49	5	2.3	4	5	3.4

TABLE Ia. Transition Analysis scores assigned to males 18 to 49 years of age.

Case ID	Side	Age	Symphyseal Relief score	Symphyseal Texture score	Superior Apex score	Ventral Symphyseal Margin score	Dorsal Symphyseal Margin score
263	L	50	4	3	3	NA	4
310	R	50	4	3	3	3	4
231	R	51	5	2	2	5	3
412	L	51	5	2	3	5	4
149	R	52	5	4	4	5	3
703	L	53	6	4	3	7	4
228	L	54	4	2	3	6	3
322	R	55	6	2	4	7	4
398	L	55	5	2	2	4	4
166	R	56	5	3	3	5	3
407	L	57	5	3	3	5	4
600	L	57	5	3.4	3	5	3
257	R	58	5	4	3	7	4.5
375	L	59	4	1	1.2	2.3	4
653	R	59	5	3	3.4	5	5
161	L	60	5	3	4	6	4
355	R	60	5.6	3	NA	5	3
393	R	61	6	3.4	4	5	3
261	L	62	6	4	3	5	3
276	L	63	5	2	2	4	3.4
337	R	63	5	4	4	6	4
129	L	64	6	2	4	5	4
787	R	64	5	2	3	4	4
177	R	65	5	4	4	6	4
172	R	66	4.5	2	1	6	4
780	L	66	5.6	3	3	5	3.4
601	R	67	6	4	4	4	3
400	L	68	6	3.4	4	5	4
390	L	69	6	2	4	6	4
404	L	69	5.6	3	3	5	3

TABLE Ib. Transition Analysis scores assigned to males 50 to 69 years of age.

Case ID	Side	Age	Symphyseal Relief score	Symphyseal Texture score	Superior Apex score	Ventral Symphyseal Margin score	Dorsal Symphyseal Margin score
201	R	70	6	3.4	NA	5	4.5
346	L	70	6	3	4	4	4
73	R	72	5	3	2	3	4
301	L	72	4	2	NA	3	3
111	L	73	6	2	3	5	4
221	L	74	5.6	3	NA	5	NA
84	R	75	4	3	3	3	3
306	R	75	6	4	NA	NA	4
588	L	76	6	4	4	6	4
88	R	77	5	3	3	NA	3
233	L	77	5	3	NA	4	4
76	L	78	6	4	4	7	4
673	L	78	5.6	3	3	4	4
311	R	79	5.6	4	4	7	4.5
91	L	80	4	2	3	4.5	2.3
138	R	80	6	4	4	7	5
265	R	80	5	3	4	3	3
592	L	81	4	3.4	3	6	3.4
303	L	82	5	2	4	5	4
154	R	84	6	4	4	7	4
224	R	84	5	4	4	7	4.5
80	L	85	6	4	4	7	4
90	L	85	5	4	4	6.7	4.5
345	R	86	6	4	4	7	5
148	R	87	6	3.4	2	4.5	3
180	R	87	6	2	NA	NA	4
646	R	89	5	2	4	7	5

TABLE Ic. Transition Analysis scores assigned to males 70 to 89 years of age

Case ID	Side	Age	Symphyseal Relief score	Symphyseal Texture score	Superior Apex score	Ventral Symphyseal Margin score	Dorsal Symphyseal Margin score
298	L	18	1	1	NA	1	1
113	R	21	2	1	2	2.3	1
297	L	34	5.6	3.4	NA	NA	3
189	R	45	5	3.4	4	6	4.5
185	R	60	5	3	4	6	4
238	R	64	6	4	4	5	4
256	L	66	6	3.4	3	4	4
269	L	69	4	3	3	4	2
415	R	69	5	3	4	6	3
250	R	73	5	3	3	7	5
45	R	75	5	3	NA	7	5
230	L	76	6	4	4	6	5
98	L	79	5	3	4	5	4
55	L	85	6	4	3	7	4
267	R	93	3	2	NA	2	2

