UNIVERSITY OF READING

EXTENDING THE LIFE COURSE: Developing new methods for identifying the "elderly" in the archaeological record

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Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

ABSTRACT

Documentary evidence confirms the existence of the elderly in the past, but osteological ageing categories traditionally end at ‘46+ years’. Current techniques consistently underage the very old, rendering them ‘invisible’ in the archaeological record, and hindering any research into their social treatment in the past. To rectify this, degenerative traits of new regions of the skeleton were examined for their ability to aid in age estimation, beyond limits of current methods.

Criteria were developed based on 630 white individuals (353 males, 277 females), with a minimum age of 40 years, from four known-age skeletal assemblages: Hamann-Todd (U.S.A.), Pretoria (South Africa), St Bride’s (London), and Coimbra (Portugal). The accuracy of established methods of the endocranium and pelvis were evaluated and revised where possible, and new criteria developed based on the cervical vertebrae, clavicle, manubriosternum, ilium and ischium. Distinct stages of degeneration were identified, resulting in new non-population specific ageing criteria, with concise 95% confidence intervals and broader age phases.

A blind test of 90 individuals from Christ Church Spitalfields, confirmed the use of these new methods to accurately estimate age in 80-100% of individuals, depending on the region under study. Progressive changes to the clavicle, ischium and clavicular notch were most highly correlated with age, while the cervical spine, iliac crest, auricular surface, pubic symphysis and arachnoid granulations were least promising. Sexually dimorphic criteria were not required for the atlas, lateral end of the clavicle and ischium. Three new adult ageing methods are presented, and supplementary observations that will aid in the identification of the “elderly” in skeletal populations have been proposed. Further research to assess the relationship between asymmetrical observations and activity is required. The findings of this thesis provide the means to challenge the assumption that individuals did not live into old age in archaeological populations, and will allow life course studies to extend into the latest stages of life.

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SUPPORTING PUBLICATION

Falys, CG and Lewis, ME (2011) Proposing a way forward: A review of standardisation in the use of age categories and ageing techniques in osteological analysis (2004–2009). *International Journal of Osteoarchaeology* **21**: 704-716.

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CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

This research develops osteological criteria to identify the eldest members of past populations. The human skeleton not only retains the biological information of the individual (i.e. age, sex, health status), it also provides a biography of a person who once lived in, and interacted with, the social and physical environment of a community during their life span. Every person has a personal and social identity that constantly changes throughout their lives, reflecting many factors such as their age, sex and status. Archaeologically, identity may be integrated into burial practices, with transitions in social identity marked by rites of passage, as traced through life course studies.

Recent interest in the social archaeological theory of the life course has highlighted several areas of weakness in archaeology and biological anthropology. One issue is our current inability to accurately determine the age-at-death of individuals over the age of 45 years. Many studies have identified the consistent underestimation of older skeletal ages using standard osteological techniques, leaving the elderly virtually invisible in the archaeological record (Gilchrist, 2004). This point was emphasized when Gilchrist (1999) questioned the experience of the aged within the medieval period**,** with issues relating to their treatment, health status, longevity and burial. Unfortunately, this topic could not be investigated and still cannot be undertaken, as at present, it is impossible to confidently identify the "very old" within archaeological skeletal samples. It is clear that "attempts to identify the life span of extinct populations are limited to the maximum reaches of age estimation methodology" (Loth and İşcan, 1994:414), an issue that this study aims to rectify.

It is important to acknowledge that some osteological ageing techniques are able to estimate ages up to 60+ years and 70+ years (auricular surface and sternal rib ends, respectively). However, osteologically derived adult age estimations in European archaeological contexts are traditionally classified into broad age ranges, which account for the variability of trait expression that occur as bony joints begin and progress through degenerative processes, as chronological age is suggested based on biological ageing. The "adult" ranges commonly employed are: 16–25 years, 26–35 years, 36–45 years and 46+ years. The 46+ year age range encompasses ages estimated over the age of 45 years, including those estimates of 60+ years and 70+ years. It is the aim of this study to produce morphological criteria that will provide the ability to subdivide this 46+ year age category into more than one age category.

1.2 BACKGROUND TO THE RESEARCH

Integration of social science theory of life course into archaeological practice has increased over the past 20 years, allowing investigations of personal and social identity in past populations. The social construction of factors such as sex and status has been the subject of identity studies on worldwide populations, ranging from prehistoric societies through to the medieval time periods. Age and its relationship to identity has primarily focused on childhood, rendering the later stages of life unexplored until very recently. Old age in archaeology is still very much a work in progress and is only in the very early stages of interpretation, as osteological shortcomings are directly inhibiting the expansion of the life course into older age ranges. Few studies have provided suggested resolutions to rectify the inability to identify the "elderly", notably statistical manipulation of skeletal age-at-death derived using established osteological methods (Gowland, 2007a), and through palaeopathological studies of diseases known to affect only the most aged individuals (Appleby, 2010). While these studies accomplish what they set out to do, they do not investigate the root of the problem, our most frequently applied osteological techniques do not accurately age adult skeletons.

Adults do not age at the same rate, as an individual's life experiences, genetics, environment, culture, health (e.g. illness, nutrition), occupation, activity levels, and socio-economic factors all contribute to the overall ageing process. Manifestation of age in the human skeleton has been subject to numerous studies over the past 200 years. While currently used standard skeletal ageing criteria (the majority located in the pelvis) have been re-evaluated to determine the accuracy of the age estimation, and the methods have been revised for the examination of modern individuals in forensic anthropology (e.g. Djurić et al., 2007; Berg, 2008), no work has been carried out to re-evaluate such morphological changes in the elderly. Reasons for the lack of study of the eldest members of a population may be due to several factors. It is possible that, until now, age-at-death estimation techniques were focused on one specific region of one specific skeletal method (e.g. the pubic symphysis, the sternal end of the 4th rib). Each method has its minimum and maximum ages, which are accepted and applied by the osteological community, without further research into how to age above those maximum ages using other aspects of the skeleton.

Much of the focus on ageing process has been on the re-evaluation and revision of existing techniques. Criticisms of these methods (i.e. underageing older individuals and overageing the younger; high degrees of intra- and inter-observer error) are stated time and time again following their application to new and varied documented collections, however, very rarely are revisions made to the criteria to improve the application or accuracy of the method.

Although not able to provide an age estimate, pathological processes affecting skeleton have also been used to identify the elder members of populations. As age increases, so does the likelihood that certain diseases will appear and increase in severity. Osteoarthritis, antemortem tooth loss, decreased bone density (i.e. osteoporosis and related fractures), and diffuse idiopathic skeletal hyperostosis (DISH) tend to occur in older people. Pathology, like ageing, is strongly related to genetic and environmental factors, the amount of wear and tear placed on the body, and diet, and, unfortunately, tends to re-enforce the idea of the elderly as frail or disabled individuals. Confounding all of these problems, some aspects of skeletal biology are still not understood, such as why some individuals are "bone formers" and some are "non-formers" (Schmitt et al., 2007). Also, the effects of occupation and activity on age-related skeletal degeneration are also not fully documented. Musculoskeletal stress markers (MSMs) are known to vary with age, however, they also strongly depend on overall body size and handedness, and thus are not strictly the direct result of activity over the life span. However, degeneration of joints of the skeleton are characterised by the appearance of traits linked to osteoarthritis (i.e. surface contour change, porosity, osteophyte formation and eburnation), and will be examined in this study.

1.3 RESEARCH AIMS

This research developed out of the need for osteological methods to accurately estimate the age of adult skeletal individuals beyond 45 years old. This is accomplished by using and adapting standard osteological techniques to investigate their true maximum age limit, and exploring inaccuracies and biases that occurred with advancing age. The hypothesis tested is that regions of the skeleton, outside of those previously investigated for ageing abilities (i.e. non-weightbearing joints such as the pubic symphysis, auricular surface, and sternal rib ends), may also display observable age-dependent degenerative progression in older individuals. The ultimate goal of this research is to identify new sites of skeletal degeneration that display age-dependent progression, and develop reliable and reproducible ageing criteria that can be used by the rest of the osteological community to identify the eldest members of a skeletal population within sufficiently broad ranges to produce distinct stages of senescence of older individuals (e.g. 45–60 years, 60–75 years etc). This will enable extended studies of the life course from infancy, childhood, adolescence, and adulthood, into later life.

The hypothesis is tested through the examination of the cranial and postcranial remains of white individuals with known age-at-death of 40 years and older from four contrasting documented skeletal collections located in Europe, North America and Africa. As the rate of biological ageing depends on a multitude of interacting factors, the skeletal collections were chosen based on their geographical location, potentially large sample size, socio-economical status of individuals, and time period represented by the remains. The collections chosen for inclusion in this study were: the Hamann-Todd Osteological Collection, USA (late 19th to early 20th centuries; low socio-economic status; pre-antibiotic era), the Pretoria Bone Collection, South Africa (late 20th century; middle-high socio-economic status; access to healthcare and antibiotics), St Bride's Documented Skeletal Collection, UK

(18th to 19th centuries; middle to high socio-economic status), and the Coimbra Human Identified Osteological Collection, Portugal (19th-20th centuries, low socio-economic status, pre-antibiotic era).

The established ageing methods investigated are: the presence and frequency of arachnoid granulations located on the endocranial surface of the parietal bones (Barber, 1997), the morphological changes to the pubic symphysis (Brooks and Suchey, 1990; Berg, 2008), and the auricular surface of the ilium (Lovejoy et al., 1985b; Buckberry and Chamberlain, 2002). Although not a formal ageing technique, degenerative joint disease of the cervical vertebrae is also evaluated, as Sager (1969) noted an increase in severity with advancing age.

Identification of new ageing criteria is made through the observation and analysis of a selected range of skeletal elements. The joint present between the manubrium and sternum was chosen due it its similarities with the pubic symphysis (i.e. non-weightbearing, fibrocartilaginous). The remaining elements investigated were primarily the sites of late epiphyseal fusion (e.g. the clavicle and iliac crest), and were sites of muscle and/or ligament attachments (e.g. ischium), rather than articular surfaces with other skeletal elements. As found in established methods, degenerative traits (i.e. change in surface texture and topography, porosity, and osteophyte formation) were recorded for left and right elements in all examined individuals in all study samples.

The aim of this study is to identify criteria that have the potential to aid in estimation of advanced age. The use of a truncated reference sample, comprising only those individuals aged 40 years or older, allowed new regions of skeletal degeneration to be observed and recorded. These skeletal changes appear to be progressive with advancing age, and look promising for substantial further research, however, it is ill-advised to apply the developed criteria to unknown skeletal adults as these alternations have not been investigated in the full spectrum of adult ages. Although it is hypothesised that degeneration of the investigated skeletal regions does not occur until after the age of 40 years, it cannot be emphatically stated until the criteria are assessed in an unbiased skeletal sample. This thesis presents fully described newly identified degenerative traits and links them with chronological ages of expression, based on the truncated 40+ year reference sample. The suggested age estimates are subject to change if, and when, these criteria are applied to younger adults (<40 years).

1.3.1 THE OBJECTIVES OF THIS RESEARCH

The objectives of this research focused on identifying new criteria within the human skeleton that demonstrated potential to increase the maximum reaches of osteological age estimation by:

- using and adapting the most well-known and frequently used osteological age estimation techniques in attempt an to extend the current maximum age limits

- identifying new regions of the skeleton that display progressive stages of degeneration, which may be proven to correlate with age
- identifying specific trait(s) that contribute to the overall surface appearance and morphology
- developing qualitative and/or quantitative scoring systems to accurately assess the degree of degeneration (trait expression), that will be reproducible by other researchers
- describing each location of skeletal degeneration, and the specific aspects of degeneration (i.e. relationship of trait expressions with one-another) that may be useful in age estimation
- within each skeletal sample, investigating all trait expression(s) for differences between:
    - the left and right sides of the body (where applicable),
    - the sexes
- investigating the correlation between independent trait expression(s), and combination of expressions (composite scores), with distinct stages of degeneration (combination of composite scores)
- devising reproducible criteria to associate trait expression(s), composite scores, and stage of degeneration with sufficiently broad ranges of chronological ages
- comparing trait expression and stages of degeneration between the documented collections. If similar patterns of degeneration are observed:
    - to develop new ageing technique(s) that can be used by other biological anthropologists through the combination of results to allow for maximum variation of trait expression to be displayed between individuals of similar ages through the ageing process
- blind testing developed ageing criteria using an archaeological known age skeletal sample.

1.4 STRUCTURE OF THE THESIS

The following chapters provide critical discussions of previous research in social archaeology and biological anthropology that highlighted the need for a resolution of the issues with adult skeletal ageing. Chapter Two introduces the interrelated theories of age, identity and the life course. Age is an integral part of a person's identity, which continually alters over a life span. This chapter focuses on how changes of identity are traced using life course studies, and have been identified in archaeological contexts through information recovered in the burial environment. The inability to accurately identify the "elderly" adult skeletons in skeletal populations is stressed at the end of the chapter, and through their absence, the understanding of the life course and culture of any past population under study is incomplete.

Chapter Three continues with the concept of age by discussing the physical manifestation of age and ageing in the human skeleton, as currently understood by biological anthropology. With the focus on the fully developed skeleton (i.e. adult), past research of skeletal age and currently employed macroscopic osteological ageing methods is provided, with critical review of the strengths and weaknesses, and areas of further research that are essential to rectify current osteological shortcomings.

Summaries of the documented skeletal assemblages and study samples examined during the course of this research are provided in Chapter Four. The historical background of each collection is presented, evaluations of the credibility of “known age” and strengths and limitations of each sample, in addition to the demography of the individuals assessed for this study.

The methods employed during the course of this research are outlined in Chapter Five. Written descriptions, scoring systems and photographs of surface features and trait expressions are provided, all of which were present for comparison during the data collection phase of this project.

Chapter Six is the Results chapter, and presents the analysis of individual surface trait scores, combined trait scores (composite scores), surface stages of degeneration (combined composite scores) and their correlations with chronological age. All of these pieces of information were used in the development of new ageing criteria. The results of the blind tests of each method are also provided. The raw data from the skeletal analysis, statistical analyses and blind tests are presented Appendices 4 to 6.

The developed ageing criteria are formally presented in Chapter Seven. The degenerative age stages of each skeletal region are described in detail, with supporting photographs and descriptive statistics that can be used to estimate age in unknown skeletal individuals. Chapter Eight provides discussion of the study as a whole, as well as each skeletal region. The outcomes of this project are put within context of previous research on ageing in biological anthropology. Recommendations for future research are provided for each newly proposed method, as well as for the advancement of future studies of the elderly in general. Final conclusions are made in Chapter Nine.

CHAPTER TWO

AGE, IDENTITY AND THE LIFE COURSE

> "…the aging body is never just a body subjected to the imperatives of cellular and organic decline, for as it moves through life it is continuously being inscribed and reinscribed with cultural meanings." (Featherstone and Wernick, 1995:2-3)

2.1 INTRODUCTION

Age is an ever-progressing and unstoppable process experienced by all human beings, a process which is integral to our identity. Until recently, the concept of age as part of an individual's personal and social identities has been limited, especially in archaeological contexts. While the social sciences are increasingly studying the theoretical ramifications of age over the entire human lifespan in modern populations, archaeological investigations of age have primarily been limited to investigations of childhood. Ageing is both a biological and a culturally constructed process. Following an introduction to what age is, this chapter focuses on the socially constructed aspect of age. The social science theory of a person's identity, its relationship to the life course, and how it underlies the structure of society are initially discussed. The modern (Western) construction of the life course highlights the inescapable interaction between age, sex and status in the formation of a person's identity, and how the intercepting boundaries are formed, rationalized and maintained. It is these fundamental theories that are integral to the emerging field of social archaeology. Age, its place in social archaeology, and investigations of the life course of past populations is then the focus of the remainder of this chapter.

Finally, a critical analysis of biases currently inhibiting the advancement of life course examination in archaeological populations will provide support for the aims of this research, notably the need to identify the eldest members of past populations. The next chapter will discuss the physical ramifications of age in biological anthropology.

2.2 AGE AND SOCIAL IDENTITY

2.2.1 AGE

Ageing is continuous over the entire life span, from birth to death. It is not only identifiable in the process of physical development and maturation through the early years (i.e. infancy, toddler, child, adolescent to young adulthood), or greying hair and etching of wrinkles on an aged face, ageing is an interactive process between biological, psychological and social factors (Kertzer and Keith, 1984).

As Fry (1996:117) suggests "[a]ge can be reduced to the simple passage of time, but lots of things are altered in time. Bodies age, societies change, and lives are lived. Age is a multifaceted and incredibly diverse experience". Three types of ageing have been described: biological, chronological and social (Beall, 1984; Arber and Ginn, 1995). Biological age is a developmental process that progresses in sequential stages from birth to maturity, which is measurable and irreversible (Beall, 1984). It is assessed by physiological milestones, such as skeletal development, or skeletal degeneration once the skeleton is fully mature. Ageing in adulthood proceeds at unpredictable rates which can vary significantly between individuals and populations (Borkan, 1986), as the physiological ageing process depends on a multitude of inter-related factors such as: genetic disposition, lifestyle (e.g. mechanical stresses), nutrition, health, and the passage of time (Crews and Garruto, 1994).

Chronological age is a universally applicable ordinal scale describing the amount of time elapsed since birth, completely independent of the body itself. It is progressive and irreversible, however, unlike biological age, it progresses at a regular pace and is not influenced by the individual's surrounding environment or genetics. Fortes (1984) suggests that non-Western, pre-literate, pre-industrial societies placed less focus on a numerical age. It is probable that chronological age was both unknown and irrelevant in some past populations (Cox, 2000), with rites of passage marked by developmental or maturational events (e.g. weaning, walking, puberty, menopause), and ultimately used to describe age.
For example, females in ancient Rome progressed through biology-related ageing transitions: menarche marked the transition from childhood, becoming a wife indicated entrance into adulthood, becoming a mother, and finally menopause indicated the end of the woman's reproductive life (Harlow and Laurence, 2002; Revell, 2005). Social transitions based on non-biological processes (e.g. marriage, widowhood) may have been more significant rites of passage in past populations.

Social age is culturally determined and is underpinned by biological age, and loosely linked to chronological age. Societies develop preconceptions of the normative behaviours and activities of individuals within a specific age group (i.e. child, adolescent, adult, and elderly). These terms imply a generalized chronological age during which culturally acceptable way of acting. Social age is not permanent, individuals are transient with ritual and symbolism determining the transference between pre-established stages (La Fontaine, 1978).

The osteological methods developed and employed in biological anthropology assess the biological age of individuals based on skeletal interpretation, and attempt to relate it to a chronological age. Individuals are allotted into age categories: for example infants (birth to 1 year), child (1–12 years), adolescent (13–17 years), young adult (18–25 years), adult (26–45 years), and mature adult (46+ years). It is apparent that these categories are also imbued with culturally loaded terminology, which is not universal in application (Falys and Lewis, 2011). It is possible that by dividing individuals into these constructed age groups, modern Western views of age and social norms are erroneously projected onto past populations (e.g. the roles, responsibilities, and behaviours expected from individuals within the age category). For example, in modern Britain, adolescence is the period of time between childhood and maturity, where individuals are experiencing puberty, awkwardness, and are commonly still very much cared for by and reliant on their parents. In contrast to this, adolescent females in ancient Rome who had reached physical maturity, as marked by puberty, were no longer viewed as children, but rather as being old enough to become wives and mothers (Harlow and Laurence, 2002). Such events at a young age in modern Britain would be criticised.

It is the culturally determined aspect of age that is of primary interest to the social sciences and social archaeology, as no two societies are the same (Parker Pearson, 1999). The socio-cultural approach gauges people's lives against societal norms of age appropriate behaviour, roles and status (Kertzer and Keith, 1984). Individuals of equivalent ages will be viewed differently between two separate populations, as this is unique to each society's cultural timetable. Social identity using age stratification considers age, sex and status, and the changing experiences of an individual subset of a population over time, in relationships at one point in time among other subsets of the same population, and the population as a whole (Kertzer and Keith, 1984). For example, in today's society, the ages at which individuals are legally allowed to drink, learn to drive, and marry are not uniform, they differ between countries across the world. Certain age-dependent events can also differ between subdivisions within each country (e.g. the legal drinking age and age at which teenagers may start driving differ between provinces within Canada).

2.2.2 IDENTITY IN THE SOCIAL SCIENCES

Many factors, both physical and behavioural, contribute to who we are, and how we are viewed and integrated into our society. Age, sex, and status are subjected to underlying, usually unspoken, cultural norms which place us in a stage of life. These stages of life are fluid, and change multiple times between birth and death, altering our identities over the life span. An example of how identity changes can be most easily illustrated by the physical development and subsequent degeneration of the body during the human life span from infancy, through the growth and developmental stages of childhood and puberty into adolescence, fully mature adulthood, and ultimately becoming old, when the body begins to feel the affects of a lifetime of movement and activity. These phases of growth, maturation and senescence are culturally incorporated into the social life (Arber and Ginn, 1995). As these physical changes occur, the social identity of the person also transforms, which can differ between both public and personal life. Individuals undergo cultural transformation as they progress from dependent children to independent self-sufficient adults, and then into the eldest members of our communities.

Every person lives a biographical history during their life span, punctuated by a series of significant personal events (Sofaer Derevenski, 2000). It has been suggested that rites of passage mark the passage of time and passing through boundaries of one life stage to the next (Van Gennep, 1960). Examples of these events may be biological or physical; such as weaning onto solid food, learning to walk or talk as a toddler, menarche, menopause, or symbolic/ritual such as passing a driving test, leaving home to go to university, getting married, or retiring from a long working career. These stages are regularly observed in human development, and prompt theories of their significance in social behaviour. With each alteration comes a differing set of socially expected behaviours and morals (La Fontaine, 1978), which rationalize and form the boundaries between stages. The occurrence, timing and sequencing of life events are integral to the psychological changes that take place over the life course (Keith and Kertzer, 1984). Baxter and Almagor (1978) suggest that a hierarchy is made out of natural processes.

Increasingly, the social sciences are investigating life course perspectives with an "explicit attempt to view the individual biography within the context of society, and to take a historical perspective on both the individual and society" (Marshall, 1996:22). Ethnographic and cross-cultural studies of the life course allow for identification of how lives are divided into stages, and how the stages are constructed and maintained by behavioural boundaries. An inescapable relationship between age, gender, and status has been universally identified. Age transitions throughout the life span are gender specific, which ultimately reinforce social status and power within the community, which also vary over the life course.

2.2.3 AGEING AND THE LIFE COURSE IN SOCIAL SCIENCES

As Fry (1996:117) states: "[c]ulture is seen as separate from biology and secondary to the physical aspects of aging. To the contrary, it is impossible to separate the cultural and biological aspects of being human". Differing aspects of society that interact in the life course are the cultural norms, symbols and ritual, marriage and the family, kinship and power and conflict (Kertzer and Keith, 1984). The life course perspective is a holistic approach interpreting pathways and transitions that occur during life, not strictly differences within a specific age category (Moen, 1996). The life course allows analysis of influences that affect and/or contribute to the life experience of different groups of people at particular stages of their lives (Arber and Evandrou, 1993), with emphasis commonly placed on the interlinking of phases of the life course. For example, age as an identity is closely related with sex and status (Fortes, 1984), kinship (Maybury-Lewis, 1984), culture (Cohen, 1984).

Age, sex, and status are all interrelated, forming the social identity of an individual, or social differentiation (La Fontaine, 1978), and act as the dividing factors for characterising individuals into stages of the life span. Boundaries between transitions are formed and reinforced by cultural norms of expected behaviours of individuals within a specific segment of the life course. Differences between stages are commonly emphasized. For example, O'Rand (1996) suggests that childhood is a time of socialization, adolescence is the time of identity formation and achievement, while old age is a time of disengagement. Transition between such stages is commonly marked by rites of passage, culturally symbolic events in an individual's life.

The remainder of this chapter will focus on these theoretical concepts as applied to the archaeological context, within which the physical remains of a human individual, as well as associated artefacts can be used as evidence of social identity and aid in the study of the life course in past populations.

2.3 AGE, IDENTITY AND THE LIFE COURSE IN ARCHAEOLOGY

Archaeology studies the history of humans, by understanding past civilizations through interpretation of their material remains. Written and pictorial records still exist for some archaeological populations, providing documentary evidence such as poetry, gravestones, inscriptions, medical literature, philosophical writings, and sculpture for assessment and inference into the life events of individuals. In prehistoric societies, only the material artefacts (e.g. pottery, metalwork), mortuary contexts and skeletal remains themselves are the primary evidence to provide insights into social identity and the life course.

2.3.1 THE BODY AND MATERIAL CULTURE

Material culture (archaeological artefacts) is a social product (Sofaer Derevenski, 1997a). Until recently, it was these artefacts surrounding the body in a mortuary context (e.g. non-organic objects such as pottery, jewellery, and metalwork) which were sought for insights into the social position the individuals held in life (Bradley, 1988). Initial identity investigations ranked the social status of the individual based on the perceived wealth of the grave goods, perhaps creating a limited and biased understanding of archaeological populations. New Archaeology stimulated the integration of skeletal analysis into the study of mortuary practices, opening new cultural avenues to the study of the archaeology of death (Chapman and Randsborg, 1981). The creation and experience of age grades can also be marked with material culture (like studies of status), through distinctive forms of artefacts reflecting specific costumes, ornaments and practices of body modification (Gilchrist, 2000).

Skeletal remains are traditionally investigated for their age, sex, and pathological alterations, however, their inherent ability to act as material culture has been overlooked in the past. It is only in the last ten years that osteological evidence has been integrated into the study of social identity. Meskell (2000:20) suggests that "most archaeological studies on the body leave their bodies uninhabited and without materiality". Skeletons are the physical remains of the people who actually experienced and interacted with their society and environment (Sofaer, 2006; Gowland, 2007a). The lived social identity and experiences of the body are closely related (Shilling, 2003). The life and death of individuals has been assessed through grave goods left with the body at the time of burial, however, the skeleton itself has the ability to record modifications inflicted during life, which remain visible after death and can add to the interpretation of the individual's life, what people did and how they lived (Sofaer, 2006).

Age is one attribute which modifies the skeleton over the life span, and can be read from the remains long after death. Age-at-death of younger individuals can be reliably assessed based on distinct stages of skeletal development. Unfortunately, the methods employed for assessing degenerative changes in adult skeletal remains have been shown to produce less accurate age estimates (i.e. under-ageing) (Bocquet-Appel and Masset, 1982; Molleson and Cox, 1993; Aykroyd et al., 1999; Cox, 2000). This very important factor has supported the inference by some archaeologists and biological anthropologists that individuals in past populations did not survive beyond the approximate age of 50 years (Van Gerven and Armelagos, 1983; Meindl and Russell, 1998). However, there is archaeological evidence that the human lifespan did indeed extended past the age of 50 years in past societies. For example, Mays (1998) found that 40% of the adult skeletal sample excavated from the rural medieval village of Wharram Percy was aged over 50 years. These concepts within biological anthropology will be discussed in much greater depth in the following chapter.