TABLE Id. Transition Analysis scores assigned to females

APPENDIX II

Case ID	Side	Age	Transition Analysis single indicator interval upper limit	Transition Analysis single indicator interval lower limit	Transition Analysis single indicator age estimate	Transition Analysis final interval upper limit	Transition Analysis final interval lower limit	Transition Analysis final age estimate
235	R	23	30.64	16.8	22.5	30.46	16.29	22.25
196	L	29	28.9	16.52	22	28.8	16.02	21.75
320	L	29	29.73	16.57	22.25	29.58	16.03	22
87	L	30	32.78	19.32	25	32.8	18.75	24.75
271	R	30	75.38	25.13	40.25	64.66	23.11	35.5
307	R	30	82.21	27.24	52.25	73.64	23.7	40.25
294	L	31	32.1	19.06	24.75	32.06	18.52	24.25
340	L	31	89.35	26.08	46.75	72.12	23.38	38
416	R	31	100	33.52	74.5	90.93	24.34	48.25
830	R	31	109.41	27.63	54.25	78.64	23.84	40.75
342	R	32	56.4	23.35	33	52.42	22.13	31.25
706	R	33	83.78	25.61	42.75	68.28	23.3	36.75
35	R	36	108.18	26.91	52.25	77.18	23.59	39.5
420	L	36	59.26	23.67	34	54.38	22.32	32
164	R	37	34.53	19.89	25.75	34.43	23.29	25.5
193	R	37	37.48	20.74	27	37.24	20.05	26.5
199	L	37	48.07	22.52	30.5	46.34	21.53	29.5
652	L	39	100	47.65	92	104.08	25	58.5
618	R	40	32.82	19.32	25	32.8	18.75	24.75
232	R	41	47.99	22.52	30.5	46.3	21.53	29.5
363	R	42	78.98	26.84	49	39.25	23.69	71.33
829	R	42	88.66	31.2	62.75	80.87	24.31	46.5
66	L	44	47.99	22.43	30.5	46.22	21.44	29.5
272	R	44	110	77.23	110	110	40.34	79.5
179	R	45	89.85	25.64	44.25	70.24	23.23	37
382	R	45	103.61	28.93	59.5	81.52	24.06	43
694	R	45	62.17	24	35.25	56.46	22.54	32.75
147	L	46	25.05	1	19.5	24.96	19.48	19.5
683	R	46	96.54	41.53	69.75	90.36	25.69	58
121	R	47	100	63.04	94.25	109.98	34.53	73
613	L	47	100.99	45.48	72.25	93.88	26.49	61.25
110	R	48	40.51	18.88	26.75	39.56	18.12	26
118	L	49	73.3	24.87	39	62.95	23	34.75

TABLE IIa. Transition Analysis single indicator and final age estimates and intervals assigned to males 18 to 49 years of age

Case ID	Side	Age	Transition Analysis single indicator interval upper limit	Transition Analysis single indicator interval lower limit	Transition Analysis single indicator age estimate	Transition Analysis final interval upper limit	Transition Analysis final interval lower limit	Transition Analysis final age estimate
263	L	50	86.76	23.42	41.75	68.13	20.88	34.75
310	R	50	51.75	22.9	31.75	49.08	21.81	30.25
231	R	51	40.31	21.39	28	39.85	20.59	27.5
412	L	51	75.38	25.13	40.25	64.66	23.11	35.5
149	R	52	86.18	25.8	43.75	69.35	223.36	37
703	L	53	110	56.6	82	105.84	30.75	69.25
228	L	54	67.85	24.5	37.25	60.55	22.81	34
322	R	55	100	58.1	84.25	107.6	31.64	70
398	L	55	44.89	22.07	29.5	43.77	21.14	28.75
166	R	56	62.1	24	35.25	56.46	22.54	32.75
407	L	57	75.38	25.13	40.25	64.66	23.11	35.5
600	L	57	62.39	24	35.25	56.57	22.54	32.75
257	R	58	109.78	51.03	76	99.42	28.09	65.5
375	L	59	38.01	18.14	24.75	37	17.55	24.25
653	R	59	110	31.02	70.75	87.75	24.07	45.5
161	L	60	85.39	30.14	59.75	78.4	24.27	45
355	R	60	73.5	23.47	36.75	61.26	21.79	33.25
393	R	61	90.05	25.97	45	70.76	23.42	37.5
261	L	62	83.78	25.61	42.75	68.28	23.3	36.75
276	L	63	41.65	21.58	28.5	40.98	20.75	27.75
337	R	63	90.18	34.65	65.25	83.91	24.83	51
129	L	64	105.81	29.46	61.5	82.84	24.14	43.75
787	R	64	89.35	26.08	46.75	72.12	23.38	38
177	R	65	90.18	34.65	65.25	83.91	24.83	51
172	R	66	73.38	24.16	39.75	64.6	22.12	34.75
780	L	66	64.44	24.07	35.5	57.57	22.58	33
601	R	67	110	31.99	77.75	90.78	24.14	46.25
400	L	68	108.25	29.56	62.25	83.4	24.13	44
390	L	69	90.94	35.49	66	84.78	24.92	52
404	L	69	64.44	24.07	35.5	57.57	22.58	33