Theoretical investigations of social identity and life course have been much more limited in the archaeological context when compared to the social sciences, although it is emerging as a focus of research. It attempts to integrate the skeletal remains and artefacts into the socio-cultural context the individuals originally belonged to. The skeleton is the physical remains of the human body, a body which social theory views as a construction of both cultural and historical factors (Sofaer, 2006), in other words, they are embodiments of material culture. Artefact change means social change (Shanks and Tilley, 1987). Sofaer (2006) suggests that these changes in artefact/object form and function can highlight an individual's stage of the life course (i.e. age and gender identities). Material culture changes with transitions through rites of passages, and reflect the culturally specificity of biology and culture (Sofaer Deverenski, 2000; Gowland, 2007a). Gowland (2007a) suggests that identification of age-related grave goods (e.g. type, quantity, position) within burials and patterns of mode of burial may change over the life course. Current archaeological investigations of age identity distinguish the human life span into two very broad age (and social) categories: childhood (skeletally developing) and adulthood (skeletally mature), with subsequent subdivisions made wherever possible.

2.3.2 IDENTITY IN ARCHAEOLOGY

Archaeology was long dominated by the male perspective, seemingly being written and populated by adult males (Scott, 1997). Feminist critiques of this long held tradition propagated gender approaches to archaeology, in order to investigate what role gender plays in cultural change. Feminist archaeology highlighted the male gender bias, and sought to rectify the uneven perspective with initial identity studies aimed at investigating the people little discussed in the archaeological record, namely women and children (Moore and Scott, 1997). Although material evidence of women and children is commonly found in archaeological excavations, their roles in society were rarely discussed. The role of men took precedence, with physically labour-intensive roles of male individuals prioritised in archaeological reconstructions. This resulted in a limited and biased look at the past, created by gender and age assumptions made by archaeologists (Hurcombe, 1997).

Engendered studies focusing on the role of women (Gilchrist, 1994; 1999) slowly shifted from the development of feminist archaeology to concentrate on the structuring process of gender itself and its relationship to material culture and social identity within the archaeological setting (Lesick, 1997). Ultimately, these subjects propagated investigations of age identity, as gender and age are inseparable.

2.3.3 AGE IDENTITY IN ARCHAEOLOGY

2.3.3.1 Childhood

Age identity followed on from gender studies, and frequently drew together all aspects of identity: age, sex, and status. Initial investigations of age focused on children and childhood, as like women, children were notably absent in the archaeological record. Baker (1997:187) suggested that this lack of acknowledgement of children in the archaeological record resulted from "contemporary culturally constructed social knowledge, embedded as it is in masculist ideologies, fits 'children' in the interpretative framework of incomplete humans, that is, not male/masculine".

Like the studies of gender identity in archaeology in which individuals are assessed into one of two categories (male or female), current investigations of the social ramifications of age appear to also be allotted into one of two types (i.e. child or adult). The developmental childhood phase of life is reliably and easily identifiable osteologically. Although confident sex determination of immature skeletal remains is poorer than would be desired, social archaeological theory is increasingly assessing gender in childhood through analysis of the mortuary context as a whole, including the skeletal remains themselves (e.g. pathologies) and/or in comparison with the associated artefacts (Sofaer Derevenski, 1997b; Stoodley, 2000; Gowland, 2007b; Redfern, 2007; Sánchez Romero, 2008). These investigations integrating biological and social aspects of childhood are very site specific, and have been subjected to critical analysis. The most commonly highlighted limitations of such studies are the questionable ability to confidently determine the sex of immature remains through osteological methods, the presumed poor preservation of non-adult skeletal remains in archaeological contexts, and the inconsistent terminology and age divisions within subadulthood (Halcrow and Tayles, 2008).

2.3.3.2 Adulthood

Despite investigations of childhood acting as a catalyst for other studies of identity involving age, examinations of adulthood have been significantly more limited. Although age-at-death of skeletons is made using standardised osteological techniques, the eldest remains are commonly grouped into a very broad “46+ years” category for ageing studies, without further demarcation of age possible. This infers that the past was populated by adult individuals (Lucy, 2005), lacking acknowledgement of the older members of the community. The interrelationships of skeletal-derived information with gender studies and/or inferences of ethnicity and/or social status become the primary focus (Lucy, 1997; Robb et al., 2001). This broad stage of “adulthood” seems to infer that once an individual is past the identifiable maximum age limits of osteological methods, they are permanently locked into an unchanging stage of life until death, which is unlikely.

2.3.3.3 Old age

Achenbaum (1996:145) states that “old age came to be perceived as a “problem” in Western civilization early in the twentieth century”. Since then, the elderly have been identified as a distinct subgroup of society (Arber and Evandrou, 1993a; Hareven, 1995). However, this concept has not been fully integrated into archaeology, as currently, the eldest members of past populations are invisible in the archaeological record (Gilchrist, 2004). Old age, in general, is an only fairly recently progressing area of research in sociology (Arber and Ginn, 1995; Featherstone and Wernick, 1995a), anthropology (Keith, 1980; Kertzer and Keith, 1984), historical studies (Pelling and Smith, 1991; Rosenthal, 1996; Shahar, 1997), and documented archaeological contexts (Cokayne, 2003, 2007; Parkin, 2003; Moore, 2010).

Senescence imbues two main theories of social treatment. Some researchers believe there is a risk of inferring that elderly members of communities have always been treated with great respect (Foner, 1984; Shahar, 1997). In contrast, Harlow and Laurence (2002) suggest that, as is common with children and adolescents, the old are viewed as being not adult, or in a state of unbecoming adult, as there is commonly an increase of dependence on their children or community as physical and mental faculties degenerate. While Arber and Ginn (1991) argue that parallels can be drawn between the social construction as women as the weaker sex and the negative aspects of old age, other disciplines depict old age as very similar to childhood. The need for increased physical help and care with advancing age make older individuals almost seem as burdens on society (Arber and Evandrou, 1993b). Physical disability may accompany the normal ageing process (i.e. development of joint degeneration, kyphosis, osteoporosis, cancer), which potentially render the individual as socially "different" (Roberts, 2000). However, a cautionary statement by Dettwyler (1991:382) that "[c]ompassion, cruelty and indifference leave few traces in the archaeological record" must be heeded when making assumptions about the degree of care or neglect older individuals were subjected to in past populations. In contrast to Roberts' (2000) suggestions of physical disability as a differentiating factor, Appleby (2010; 2011) argues that it is the changes in physical appearance related to ageing (e.g. tooth wear and loss) and changes in physiological function (e.g. fracture caused by age-related bone thinning) that provide the evidence that may differentiate older individuals from the rest of the community, and through which "what it means to be old" can be assessed.

Rites of passage among the aged are likely gender-specific, and may relate to biological events such as menopause. Menopause is an inevitable and unalterable life history characteristic of all female human beings throughout time, universally occurring around the approximate age of 50 years (Pavelka and Fedigan, 1991), signifying the end of the reproductive phase of the life span. Although the resulting change in hormonal levels in the body may not be observable in the skeleton, it may be visible in the archaeological record as transference from one life stage to the next, as demonstrated in Harlow and Laurence's (2002) work. As a result of the menopause transition, women either disappear from the historical records, or become stereotypical "evil witches, grasping widows and stepmothers, or lustful hags" in works of poetry and/or plays written by men (Harlow and Laurence, 2002:119).

2.3.4 THE LIFE COURSE AND ARCHAEOLOGY

There are many factors that can be used to assess social identity during several distinct stages of the life of a human being, these site/culture aspects can be woven together to form the life course of a population in a specific place and time. It is important to understand each stage or mode of transition between stages, in relationship to the whole life course of a society (Harlow and Laurence, 2002). As the life course is part of the organizing structure of a society, all individuals of a particular society follow a similar life course, although critical stages of transition can vary according to status, gender, personal choice and empowerment; age and maturity can predispose transition rather than always following biological stage of development (Harlow and Laurence, 2002).

Only in the last 10 years have researchers begun to investigate the life course over the entire life span of individuals, from childhood through senescence ("elderly") and death. Examples of this have been possible in medieval populations (Gilchrist, 2000) and in the Roman society (Harlow and Laurence, 2002, 2007; Revell, 2005). These studies emphasise the interrelationship between age, sex and status, identifiable through the documentation of these time periods (i.e. funerary epitaphs, sculpture, written documents). Archaeologically, Gowland (2007a) and Sofaer Derevenski (1997a) have both attempted to trace the life course of specific populations by relating skeletally derived demographic information with excavated grave goods.

An archaeological example of life course investigations is that of females in Anglo-Saxon Oxfordshire and Hampshire. Through the association between skeletal sex, age category and funerary evidence (grave goods), Gowland (2006, 2007a) examined age identity of a past population (age-related grave good patterns). Grave goods can be gendered; for example as masculine, including artefacts as swords and shield-bosses, or feminine, like brooches, beads and jewellery, while other grave goods are gender neutral, and do not suggest males or females specifically. The type (e.g. disc, saucer), quantity and placement of brooches and other items of personal adornment, such as beads, were correlated with age groups to investigate different patterns that signify transitions of identity over the life span (e.g. one or more brooches could be present in the graves of individuals of any age, however, adults displayed placement of one brooch on each shoulder). Gowland (2006:148-151) found the "older females were generally buried with slightly fewer items of personal adornment than younger females" (Gowland, 2006:150), most notably a decreased quantity of beads. The older ages were, however, found to have a wider variety of brooch types compared to the younger females, and more gender neutral artefacts such as buckles and buckets.

Differences in the patterns of grave goods between the different age groups indicated transitions in identity over the life span. A suggested age transition occurred in females in the 8–12 year age category, as identified by the increase in gendered grave goods. A second transition occurred around the age of 18 years, highlighted by the marked increase of inclusion of beads in graves, "possibly signifying marital status?" (Gowland, 2006:148). The youngest and oldest ends of the age spectrum were buried with fewer gender-specific items, suggesting that gender was not "an over-riding characteristics at these stages of the life course" (Gowland 2006:151), and/or jewellery of older females has already been passed down to their children.

2.4 DISCUSSION

This chapter has introduced the concept of age as part of an individual's personal and social identity, and has stressed that age is inseparable from other factors such as gender and status. While people universally progressively age (physiologically/biologically) in very similar ways, identity is a fluid characteristic that alters many times over the life span, and varies greatly over time and space. A specific age stage has within it a set of culturally accepted ways of behaving, and responsibilities within the community. Transitions between these stages are marked by rites of passage. Life course investigations are population-specific and trace the pattern and meanings of these rites of passage over the life span.

While the life course has been successfully applied to historic archaeological populations (e.g. medieval- Gilchrist, 1999, and Rome- Harlow and Laurence, 2002, 2007), there is an essential aspect of the human life span that is absent to allow these studies to progress into non-documented sites and populations: being able to identify the very old in archaeological populations.

Studies of identity have been successful when examining the concept of childhood in archaeological contexts. As previously discussed, investigations of “adulthood” have been limited. The human life span in constructed of growth, maturation, and senescence. Currently in osteoarchaeology, adult ageing methods do not provide adequate means to accurately estimate age, especially at the older end of the spectrum. It is not possible to fully understand the senescence part of life. Without this final chapter of life, the life course cannot be entirely known and understood. As Harlow and Laurence (2002, 2007) have shown, rites of passage still occur in the Roman life course well into the ages of 50s and 60s. A modern misconception also exists about the short duration of the life span in the past, as archaeological assemblages commonly display low mean age-at-death. This value, however, is the result of both high fertility and infant mortality rates rather than large proportions of the adult population dying young (Sattenspiel and Harpending, 1983). This short life misconception is supported by the limitations of osteological ageing methodologies, are detrimental to investigating these eldest members of archaeological communities, and prohibiting an essential portion of life course study.

Three factors have been identified, which act as hindering agents to the progression of archaeological investigations of age over the life course. Taphonomic biases, methodological shortcomings in osteological practice, and intellectual biases (Gilchrist, 2000) are actively prohibiting studies of the elder members of populations, equivalent to those investigations of childhood. At the biological level, taphonomic biases hinder assessment of skeletal remains of the very young and the very old, through insufficient preservation of necessary skeletal elements (Gilchrist, 2004; Gowland, 2007a). Older individuals are more prone to decreased mineral content of their bones (i.e. osteoporosis), perhaps decreasing the ability of their skeleton to withstand the burial environment. Selected areas of the body are required for adult age estimation, which may or may not be adequately preserved (e.g. the pubic symphysis, sternal rib ends).

Chronologically, inherent flaws have been identified in osteological adult age estimation techniques (Gowland, 2007a), most notably, the inability to confidently determine the age of individuals over the approximate age of 45 years. There is a tendency to under-estimate older individuals (45+ years), and over-age younger individuals (<45 years) (Molleson and Cox, 1993; Cox, 2000). If older individuals are indeed present in past populations, they are not able to be identified using standard age estimation techniques.

On a social level, an intellectual bias exists. Gowland (2007a) suggests that the modern tendency to overlook older members of the population has been subconsciously transferred to the studies of past societies. Gilchrist (2000) believes that there is a lack of acknowledgement for the spectrum of age diversity within archaeological groups, much like the initial gender bias discussed previously.

It is in response to these limiting factors that this research is aimed. While taphonomic biases are beyond the control of social archaeology, the osteological shortcomings and intellectual biases can be address, and rectified. Appleby (2010:147) emphatically states that osteological methods of adult age estimation "are ultimately destined to fail at producing an age estimate that is both precise and accurate, because of the lack of a one-to-one relationship between skeletal changes and chronological age". While it may be true that skeletal changes and chronological age do not display a strictly linear relationship, previous ageing techniques have shown that they can provide accurate results given an appropriately broad age range.

Appleby (2010:150) also argues "[a]pproaches that focus upon the search for more accurate attributions of chronological age from the skeleton, though useful from a technical point of view and necessary for investigating disease prevalence or population structure, thus lack an adequate theorization of what it *means* to grow old". Appleby (2010; 2011) suggests that through the correlation of selected diseases known to only effect the elderly, and the burial context, the social changes caused by growing old can be investigated. While skeletal changes such as tooth loss, and pathologies relating to old age (e.g vertebral crush factors, Colles' fractures and hip fractures due to osteoporosis, or osteoarthric changes) may contribute to the identification of older individuals, they also highlight a difference in physical appearance or disability in the person or subgroup of the population affected. It is imperative to stress that being "old" and being "disabled" are not the same. Pathology is related to health and ability, and as a result cannot be used as an independent measure of attitude to chronological age. Without a consistent baseline for comparison (i.e. estimate of age-at-death), further interpretations of age-related patterns, such as disease, trauma and disability, are not possible (Sofaer, 2011; Gilchrist, 2012).

2.5 SUMMARY

The human life span is separated into three main phases: development, maturation, and senescence. Current osteological methodologies accurately and reliably assess the former two categories, although once full maturation is reached, criteria have not been investigated to identify differing states of advanced senescence and skeletal degeneration. Biological anthropological research has not explored new sites of the skeleton that may extend our ability to assess the age of older individuals, as most current ageing techniques have reached their limit at approximately 46 years. This results in grouping all individuals over the age of 45 years into a single category, which is problematic, as this potentially incorporates half of human “adulthood”. Both contemporary and historical evidence strongly suggest that there is a difference, both physically and mentally, between individuals that are 40 years, 60 years, and even 80 years old (Harlow and Laurence, 2002). All age categories have differing personal and social identities in their communities.

Developing methods to identify the eldest members of past populations will enable these individuals to no longer be invisible in the archaeological record. It is likely that young adults were a socially distinct group from the middle aged, and the elderly, and vice versa. Enabling osteoarchaeologists to “find” these individuals, it will predispose advancement of social archaeological theory. By developing a reliable physical, biological, and scientific criterion for identifying eldest members of past communities, investigations of the life course are enhanced and extended, as the elderly are brought into the light from the shadows of archaeological time, and perhaps dispel the belief that a low adult life expectancy was typical in past populations (Van Gerven and Armelagos, 1983; Meindl and Russell, 1998). This may also provide a means of identifying patterns of life course identified through historical narratives across different geographical locations as people migrated, for example Harlow and Laurence (2002:147) hope “it is in the burial that we may begin to understand the spread of what we have defined as the life course at Rome across the Empire.”.

While this chapter summarized the importance of age in an individual’s persona, age in archaeology, and how the two are theoretically linked via the life course, the following chapter details the physical aspect of age with respect to the human skeleton, how it is expressed and quantified by biological anthropology. It summarizes the history of age estimation techniques, and critically examines the accuracy of current ageing methodology.

CHAPTER THREE

SKELETAL AGE ESTIMATION IN BIOLOGICAL ANTHROPOLOGY

Age estimation of skeletal remains is "…an art, not a precise science" Maples (1989:323)

3.1 INTRODUCTION

Human skeletons are the most direct evidence for the lives lived by past populations, as they are the physical remains of those individuals who lived in and interacted with their surrounding environments. In addition to determination of sex, ancestry, and stature, accurate and reliable estimations of age are the primary contributors to the development of osteobiographies of skeletal remains. These biological profiles are integral to aspects of, not only biological and forensic anthropology, but also social archaeology. Age aids in the description of the biological and social life history of past populations (Kemkes-Grottenthaler, 2002; Gilchrist, 2004; Wittwer-Backofen et al., 2008), palaeodemography (i.e. mortality and fertility rates, life expectancy, population growth), and palaeopathology (e.g. disease aetiology, population prevalence, trauma rates).

As demonstrated in the previous chapter, the age at death of an individual is integral to social archaeology, as it contributes to debates about the life course, and in particular the way in which the very young and very old were treated by past societies. It is essential that consistent "physical age" baseline-standards are available by which "cultural age" can be measured. As this chapter will illustrate, adult age-at-death estimation is one of the essential, yet most challenging, aspects of the study of human skeletal remains.

Adult skeletal age is most accurately described as an approximation (Maples, 1989). Unlike skeletal sex determination, which can be predicted with up to 90% precision (St. Hoyme and İşcan, 1989), adult age estimation is significantly less reliable, due to many conceptual, methodological, and interpretive shortcomings. The past several decades of research have investigated and re-investigated numerous skeletal elements for their ability to accurately and reliably estimate age-at-death. This has produced widely published standardized osteological methods in an attempt to make universal criteria for age estimations and decrease the amount of inherently present intra- and inter-observer errors. Following a review of the current literature, the remainder of this chapter will focus on macroscopic adult ageing techniques, including their advantages and limitations, and rationale for the skeletal elements and traits investigated during the course of this research.

3.2 EFFECTS OF AGE ON THE SKELETON

Human ageing is a continuous process, beginning from the time of conception. Many definitions have been proposed for this biological process. Arking (1998:12) suggests ageing is “the time-independent series of cumulative, progressive, intrinsic, and deleterious functional and structural changes that usually manifest themselves at reproductive maturity and eventually culminate in death”. Despite the evolutionary theory of ageing providing insights into the cellular and molecular changes that occur (Kirkwood and Austad, 2000), ageing is a highly variable process whose causative factors and biological mechanics are not fully understood (Cox, 2000). Physical ageing proceeds at unpredictable rates which can vary significantly between individuals and populations (Borkan, 1986), as the physiological ageing process depends on a multitude of inter-related factors such as: genetic disposition, lifestyle (e.g. mechanical stresses), nutrition, health, and the passage of time (Crews and Garruto, 1994). The living skeleton is dynamic and capable of limited adaptability, that alters in response to stresses, disease, and trauma the body is exposed to during life. Ageing has also been identified to have the ability to alter the morphology of bone (İşcan, 1989). However, in archaeological contexts, aspects of an individual’s lifestyle are often unknown, meaning that these markers of ageing may be delayed or advanced in relation to their actual age. Biological anthropologists strive to identify progressively changing biological states and relate them to chronological ages.

In the skeleton, increasing age causes areas of degeneration in the joints and enamel wear (Cox, 2000), that increase in severity over time. However, many researchers criticise biological and forensic anthropologists for rarely acknowledging how complex and variable physiological ageing is in adult individuals, and emphasise that there is little linear relationship between chronological age and skeletal age indicators (Borkan et al., 1982; Cox, 2000; Kemkes-Grottenthaler, 2002; Schmitt et al., 2002; Corsini et al., 2005).

3.2.1 NON-ADULT

The age of immature skeletons is estimated through chronological milestones provided by the development of the skeletal elements and dentition. The timing of these processes only slightly varies between the sexes (Scheuer and Black, 2004), commonly between one and three years between the epiphyseal fusions of skeletal elements in females compared to males, as girls tend to physically mature slightly earlier than boys. Osteological age estimation of non-adults relies on dental development, and postcranially, the fusion of epiphyses to the metaphyses. With the exception of the clavicles and the innominates, the appendicular skeleton (namely the long bones) complete development by the age of 20 years, while the axial skeleton continues development into the mid 20s.

3.2.2 ADULT

Once an individual nears skeletal maturity, estimation of “adult” age becomes more problematic with ever-advancing years. Although few in number, there are epiphyses/apophyses that are still unfused over the age of 20 years, that allow for concise age estimations to be made. The iliac crest may not be fully fused until 23 years, the first and second sacral vertebral bodies do not commonly fuse until 25-35 years, and the last epiphysis to fuse is the medial end of the clavicle, which normally completes fusion by the age of 30 years (Scheuer and Black, 2004). In addition to these sites of fusion, a selection of joints begin to degenerate (i.e. bony remodelling, erosion, osteophyte formation). Degeneration occurs as the result of wear-and-tear on the skeleton, as the thickness of cartilage decreases, allowing the skeletal elements that form the joints to come into closer contact with each other.

Macroscopic ageing techniques focus on regions of the skeleton that show age dependent characteristics (degeneration) that accumulate at a slow rate. Some of these methods rely on the identification of the extent of these degenerative processes on joints where movement is limited (i.e. the pubic symphysis, auricular surface of the ilium, and sternal rib ends). However, these manifestations of age are subtle, irregular, and variable both within the same individual and between persons of the same, and differing populations (Loth and İşcan, 1994). Quantifying the amount of age-induced variation present has not been possible, as the rate of degenerative changes to the adult skeleton is strongly influenced by many internal and external factors (Cox, 2000) that are often immeasurable, or whose exact role is undetectable, such as the individual’s life experiences, genetics, environment, culture, health (e.g. illness, nutrition, endocrine function, trauma), occupation, activity levels, cultural and socio-economic factors. Although biological age does not equate to chronological age, osteological adult ageing methods provide morphological criteria commonly observed in distinct stages throughout the degenerative process. The most successful techniques have produced schemes to identify and qualify these degenerative characteristics, and link them to a chronological age.

3.3 AGE ESTIMATION IN THE ADULT SKELETON

While it is true that the human adult skeleton does not provide precisely timed sequences of events like the developing skeleton, numerous osteological techniques have been published over the past 60 years, all claiming accurate and highly reproducible age-dependent assessments of adult skeletal remains (Lovejoy et al., 1985b; İşcan and Loth, 1989; Brooks and Suchey, 1990). These methods fall into one of three categories: evaluation of bone’s (primarily joint surface) macroscopic morphology, evaluation of bone’s microscopic structure, or age changes documented by radiographic images. As “normal” ageing does not exist, the recent decades have been dedicated to studying diverse populations to assess variability in the ageing process, resulting in the production of population-specific standards for comparison with unknown skeletons.

Each type of technique has its own advantages and disadvantages. Microscopic methods are destructive, they commonly require a cross-section of bone for analysis, they are not readily usable by all researchers as they require both specialized equipment and training, and they are costly and time consuming. Microscopy allows assessment of structures to be visualized in histological sections (i.e. osteons (Kerley and Ubelaker, 1978; Robling and Stout, 2000), cementum annulation of teeth (Charles et al., 1986a,b; Wittwer-Backofen et al., 2004), and translucency of teeth (Bang and Ramm, 1970; Lamendin et al., 1992)), which fluctuate over the lifespan of bone remodelling, allowing for age estimations to be made though regression equations and calibrations.

The benefits of microscopic methods are primarily the usefulness for age estimation of highly fragmented or incomplete remains. High reproducibility and accuracy of results are also reported, making these techniques more frequently used in forensic contexts (Buikstra and Beck, 2006). However, for many researchers, these advantages are overshadowed by the disadvantages.

Age estimation through radiographic means (e.g. x-ray or CT scan) is most common in forensic settings, in which the skeleton is obscured by tissue. They have primarily been used to evaluate the degree of epiphyseal union in children, adolescent and young adult skeletons. However, other aspect of ageing bone, such as the changes trabecular bone of the clavicle, proximal femur, and the os pubis (Walker and Lovejoy, 1985; Wade et al., 2011) have been examined, in addition to evaluation of bone demineralisation, identification of age-specific pathologies (e.g. arthritis, Paget's disease etc.), and calcification of soft tissues (i.e. sternal rib cartilage ossification) (Sorg et al., 1989). With ever increasing technology, the use of computed tomography (CT) scanners has become a more common area of research to aid in the study of human skeletal remains. The CT scanner allows for a high quality, three-dimensional image to be created enabling minute measurements to be taken of skeletal elements. It has been suggested that morphological ageing criteria are now able to be numerically described using quantitative measurements, angles, and densities (Ferrant et al., 2009), which theoretically allows for more accurate/universal description of senescent changes present (decreases inter-observer error).

As with all osteological techniques, these methods provide both benefits and disadvantages. The advantages are few when compared with macroscopic methods, although both are non-destructive. Radiography can often identify the state of epiphyseal fusion with much more precision than through visual observation (Sorg et al., 1989). The extent of demineralization is also much better observed through radiographic means when compared with macroscopic examination, however, it is surpassed by assessment of trabecular bone construction demonstrated by a cross-section through the skeletal element. The disadvantages of such techniques are primarily methodological, due to the necessity for specialized equipment and training in order to obtain the desired results. It has also been found that the fusion line between the epiphysis and diaphysis may still be identified on a radiograph many years after physical (i.e. macroscopic) fusion occurs (Lewis, 2007), which would result in the underageing of an individual. Also very few (if any) studies have been done to compare the observations made by radiography and relate them to findings made through macroscopic osteological examinations.

As radiographic and microscopic methods are not able to be used by all researchers due to the cost, specialist equipment and knowledge required to obtain results, only macroscopic methods (as described below) were investigated in this study.

3.3.1 MACROSCOPIC AGEING CRITERIA

Macroscopic ageing techniques primarily involve observation of morphological traits of progressive degeneration of articular surfaces of joints that are non-weightbearing and with limited-movement. These methods do not require destruction of the bone under study, and they rarely require specialist equipment or hidden monetary costs. These methods can be applied anywhere (most useful for archaeological sites during skeleton excavation or in forensic cases in the field), given the specified skeletal element is present. However, familiarity with the published method itself is needed to apply each method. Due to these factors, macroscopic ageing techniques are the most commonly used across the world (Falys and Lewis, 2011).

The main advantages of these types of methods are that they are commonly well known by all practicing biological anthropologists. They have been subjected to consistent re-evaluations that have simplified and explained the degenerative processes, trait identification, and accuracy of age estimations. Disadvantages of such techniques are the high degree of inter- and intra-observer error, which are ultimately produced as age estimation relies on the observer’s judgement and interpretation of published trait descriptions and expressions. It is not possible to ensure all investigators are making the same judgements using qualitative characteristics.

Many regions of the adult human skeleton have been investigated for their ability to assess age-at-death. These include late fusing epiphyses (i.e. fuse after the age of 20 years), and the identification of joint surfaces that degenerative traits accumulate at slow rates. Adult ageing criteria are developed through observation of emerging patterns of degeneration derived by systematic research of large samples of skeletal remains with known age. These observations are grouped into stages (or phases) of distinct trait progression. These stages are then statistically associated with chronological age, which are then used as osteological standards for comparison of age estimation of unknown individuals (i.e. age-at-death is not known from documentary records).

All methods have a minimum and/or a maximum age between which the published criteria can "reliably" estimate age. Sex has been found to be statistically significant in some adult ageing techniques, although not all. Osteological ageing methods are believed to be applicable to both archaeological individuals as well as modern populations.

The primary limitation of these methods ultimately relies on the investigator's ability to interpret the written descriptions, photographs or casts. Re-evaluations and revisions of techniques are undertaken to refine and clarify descriptions and methodologies, assess trait applicability to differing populations (i.e. produce population-specific standards), and to test validity of accuracies, including intra- and inter-observer errors. Despite all of these checks, accuracy of these techniques relies primarily on the investigator's experience and judgement, which is something that cannot be taught.

3.4 DEVELOPMENT OF AGEING CRITERIA

Several criteria must be met to ensure an age-at-death estimation technique is reliable. Spirduso (1995) suggested, the skeletal area or age indicator under scrutiny must have a strong correlation with age (i.e. continuously remodelling throughout the entire lifespan), and should not be altered by pathological events, including response to metabolic or nutritional changes. Techniques must have a wide application across the species, with reliable and identifiable changes that occur within relatively short time intervals when compared to the total lifespan (Spirduso, 1995). Often not stated, but of the utmost importance, is that the skeletal element required for the application of the ageing criteria should consistently demonstrate sufficient preservation in any burial (Lovejoy et al., 1985b; Walker et al., 1988; Walker, 1995; Bello et al., 2006).

If these criteria are satisfied, the resultant ages must be tested for their reliability and their validity. Ageing techniques commonly report highly reliable age estimates, but disappoint with practical use (Maples, 1989). The reliability of the method takes into account the degree of inter- and intra-observer errors. Differences of trait expression are investigated between the sexes and ages (inter-personal differences), as well as for the symmetry of trait expression (or intra-individual differences) and the inter-population differences (i.e. effects of ancestry, geographical region, time period, socio-economic and cultural backgrounds). The validity of the ageing technique is demonstrated by its ability to accurately estimate age within a concise age range despite all these variables.

In order to progress research into skeletal age-at-death, it is essential to assess what has previously been done, exchange methods, ideas and experiences (İşcan, 1989). Consistent critical evaluation, re-evaluation and revision of osteological techniques allow the specific ageing method to be assessed, along with the validity of resultant age estimations in different documented skeletal populations. Re-examination of methods and their subsequent revisions, whether positive or negative, are ultimately beneficial in the development of reliable demographic techniques.

3.5 ESTABLISHED ADULT AGEING METHODS

While it is true that the human adult skeleton does not provide a precisely timed sequence of events like the developing skeleton, numerous osteological techniques have been published, all claiming to satisfy the above criteria and produce accurate and highly reproducible age-dependent assessments of adult skeletal remains. Many elements in all regions of the skeleton (skull, thorax, spine, pelvis) have been investigated for their ability to age the adult skeleton. A summary of ageing methods proposed for the adult human skeleton are presented by skeletal region below. Advantages and limitations are provided, which support the inclusion of particular elements in the current study.

3.5.1 AGEING STUDIES BASED ON THE SKULL

Adult age determination of the skull relies on the degree of fusion between the cranial sutures, the presence of arachnoid granulations on the endocranial surface of the parietal bones, and the degree of dental attrition of the occlusal surfaces.

3.5.1.1 Cranial Sutures

The first cranial ageing methods were published in the 1920s, by Todd and Lyon who pioneered studies of the relationship between the degree of cranial suture fusion (both endocranial and ectocranial), age, sex and ancestry (Todd and Lyon, 1924; 1925a; 1925b; 1925c). Subsequent reports on the unreliability of cranial suture ageing first began in the 1950s (Brooks, 1955; Molleson and Cox, 1993; Key et al., 1994; Hershkovitz et al., 1997). In response to the early criticism, new criteria were produced to assess age using the endocranial sutures (Ascádi and Nemeskéri, 1970), and ectocranial sutures (Meindl and Lovejoy, 1985). Ageing criteria have also been developed for other sutures: the maxillary sutures (Mann et al., 1987; Ginter, 2005; Beauthier et al., 2010), frontosphenoidal suture (Dorandeu et al., 2008; Dorandeu et al., 2009), and the frontonasal suture (Alesbury et al., in press).

Re-evaluations of these techniques found sex differences in the extent of closure, depending on the anatomical location of the suture, the method being applied, and the skeletal sample under study (Brooks, 1955; Meindl and Lovejoy, 1985; Mann et al., 1987; Key et al., 1994; Hershkovitz et al., 1997; Galera et al., 1998; Ginter, 2005; Dorandeu et al., 2008). Also, despite the claims of successful ageing using the skull, the re-evaluations questioned the reliability to which cranial suture fusion can provide accurate age predictions (Molleson and Cox, 1993; Key et al., 1994). Hershkovitz et al. (1997) reported sagittal suture closure to be independent of age and sexually biased, in addition to other findings. Molleson and Cox (1993) found the technique to under-age older adults, while over-ageing younger individuals. Key et al. (1994) argued that Acsádi and Nemeskéri's (1970) endocranial suture technique was only able to broadly identify the young and old, but not specific ages, and the Meindl and Lovejoy (1985) ectocranial suture method was, again, found to be sexually biased. It is important to note that the biological processes behind cranial suture closure are unknown and not understood, as it is also found in congenital pathological conditions, causing premature suture closure, and some individuals even demonstrate non-closure. Given these identified shortcomings of cranial suture closure techniques, it has become universally inadvisable to rely too heavily on such methodology.

3.5.1.2 Arachnoid Granulations

Several studies have attempted to correlate the frequency and the overall size of arachnoid granulation pits and depressions located on the endocranial surface of the calvarium with age (Basmajian, 1952; Barber et al., 1995; Barber, 1997; Duray and Martel, 2006). It has long been accepted that these pits and depressions increase both in number and in size with age (Basmajian, 1952). The first study to statistically interpret these appearances was Basmajian (1952), who aimed at assessing the relationship between pit size and depth with known age. Although a general pattern of increasing size with increasing age was found, marked discrepancies between individuals of similar age groups did not provide sufficiently reliable criterion for age estimation (Basmajian, 1952).

Duray and Martel (2006) continued research in to size and depth of arachnoid fovea by developing a method to quantify the volume of the pits. Each arachnoid granulation pit was filled with sand, which was subsequently weighed. The maximum length, width and mass of sand recovered from the foveae were subjected to linear regression analysis. The results showed a statistically non-significant relationship between the total volume of pits and age. Although not the focus of the study, the frequency of arachnoid fovea and age was also non-significantly correlated (Duray and Martel, 2006), and suggests their presence may be more related to an individual's health rather than age.

In contrast to arachnoid granulation size, Barber (Barber et al., 1995; Barber, 1997) found that the number of arachnoid granulation pits and depressions affecting the parietal bones correlated to skeletal age. A new ageing technique using regression equations was proposed that reportedly provided no maximum cut-off for ageing of older adults, and was more accurate than using the pubic symphysis and dental attrition (Barber, 1997). It was claimed that the number of pits and depressions could accurately estimate the age of individuals over the age of 50 years within 10 years, and was equally applicable to males and females, as well as black and white individuals. Although Barber's thesis remains unpublished, Cox (2000) suggested this technique was worthy of further investigation.

The age estimation technique proposed by Barber (1997) was chosen for evaluation in this thesis as it provided an entirely visual macroscopic method, did not require additional equipment and claimed to provide age for older individuals, which has not been re-evaluated. It was also developed on a study sample similar in construction to the samples used in this research, (i.e. it had a large number of individuals aged 50+ years). One drawback of the arachnoid granulation method is that it cannot be performed on complete crania, and thus limits its applicability to well-preserved cranial remains. Conversely, it cannot be applied to fragmentary material, as intact parietal bones are essential.

3.5.1.3 Dental Wear and Antemortem Tooth Loss

Dental wear (Miles, 1963; Brothwell, 1981; Lovejoy, 1985; Mays et al., 1995; Miles, 2001) is a very commonly used ageing method in the osteological community (Falys and Lewis, 2011), likely the result of the teeth being well preserved in the burial environment. These methods require interpretation of the pattern of wear on the occlusal surface of the teeth by scoring the amount of enamel that has been worn away to display the underlying dentine. The degree of dental wear in an individual is time-dependent, increasing in severity as the individual ages, however, it is accelerated by many factors, such as diet, disease and the habitual use of teeth as tools (Brothwell, 1981). These factors are population specific, and limited to the study of archaeological populations, as modern individuals do not demonstrate the same extent of dental attrition due to differences in food production technology. Although not an age estimation technique like dental attrition, it is a commonly held assumption that "elderly" people display antemortem tooth loss, with the very old being edentulous. The loss of teeth before death can result from many reasons, including severe dental attrition, caries, periodontal disease, and abscesses. It is characterised by healing of the tooth socket. To the author's knowledge, there have been no formal studies into the relationship between age and antemortem tooth loss. However, this method renders the applicability of assessment of dental wear to be highly limited in older adults, and as a result, the degree of dental wear was not investigated during this study.

3.5.2 AGEING STUDIES BASED ON THE THORAX

Several ageing methods have been developed using the skeletal elements of the chest, including examinations of the scapula, clavicle, ribs and manubrium/sternum/xiphoid.

3.5.2.1 Ribs

Adult ageing criteria have been developed for the first and the fourth ribs. The original studies into rib age were widely published by İşcan and colleagues in the early 1980s (İşcan et al.; 1984a; 1984b;

1985). These methods focused on the sternal end of the fourth ribs, with subsequent casts made to ease trait comparison (İşcan et al., 1993). Sex and ancestry were found to be statistically significant factors affecting the rate of ageing (İşcan et al.; 1984a; 1984b; 1985), as the sternal rib end differed between male and female individuals of equivalent ages, as well as between individuals of different ancestries.

Subsequent studies found the degeneration process was also applicable to the third and fifth rib sternal ends (Aktas et al., 2004). Many tests of the methodology followed, for applicability to individuals derived from both archaeological and forensic contexts (Saunders et al., 1992; Russell et al., 1993; Kimmerle et al., 2008b; Fanton et al., 2010; Hartnett, 2010b). The majority of studies indicated that the ribs are difficult to assess due to difficulties in reproducing and repeating necessary assessments (Fanton et al., 2010), a large and inter-observer error resulting from the interpretation of broad descriptive phase categories (Kimmerle et al., 2008b; Hartnett, 2010b), and problematic identification of the fourth rib in archaeological or fragmentary remains (Saunders et al., 1992; Cox, 2000).

The ageing potential of the first rib followed the early criticisms of the İşcan (1984a,b; 1985) methods, as its morphology is much more robust and identifiable than the fourth rib. Kunos et al. (1999) developed criteria to assess the age dependent metamorphosis of the head, tubercle and costal face using the Hamann-Todd documented collection in Cleveland, USA. Subsequent tests of the method found different results. Kurki (2005) found high degrees of inaccuracy and bias for younger age ranges (< 50 years), although showed potential for ageing individuals 60+ years old. However, Schmitt and Murail (2004) found the morphological alterations were more variable with age than suggested, the technique was difficult to apply, and population differences existed in trait expression. DiGangi et al. (2009) modified the Kunos et al. (1999) first rib method and developed ageing criteria based on the tubercle and costal ends of a modern Balkan sample, which has not yet been evaluated for its applicability to other samples.

Although the sternal end of the fourth rib is reported to age up to the eighth decade, in archaeological skeletons, ribs are poorly preserved and frequently fragmented. It is also a challenging and time consuming task to correctly identify the necessary ribs (i.e. third to fifth ribs), despite attempts to ease rib seriation (Dudar, 1993; Mann, 1993; Hoppa and Saunders, 1998; Owers and Pastor, 2005). This difficulty in identification limits its application to past populations, and was thus excluded from this study. The first rib is also reported to have the ability to age older adults, and although it may suffer from the same preservation in the burial environment, it has a unique, easily identifiable morphology which may be more applicable for archaeological investigation. Criteria proposed by both Kunos et al. (1999) and DiGangi (2009) were recorded in the course of this study.

3.5.2.2 Manubrium, Sternum and Xiphoid Process

The usefulness of the sternum in assessing age-at-death, in both non-adults and adults, is less clear and has had conflicting reports of accuracy. While fusions of the sternal "vertebrae" and associated costal epiphyses, and manubrium costal and clavicular epiphyses can suggest age in non-adults (Scheuer and Black, 2004), limited research of the sternum's ability to characterise the age of adult individuals has been published. Although the cause and timing of the manubrium's fusion to the sternum is not clear, advanced age has long been thought to be contributing factor to the fusion of the xiphoid process to the sternal body (Bass, 1995). Molleson and Cox (1993) found that the fusion of the manubrium to the sternum occurred independently of age and sex, although ossification of the xiphoid process increased with age. Scheuer and Black (2004:238) supported this suggestion, and stated that at 40+ years the "xiphoid process commences fusion to the mesosternum". It is here that a portion this study is aimed. This study assesses whether the fusion of the manubrium and the xiphoid process have the ability to indicate age in adult skeletal individuals. The degeneration of the clavicular notches of the proximal manubrium was also recorded, in addition to the general state of costal cartilage ossification of the manubrium and sternal bodies.

3.5.2.3 Clavicles

The general trabecular bone structure of the clavicle itself has been used to investigate age in the adult via radiographic techniques (Walker and Lovejoy, 1985). The ageing potential of the sternal end of the clavicle has been limited to its development, and subjected to numerous studies investigating the timing of the fusion of the epiphysis (Stevenson, 1924; Todd and D'Errico, 1928; McKern and Stewart, 1957; Szilvássy, 1980; Meijerman et al., 2007; Cardoso, 2008a; Langley-Shirley and Jantz, 2010). Although the sternoclavicular joint is important in adult ageing as it provides concise age estimations of individuals between 16-30 years, no osteological studies have been published that record changes in morphology once the sternal epiphysis has fused.

Many clinical studies have investigated the degenerative processes of the sterno-clavicular joint (DePalma, 1957; Arlet and Ficat, 1958; Silberberg et al., 1959; Yood and Goldenberg, 1980; Waterman and Emery, 2002). DePalma (1957) performed a clinical study of the degenerative soft tissue changes of the sternal and lateral ends of the clavicle. His study was aimed at surgeons and general practitioners, as a way of having a physical understanding of the pain patients often experienced. DePalma (1957) found that degeneration of the lateral end of the clavicle (acromio-clavicular joint) occurred earlier than that of the manubriosternal joint, which commenced around the fourth decade and continued through the ninth decade. DePalma (1957) theorized that ends were subjected to different amounts of wear and tear to the fibrous discs, caused by movement. The disc between the clavicle and manubrium degenerated at a delayed rate to the lateral end disc, as the latter is directly involved in all arm movements, as the acromioclavicular joint acts as a stabilizing part of the shoulder joint. The differences found in the rate of degeneration between the ends of the clavicle could also be related to the earlier fusion of the lateral epiphysis compared to the medial epiphysis.

Following DePalma's (1957) study, Miles (1999) developed a grading system for degenerative changes observed in the acromio-clavicular joint, based on the microscopic and macroscopic observations of the Spitalfields documented collection. He found a correlation between increasing degenerative changes and advancing age.

Examinations of both the lateral and sternal ends of the clavicle were investigated in the current study. While Miles (1999) proved morphological alterations of the lateral surface with age that were identifiable in dry bone, equivalent observations had not been made for the sternal surface in his study. It was hypothesised that the manubrium facet on the inferior surface of the sternal clavicle would provide the most significant amount of degenerative change due to its close proximity to the clavicular notch of the manubrium, however, the larger sternal surface itself was also recorded.

3.5.2.4 Scapula

The usefulness of the scapula to assess adult age has only been investigated in one study. Graves (1922) found that older individuals commonly displayed translucent spots on the scapula blade. This method was not included in the current study, as the fragile nature of the blade of the scapula leaves it highly susceptible to damage in the burial environment.

3.5.3 AGEING STUDIES BASED ON THE SPINE

Both the development and degeneration of selected regions of the spine have been investigated for their ability to estimate adult age. The vertebral end plates are among the late fusing epiphyses, which occur between late teenage years and early adulthood (Albert and Maples, 1995; Albert, 1998; Albert and McCallister, 2004; Albert et al., 2010), while fusion of the first and second sacral vertebrae can occur up until the age of 35 years (Belcastro et al., 2008). Once the vertebrae have completed their development, degenerative changes to the spine (vertebral osteoarthritis) occur to both the vertebral bodies themselves as well as the superior and inferior articular facets. Degeneration (primarily osteophyte development) in all regions of the spine has been the focus of many ageing studies (Stewart, 1954; Stewart, 1958; Sager, 1969; Acsádi and Nemeskéri, 1970; Ericksen, 1976; Ericksen, 1978a; Ericksen, 1978b; Prescher, 1998; Snodgrass, 2004; Van der Merwe et al., 2006; Watanabe and Terazawa, 2006). Investigations of vertebral osteophyte formation were commonly found to be too variable to predict age.

A study by Sager (1969) developed a scoring system to quantify the progression of degenerative joint disease in the neck vertebrae (both bodies and facets), and found the general pattern of osteoarthritic changes in the cervical vertebrae increased with age. Sager (1969) did not relate these observations to specific ages-at-death. Molleson and Cox (1993) recorded the spine following Sager (1969), and noted the frequency of vertebral body lipping increased with age in both sexes, although the pattern was clearer in females.

This degenerative change of the cervical vertebrae was included in this study, as unlike the thoracic and lumbar vertebrae, they are not weight-bearing, although they do provide mobility for movement of the skull. As so many factors contribute to the rate and severity of degenerative joint disease (e.g. genetics, occupation, trauma, health), it not expected that specific age ranges of distinct degeneration will be observable, however, it is hoped that individuals will be able to be allotted into broad, ranked, age categories that will identify older individuals from younger ones.

3.5.4 AGEING STUDIES BASED ON THE PELVIS

The pelvis is one of the most sexually dimorphic regions of the human skeleton, and is also the location of two of the most widely relied upon postcranial ageing methods (i.e. pubic symphysis and auricular surface of the ilium) (Falys and Lewis, 2011). In addition to these two methods, several new techniques have focused on the degeneration of the acetabulum. These aspects of the innominate are frequently applied in both archaeological and forensic contexts, although the auricular surface is commonly better preserved than the pubic symphysis. Other aspects of the innominate (i.e. iliac crest and ischial tuberosity) are also discussed, in addition to the sacrum.

3.5.4.1 Pubic Symphysis

The pubic symphysis is the most frequently re-examined adult ageing technique (Klepinger et al., 1992). The first formal skeletal age-at-death estimation technique using the pelvis was published in the early 1920s by T. Wingate Todd. These early studies investigated morphological age changes of male pubic bones (Todd, 1920), and later the affects of sex and ancestry on the pubic symphyses ageing processes (Todd, 1921). The Hamann-Todd documented skeletal collection was used to develop the criteria, which at the time was a modern sample, with aims of developing a technique for forensic use. Todd was able to identify nine aspects of the pubic symphysis that changed through ten different phases of development and degeneration, irrespective of sex. The age-related changes of the pubic symphysis remained largely unquestioned for three decades.

In 1955, Brooks (1955) examined both Todd’s pubic symphysis and cranial suture closure methods on a large skeletal sample of 470 American Indian individuals. Discrepancies of methodology and accuracy of resultant age estimations highlighted the necessity of continuous testing and revision of published demographic techniques, and thus began gradual revisions of the pubic symphysis technique which continued over the subsequent decades (Brooks, 1955; McKern and Stewart, 1957; Acsádi and

Nemeskéri, 1970; Gilbert, 1973; Gilbert and McKern, 1973; Hanihara and Suzuki, 1978; Meindl et al., 1985; Katz and Suchey, 1986; Suchey and Katz, 1986; Suchey et al., 1988; Suchey and Brooks, 1988; Brooks and Suchey, 1990). During these evaluations, the need for sexually dimorphic ageing criteria was found, and provided.

The Suchey-Brooks method (Brooks and Suchey, 1990) is the most popular method for pubic symphysis ageing. The criteria were based on the observation of 1225 pubic bones from modern autopsied individuals (i.e. fully documented) from the Office of the Chief Medical Examiner, County of Los Angeles (Brooks and Suchey, 1990). The degeneration of the pubic symphysis was allotted into six distinct phases for males and females separately. Descriptive statistics (i.e. mean age, standard deviation, and 95% range) were provided for each phase in order to estimate age. It is suggested that "Suchey-Brooks Phases V and VI can be used for lower limits in the age estimation of more mature individuals (30+ for Phase V, 40+ for Phase VI)" (Brooks and Suchey, 1990:237). Casts were made for comparison to ease trait identification and make age estimation simpler. In contrast to the descriptive statistics for each age phase provided by Brooks and Suchey (1990), the suggested lower limit of 40+ years for the presence of Phase VI confirms the findings of Katz and Suchey (1986) who suggested that 40 years was the maximum cut-off point for which age could accurately be estimated by the pubic symphysis**.**

Although Todd (1920), Brooks (1955) and Brooks and Suchey (1990) all developed their methods on a contemporary forensic assemblages, the subsequent methods are being universally applied to archaeological populations (Falys and Lewis, 2011). Most recent examinations of pubic symphysis ageing have tested the method's applicability to differing geographical populations, using modern forensic assemblages, differing statistical methods and inter- and intra-population variability (Saunders et al., 1992; Sinha and Gupta, 1995; Hoppa, 2000; Schmitt, 2004; Djurić et al., 2007; Berg, 2008; Chen et al., 2008; Hens et al., 2008; Kimmerle et al., 2008a; Kimmerle et al., 2008b; Hartnett, 2010a; Chen et al., 2011). Berg (2008) developed criteria to identify a "Phase VII" for female pubic symphyses using two modern known age collections of Balkan and American origin (William Bass Donated Collection). Other studies found that the rate of ageing was affected by severe physical trauma or disability-induced lack of activity (Klepinger et al., 1992), and the pubic symphyses can demonstrate asymmetry (Overbury et al., 2009).

This method does have its shortcomings. For example, the pubis is not always well preserved in the burial environment. Also, younger individuals are aged with a higher degree of accuracy than the older adults, and this method provides age estimations in ranges that are "…so broad with such enormous areas of overlap as to be almost meaningless" (Cox, 2000:69). The pubic symphysis has an observed trend to underestimate the age of older individuals. Hens (2008) found that bias and inaccuracy increase with age, and underestimation of ages 40+ years. This fact was highlighted during the development of the method for females, as noted by Katz and Suchey (1986:432), "examination of our data suggest an age of 40 years as a reasonable cutoff point", as beyond 40 years, estimations cannot be made accurately. This was substantiated when an increase in accuracy with age estimation was observed when individuals 40 years and over were removed from the original study samples (Katz and Suchey, 1986). This age ties in with the timing of the fusion of the ventral rampart, as the fusion and remodelling of this epiphysis "signals the end of the role of the pubis as the most easily interpreted and reliable indicator of age-at-death in the human skeleton" (Meindl et al., 1985). High rates of inter- and intra-observer errors were indicated by Saunders et al. (1992) when they tested the Suchey-Brooks method on a documented sample from Bellville, Ontario, Canada, as well as Baccino et al. (1999) using a small sample of French autopsied individuals. They also found high levels of inaccuracy. Differences in accuracy have been found between the sexes. Klepinger (1992) found a greater accuracy for males than females using the Suchey-Brooks (1990) casts. Females have been found to be more difficult to age than males, due to the high degree female pubes variability (the possible result of obstetrical factors) and as a result, are harder to evaluate than males. And finally, population specificity was suggested by Schmitt (2004) who found that application of the Suchey-Brooks method should be avoided in Asian skeletons, as the criteria were developed on modern American individuals, and were difficult to identify (i.e. high intra- and inter-observer errors) and did not provide accurate results on the Asian sample. Schmitt (2004) suggested that there may be a difference in the pattern of ageing between the Asian sample and the American population, on which the method was developed.

The advantage of this skeletal region is that it has been widely tested and is well known to all biological anthropologists. If the maximum age limit can be extended through development of new phases of degeneration, it will be easily understood by all researchers. During this research, the pubic symphysis was recorded following the Suchey-Brooks phase system, using the casts, in addition to Phase VII, as proposed by Berg (2008).

3.5.4.2Auricular Surface of the Ilium

The auricular surface has long been the focus of research into the identification of both the sex and age-at-death of adult human skeletal remains. Brooke (1924) observed changes in the mobility of the sacro-iliac joint and linked them definitively with sex and age for the first time. It was noted that although limited movement was possible in the sacro-iliac joint, there was a progressive decrease in this mobility with increased age, until around 50 years, when complete ankylosis was found to occur more frequently in males than females (Cox, 2000). The auricular surface soon became an area of interest for many osteologists. Sashin (1930) attempted to associate regular changes in the sacro-iliac joint with increasing age. Weisl (1955, as cited in Lovejoy et al., 1985b) was able to correlate the shape of the auricular surface with sacral movements. He noted that the height of the sacral elevations increased gradually in the first 30 years of life and became prominent in the third and fourth decades, with little change thereafter. With encouraging results from the aforementioned studies, the hypothesis was put forth that the auricular surface could display age changes in two ways: changes in the topography and texture that were visible and recordable, and the observable ankylosis of the joint itself primarily in males after the age of fifty (Cox, 2000).

The original study by Lovejoy et al. (1985b) described eight phases of age-related changes affecting the morphological characteristics: billowing, granularity, density, and porosity. Metamorphosis of the surface was proposed to occur in 5-year intervals between ages of 20 and 49 years, and a 10-year interval between 50 and 59 years. The maximum age estimation was an open-ended category for individuals beyond age 60. Unlike age estimations from the pubic symphysis, the auricular surface offers the possibility of improved ageing of older individuals. While the initial study was scrutinized as being based on an unreliably documented assemblage (the Todd Collection), the method was subsequently put to a test several times using material of known age and sex. Photographs were also distributed for ease of trait identification (Bedford et al., 1989).

Many researchers have re-evaluated the Lovejoy et al. (1985b) method and found that it performed differently in different populations. Three studies (Murray and Murray, 1991; Bedford et al., 1993; Schmitt, 2004) found a tendency to overestimate the age of younger individuals, and underestimate the age of older individuals. Saunders et al. (1992) used a documented archaeological population from Belleville, Ontario, to test the method. Their results indicated that while there was overall agreement with the results of Lovejoy et al. (1985b), the reliability of age estimates decreased in individuals beyond the age of 45 years. Bedford et al. (1993) felt that the original description of age-typical changes required more clarity but the applicability of the method was not questioned. Osborne et al. (2004) attempted to increase the accuracy of the original Lovejoy et al. (1985b) criteria by combining stages 1 and 2, and 5 and 6, after statistically significant differences in age were not found between these stages.