TABLE IIb. Transition Analysis single indicator and final age estimates and intervals assigned to males 50 to 69 years of age.

Case ID	Side	Age	Transition Analysis single indicator interval upper limit	Transition Analysis single indicator interval lower limit	Transition Analysis single indicator age estimate	Transition Analysis final interval upper limit	Transition Analysis final interval lower limit	Transition Analysis final age estimate
201	R	70	106.73	27.19	58.25	40.75	22.91	80.23
346	L	70	110	36.12	78.75	94.01	24.48	50.5
73	R	72	38.18	20.91	27.25	37.91	20.21	26.75
301	L	72	47.79	21.41	29.75	45.71	20.42	28.5
111	L	73	88.38	26.42	47.25	72.28	23.56	38.5
221	L	74	110	23.74	42.5	71.05	21.39	35
84	R	75	46.46	22.31	30	45.08	21.33	29.25
306	R	75	110	45	91.75	102.41	20.87	55.75
201	R	70	106.73	27.19	58.25	40.75	22.91	80.23
588	L	76	96.54	41.53	69.75	90.36	25.69	58
88	R	77	71.07	22.32	36	60.33	20.42	32.5
233	L	77	106.17	26.68	58.25	79.77	22.69	40
76	L	78	110	63.04	94.25	109.98	34.53	73
673	L	78	98.41	26.37	49.5	75.11	23.42	38.5
311	R	79	110	60.63	91.25	109.98	31.9	71.5
91	L	80	45.76	22.1	29.75	44.36	21.16	28.75
138	R	80	110	77.23	110	110	40.34	79.5
265	R	80	52.55	23.02	32	49.73	21.89	30.5
592	L	81	68.14	24.5	37.25	60.7	22.81	34
303	L	82	90.38	26.66	48.5	73.44	23.65	39
154	R	84	110	63.04	94.25	109.98	34.53	73
224	R	84	110	57.35	83	106.8	31.16	69.75
80	L	85	110	63.04	94.25	109.98	34.53	73
90	L	85	110	37.06	78.5	94.5	24.78	51.5
345	R	86	110	77.23	110	110	40.34	79.5
148	R	87	43.74	21.89	29.25	42.76	21.02	28.25
180	R	87	110	31.59	77.75	91.35	20.28	46.5
646	R	89	110	62.09	92	109.98	33.97	72.5

TABLE IIc. Transition Analysis single indicator and final age estimates and intervals assigned to males 70 to 89 years of age

Case ID	Side	Age	Transition Analysis single indicator interval upper limit	Transition Analysis single indicator interval lower limit	Transition Analysis single indicator age estimate	Transition Analysis final interval upper limit	Transition Analysis final interval lower limit	Transition Analysis final age estimate
298	L	18	21.29	1	15	21.05	15	15
113	R	21	23.57	1	18.5	23.53	18.49	18.5
297	L	34	50.53	21.17	32.5	48.61	19.55	31
189	R	45	88.55	32.34	60.25	78.96	27.52	44.5
185	R	60	85.34	32.18	58.5	77.65	27.5	44.25
238	R	64	81.43	29.19	43.25	69.01	26.53	39.25
256	L	66	51.92	25.42	34.5	50.51	24.11	33.25
269	L	69	37.37	21.95	27.75	37.29	21.29	27.25
415	R	69	54.27	26.59	36	52.74	25.01	34.75
250	R	73	100	55.55	81.25	104.95	31.78	68.5
45	R	75	110	61.6	92.25	109.98	33.27	72.25
230	L	76	110	52.06	77.5	101.13	30.68	66.25
98	L	79	62.75	27.6	38.5	58.66	25.69	36.5
55	L	85	110	56.46	82.25	105.98	32.13	69
267	R	93	28.4	17.25	22.25	28.38	16.85	22