In an attempt to ease the difficulties in trait interpretation, Buckberry and Chamberlain (2002) responded with a new quantitative system to aid in the identification of morphological age-related surface changes, using the Christ Church Spitalfields Collection. Rather than identifying phases from complex conglomerates of different traits, they followed individual traits in their age-related progression. Accordingly, the revised method examined different features independently and then combined them to produce a composite score, which related to an age range. Several tests of this new technique have found it easier to apply than the original Lovejoy et al. (1985b) methodology (Mulhern and Jones, 2005; Falys et al., 2006), although the accuracy with which the revised method could predict age was not favourable in all studies (Falys et al., 2006; Wittwer-Backofen et al., 2008). The revised method, however, did provide evidence that it had the ability to estimate age over 60 years (Mulhern and Jones, 2005; Falys et al., 2006). Several researchers have found this method to provide the ability to assess ages over 60+ years (Mulhern and Jones, 2005; Falys et al., 2006; Hens and Belcastro, 2012), although it has also been proposed that the auricular surface can only distinguish between young, middle and old individuals (Falys et al., 2006; Hens and Belcastro, 2012), in contrast to Buckberry and Chamberlain (2002), who found seven distinct stages of degeneration of the auricular surface. Rissech et al. (2012) suggest the accuracy of this method depends entirely on the broadness of the 95% age ranges that provide the age estimation, not the criteria itself.

The advantage to the auricular surface is that it is commonly well preserved in the burial environment, when compared to the ribs or pubic symphysis. Also, like the pubic symphysis, it has been widely re-evaluated and revised. Despite the female pelvis facilitating birth, age dependent traits of the auricular surface of the ilium (Lovejoy et al., 1985b; Buckberry and Chamberlain, 2002) do not appear to differ between the sexes. Both the Lovejoy et al. (1985b) and the Buckberry and Chamberlain (2002) methods were recorded in this research, in addition to ankylosis of the sacro-iliac joint, and a newly proposed trait of raised surface texture.

3.5.4.3 Acetabulum

The most recent of all adult ageing methods have been developed using the degeneration of the acetabulum. It is only within the last decade that three differing methods have been proposed (Rissech et al., 2006; Rissech et al., 2007; Rougé-Maillart et al., 2007; Calce and Rogers, 2011; Calce, 2012). Each technique supplies a scoring system of trait expression for each of the specific aspects of the acetabulum (e.g. the lunate surface, apex, acetabular fossa, and rim). The Rissech et al. (2006; 2007) method requires seven traits to be graded, while the Rougé-Maillart et al. (2007) method requires observation of four, and Calce (2012) records three traits. These methods cannot be applied if one or more of the traits are absent, which will limit their applicability to archaeological remains. While Calce (2012) has proposed a simplified method comprising assessment of three variables, the Rissech et al. (2006) method is very complex, with many trait expressions to identify for each of the seven regions of the acetabulum, leading to a high degree of intra- and inter-observer error. The traits include assessments of the: acetabular groove, rim shape, and rim porosity, apex activity, activity on the outer edge of the acetabular fossa, as well as activity and porosity of the acetabular fossa itself (Rissech et al., 2006:215-217). Calce (2012) also found that only three of the seven traits recorded were actually correlated with age-at-death, and also highlighted the fact that specialist knowledge of specific computer software is needed to derive an age estimate. Difficulties in method application have also been identified, as Stull and James (2010) suggested, the Rougé-Maillart et al. (2007) method requires an improved coding system.

Although all very new and relatively untested, these methods claim the ability to provide estimates well into old age (e.g. 60s, 70s, 80s). Criteria proposed by Rissech et al. (2006) and Rougé-Maillart et al. (2007) were recorded in the course of this research. However, they were not included in the final work, due to the difficulty experienced in trait identification, the necessary specialist knowledge required to form the age estimation, and the limited applicability to archaeological specimens, as suitable preservation of so many necessary aspects of the acetabulum was rare.

3.5.4.4 Iliac Crest

Previous osteological studies of the iliac crest have been limited to the timing of epiphyseal fusion (Stevenson, 1924; McKern and Stewart, 1957; Ferembach et al., 1980; Webb and Suchey, 1985; Coqueugniot and Weaver, 2007; Cardoso, 2008b). The anterior crest epiphysis and the posterior crest epiphysis eventually unite in the middle of the iliac crest and fuse to the rest of the ilium relatively late in skeletal development, with fusion complete by the age of 23 (Scheuer and Black, 2004). As it is a site of ligamentous attachment, the iliac crest may be affected by DISH. The extent of osteophyte development was recorded in this study.

3.5.4.5 Ischium

Previous osteological ageing studies of the ischium have been strictly limited to non-adults based on the growth, development, and timing of epiphyseal fusion (Rissech et al., 2003; Cardoso, 2008b), which completes development between ages 16 and 18 years (Scheuer and Black, 2004). No previous studies regarding the ability of the ischium to supply information of adult age were discovered. During the early stages of the data collection for this study, morphological variations of surface appearance of the ischial tuberosity was an unexpected observation. As the cause was unknown, it was recorded in all study samples. Although both the upper and lower portions of the ischial tuberosity were recorded, the lower aspect was frequently damaged. For consistency, only the upper portion of the ischial tuberosity was included in this research.

3.5.4.6 Sacrum

The sacrum has also been investigated for its ability to age adults. The state of fusion between the sacral vertebrae (Ríos et al., 2008) has been examined, in addition to the articular surfaces that form the sacro-iliac joint with the auricular surface of the ilium. Using a scoring system of trait expression similar to that of Buckberry and Chamberlain (2002), Passalacqua (2009; 2010) proposed a method that provides six distinct stages of degeneration, with the ability to age into the older ranges (i.e. Phase 6, mean age, 62.8 years; 95% range, 36–91 years). Due to the similarity of this technique with the metamorphosis of the auricular surface, assessment of the sacrum was not included in this research.

3.5.5 MULTI-METHOD AGEING STUDIES

Many osteologists use a multi-method approach to provide a general overview of the age of the individual. They use the range of these estimates to provide an age assessment, and place the individual into an age category. This provides a more holistic assessment of age in the individual, combining the different resultant ages to construct the most well-informed estimation. This is believed to be the best means to estimate adult age (Baccino et al., 1999; Kemkes-Grottenthaler, 2002). Multifactorial methods weight each age indicator according to their reliability and subject them to principle components analysis. The first factor is assumed to represent the true chronological age while the final age for the individual is based on an average of all available age indicators (Lovejoy et al., 1985a; Bedford et al., 1993).

Formalized multi-method techniques are the Complex Method (Acsádi and Nemeskéri, 1970), combining ages derived from the pubic symphyseal face, the spongiosa structure of the femoral and humeral head, and the obliteration of the endocranial sutures. Lovejoy et al. (1985a) published a multifactorial system using five skeletal traits including the pubic symphysis (Meindl et al., 1985), the metamorphosis of the auricular surface of the ilium (Lovejoy et al., 1985b), the trabecular involution of the proximal femur (Walker and Lovejoy, 1985), and dental wear (Lovejoy, 1985). Saunders et al. (1992) and Molleson and Cox (1993) both tested the Complex Method. Saunders et al. (1992) found the method to overage younger adults and underage older adults. Molleson and Cox (1993) also found a very poor accuracy of resultant age estimations (based on ± 5 years of documented age). Bedford et al. (1993) tested the multifactorial method, which was also shown to underage older individuals and overage younger individuals. As these established multi-method techniques include radiographic or destructive aspects, they were not investigated for this research.

3.6 AGE RANGES AND AGE CATEGORIES

As the human skeleton does not degenerate at a constant or predictable rate, osteologically derived estimated ages are placed within a ‘range’ to account for trait expression variability within and between individuals. As previously stated, in adults, concise age estimations are only possible for remains in the last stages of skeletal development. Once the skeleton has ceased growth, age ranges must be substantially expanded, paradoxically, to compensate for inaccuracy. For this reason, older methods (e.g. tooth wear or Lovejoy’s auricular surface) provide age estimates spanning 5-year to 10-year intervals, while many of the most recent methods provide age estimates based on descriptive statistics (i.e. mean age, standard deviation and the 95% confidence interval) for each stage or phase of degeneration. However, Nawrocki (2010) suggested that based on biological reality of the amount of variation of the ageing process in adults, correctly constructed error ranges should not be less than 15 to 20 years.

After comparing as many ageing methods as possible per individual, skeletal individuals are allocated to age ranges commonly spanning 10 to 15 years through "adulthood" (e.g. 16–25 years, 26–35 years, 36–45 years, 46+ years; or 20–34 years, 35–45 years, 46+ years). These segments of adulthood are often stated in combination with a descriptive term, such as "young adult", "middle adult", "young middle adult", "middle aged adult B" or "old adult", however, these terms reflect cultural rather than physical ages.

A study by Falys and Lewis (2011) investigated the universal use of age ranges and descriptive terminology based on published articles in the top four journals of biological anthropological research. The results showed a wide range of variability in:

- the age at which individuals were determined to be "adult" (from 14 to 25 years).
- the use of age ranges.
- the use of descriptive age categories.

It was concluded that to ease comparisons between age-at-death profiles in skeletal samples from different periods and cultures, age estimations need to be stated in clear and concise terms, and within sufficiently broad ranges. Adult age estimations should be strictly numerical unless there are valid cultural reasons to apply these terms to a particular study sample (Falys and Lewis, 2011).

3.7 PROBLEMS AND LIMITATIONS

Inherent flaws in adult age estimation techniques have been highlighted over the past 30 years (Bocquet-Appel and Masset, 1982; Maples, 1989; Jackes, 1992; Cox, 2000; Kemkes-Grottenthaler, 2002). A major focal shift from methodological factors to the accuracy and reliability of adult skeletal ageing techniques began in the early 1980s, when Bocquet-Appel and Masset (1982) stated that the ability to osteologically infer adult age was inherently flawed. These researchers were alerted to the problems upon identifying pathological conditions, known to only affect older members of the population, within the remains of individuals skeletally determined to be 35 years of age.

The increased investigations into adult age determination highlighted a multitude of conceptual, methodological and interpretive deficits. Some have been examined and rectified, while others appear to be beyond remedy. It has become apparent that "…the multitude of confounding factors of the aging process has shattered the long-held assumption that age estimation requires merely the routine application of textbook standards" (Kemkes-Grottenthaler, 2002:49). Issues affecting the identification of "older" adults are highlighted where possible.

3.7.1 CONCEPTUAL

The primary conceptual criticism is the direct result of the actual variability of the biological process of ageing. Ageing techniques attempt to predictively correlate non-linear biological alterations with a linear chronological age (Cox, 2000). As Arking (1998) suggested, biological age markers are more an estimate of physiological status of the individual, rather than a true representation of chronological age. Investigation is necessary to understand the causes of the variation of ageing both within the same and different individuals, as well as differing populations. Currently, this variation is often underestimated in osseous ageing criteria (Corsini et al., 2005). This variability produces a low correlation between skeletal indicators and chronological age, with increasing trait variability with age, the inaccuracy also increases with advancing age. However, Nawrocki (2010) suggests that each trait, no matter how well or poorly correlated with age, accounts for a different portion of the overall variance in ageing and provides information on the ageing process.

As Maples (1989:320) stated, "there is too much biological variation in humans for perfect age estimation. I doubt that any technique will yield dependable estimates with ranges smaller than 5 to 10 year range for mature adults". Although unacceptable for forensic uses, even the ability to age elderly skeletons to within a 10 year range would, at the very least, acknowledge that individuals did indeed survive the excessive young adult mortality inferred by modern archaeologists and some biological anthropologists.

Adding to inter-individual variability, it has been suggested that some individuals are more prone to form bone than others. It is unknown what, if any, effect these processes have on the degenerative traits necessary to estimate age-at-death (i.e. joint surface porosity/erosion and/or osteophyte formation). However, Schmitt et al. (2007) found that some individuals within a population are not likely to develop osteophytes.

3.7.2 METHODOLOGICAL

Pitfalls have been identified at all stages of the development of adult ageing methods, including: the elements necessary for age estimation, identified methodological inadequacies, difficulties in applying the techniques or interpreting the resultant age estimations, and inter-population inconsistencies (Hoppa, 2000). Some proposed skeletal alterations have even been found to be inaccurately correlated with chronological age (e.g. cranial suture closure).

3.7.2.1 Preservation

Techniques have been developed using elements that are not always easily identifiable or subjected to suitable preservation in the burial environment. For example, it is often not possible to identify the fourth rib for use in the İşcan and colleagues' (1984a,b; 1985) method from archaeologically derived skeletal material. In such contexts, the ribs are often fragmentary, and unless tagged or bagged at the time of excavation, the fourth rib may never be identified. With regards to preservation, the pubic symphysis is less frequently preserved than the auricular surface of the ilium (Lovejoy et al., 1985b). Walker (1995) discussed the differences in the preservation of skeletal remains with age (and sex), and suggests that the remains of elderly individuals could be more poorly preserved than those of younger adults due to the overall decreasing of skeletal mass of ageing bone.

3.7.2.2 Method Development

Many methodological difficulties have come to the forefront with the general increase in research. These problems range from issues formed at the time of method development, through biases and high amounts of inter- and intra-observer error.

3.7.2.2.1 Reference Collections

The documented reference skeletal collections used to develop ageing criteria contribute several challenges to osteological research. Methods are developed on collections of either archaeological or modern individuals, for whom age is known either through documentation (birth and death certificates, or by association with gravestones or coffin plates) or family accounts. However, the accuracy of these ages has been questioned previously in the Hamann-Todd reference collection.

Many of the early investigations of skeletal ageing were undertaken using the Hamann-Todd collection. Methods were developed that are still used in osteology today, such as the metamorphosis of the auricular surface of the ilium (Lovejoy et al., 1985b), cranial suture fusion (Meindl and Lovejoy, 1985) and the multifactorial method (Lovejoy et al., 1985a). It is apparent that during the early years of the collection, age and sex of some individuals were determined through observation of soft tissue features. While identification of sex was relatively straight forward, determination of age from physical characteristics could not be reliably assessed, rendering any developed inherently flawed due to the lack of "known age". This issue is fully described in the following chapter (Section 4.2.3).

3.7.2.2.2 Sample Size

Another issue is the development of demographic techniques on small sample sizes. Initially, many documented collections appear to house a significant number of individuals, yet once the sexes and ancestries are analysed separately, sample size decreases. Some resultant small samples contribute skewed age distributions, with disproportional sex and ancestry distributions. Biases can also be introduced into the developed methods if the ages were poorly balanced within the study sample. A larger amount of younger individuals may provide overall age estimations that are more concise than if older individuals were present. For example, the removal of 40+ year olds from the Katz and Suchey (1986) study increased the accuracy in younger individuals (see below).

3.7.2.2.3 Outliers

Some techniques removed biological outliers at the time of method development, greatly increasing their reported accuracy for age determination. It is necessary to leave these "abnormal" individuals in the samples to give some idea of variation between individuals. For example, in their study of pubic symphysis degeneration in males, Katz and Suchey (1986:433) found that "all approaches performed poorly for "older" groups. Substantial improvement resulted from deletion of individuals with age greater than 40, and intermediate improvement was obtained by deleting all cases with advanced patterns".

3.7.2.3 Method Application

Many issues have also been identified in the practical application of ageing methods, and interpretation of resultant age estimations. Published criteria can be difficult to visualize and apply, even with associated photographs or casts for comparison of trait expression. For example, the application of the Lovejoy et al. (1985b) method is notoriously complex in its identification of traits making it difficult to apply. Lovejoy and his colleagues (1985b) stated that the method is difficult to master, but well worth it for the auricular surface's ability to accurately assess age. The researcher must use their own interpretation of the terminology and judgements based on experience, which ultimately increases the amounts of intra- and inter-observer error.

Inappropriate application has been found of population-specific ageing methods being applied to other skeletal samples. For example, the world-wide use of Brothwell's (1981) dental age estimation method is not advisable, as while the degree of dental wear in an individual is time-dependent, increasing in severity as the individual ages, it is accelerated by many factors, which are population specific. Brothwell (1981) developed his method on British adults and children dating from the Neolithic to medieval periods, although it has been found to have been applied to many non-UK populations (Falys and Lewis, 2011). These age estimates may be inaccurate, as each population is likely to have differed from the UK samples in their dietary or cultural practices.

Osteological analysis hypothesizes that both the pattern and rate of age-related morphological changes observed in modern reference populations are not significantly different than in past populations. However, using the pubic symphysis as an example, Hoppa (2000) found that the differences in the timing of age-related changes for osteological criteria may be significant between reference and target samples. This may suggest that age estimation of past populations is not possible, as all adult ageing methods are developed on individuals of modern origin, and thus cannot be population specific for archaeological contexts.

3.7.2.3.1 Stating Age Ranges and Categories

Adding to the problems with age estimation, once age estimations are made, there is a world-wide inconsistency in the age at which individuals are determined to be adult (from 14 to 25 years), and there is high variability in the stated age ranges and the use of descriptive age categories (Falys and Lewis, 2011). Such discrepancies make comparisons between skeletal samples difficult. Without a reliable physiological baseline of age, it is not possible to interpret age-related patterns regarding health or pathology, or to develop theoretical questions regarding life course and identify any cultural differences that may exist.

3.7.2.3.2 Interpretation of Results

Inadequacies and biases plague age estimations. Using the fusion of epiphyses, younger individuals can be confidently aged (i.e. under 30 years old), however, current adult ageing methods are consistently shown to underage older individuals. This underageing bias is the direct result of the age structure of the documented skeletal sample from which an ageing method was developed. Ageing methods based on known age samples that are comprised of large numbers of younger adults than older individuals skew the final age estimation towards a younger age. Ultimately, age distributions are produced that mimic the originating study sample's age distribution, which differ from "normal" cemetery populations (Bocquet-Appel and Masset, 1982; Sattenspiel and Harpending, 1983; Konigsberg and Frankenberg, 1992; Aykroyd et al., 1997; Aykroyd et al., 1999; Chamberlain, 2006). For example, McKern and Stewart (1958) based their ageing methods on young adult male soldiers who died in the Korean War, while Brooks and Suchey (1990) derived the pubic symphysis criteria from a sample comprised of forensic cases. This underageing has resulted in the inability to accurately age over 40 years and ultimately limiting the determination of the true lifespan of past populations, which has leant support to the view by some researchers that a low adult life expectancy was typical in past populations (Van Gerven and Armelagos, 1983; Meindl and Russell, 1998).

An apparent "attraction to the middle" has been frequently identified in the palaeodemographic profiles of archaeological populations, with a peak of individuals falling within the 30 to 45 year range, and is associated with an almost total lack of individuals aged 60+ years (Chamberlain, 2000). Bocquet-Appel and Masset (1982) found that the age distribution of archaeological populations were largely dependent on the age structure of the skeletal assemblage from which a specific ageing method was developed. This statistical bias is increasingly problematic when comparing profiles of different skeletal populations which were analysed using different age estimation techniques.

These issues relating to statistical bias in skeletal ageing have been investigated by many researchers (Konigsberg and Frankenberg, 1992, 2002; Chamberlain, 2000; Hoppa and Vaupel, 2002). In attempt to alleviate the statistical bias, the Rostock Manifesto was created in 2002, in which four areas in need of increased research were highlighted as being key to improving skeletal age estimation to ensure reliable demographic profiles in the future. The four major elements identified were (Hoppa and Vaupel, 2002:2-7):

- the need for better osteological methods, as the accuracy and reliability of ageing methods (i.e. underageing of older individuals, and age mimicry) have been frequently questioned.
- the need for better reference samples, as skeletal appearances (or stage of degeneration) are compared against age in documented reference samples. However, these “known ages” must be validated as void of misreporting.
- the need to use Bayes’ theorem, as the age structure of the reference sample is the most important when devising new skeletal ageing methods. The use of Bayes’ theorem acts to remove the bias of age estimations/distributions in target populations, as previously introduced by the reference sample.
- the need to assess the distribution of lifespans in the target population. Palaeodemographic studies have the potential to provide information on the dynamics of past populations, however the previously available tools have been found to be insufficient.

These measures aim to produce ageing criteria can be compared to all others easily and without the current and inherent statistical biases.

3.8 SUMMARY

Biological age does not always equate to chronological or social age. Adult skeletal age estimation is challenging and imperfect. Constant re-evaluation and revision of ageing criteria have increased the applicability and accuracy of established ageing methods, however, the generally observed “…acceptance by practitioners of such low upper age limits” (Cox, 2000:62) are perpetuating contemporary misconceptions about the length of the life span in past populations. Many issues must be addressed and rectified in order for human osteology to contribute accurate and reliable information to allow for advancements in biological anthropology and social archaeology.

Firstly, it is essential to have a reliable physiological baseline from which we can develop theoretical questions regarding the life histories of individuals in, and between, past populations. It is acknowledged that “adulthood” is primarily culturally-defined, however, at the moment, what skeletally makes an individual an “adult” varies between researchers. It is also unclear at what age a person becomes “old”. Using the often confusing, culturally-loaded, and inappropriately descriptive terminology to describe stages of adulthood, a 46 year old individual is commonly considered ‘elderly’. Use of standardised numerical age ranges is a necessity to provide consistency with adult age estimations, and omission of descriptive age categories will act to limit the attribution of culturally-defined ideals to unknown skeletal remains. There is a need for adult age estimation to be standardised to allow cross-population and world-wide comparisons of adult mortality in archaeological populations.

Secondly, more research is needed to establish population differences of maturation at the later stages of skeletal development and degeneration into “old” age. This chapter has shown the state of current biological anthropology, with the consistent underaging of individuals aged 40+ years using established methods. It is essential that revisions of established criteria is undertaken to limit the degree of underageing, and new regions of the skeleton are investigated for age-related degeneration. It is imperative that this issue is subjected to new research otherwise a large proportion of past populations will remain invisible in the archaeological record, as it is believed that the human lifespan did indeed extend past the age of 50 years in most past societies.

The following chapter presents the study samples assessed during the course of this research, as well as the blind test sample.

CHAPTER FOUR

MATERIALS

4.1 INTRODUCTION

Documented skeletal collections are essential for the development and refinement of osteological demographic methods (e.g. assessments of age, sex, ancestry). As the previous section has shown, age related changes of the adult skeleton are affected by many factors, both intrinsic and extrinsic to the human body. These factors result in intra- and inter-population variability. In order to gain a fully comprehensive understanding of the human ageing process, examination of individuals of known age and sex is essential. Documented skeletal assemblages have the potential to provide large numbers of well-preserved known-age individuals of both sexes, representing a broad range of age groups, and occasionally, differing ancestral backgrounds.

Documented collections are not common, although increasingly, modern (20th–21st century) forensic anatomical collections are being developed and expanded across the world. These assemblages consist of bodies which have been either donated, or were unclaimed from hospitals after death. Unclaimed bodies tend to be younger individuals of lower socio-economic status, when compared to those individuals who have donated their remains following death (Steyn et al., 2010). Donated bodies tend to be of the higher social status, and usually older individuals. The social differentiation may be reflected in overall health and nutritional status of the individual, and identifiable in the skeletal remains.

Unfortunately, known assemblages are even rarer for archaeological populations. Very few assemblages include individuals who died prior to the 1900s. Historic assemblages usually arise from cemeteries or crypts, and reflect the population as a whole, when compared to remains originating in modern dissection rooms. The collections of Christ Church Spitalfields and St Bride’s church, both in London, are the largest established British examples of historical documented assemblages, with individuals who died during the 18th–19th centuries. The demographic details for these collections were recovered from coffin plates and grave stones.

It is not uncommon for ageing methods to be developed in archaeologically derived skeletal remains, for which age and sex and age were first determined by osteological means. For example, Barber’s (1997) arachnoid granulation criteria were developed using the undocumented Barton-on-Humber collection originally; Buckberry and Chamberlain’s (2002) revised auricular surface was developed on the unknown age archaeological skeletal collection from Blackgate, Newcastle-upon-Tyne. Ultimately they do not provide a known chronological age to compare against skeletal age, making any inferences about display of skeletal age-dependent changes unreliable. As a result, only assemblages of individuals of known age and sex were examined in the current study.

Four documented skeletal collections were studied during the course this research. The criteria used to determine the assemblages to be included in this study were:

- large sample size (i.e. number of white individuals aged over 40 years).
- geographical location. In order to assess the universal applicability of observed degenerative traits, diverse locations of the collections were sought (i.e. European, African, North American).
- the time period during which the individuals lived. It was necessary to study both modern individuals and historic populations in order to assess the applicability of degenerative traits to both forensic and archaeological contexts.
- socio-economic status (i.e. differing social classes vary in overall health and nutritional status, which contributes to the rate of ageing).

The collections chosen for inclusion in this study were: the Hamann-Todd Osteological Collection (late 19th to early 20th centuries), the Pretoria Bone Collection (late 20th century), St Bride's Documented Skeletal Collection, London (18th to 19th centuries) and the Coimbra Human Identified Osteological Collection (19th to 20th centuries). A fifth known age collection was employed during a blind test of the newly developed ageing methods, Christ Church, Spitalfields (18th to 19th centuries). This chapter provides a brief history of each skeletal assemblage, the limitations of the collections, and the demography of the study and blind test samples.

4.2 HAMANN-TODD OSTEOLOGICAL COLLECTION (HTH), USA

4.2.1 INTRODUCTION

The Hamann-Todd Human Osteological Collection (HTH) is an early 20th century American anthropological skeletal collection comprised of individuals who died in and around Cleveland, Ohio, USA. Research for this study was carried out during a four week period between 17 May and 11 June, 2010.

4.2.2 HISTORICAL BACKGROUND

The Hamann-Todd Human Osteological Collection (HTH) is housed at the Cleveland Museum of Natural History, Ohio, USA. It is composed of 3,422 skeletons collected between AD1912 and

AD1938 from local Cleveland hospitals, by the Department of Anatomy at Western Reserve University (Lovejoy et al., 1985a; Kern, 2006). The individuals are largely of black and white ancestries, who were born between the years AD1825 and AD1910. They were likely of a low socio-economic status that lived in an urban community prior to modern medical treatments (e.g. before antibiotics and nutritional dietary supplements) (Mensforth and Latimer, 1989).

The Hamann-Todd Osteological Collection is one of the most frequently studied documented reference samples, and has contributed to the development of many of the first published ageing methods and techniques currently used in osteology, such as the auricular surface, cranial suture fusion, and the multifactorial ageing technique (Todd, 1920, 1921; Todd and Lyon, 1924, 1925a, 1925b; Todd and D'Errico, 1928; Lovejoy et al., 1985a, 1985b; Meindl and Lovejoy, 1985). Despite being an integral part of these diversely used methods, the accuracy of the Hamann-Todd "documented" ages have been questioned.

4.2.3 LIMITATIONS OF THE SAMPLE

Todd (1920:289-292) himself questioned the accuracy of the "known ages" at the Western Reserve University collection of skeletons (now the Hamann-Todd collection). Todd (1920:289) stated, "the difficulty of getting precise and reliable data regarding age was greatly underestimated at the beginning of our skeletal investigation". In addition to a heavy reliance on the official Municipal records and hospital files, stated age from the individual or family, the physical external characteristics of the cadavers such as hair and skin, and evidence of pathology were noted in the laboratory. Doubts as to the accuracy and reliability of known age were enhanced by discrepancies between ages provided by official Municipal records, and those from hospitals. Although in the later years Todd (1920:289) stated "there has been great improvement in the records and this source of error can be largely discounted."

Another indication of the unreliability of the known ages was observed in the irregularity of the age curve, as there were high numbers of individuals aged 35, 40, 45, 50, and 55 years (Todd, 1920:289), suggesting that the collection included individuals who had their ages rounded up or down.

Todd (1920:292) stated:

> "in the present state of our knowledge it would be unwise to eliminate any of those skeletons whose ages are not called in question by gross and obvious contradictions in the bones…To decline to do this before our knowledge is much more perfect than it is at present is to invite the disaster which is bound to follow the retention of preconceived ideas. Until we can prove beyond shadow of a doubt that misstatements have been made regarding age, it is safer to accept the records, controlled as they are in various ways

elsewhere enumerated. We can at least feel sure that subject to the limitations common to all humanity our age records are dependable."

Todd's (1920) statements have been dismissed by many researchers (Katz and Suchey, 1986; Cox, 2000), who perpetuate that the Hamann-Todd collection contains individuals of undocumented age. As a result, for the purposes of this research, care was taken to use only those individuals whose ages were deemed the most reliable. To test this, white Hamann-Todd individuals with stated ages of 20 years and over were assessed for evidence of having "estimated" ages-at-death. Todd (1920) suggested that potentially estimated ages were rounded up to the nearest "0" or "5". The final digit of the stated age (i.e. 0–9) was compared for its frequency of use in the official Hamann-Todd database, with the aim of identifying whether or not the integers "0"and "5" occurred more frequently than numbers "1", "2", "3", "4", "6", "7", "8" and "9" (Figure 4.1).

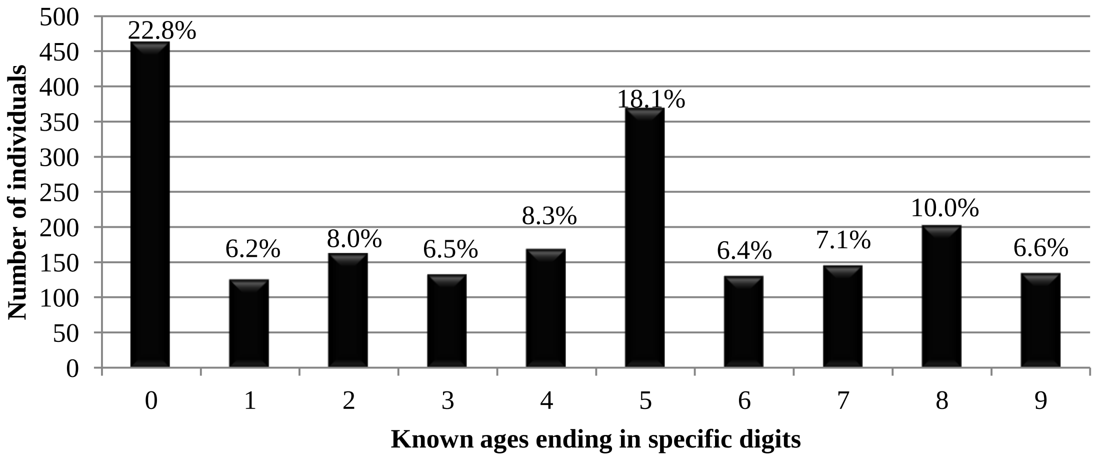


Figure 4.1: *Prevalence of Hamann-Todd ages (20+ years, N = 2028) ending in specific numbers.*

As Figure 4.1 illustrates, there is a bias of adult ages (i.e. 20+ years old) ending in "0" and "5", when compared to ages ending in all other digits. Ages ending in "0" were the most frequently occurring ages, with 22.8% of all ages, followed by those ending in a "5" (18.1%). It is interesting to note that of the 22.8% (N = 462) ending in a "0", 191 (41.3%) of those are assigned to the earliest skeletons accessioned into the collection (i.e. HTH 004–HTH 999). Equivalently, of the 18.1% (N = 368) whose ages ended in "5", 39.1% (N = 144) were also within the first 1000 individuals entered into the assemblage. This may suggest that the documented ages assigned to the earliest skeletons added to the Hamann-Todd Osteological Collection (i.e. HTH 004–HTH 999) may be less reliable than the later inductees (i.e. HTH 1001–HTH 4788).

This possible inaccuracy was also investigated for the individuals fitting the criteria to be included in this study (i.e. white individuals, over the age of 40 years, with both cranial and postcranial remains present for analysis). A total of 1414 were suitable for inclusion. Figure 4.2 confirms a bias also exists within the individuals available for inclusion in this study. Stated ages ending in “0” and “5” were the most frequently occurring when compared to ages ending in all other digits. Very similar to the results of the overall demography of the white adult individuals in the HTH collection, ages ending in “0” were the most frequently occurring ages in the over 40s, with 25.6% of all ages, followed by those ending in a “5” (17.2%). As a result, examination of individuals with ages ending in “0” and “5” were avoided wherever possible.

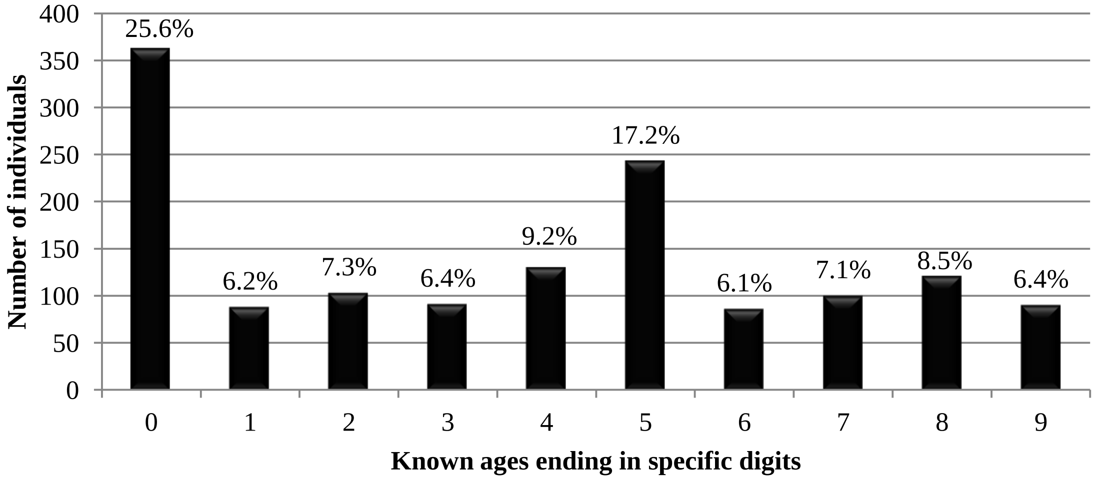


Figure 4.2: *Prevalence of Hamann-Todd ages (40+ years; N = 1414) ending in specific numbers.*

4.2.4 DEMOGRAPY OF THE STUDY SAMPLE

The study was performed on 160 white individuals over the age of 40 years at the time of death. The sample comprised 95 males with ages-at-death ranging from 42–96 years (mean age, 62.0 years) and 65 females, ranging between 41–93 years (mean age, 55.7 years). Figure 4.3 shows the age composition of the sample in more detail. Although it was attempted to assess equal numbers of males and females within each age category (i.e. 40–49 years, 50–59 years, 60–69 years etc.), it was not always possible. For example, there were few individuals over the age of 90 years. It would also have been desirable to assess whether occupation affects the rate of ageing and/or skeletal degeneration, unfortunately records on individual occupations were not available (or did not exist).

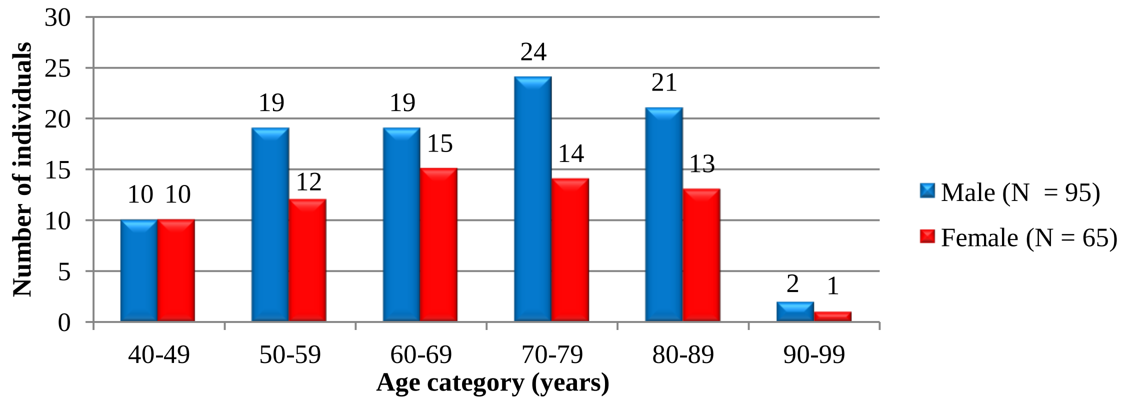


Figure 4.3: *Summary of individuals in the HTH study sample (N = 160).*

4.3 PRETORIA BONE COLLECTION (PBC), SOUTH AFRICA

4.3.1 INTRODUCTION

The Pretoria Bone collection is a very modern collection comprised of individuals who died in the later part of the 20th century. These individuals are all of known age, sex and racial affinity, and are held in the Department of Anatomy at the University of Pretoria, Pretoria, South Africa. Many of the assessed white individuals displayed signs of medical intervention (e.g. hip and knee replacements, pinned fractures, and dental work). The collection is constantly being added to at a rate of approximately 50 skeletons a year from the medical school dissection halls (L'Abbé et al., 2005; Van der Merwe et al., 2006).

4.3.2 HISTORICAL BACKGROUND

The Pretoria Bone Collection began in 1943, to provide skeletal remains as study material for medical, dental and health care students (L'Abbé et al., 2005). Up to the year 2005, almost 6500 cadavers had been received by the Department of Anatomy at the University of Pretoria for the collection, bodies originating either by donation or as an unclaimed body. Not all individuals are complete and have been categorised as complete skeletons, complete skulls, incomplete skulls, complete postcranial and incomplete postcranial remains (L'Abbé et al., 2005). Male and female individuals of all ages are present of both black and white ancestry, although young black males predominate. The South African black individuals reflect a lower socio-economic status compared to the South African whites, whom are from middle to higher socio-economic classes and donated their remains (Steyn et al., 2010). White individuals are most numerous over the age of 50 years.

The individuals included in this study (i.e. white individuals over the age of 40 years) were investigated for any evidence of their ages having been estimated (i.e. dominance of ages ending in

"0" or "5"). As Figure 4.4 illustrates, of the 215 skeletons in the Pretoria Bone Collection fitting the needed criteria, there is no clear evidence of age rounding. Although the last digit of the ages (i.e. 0–9) varied with frequency of use, ranging from 6.5% (i.e. ages ending in "9") to 14.4% (i.e. ages ending in "7"), there is no clear distinction that an integer is markedly used more than any other, as was observed in the HTH collection (see Figure 4.2).

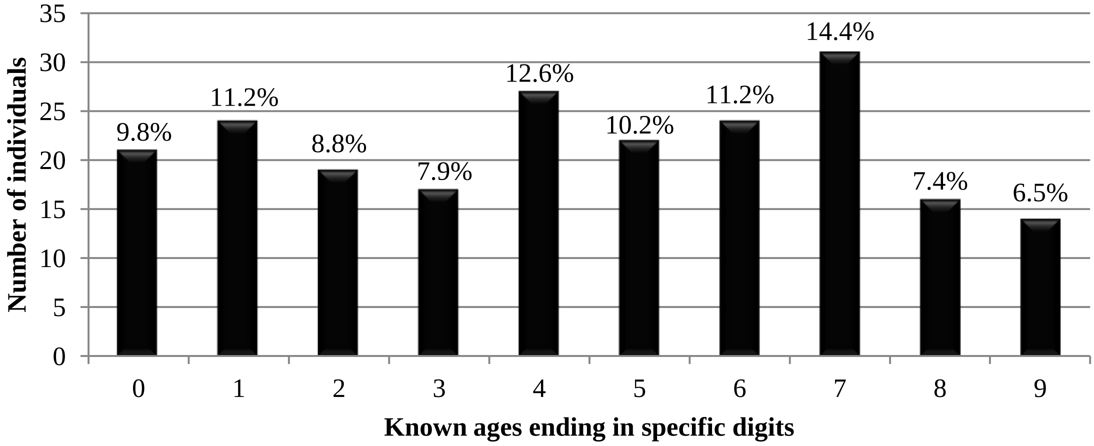


Figure 4.4: *Prevalence of Pretoria Bone Collection ages (40+ years, N = 215) ending in specific numbers.*

4.3.3 LIMITATIONS OF THE SAMPLE

Modern autopsy practices inhibited the study of some required skeletal elements, primarily those of the chest (i.e. sternal portions of the first ribs and clavicles, manubrium and sternum). Portions of these elements were commonly severed by autopsy saws or were completely absent. The people comprising the Pretoria assemblage were fully immersed in a medical society, complete with antibiotics to fight infections, and stainless steel to replace failing hips. Such medical intervention limited and altered the expression of degenerative traits of the acetabula. Also, as the majority of the white individuals in this collection were donated, there were few skeletons available for study aged between 40 and 60 years, and older than 90 years at the time of death. Lastly, information pertaining to the occupation does not exist for this skeletal collection.

4.3.4 DEMOGRAPHY OF THE STUDY SAMPLE

When the collection was visited for a four week period (17th January–11th February, 2011), the Pretoria Bone Collection contained a total of 215 complete (cranial and post-cranial remains present) white documented skeletal individual over the age of 40 years. All of these individuals were studied during the course of this research. The sample comprised 127 males with ages-at-death ranging from 40–94 years (mean age, 70.2 years) and 88 females, ranging between 42–94 years (mean age, 72.9 years). Figure 4.5 shows the age composition of the sample in more detail.

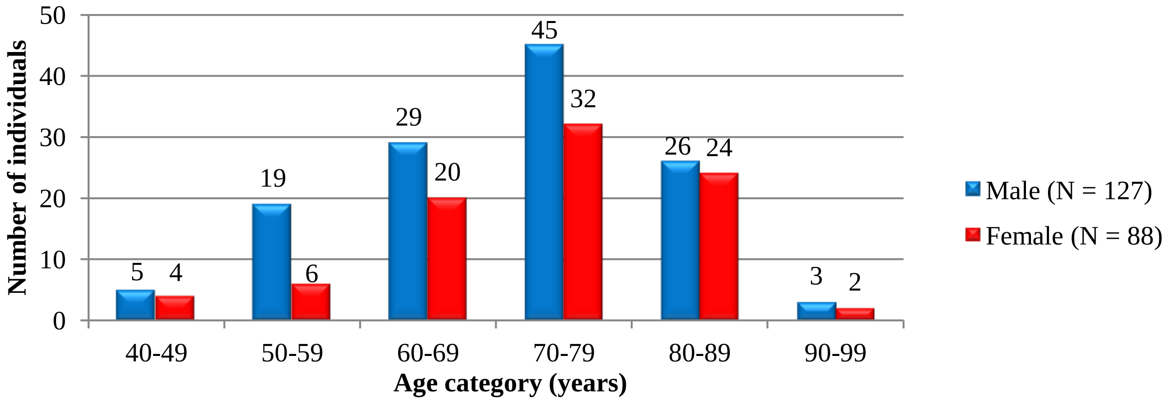


Figure 4.5: *Summary individuals in the PBC study sample (N = 215).*

4.4 ST BRIDE'S DOCUMENTED SKELETAL COLLECTION (SB), UK

4.4.1 INTRODUCTION

The St Bride's documented collection is housed in the crypt of St Bride's Church, Fleet Street, London, England. The assemblage is comprised of 227 individuals who died between AD1740 and AD1852. Of these, 153 were over the age of 40 years at the time of death (78 male, 75 female). This collection was visited for a two week period (4th–15th April, 2011), during which a total of 80 individuals were assessed. Not all 153 adult individuals were able to be examined, due largely to the incompleteness or poor preservation. As it is not as modern as the assemblages previously visited, this collection provided an essential comparison between modern and past populations. Although not strictly archaeological, these individuals lived in a time before medical intervention was common practice (both surgical and chemical).

4.4.2 HISTORICAL BACKGROUND

These crypts were in use for approximately two hundred years, and sealed along with all the other crypts in London following an 1854 cholera epidemic, when all burials within the city churches were outlawed (Litten, 1991; Scheuer and Black, 1995). It was feared within the community that the dead were still able to infect the living, resulting in all subsequent human burials to occur outside of the city walls (Litten, 1991). The crypts under St Bride's, as well as their inhabitants, appeared to have been forgotten over the subsequent decades until their discovery following the bombing. St Bride's church was severely damaged in World War II following bombing during the Blitz in 1940. The lead coffins containing these individuals were discovered while investigations of the foundations were undertaken during the rebuilding process. These long-forgotten crypts of St Bride's Church were once again uncovered and excavated (Milne, 1997).

Of the nearly 300 individuals recovered, 227 skeletons were excavated from their coffins (Litten, 1991; Scheuer and Black, 1995). In association with the triple shell coffins, lead coffin plates were recovered, which later served as the primary source of identification and other personal details for the interred skeletal remains (Scheuer and Black, 1995). Surname, forename(s), sex (inferred from name), date of birth and date of death were documented on the coffin plates. Additional information as to the cause of death, place of burial within the church itself or the churchyard, parish member who performed the burial service, employment, address of habitation, and, to a limited extent, family members, were obtained from the Parish Records and International Genealogical Index (Forbes, 1972; Scheuer and Black, 1995). This information was held at the Guildhall Library. The most commonly stated causes of death were identified as: debility, decline, and consumption (Forbes, 1972:21). This very unusual assemblage of individuals, and priceless information, later allowed for the production of a documented skeletal collection.

4.4.3 LIMITATIONS OF THE STUDY SAMPLE

The varying state of preservation observed within the St Bride's individuals was a key limitation. Interment in lead coffins contributed to the overall presence of dried soft tissue and hair, which hindered assessment of many aspects of the cranium, primarily. Variable degrees of preservation of cortical bone and trabecular bone also limited the individuals and skeletal elements that were suitable and available for assessment.

These individuals may be of higher social status than other documented skeletal collections, due to the costly manner of their burial (i.e. in lead coffins within a crypt). The documented occupations also suggest affluence. In addition to merchants, printers, jewellers, and "licenced victular" other jobs were "Gentleman", "Govenor of the Bank of England", "Sherif of London and Middlesex" and "Lord Mayor of London 1823-1824". Unfortunately, occupations were only recorded for the male individuals.

To ensure the accuracy of recorded observations, the SB individuals meeting the criteria for this study were also investigated for evidence of age rounding. It is acknowledged that it is not expected that an equal number of individuals are present with ages ending in each integer. As is depicted in Figure 4.6, and as was found with the PBC sample, a more even distribution of ages was present in the SB individuals over the age of 40 years. This suggests the documented ages were likely not estimated or rounded.

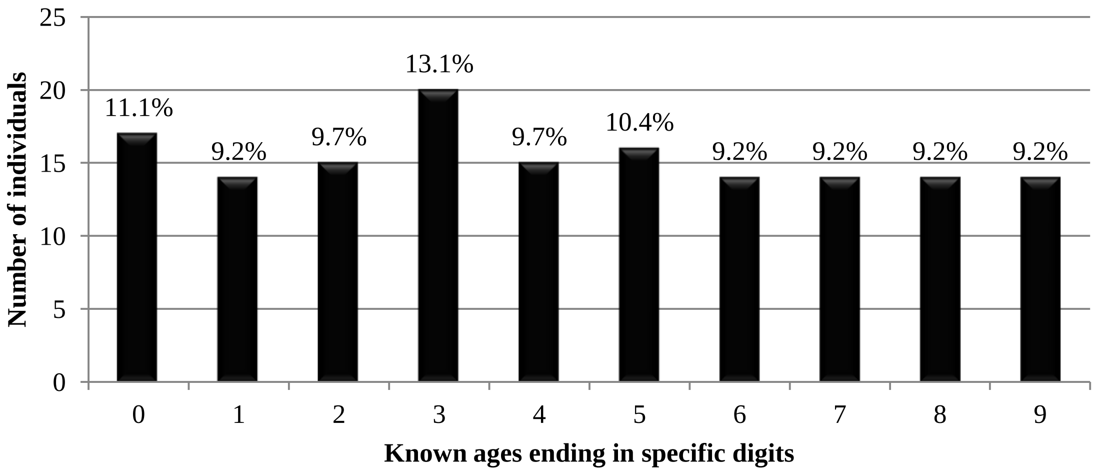


Figure 4.6: *Prevalence of SB ages (40+ years, N = 80) ending in specific numbers.*

4.4.4 DEMOGRAPHY OF THE STUDY SAMPLE

The sample comprised 40 males with ages-at-death ranging from 41–88 years (mean age, 64.2 years) and 40 females, ranging between 42–91 years (mean age, 64.8 years). Figure 4.7 shows the age composition of the sample in more detail.

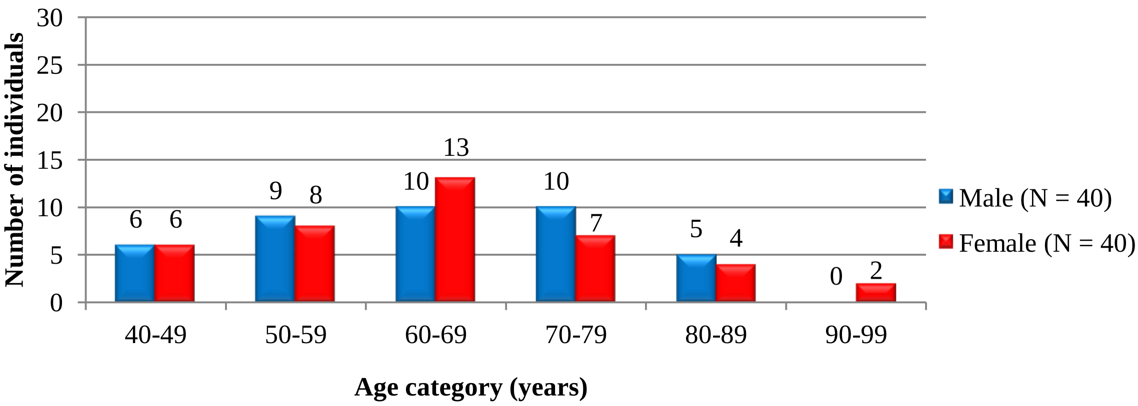


Figure 4.7: *Summary of individuals in the SB study sample (N = 80).*

4.5 COIMBRA HUMAN IDENTIFIED OSTEOLOGICAL COLLECTION (CHC), PORTUGAL

4.5.1 INTRODUCTION

The Coimbra Human Identified Osteological Collection is comprised of individuals who were buried during the late 19th and early 20th centuries. The remains are housed in the Anthropology Museum in the Department of Anthropology at the University of Coimbra. The collection was visited for a three week period between 19th September and 7th October, 2011.

4.5.2 HISTORICAL BACKGROUND

The collection comprises 505 individuals (both adults and non-adults, ranging ages from 7 years to 96 years), for whom existing records provide details on, amongst other things, dates of birth and death, cause of death and occupation. The vast majority of individuals are Portuguese, who were born between AD1826 and AD1922, and died between AD1904 and AD1936, again in the pre-antibiotic era (Santos and Roberts, 2001). The collection was first started by Professor E. Tamagnini between AD1915 and AD1942, after being given permission by the city council of Coimbra to expand an already existing non-documented skeletal collection at the university by adding 498 unclaimed individuals excavated from the largest cemetery in Coimbra (called Cemiterio da Conchada) (Rocha, 1995). A further seven individuals were collected following dissection from the anatomical museum at the university.

Occupations are known, and suggest that these individuals were of low socio-economic status, for example farmers, servants, housekeepers, housewives, workers, soldiers and artisans. Infectious and contagious diseases (e.g. tuberculosis) were the cause of approximately 40% of adult deaths, followed by circulatory and heart disease, and respiratory disease (Coqueugniot and Weaver, 2007; Silva et al., 2009).

To ensure the accuracy of recorded observations, the CHC individuals meeting the criteria for this study were also investigated for evidence of age rounding. As with the PBC and SB samples, a generally even distribution of ages was present in the CHC individuals over the age of 40 years (Figure 4.8). Ages ending in “0” and “5” were slightly elevated, although not to the extent of the HTH collection (see Figures 4.1 and 4.2), however, there is the possibility the known age was rounded to the nearest decade (i.e. 50 years, 60 years, 70 years etc.).

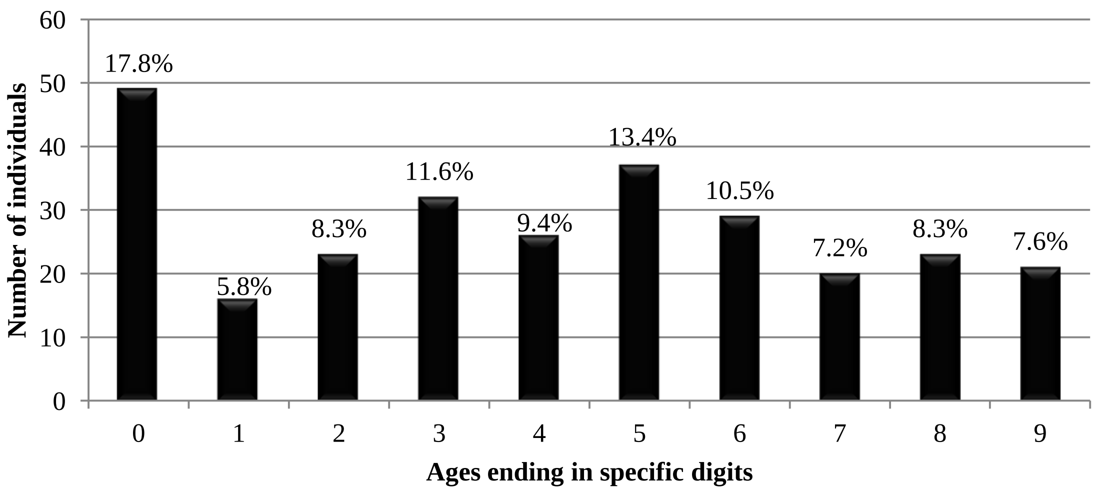


Figure 4.8: *Prevalence of Coimbra ages (40+ years, N = 175) ending in specific numbers.*

4.5.3 LIMITATIONS OF THE SAMPLE

As these individuals were recovered from a cemetery context, it provided the natural age ranges expected for the cross-section of the population. This included the general pattern of deaths of males occurring younger than the females, and few males over 75 years. The excellent preservation of the cranial remains also hindered the assessment of arachnoid granulations in this study sample.

4.5.4 DEMOGRAPHY OF THE STUDY SAMPLE

A total of 276 individuals in the collection are aged 40 years or older (141 males, 135 females). The study was performed on 175 white individuals aged 40+ years. The sample consists of 91 males with ages-at-death ranging from 40–96 years (mean age, 61.6 years) and 84 females, ranging between 40–95 years (mean age, 65.4 years). Figure 4.9 shows the age composition of the sample in more detail. Time constraints limited the number of individuals that could be assessed.