TABLE IId. Transition Analysis single indicator and final age estimates and intervals assigned to females

APPENDIX III

Case ID	Side	Age	Suchey-Brooks phase assigned	Suchey-Brooks interval upper limit (2sd)	Suchey-Brooks interval lower limit (-2sd)	Suchey-Brooks age estimate
235	R	23	2	33.4	16.2	24.8
196	L	29	1	23	14.6	18.8
320	L	29	3	35.9	19.5	27.7
87	L	30	3	35.9	19.5	27.7
271	R	30	4	57.2	19.6	38.4
307	R	30	4	57.2	19.6	38.4
294	L	31	3	35.9	19.5	27.7
340	L	31	4	57.2	19.6	38.4
416	R	31	4	57.2	19.6	38.4
830	R	31	4	57.2	19.6	38.4
342	R	32	3	35.9	19.5	27.7
706	R	33	3	35.9	19.5	27.7
35	R	36	3	35.9	19.5	27.7
420	L	36	3	35.9	19.5	27.7
164	R	37	3	35.9	19.5	27.7
193	R	37	4	57.2	19.6	38.4
199	L	37	5	80.3	25.5	52.9
652	L	39	5	80.3	25.5	52.9
618	R	40	3	35.9	19.5	27.7
232	R	41	4	57.2	19.6	38.4
363	R	42	6	86	42	64
829	R	42	5	80.3	25.5	52.9
66	L	44	4	57.2	19.6	38.4
272	R	44	6	86	42	64
179	R	45	3	35.9	19.5	27.7
382	R	45	4	57.2	19.6	38.4
694	R	45	4	57.2	19.6	38.4
147	L	46	1	23	14.6	18.8
683	R	46	5	80.3	25.5	52.9
121	R	47	5	80.3	25.5	52.9
613	L	47	5	80.3	25.5	52.9
110	R	48	3	35.9	19.5	27.7
118	L	49	3	35.9	19.5	27.7

TABLE IIIa - Suchey-Brooks scores, age estimates, and intervals assigned to males 18 to 49 years of age.

Case ID	Side	Age	Suchey-Brooks phase assigned	Suchey-Brooks interval upper limit (2sd)	Suchey-Brooks interval lower limit (-2sd)	Suchey-Brooks age estimate
263	L	50	4	57.2	19.6	38.4
310	R	50	5	80.3	25.5	52.9
231	R	51	4	57.2	19.6	38.4
412	L	51	5	80.3	25.5	52.9
149	R	52	4	57.2	19.6	38.4
703	L	53	6	86	42	64
228	L	54	4	57.2	19.6	38.4
322	R	55	6	86	42	64
398	L	55	4	57.2	19.6	38.4
166	R	56	4	57.2	19.6	38.4
407	L	57	4	57.2	19.6	38.4
600	L	57	4	57.2	19.6	38.4
257	R	58	6	86	42	64
375	L	59	5	80.3	25.5	52.9
653	R	59	5	80.3	25.5	52.9
161	L	60	5	80.3	25.5	52.9
355	R	60	4	57.2	19.6	38.4
393	R	61	6	86	42	64
261	L	62	4	57.2	19.6	38.4
276	L	63	4	57.2	19.6	38.4
337	R	63	4	57.2	19.6	38.4
129	L	64	5	80.3	25.5	52.9
787	R	64	4	57.2	19.6	38.4
177	R	65	5	80.3	25.5	52.9
172	R	66	4	57.2	19.6	38.4
780	L	66	4	57.2	19.6	38.4
601	R	67	6	86	42	64
400	L	68	4	57.2	19.6	38.4
390	L	69	4	57.2	19.6	38.4
404	L	69	6	86	42	64

TABLE IIIb. Suchey-Brooks scores, age estimates, and intervals assigned to males 50 to 69 years of age.