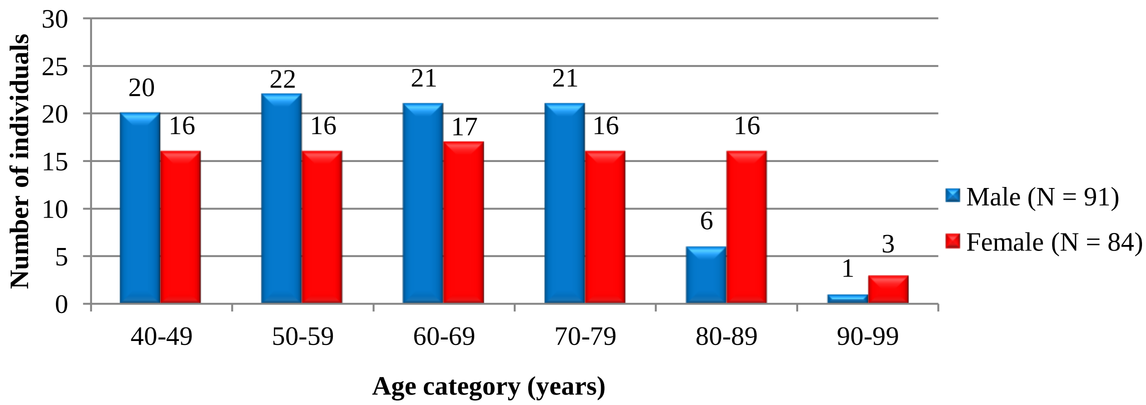


Figure 4.9: *Summary of individuals in the CHC study sample (N = 175).*

4.6 CHRIST CHURCH, SPITALFIELDS (CCS), UK

4.6.1 INTRODUCTION

The documented skeletal collection from Christ Church, Spitalfields is held at the Natural History Museum, London. The burials date to the 18th and 19th centuries. A total of 90 individuals were examined during the course of the blind test of ageing methods, undertaken over a one-week period (16th–20th April, 2012).

4.6.2 HISTORICAL BACKGROUND

Christ Church was consecrated in AD1729, and allowed people to be buried in the vaults of the crypt until AD1859. The crypt was sealed in AD1867, at which time contained the remains of over 1000 interments (Molleson and Cox, 1993:9). The church was neglected for many years and the building fell into disrepair. In 1981 it was decided that restoration of the church would require the crypt would have to be cleared of all burials (Molleson and Cox, 1993). Excavations of the crypt at Christ Church Spitalfields took place between October 1984 and April 1986, with extensive post-excavation analyses from 1986 to 1993.

A total of 968 skeletons were recovered from individual coffins. The overall preservation of the remains varied between contexts, with some bodies complete (i.e. hair, tissue, internal organs still present), to having no remaining bone.

A total of 387 (40.0%) individuals provided some form of personal identification (Molleson and Cox, 1993). Coffin plates recorded names and ages, and whenever possible, steps were taken to ensure coffin plates were associated with the correct skeletons. This unusual relationship between documented age and sex and skeletal remains allowed the study of skeletons of known individuals, and subsequent historical investigations of biographical details of their lives (Molleson and Cox, 1993). Extensive analysis of both the named and anthropological samples (i.e. those without coffin plates) took place.

Of the 968 complete skeletons excavated from Christ Church, Spitalfields, 387 individuals comprise the named sample. These individuals had known age-at-death recovered from coffin plates (in the crypt). Documented dates of death spanned AD1729 to AD1852. Of these, 63.6% (N = 246; male, N = 118; female, N = 124; unsexed, N = 4) were aged over 40 years at the time of death. These were primarily the remains of Huguenot refugees of French ancestry, who worked in the silk trade. Socio-economic status was determined through known occupations, in addition to wills, insurance policies, land tax returns and “Company membership” (Molleson and Cox, 1993:197). A total of 237 (61.2% of 387) of the named sample had a known occupation. The most common occupations were in the: silk industry (39.6%), building industry (15.6%) and food retail and manufacture industry (14.0%). Other occupations (broad categories) were artisans (e.g. shop keepers, labourers), master craftsmen (e.g. weavers, cabinet makers), professionals (e.g. in finance, law, medicine, church, public servants), merchants, wholesalers, and independently wealthy (e.g. gentlemen).

For completeness, the known ages for CCS individuals were also investigated for evidence of age rounding. As with the PBC and SB samples, a generally even distribution of ages was present in the CCS individuals over the age of 40 years (Figure 4.10). Ages ending in “0” and “5” were not elevated in comparison to the other digits, suggesting the documented ages were likely not estimated or rounded.

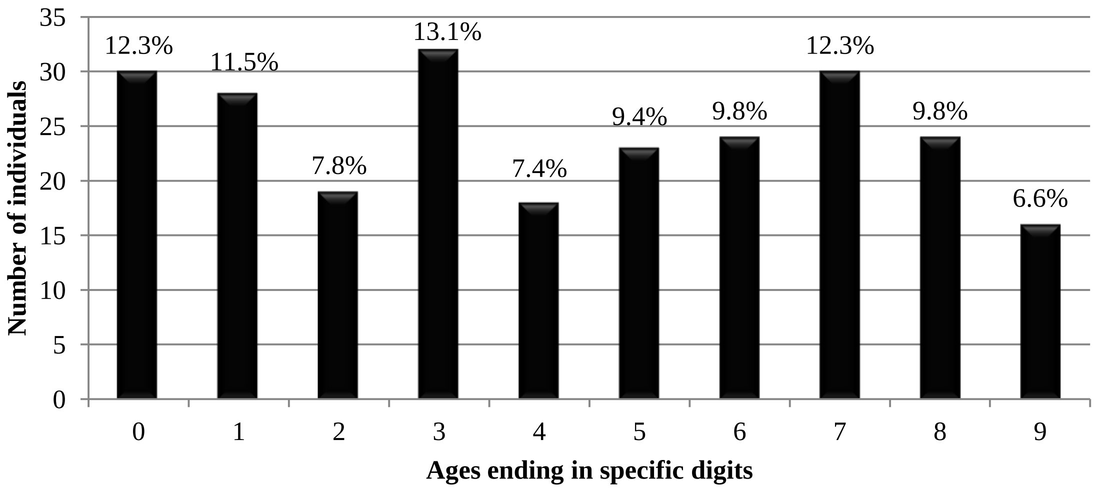


Figure 4.10: *Prevalence of CCS ages (40+ years, N = 244) ending in specific numbers.*

4.6.3 LIMITATIONS OF THE SAMPLE

The state of preservation hindered the assessment of many individuals and skeletal elements for the blind test. Also there were few male individuals over the age of 80 years to blind test the developed methods.

4.6.4 DEMOGRAPHY OF THE BLIND TEST SAMPLE

As the degenerative traits to be tested were developed on individuals with minimum ages of 40 years, the developed criteria could only be applied individuals to whom it was known their ages were 40+ years at the time of death, rather than on a sample displaying the full range of adult ages. A total of 244 individuals in the CCS collection are aged 40 years or older (118 males, 123 females, 3 indeterminate sex). The blind test of methods was performed on 90 individuals over the age of 40 years at the time of death. The sample comprised 50 males with ages-at-death ranging from 40 to 91 years (mean age, 63.7 years) and 40 females, ranging between 44–89 years (mean age, 63.0 years). Figure 4.11 shows the age composition of the blind test sample in more detail.

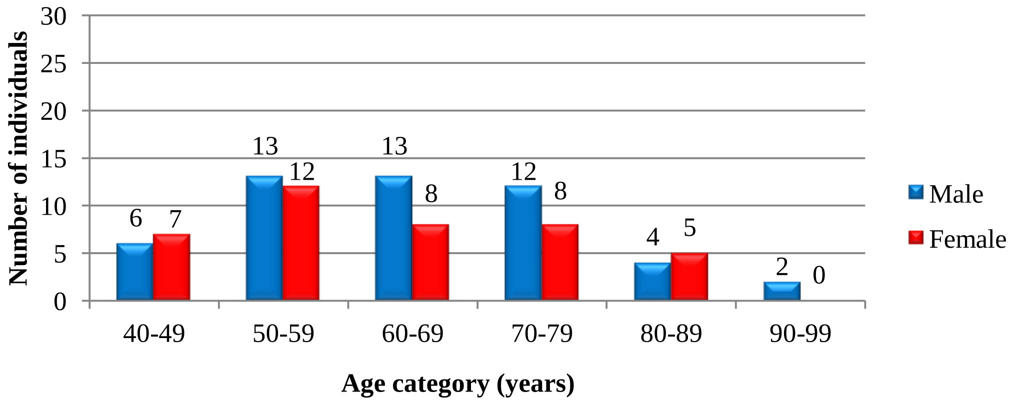


Figure 4.11: *Summary of individuals in the CCS blind test sample (N = 90).*

4.7 REPRESENTATION OF THE SAMPLES

As this research aimed at identifying new regions of the skeleton that display degeneration beyond 40 years of age, it was necessary to examine as many different skeletal areas as possible. It was also important to have as large of a study sample size as possible in order to obtain a true reflection of the amount of skeletal variation in the ageing process. Time constraints imposed by the set amount of time granted to access at each collection limited the final sample size, as did the potential truncation caused by separating the sexes. As a result, only white individuals over the age of 40 years were included in this study, as ancestry has also been shown to affect the rate of skeletal ageing in some methods (e.g. sternal rib ends). It is suggested that different ancestries be an avenue of further research in the future.

In addition to sex and ancestry, several factors contribute to the cause of skeletal variation, such as genetics, environment, nutrition, age, occupation, and disease. Although the influence genetics has on the ageing process cannot be assessed using these reference collection, each skeletal assemblage studied during this research represents a different geographical region (environment), time period (differing living conditions, nutritional status), socio-economic status (linked to occupation, activity, health and nutritional state), and access to medical intervention (disease, general health and nutrition). A summary is provided in Table 4.1.

Table 4.1: *Summary of factors that may contribute to skeletal variation in age expression.*

Collection	Geographical region	Time period (century)	Socio-economic status	Occupations	Medical intervention
HTH	North America	19^{th}–20^{th}	low	homeless	pre-antibiotic era
PBC	Africa	20^{th}	middle-high	affluent	antibiotics, surgery
SB	Europe	18^{th}–19^{th}	middle-high	merchants, printers	pre-antibiotic era
CHC	Europe	19^{th}–20^{th}	low	farmers, labourers	pre-antibiotic era

A summary of the study sample sizes by geographical region is presented in Figure 4.12. The study sample sizes varied between locations, with the number of North American (N = 160) assessed individuals fewer than those from South Africa (N = 215) and Europe (N = 255; SB and CHC combined).

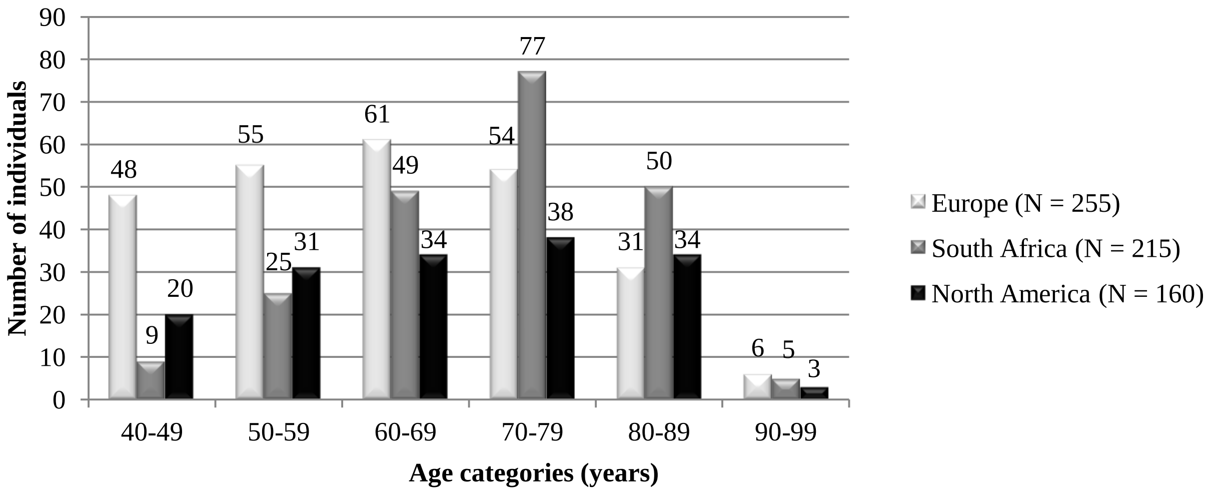


Figure 4.12: *Total number of assessed individuals by geographical region: HTH (North America), PBC (South Africa), SB and CHC (Europe) (N = 630), excluding CCS study sample.*

It is acknowledged that the distribution of ages and the mean age of each study sample will have an effect on the developed criteria. To most efficiently assess the validity of ageing criteria between populations, the study samples should be of equivalent age distributions and mean ages. Male mean ages varied between 61.6 years (CHC) and 70.2 years (PBC), however, the greatest difference in mean age was found in the females of the study samples, which ranged between 55.7 years (HTH) and 72.9% (PBC) (Table 4.2).

Table 4.2: *Summary of mean ages for males and females between study samples.*

Collection	Males				Females			
	HTH	**PBC**	**SB**	**CHC**	**HTH**	**PBC**	**SB**	**CHC**
N	95	127	40	91	65	88	40	84
Mean age (years)	62.0	70.2	64.2	61.6	55.7	72.9	64.8	65.4
Observed age range (years)	42–96	40–94	41–88	40–96	41–93	42–94	42–91	40–95

In attempt to compensate for differences in each individual study sample, the combination of all study samples, where applicable, provided a more robust sample size from which the overall trends of ageing could be assessed. This combined sample will allow the developed criteria to be applicable to a wider array of populations (white individuals of differing graphical location, socio-economic background or health status), as the developed method will not be population specific. This is important when developing ageing criteria for past populations, as these factors that are known to affect the rate of ageing will be unknown in archaeological contexts.

In addition to this, and as was established in the previous chapter, the age composition of the reference (i.e. known age) sample is of the utmost importance when developing ageing techniques, as it has the ability to introduce biases into the final age estimations. Adult ageing methods developed on samples that containing larger numbers of younger adults have been found to result in age estimations that underage older individuals (e.g. pubic symphysis and auricular surface). In contrast to this, it is acknowledged that the use of the truncated age sample used in this study (i.e. 40+ years) will also produce a bias into the derived age estimations, as the age composition of the study samples were heavily skewed towards the older end of the adult age spectrum. It is likely that age estimations produced in the course of this thesis will result in overageing of younger individuals. It is important to note, again, that the main focus of this thesis is to identify new regions of the skeleton that demonstrate increasing degeneration with advancing age, not to develop ageing methods to be applied to all unknown adult skeletons. This fact emphasizes the need for further research to apply the newly developed criteria to reference collections of equally balanced age composition."

4.8 SUMMARY

In summary, a total of 630 white skeletal individuals (40+ years) were examined for ageing criteria during the course of this thesis (excluding the blind test sample). Figure 4.13 summarizes the total study sample. The mean age of the entire sample was 67.2 years (males, N = 353, mean age 66.7 years; females, N = 277, mean age = 67.9 years).

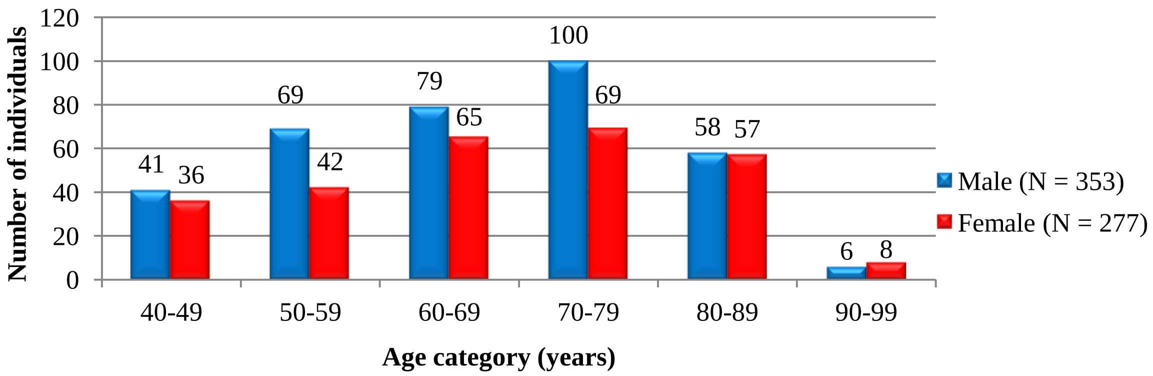


Figure 4.13: *Summary of all individuals assessed in this study (N = 630), by sex.*

The next chapter presents the criteria (i.e. trait expressions, grading scales) employed during the course of this research. Written descriptions and photographs of trait expressions are provided which were used to identify and describe the macroscopic surface morphologies recorded in each study sample. For established methods, tables of published descriptive statistics are supplied, which were used to derive estimates of age.

CHAPTER FIVE
METHODS

5.1 INTRODUCTION

Macroscopic age estimation techniques are the most frequently applied in biological anthropology today (Falys and Lewis, 2011). In contrast to microscopic and radiographic methods, macroscopic ageing techniques are entirely non-destructive, and do not require specialized equipment or money. Given sufficient element preservation, such methods can be applied in any setting, from the time the skeleton is excavated from the burial context through to analysis in a lab-based setting. Age estimations using macroscopic techniques require the practitioner to evaluate published criteria against a skeletal element of unknown age, and ultimately compare and contrast the physical morphology and trait expression. Ease of application relies heavily on personal experience and judgement, making adult age estimation "an art, not a precise science" (Maples, 1989:323). The methods employed during the course of this research were selected with the previous shortcoming in mind. Clear and concise trait expressions, simplified criteria and photographic images (where applicable) were used for comparison for each assessed individual, as a means to limit intra- and inter-observer errors.

As discussed in Chapter 3, several morphological features have been developed for age assessment of the mature human skeleton. The benefit of established techniques are that they are universally available, they are consistently used on archaeological remains, and they have been widely re-evaluated and revised using populations from different geographical locations and time periods. As adult age estimation relies heavily on the researcher's judgement and ability to understand and apply published criteria (Maples, 1989), modifying an already established method may make it easier to apply than a brand new method. This chapter provides the recorded criteria and trait expression examples for each technique and skeletal elements investigated during this study.

The established methods assessed are as follows:

- arachnoid granulations (Barber, 1997),
- degeneration of the cervical spine (Sager, 1969) (note, the original research was not proposed as a formal ageing method),
- first rib (Kunos et al., 1999; DiGangi et al., 2009),
- pubic symphysis (Brooks and Suchey, 1990; Berg, 2008),
- auricular surface of the ilium (Lovejoy et al., 1985b; Buckberry and Chamberlain, 2002),
- acetabulum (Rissech et al., 2006; Rougé-Maillart et al., 2007).

Long held assumptions were also investigated, with the aim of determining if they are justified, and whether they can be quantified or qualified:

- obliteration of cranial sutures,
- antemortem tooth loss,
- ossification of costal cartilages,
- fusion of the manubrium, sternum and/or xiphoid process.

New skeletal regions of study focused on the sites of late-fusing epiphyses and apophyses:

- sternal and lateral ends of the clavicle
- iliac crest
- ischium

In addition, pathologies, such as the presence of diffuse idiopathic skeletal hyperostosis (DISH) were recorded to allow for subsequent analyses of trait expressions. Other pathological alterations, namely hyperostosis frontalis interna (HFI) and button osteoma on the ectocranial surface were also recorded.

As emphasised in the previous chapter, it was essential to maximize the study samples during the data collection phase (e.g. including only white individuals). The choice to focus on those individuals with a minimum known age of 40 years was made to ensure an adequate assessment could be made of the ageing process between individuals of advanced age both within and between populations. It was hypothesized that, if present, degeneration (i.e. change in surface topography, increase in porosity and osteophyte formation) would not begin until after the age of 40 years, and increase in severity with advancing age. The goal was to identify and describe differing stages of degeneration that could be used to identify "elderly" individuals. This choice was made in full acknowledgement that any identified degenerative patterns observed would not result in the production of formal ageing methods that could be applied to any adult skeleton of unknown age. Although assessments of the chronological ages of expression would ultimately be linked to stages of increasing skeletal degeneration within the truncated study samples, inclusion of younger adults in the samples will alter the descriptive statistics for each stage. It is acknowledged that any derived age estimations using a 40+ year old reference sample will be skewed towards the older end of the age spectrum, which has the strong possibility, in their current state, to overage younger individuals.

Although it was known at the time of analysis that each skeleton under study had a minimum age of 40 years, the exact age-at-death was not. Each of the proposed sites of degeneration was examined for each skeleton, and both the left and right elements, where applicable. The methods were applied and recorded in the same order for each individual (i.e. skull, clavicle, first rib, manubrium, sternum, xiphoid process, cervical vertebrae, auricular surface, pubic symphysis, acetabulum, ischium). An example of the recording form is presented in Appendix 1.

Due to vast quantity of information recorded, not all skeletal regions could be included. Although information was also recorded for the cranial sutures and pathology (i.e. HFI and button osteoma), dentition, first rib, ossification of the costal cartilage and the acetabulum, following the data collection stage, it was decided that the main focus of this thesis would be on the development of new ageing criteria based on degeneration of the postcranial human skeleton through the presence and severity of the three degenerative traits: changes in the surface topography (texture and contour), porosity, and osteophytic lipping. Of the numerous established methods and long held assumptions recorded, only the Barber (1997) arachnoid granulation method, the pubic symphysis methods (Brooks and Suchey, 1990; Berg, 2008), the auricular surface techniques (Lovejoy et al., 1985b; Buckberry and Chamberlain, 2002) were included in the final study.

This chapter provides the criteria recorded for each method included in the current study. Written descriptions, scoring systems and photographs of trait expressions are provided for the established methods (i.e. arachnoid granulations, cervical spine degeneration, and metamorphosis of the pubic symphysis and auricular surface), and the developed criteria (i.e. clavicle, manubrium, iliac crest, auricular surface ankylosis, and ischial tuberosity).

5.2 ESTABLISHED AGEING CRITERIA

The established ageing methods employed during the course of this research were of two different natures. Some associate and interpret physical traits of degeneration with chronological age (arachnoid granulations, pubic symphysis, and auricular surface). Other techniques are more descriptive, detailing how degeneration of specified skeletal regions progress with advancing age, but do not attempt to relate observed surface appearances with a specified chronological age (cervical spine).

5.2.1 ARACHNOID GRANULATIONS

The number of arachnoid granulations on the endocranial surface of the parietal bones were counted following the criteria detailed in Barber (1997:175). The total number of pits and depressions counted for the left and the right parietal bones are added together to form the total number of pits and depressions present on the parietal bones of each individual. This composite score was used to calculate age following the equation: **age = 43.7 + 4.45*(total score of pits and depressions)**

Barber (1997:175) defines pits as “small indentations of varying depth which tend to be deeper than they are wide. The bottom of the pit is usually uneven, often with smaller pits inside it”. They can vary in shape and depth. Depressions "are larger indentations, wider than they are long. They can be felt easily with the finger, and do not normally contain smaller pits inside them". They may not always be visible, sometimes they can only be felt. As a result, they are more difficult to count than pits.

Barber (1997:175) found that arachnoid granulations are "individual clusters of calcified villi […] this method proposes that each definable cluster of villi, regardless of shape or size, be counted / scored as 1". So in cases where arachnoid granulation pits and depressions occurred in clusters, each definable cluster was counted as a single arachnoid granulation (given a value of 1) (Figure 5.1).

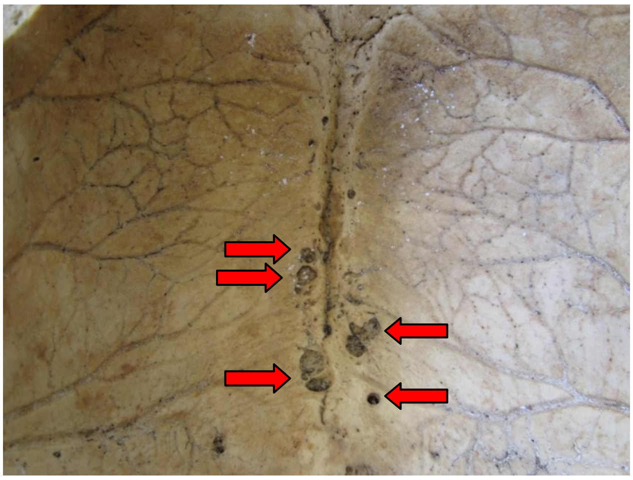


Figure 5.1: *Clusters of arachnoid granulation pits (arrowed) on the parietal bones. Each cluster counted as a single arachnoid granulation. Total score of pits and depressions is 5.*

5.2.2 CERVICAL SPINE

The degenerative changes in the cervical spine were recorded using criteria loosely based on the previous suggestions of Sager (1969). The Sager (1969) study provided a descriptive view of the degenerative changes to the cervical vertebrae, detailing how these alterations progressed with advancing age. It is important to note that the findings of the research performed by Sager (1969) were not intended to be an osteological ageing technique, and did not attempt to relate observations to chronological age.

As suggested by Sager (1969), changes of porosity, osteophyte formation and presence of eburnation were recorded on several aspects of the cervical vertebrae:

- **First cervical vertebra**: the dens facet, and superior and inferior articular facets.
- **Second cervical vertebra**: the dens (e.g. Figure 5.2), the superior and inferior articular facets, and the body.
- **Third, fourth, fifth, sixth, seventh cervical vertebrae**: generalized assessments of the superior and inferior articular facets, and superior and inferior aspects of the bodies.

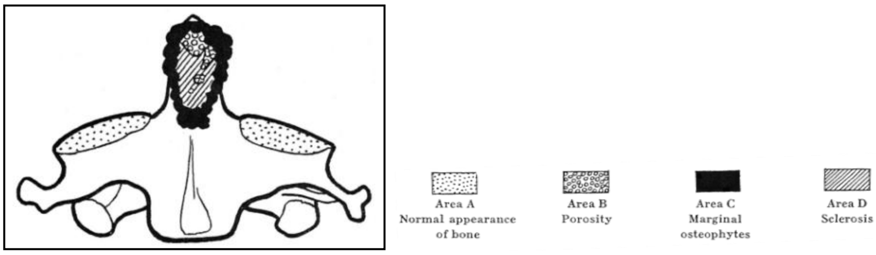


Figure 5.2: *Example of dens recording by Sager (1969:81).*

Photographs of all trait expressions can be found in Appendix 2, although Table 5.1 and Figure 5.3 provide examples of how traits were recorded.

Table 5.1: *Recording criteria for the cervical vertebrae (articular facets and bodies: C1, C2, C3-C7).*

Score	**Porosity**	**Osteophytes**	**Eburnation**
0	element not present	element not present	element not present
1	no porosity	no osteophytes	no eburnation
2	microporosity	slight osteophytes	eburnation
3	macroporosity	severe osteophytes	-
4	joint fusion	joint fusion	-

Figure 5.3a-c: *Porosity trait recording on facet of the dens process on the second cervical vertebra (axis). a) score of 1, no porosity; b) score of 2, microporosity; c)score of 3, macroporosity.*

5.2.3 PUBIC SYMPHYSIS

Two established methods for assessment of the pubic symphysis were recorded: Brooks and Suchey (1990), and Berg (2008). The Suchey-Brooks method provides criteria for all adult ages, while the study published by Berg (2008) revises the older phases of pubic symphysis degeneration in order to allow estimates of advanced age. Both methods were evaluated for their ability to accurately estimate age over 40 years.

5.2.3.1 Suchey-Brooks Method

Criteria used for this study were the Suchey-Brooks (1990) method and sex-specific casts (Suchey et al., 1988) (Figures 5.4 and 5.6), with associated written descriptions (Brooks and Suchey, 1990:232-233), and table of descriptive statistics used to derive age estimations (Brooks and Suchey, 1990:233) (Table 5.2). Additional observations as to porosity (micro- and macroporosity) and surface new bone formation were also recorded. Sample photos of male criteria are presented in Figure 5.5.

Figure 5.4: *Drawings of Suchey-Brooks (1990) pubic symphysis phases I to VI for males, from Buikstra and Ubelaker (1994:24).*

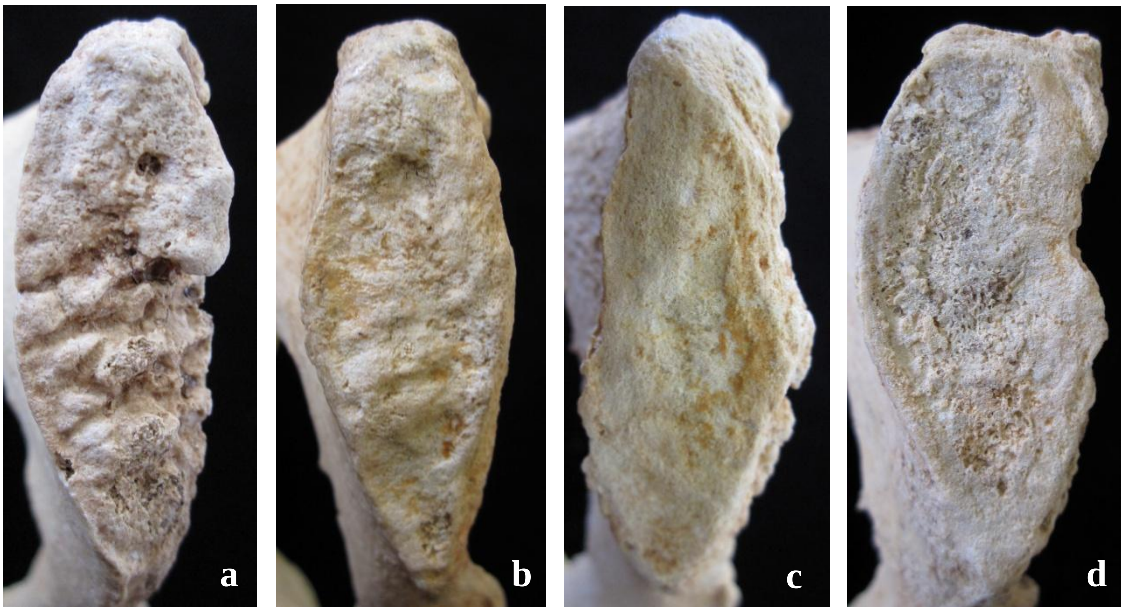


Figure 5.5a-d: *Examples of pubic symphysis phases on pubic bones of male individuals from studied samples. a) Phase I; b) Phase III; c) Phase V; d) Phase VI.*

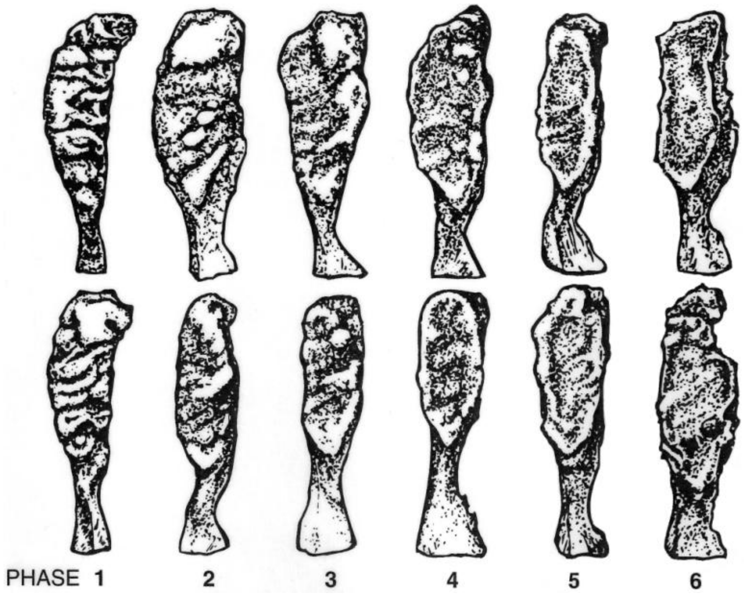


Figure 5.6: *Drawings of Suchey-Brooks (1990) pubic symphysis phases for ageing females, from Buikstra and Ubelaker (1994:23).*

Table 5.2: *Descriptive statistics used to derive age estimates from the Suchey-Brooks (1990:233) pubic symphysis system.*

Phase	Female (N = 273)			Male (N = 739)		
	Mean age (years)	S.D.	95% Range (years)	Mean age (years)	S.D.	95% Range (years)
I	19.4	2.6	15 – 24	18.5	2.1	15 – 23
II	25.0	4.9	19 – 40	23.4	3.6	19 – 34
III	30.7	8.1	21 – 53	28.7	6.5	21 – 46
IV	38.2	10.9	26 – 70	35.2	9.4	23 – 57
V	48.1	14.6	25 – 83	45.6	10.4	27 – 66
VI	60.0	12.4	42 – 87	61.2	12.2	34 – 86

5.2.3.2 Berg (2008) Phase VII

The Berg (2008) pubic symphysis criteria was developed primarily for female individuals in forensic contexts, however, it was loosely investigated for its ability to age both sexes from archaeological settings. Each pubic symphysis was recorded following the Suchey-Brooks cast system, however, the validity of aspects of the revised pubic symphysis Phases V to VII suggested by Berg (2008) were also investigated (Figure 5.7). Only the morphological aspects of this method were applied, as part of the Berg (2008) criteria is based on “weights” of the elements to determine the extent of osteopenia or osteoporosis of the bone. As preservation has the ability to alter the weight of bone in archaeological contexts, the weight of the bone was not included in this study. Also deviating from Berg’s (2008) method, the surface morphological criteria was applied to both sexes, not just females. Berg’s (2008) ideas were simply used to examine other aspects of pubic symphyseal degeneration, beyond those proposed by Brooks and Suchey (1990).

By not taking into account the weight of the bone, identification of Phase V remained the same as the Suchey-Brooks method. Differentiation between revised phases VI and VII relied on the quality of surface bone (i.e. compact bone) by the amount surface (macro)porosity and general erosion of the symphyseal face, as the degree of lipping around the rim was deemed by Berg (2008) to be highly variable, as it may be mild, moderate or severe. Phases were determined based on the following criteria (Berg, 2008:574–577):

- **Phase VI:** "The quality of bone on the articular surface is breaking down, no longer retaining the smooth, compact surface. The symphyseal face is eroded, in the form of either porosities or small channel-like structures—coalescences of smaller porosities into oblong pores or channels…Lipping of the articular surfaces can be present. Decision-making traits are: (i) less than 50% of the symphyseal surface is porous, and (ii) lipping is mild to moderate then it is scored as a phase VI".

- **Phase VII**: "The symphyseal face is extremely porous and eroded with >50% of its surface…The symphyseal face appears to be relatively flat, since the rim is highly eroded and is losing definition. The ventral surface of the symphysis is typically scarred or has striated bone with ligamentous outgrowths, occurring typically near the obturator foramen. Lipping of the articular surfaces is often moderate, but may be mild or severe. This character is highly variable".

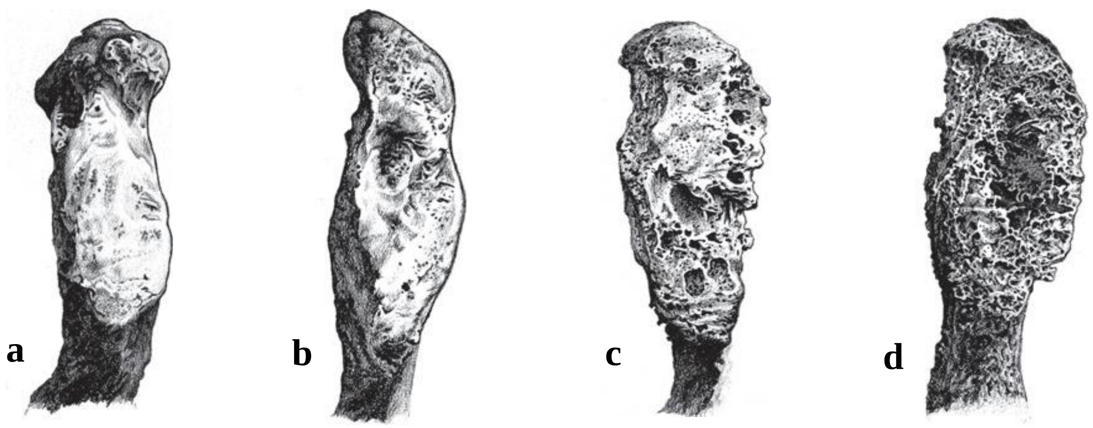


Figure 5.7a-d: *Drawings of Berg (2008:575) pubic symphysis phases a) V, b) VI, c) and d) VII for age determination of females.*

For age estimation of females, Berg (2008) suggests that individuals in Phase V are in the early 50s, while the revised phase VI is said to occur in females in their mid 50s to mid 60s, and new Phase VII only occurs after the mid 70s. Age estimates were not published for male individuals.

5.2.4 AURICULAR SURFACE OF THE ILIUM

Recording criteria for the auricular surface of the ilium followed the metamorphosis phase system published by Lovejoy et al. (1985b), as well as the quantitative description system proposed by Buckberry and Chamberlain (2002).

5.2.4.1 Lovejoy et al. (1985b) Metamorphosis of the Auricular Surface

The original ageing method produced for the auricular surface involves a complex assessment of interacting degenerative processes displayed by several aspects of the auricular surface (Figure 5.8). The phase system used to derive age estimations is provided in Table 5.3.

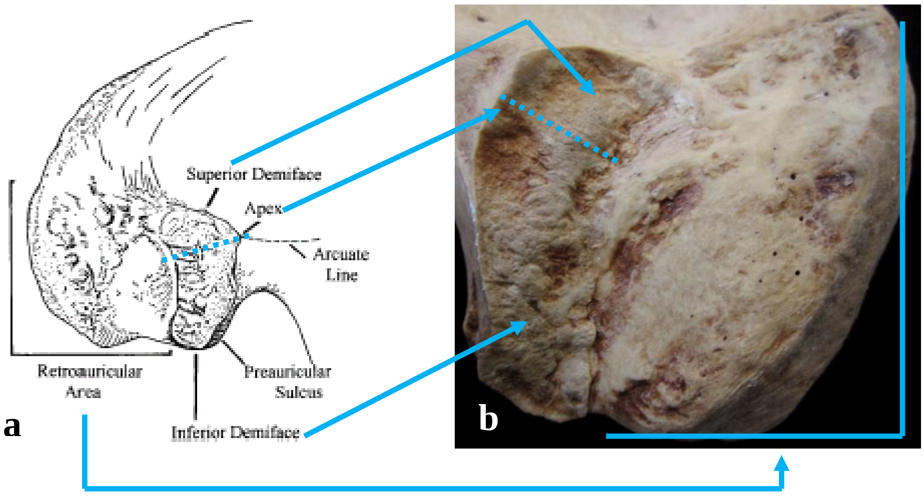


Figure 5.8a-b: *Comparison of auricular surface features. a) Original drawing published by Lovejoy et al. (1985b:18). b) Photograph of an auricular surface. Note, superior and inferior demifaces separated by the dotted line.*

Ageing causes the surface changes in granularity, billowing, density, microporosity, macroporosity, and osteophyte formation, and are summarized in Table 5.3.

Table 5.3: *Ageing trends demonstrated by the auricular surface (Lovejoy et al. (1985b:21-27).*

Age range	Description
20–24 years	Well-defined billowing/marked transverse organization and very fine granularity. Complete absence of retro-auricular activity, apical activity or porosity.
25–29 years	Reduction of billowing, replaced by striae. Granularity is slightly more coarse. Overall retention of youthful appearance. No apical activity, porosity or retroauricular activity.
30–34 years	General loss of billowing, replacement by definite striae, distinct coarsening of granularity, areas of microporosity, and slight retroauricular activity. No apical changes.
35–39 years	Uniform coarse granularity on both demifaces, no billowing, but striae present, transverse organization is present, but poorly defined, slight retroauricular activity, microporosity, and apical changes.
40–44 years	No billows or striae present, transition from coarse granularity to dense surface; this may take part over islands of the surface or one or both faces. Retroauricular changes can be slight to moderate, while apical changes remain slight. An increase of microporosity is seen, along with occasional macroporosity.
45–49 years	Completion of densification with complete loss of granularity and microporosity. No billows or striae are present, although apical changes are almost always present (slight to moderate). Moderate retroauricular activity is noted, with little macroporosity.
50–59 years	No forms of transverse organization remain. The surface is dense and irregular. Rugged topography is present with moderate to marked apical and retroauricular activity. Macroporosity may or may not be present.
60+ years	Breakdown with marginal lipping, macroporosity, increased irregularity, and marked activity in the apical and retroauricular areas. Transverse organization remains absent.

5.2.4.2 Buckberry and Chamberlain's (2002) "Revised" Auricular Surface Method

Buckberry and Chamberlain (2002) developed a quantification method of assessing the surface degeneration of the auricular surface, in attempt to ease the application of the Lovejoy et al. (1985b) technique. By providing numerical scores for each trait expression (see Table 5.4), a composite score can be produced that is linked to a chronological age-at-death. This correlation will be population-specific, and derived in the results chapter. Photographic examples of trait expressions and composite scores can be found in Appendix 3.

Table 5.4: *Revised auricular surface method criteria (Buckberry & Chamberlain, 2002:233-234).*

Morphological feature	Appearance/ related score
Transverse organization	1 = >90% of the surface shows transverse organization 2 = 50-89% of the surface is organized 3 = 25-49% of the surface is organized 4 = <25% of the surface is organized 5 = No transverse organization present
Surface texture	1 = >90% of the surface is finely granular 2 = 50-89% finely granular, some coarse granulation present 3 = >50% of the surface is coarsely granulated 4 = <50% of the surface shows dense bone 5 = > 50% of the surface shows dense bone
Microporosity (pores have diameter <1mm)	1 = None present 2 = Present on 1 demifacet only 3 = Present on both demifacets
Macroporosity (pores have diameter >1mm)	1 = None present 2 = Present on 1 demifacet only 3 = Present on both demifacets
Morphological change of the apex	1 = Apex is sharp and distinct 2 = Some lipping at apex 3 = Irregularity in surface, shape is not a smooth arc.

5.3 DEVELOPED AGEING CRITERIA

The following criteria have been developed for this thesis. For consistency, descriptive terminology is used that is commonly present in other ageing techniques, with the goal of easing method application for other researchers. Part of this research is to establish whether these developed ageing criteria do indeed progress with advancing age. It also aims to establish whether these physical traits can be correlated with chronological age, or whether the criteria can only be used more broadly to distinguish the very old.

5.3.1 CLAVICLE

The developed criteria aims to quantify the presence of degenerative change, and is to be applied to both the lateral (acromio-clavicular joint) and sternal (manubriosternal) ends of the clavicle. The change in surface topography and amount of porosity are graded on a 6-point scale, while osteophyte formation is scored on a 4-point scale, see Table 5.5.

Table 5.5: *Summary of degenerative traits recorded, their degrees/scores of severity.*

Score	Topography	Porosity	Osteophyte formation
0	element not present	element not present	element not present
1	smooth	no porosity	no osteophytic growth
2	slight granulation	microporosity (<50% surface)	slight osteophytes
3	coarse granulation	microporosity (>50% surface)	moderate osteophytes
4	nodule formation	macroporosity (<50% surface)	severe osteophytes
5	billowing	macroporosity (>50% surface)	-
6	degeneration/eburnation	complete surface breakdown	-

Definitions for Table 5.5, used throughout:

- **Surface topography** describes the general texture and contour of the surface under study.
    - slight granulation: the surface texture of the bone is that of fine sand paper, a slightly roughened surface.
    - coarse granulation: very small grains of bone form on the surface, which resemble coarse sand. The texture of the bone's surface is very rough, like sandpaper.
    - nodule formation: small rounded lump(s) of bone develop on the flat surface. These nodules appear to eventually also degenerate, leaving areas of macroporosity.
    - billowing: a change in the topography from smooth and flat to an irregular and undulating surface, resulting from development of ridges, severe nodule or osteophyte formation. The outline of the surface also becomes irregular.
    - degeneration: the surface displays complete breakdown (dense, much porosity, osteophyte growth) and has irregular contours. In many instances, the bone takes on the appearance of honeycomb, with extensive macroporosity across the entire surface/joint.

- **Porosity** was recorded following definitions suggested in Lovejoy et al. (1985b:18) and Buckberry and Chamberlain (2002: 233). The percentage of the surface displaying porosity was also recorded (i.e. <50% of the surface affected, and >50% of the surface affected), as suggested in Buckberry and Chamberlain (2002):
    - microporosity: very fine/small perforations (<1mm diameter) of the bone surface.
    - macroporosity: large, more irregular perforations (>1mm) of the bone surface.

5.3.1.1 Lateral End of the Clavicle

The above degenerative traits (Table 5.5) were recorded on two aspects of the lateral end of the clavicle: the lateral surface (acromio-clavicular joint) (Figure 5.9a), and the rim surrounding the lateral surface (Figure 5.9b).

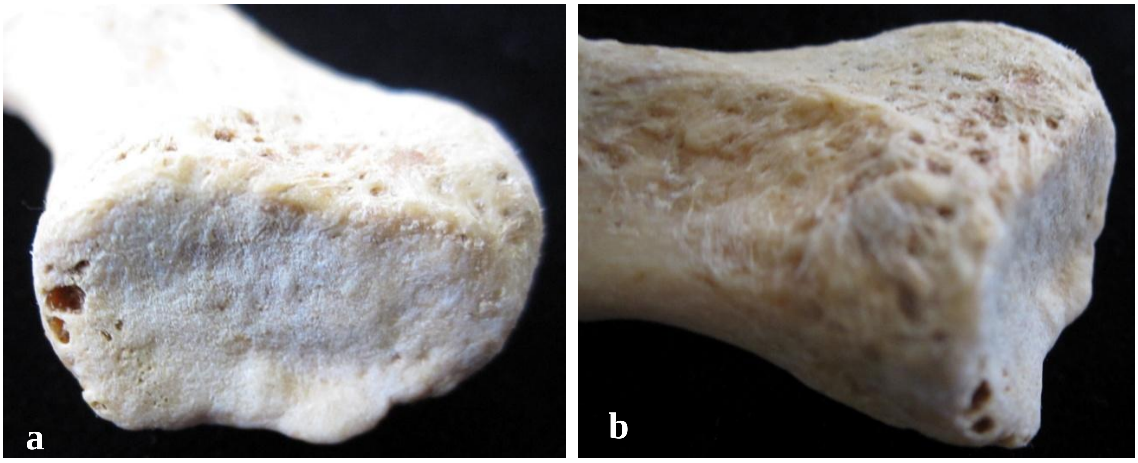
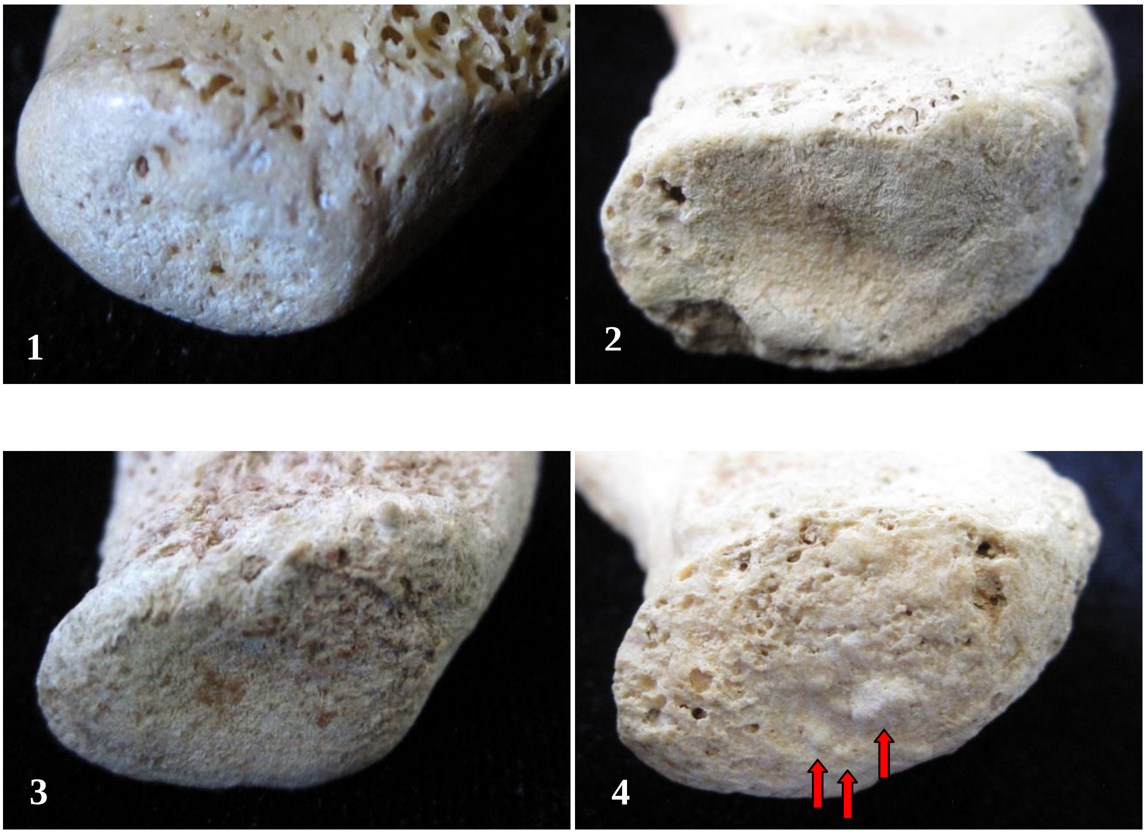


Figure 5.9a-b: *Aspects of the lateral clavicle for which degeneration was recorded. a) acromio-clavicular joint, b) surrounding rim.*

For ease of trait identification, the following photographs were taken during the course of this research, and depict examples of surface topography changes (scores 1–6) observed on the lateral end of the clavicle (Figure 5.10), displays of porosity (scores 1-6; Figure 5.11), and osteophyte formation of the rim surrounding the lateral clavicle (scores 1-4; Figure 5.12).

5.3.1.1.1 Surface Topography



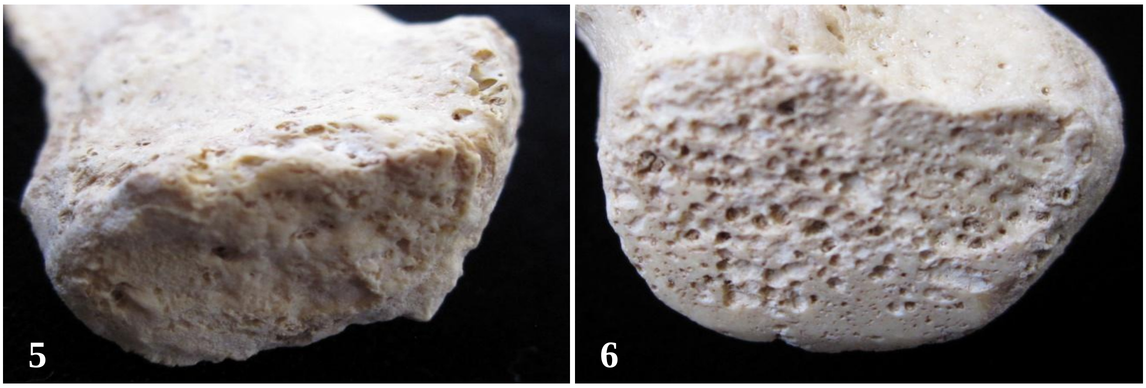


Figure 5.10: *Examples of surface topography trait expression (scores) of the acromio-clavicular joint.*

5.3.1.1.2 Porosity

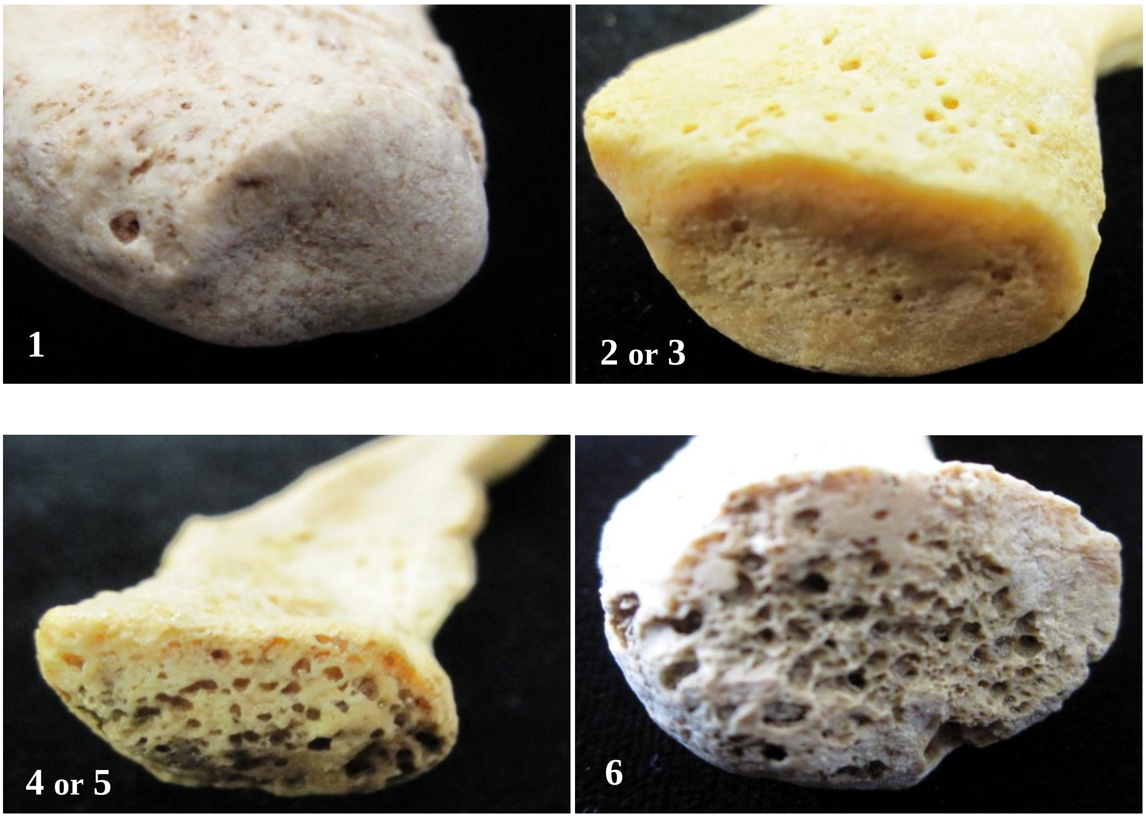


Figure 5.11: *Examples of porosity trait expressions (scores 1-6) displayed by the lateral clavicle.*

5.3.1.1.3 Osteophyte Formation

A quantification system was not feasible to describe the size of osteophytic growths of the lateral clavicular rim, due to the marked variation in general clavicle size, a metric scoring system was felt to be unrepresentative of the true osteophyte size. Examples of generalized osteophyte-size categories are presented in Figure 5.12.