Case ID	Side	Age	Suchey-Brooks phase assigned	Suchey-Brooks interval upper limit (2sd)	Suchey-Brooks interval lower limit (-2sd)	Suchey-Brooks age estimate
201	R	70	5	80.3	25.5	52.9
346	L	70	4	57.2	19.6	38.4
73	R	72	3	35.9	19.5	27.7
301	L	72	4	57.2	19.6	38.4
111	L	73	5	80.3	25.5	52.9
221	L	74	4	57.2	19.6	38.4
84	R	75	4	57.2	19.6	38.4
306	R	75	6	86	42	64
588	L	76	5	80.3	25.5	52.9
88	R	77	3	35.9	19.5	27.7
233	L	77	5	80.3	25.5	52.9
76	L	78	6	86	42	64
673	L	78	5	80.3	25.5	52.9
311	R	79	4	57.2	19.6	38.4
91	L	80	3	35.9	19.5	27.7
138	R	80	2	33.4	16.2	24.8
265	R	80	4	57.2	19.6	38.4
592	L	81	3	35.9	19.5	27.7
303	L	82	4	57.2	19.6	38.4
154	R	84	6	86	42	64
224	R	84	3	35.9	19.5	27.7
80	L	85	6	86	42	64
90	L	85	5	80.3	25.5	52.9
345	R	86	6	86	42	64
148	R	87	5	80.3	25.5	52.9
180	R	87	5	80.3	25.5	52.9
646	R	89	5	80.3	25.5	52.9

TABLE IIIc. Suchey-Brooks scores, age estimates, and intervals assigned to males 70 to 89 years of age

Case ID	Side	Age	Suchey-Brooks phase assigned	Suchey-Brooks interval upper limit (2sd)	Suchey-Brooks interval lower limit (-2sd)	Suchey-Brooks age estimate
298	L	18	1	24.6	14.2	19.4
113	R	21	3	46.9	14.5	30.7
297	L	34	4	60	16.4	38.2
189	R	45	5	77.3	18.9	48.1
185	R	60	6	84.8	35.2	60
238	R	64	4	60	16.4	38.2
256	L	66	5	77.3	18.9	48.1
269	L	69	4	60	16.4	38.2
415	R	69	4	60	16.4	38.2
250	R	73	5	77.3	18.9	48.1
45	R	75	4	60	16.4	38.2
230	L	76	4	60	16.4	38.2
98	L	79	5	77.3	18.9	48.1
55	L	85	5	77.3	18.9	48.1
267	R	93	3	46.9	14.5	30.7

TABLE IIId. Suchey-Brooks scores, age estimates, and intervals assigned to females

APPENDIX IV

Case ID	Trial 2 score	Trial 1 score	Direct observation scores
35	3	3	4
66	4	4	4
80	3	6	4
84	4	4	4
87	4	3	4
90	5	5	4
118	4	3	4
129	4	5	5
138	3	2	6
154	3	6	6
180	5	5	6
193	3	4	3
207	5	5	5
221	5	4	5
228	5	4	5
232	4	4	4
233	4	4	4
261	4	4	3
294	5	3	4
301	5	4	4
303	5	4	5
310	5	5	5
311	4	4	4
322	5	6	5
342	3	3	3
375	5	5	5
382	4	4	4
390	5	4	5
400	4	4	5
412	4	5	5
588	5	5	5
592	3	3	3
613	3	5	4
618	3	3	3
653	4	5	4
706	4	3	3
780	5	4	4
829	5	5	5

TABLE IVa Comparison of Suchey-Brooks scores assigned to digital images and actual pubic bones of males from the Grant collection

Case ID	Trial 2 score	Trial 1 score	Direct observation score
45	6	4	6
55	4	5	5
98	4	5	4
113	3	3	2
185	6	6	6
189	5	5	4
230	6	4	4
238	4	4	4
250	5	5	5
256	4	5	5
267	4	3	4
297	4	4	4
298	1	1	1
415	4	4	6

TABLE IVa Comparison of Suchey-Brooks scores assigned to digital images and actual pubic bones of females from the Grant collection

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