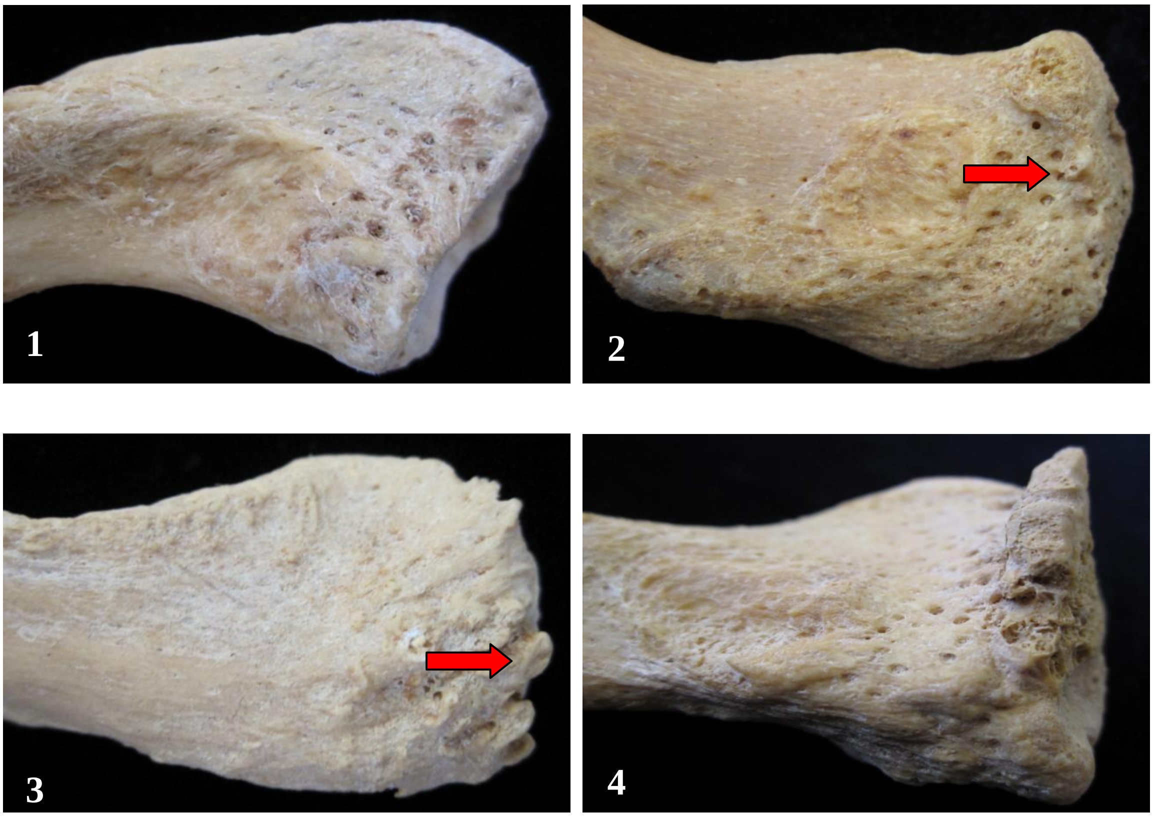


Figure 5.12: *Scoring of osteophyte formation of the rim of the lateral clavicle.*

5.3.1.2 Sternal End of the Clavicle

The above degenerative traits (surface topography, porosity and osteophyte formation) and scores (as in Table 5.5) were recorded on three aspects of the sternal clavicle: sternal articular surface itself (Figure 5.13a), the manubrium facet on the inferior aspect of the sternal clavicle (Figure 5.13b), and the surrounding rim (Figure 5.13c).

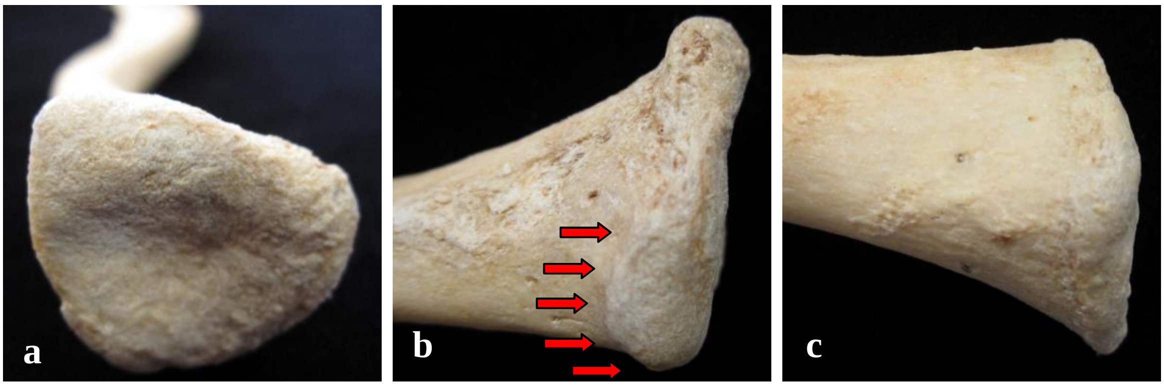


Figure 5.13a-c: *The three aspects of the sternal clavicle for which degeneration was recorded. a) sternal surface; b) manubrium facet; c) surrounding rim.*

The following figures depict the differing scores for degenerative traits recorded, with surface topography demonstrated in Figure 5.14, porosity in Figure 5.15, and osteophytic growths on the sternal clavicle surrounding rim in Figure 5.16.

5.3.1.2.1 Surface Topography

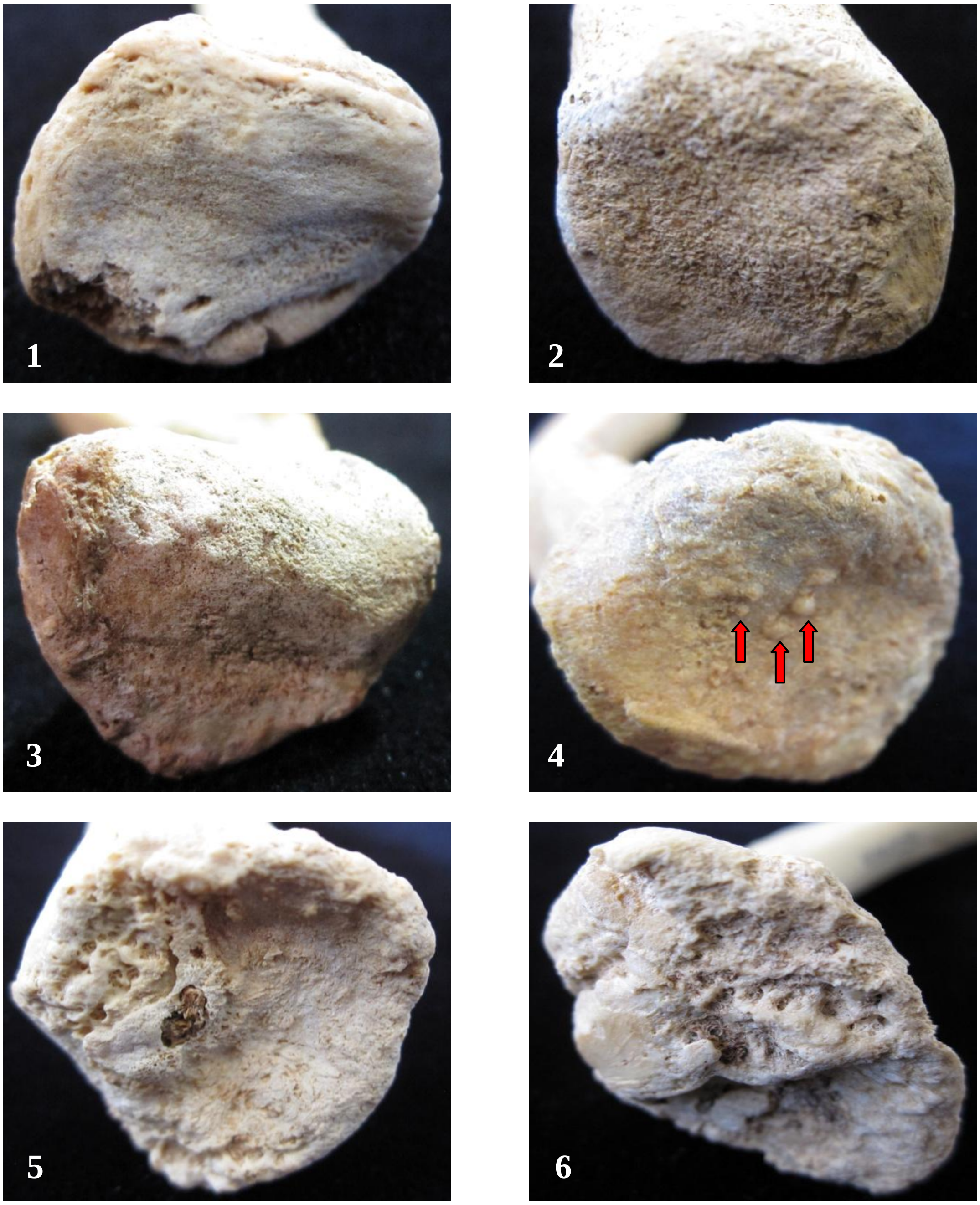


Figure 5.14: *Examples of surface topography trait expression of the sternal surface of the clavicle.*

5.3.1.2.2 Porosity

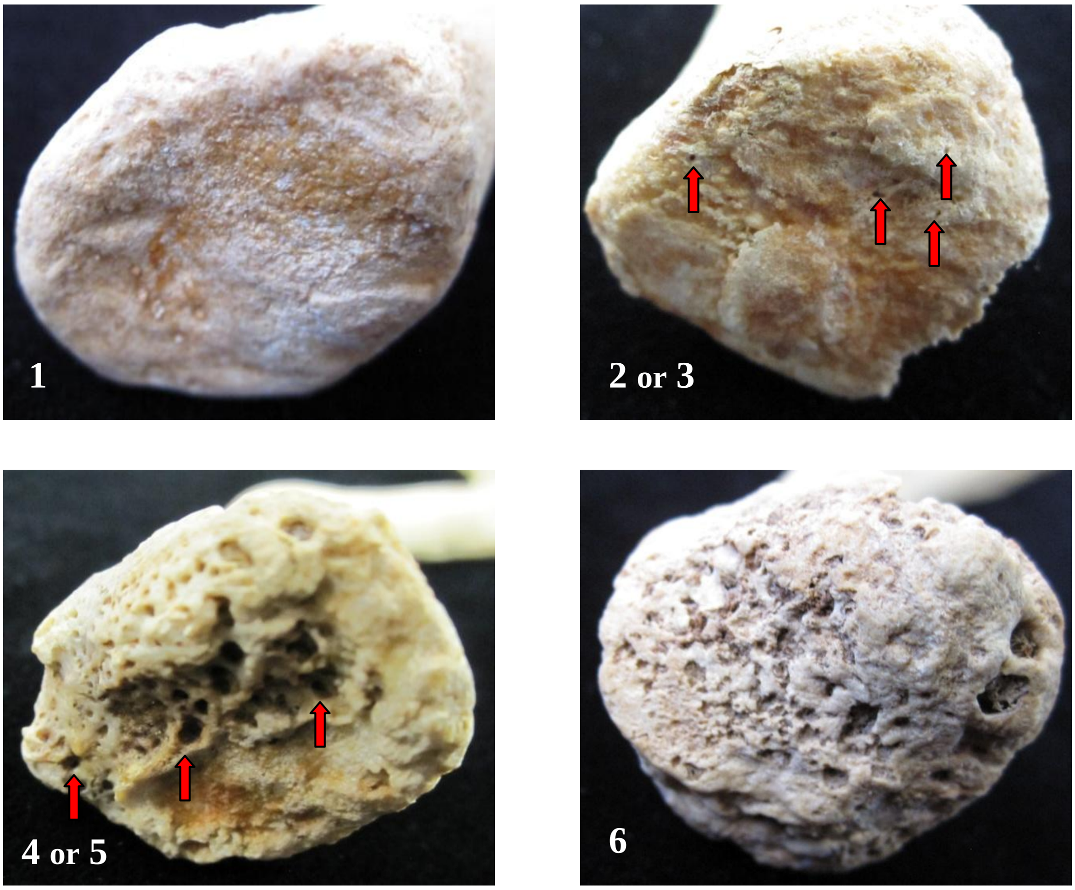
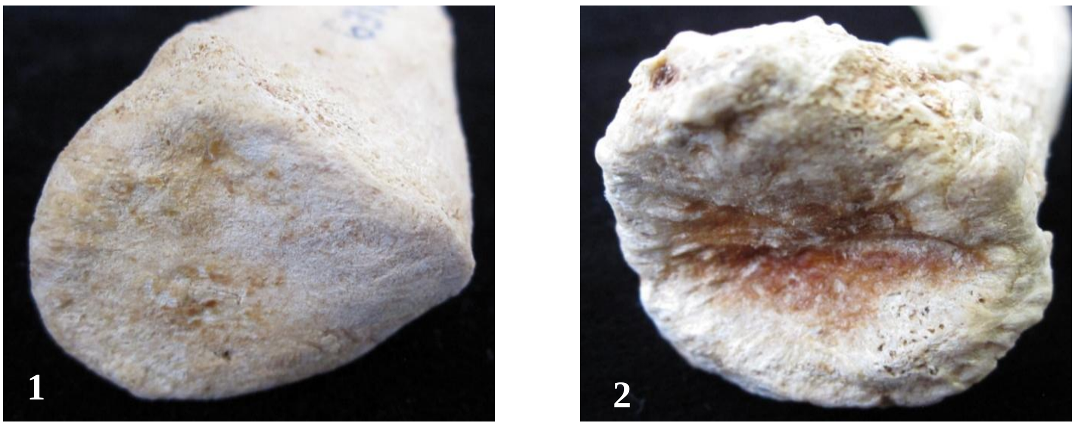


Figure 5.15: *Examples of porosity recorded on the sternal surface of the clavicle.*

5.3.1.2.3 Osteophyte Formation

As described in the lateral clavicle section, a quantification system was not feasible to describe the size of osteophytic growths of the sternal clavicular rim, due to the marked variation in general clavicle size, a metric scoring system was felt to be unrepresentative of the true osteophyte size. Examples of generalized osteophyte-size categories are presented in Figure 5.16.



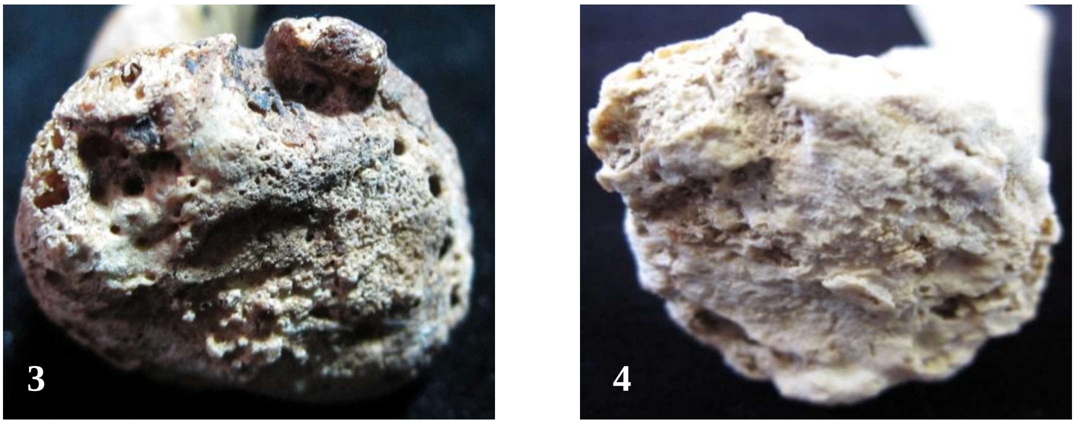


Figure 5.16: *Examples of severity of osteophyte formation recorded on the sternal surface of the clavicle.*

5.3.2 MANUBRIUM, STERNUM, AND XIPHOID PROCESS

Three aspects of the manubrium were investigated for possible age-dependent alterations. Firstly, the clavicular notches on the superior surface of the manubrium were assessed for degenerative traits (i.e. change in surface topography, porosity, osteophyte formation). Secondly, fusion of the manubrium and sternum and sternum and xiphoid were noted. If the manubriosternal joint remained unfused, degenerative traits of distal articular surface of the manubrium was also recorded.

5.3.2.1 Degeneration of Clavicular Notches and Manubrium and Sternum Articular Surfaces

The left and right clavicular facets on the superior aspect of the manubrium, and unfused manubrium/sternum articular surfaces were assessed for degeneration using criteria listed in Table 5.6. Examples of how the scores are expressed are provided in Figure 5.17 (clavicular notch) and Figure 5.18 (distal manubrium articular facets).

Table 5.6: *Degenerative traits recorded on the clavicular notch and sternal articular surface of the manubrium.*

Score	Topography	Porosity	Osteophytes
0	element not present	element not present	element not present
1	smooth	no porosity	no osteophytic growth
2	slight granulation	microporosity (<50% surface)	slight osteophytes
3	coarse granulation	microporosity (>50% surface)	moderate osteophytes
4	nodule formation	macroporosity (<50% surface)	severe osteophytes
5	billowing	macroporosity (>50% surface)	-
6	degeneration/eburnation	complete surface breakdown	-

5.3.2.1.1 Surface Topography of the Clavicular Notch of the Proximal Manubrium

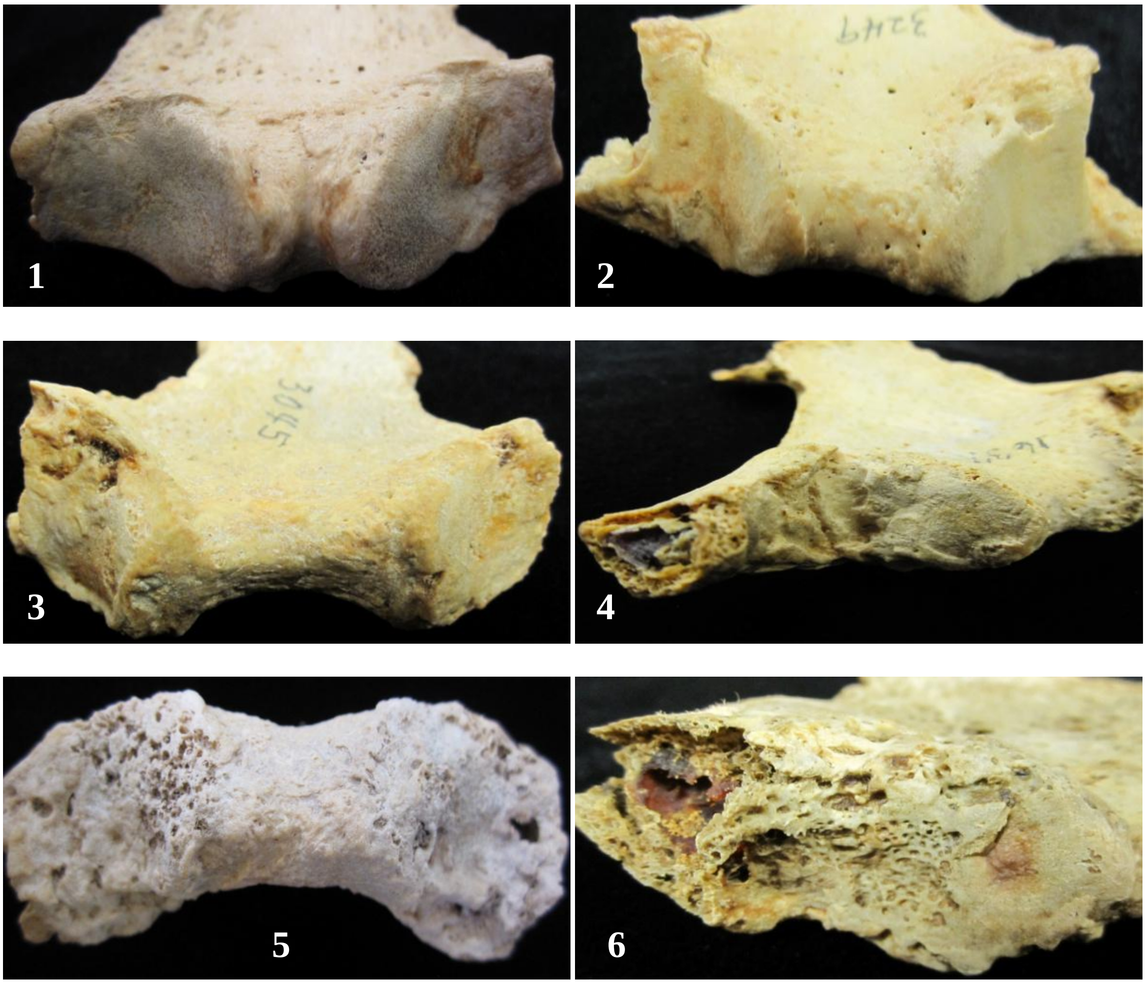


Figure 5.17: *Examples of surface topography scoring for the clavicular notches of the manubrium. All photos taken with the dorsal surface facing up.*

5.3.2.1.2 Examples of Surface Topography of the Distal Manubrium Articular Facet

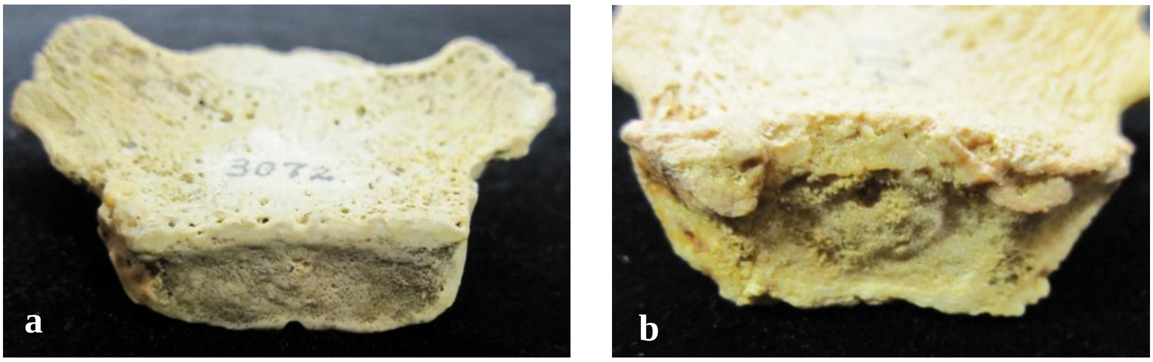


Figure 5.18a-c: *Examples of degenerative trait scoring for the sternum facets on the distal manubrium. All photos taken with the dorsal surface facing up. a) topography and porosity, scores of 2, osteophyte score of 1; b)topography and porosity scores of 4, osteophyte score of 3; c) topography and osteophyte scores of 4, porosity score of 5.*

5.3.2.2 Fusion of the Manubriosternal and Xiphisternal Joints

The ankylosis of the manubrium to the sternum and the xiphoid process to the sternum was recorded simply as unfused or fused, dependent on whether the two skeletal elements displayed complete union into a single skeletal element.

5.3.3 AURICULAR SURFACE OF THE ILIUM: ADDITIONAL OBSERVATIONS

In addition to the metamorphosis of the auricular surface, the following features were also noted:

1. <u>Raised surface texture</u>: the presence of irregular bone formation on the auricular surface itself was recorded as absent (score of 1) or present (score of 2) (Figure 5.19). These expressions could take the form of smooth sheets of bone, or irregularly rounded nodules, leading to a "bubbling" appearance of the auricular surface.

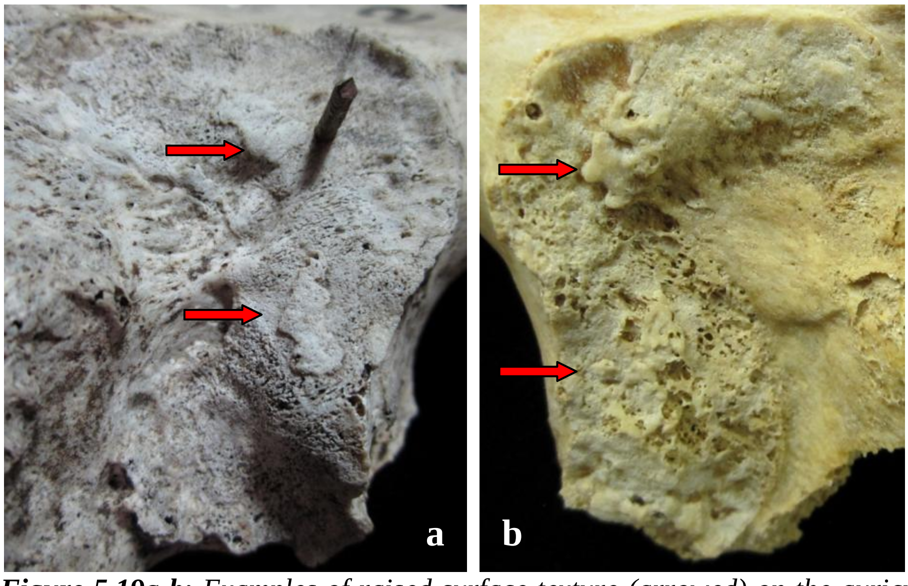


Figure 5.19a-b: *Examples of raised surface texture (arrowed) on the auricular surface. a) sheets, b) nodule-like. Both expressions given the score of 2 points.*

2. Revised Lovejoy et al. (1985b) criteria: the revised method combined the original Lovejoy age stages, based on similar surface traits (i.e. surface texture and porosity), with the aim of broadening the resulting age estimations. The presence of new surface trait raised surface texture (score of 2) is included in the revised criteria, and allocated to a proposed "Lovejoy stage 9" or new phase of V (Table 5.7).

Table 5.7: *Revised criteria for Lovejoy et al. (1985b) metamorphosis of the auricular surface method.*

Lovejoy Stage	New Phase	Morphological Criteria
1	I	fine granulation
2		no porosity
3	II	coarse granulation
4		microporosity
5	III	surface becoming dense
6		macroporosity
7	IV	surface is dense and irregular
8		macroporosity
9	V	raised surface texture, much macroporosity

3. Revised Buckberry and Chamberlain (2002) surface texture score: the revised criteria for surface texture is presented in Table 5.8, which is modified from Buckberry and Chamberlain (2002:233):

Table 5.8: *Revised Buckberry and Chamberlain (2002) surface texture criteria.*

Score	Description
1	90% or more of surface is finely granular
2	50-89% finely granular, replacement by coarse granulation, no dense bone
3	50% or more coarsely granular, no dense bone
4	dense bone is present (< 50% surface)
5	dense bone (50%+ of surface)
6	raised surface texture (any % of surface)

4. Ankylosis of the sacro-iliac joint, defined as a bony bridge extends between the auricular surface and the sacrum, fusing the sacro-iliac joint together. This can occur along the edge of the superior demiface (Figure 5.20a), the inferior demiface (Figure 5.20b), or both.

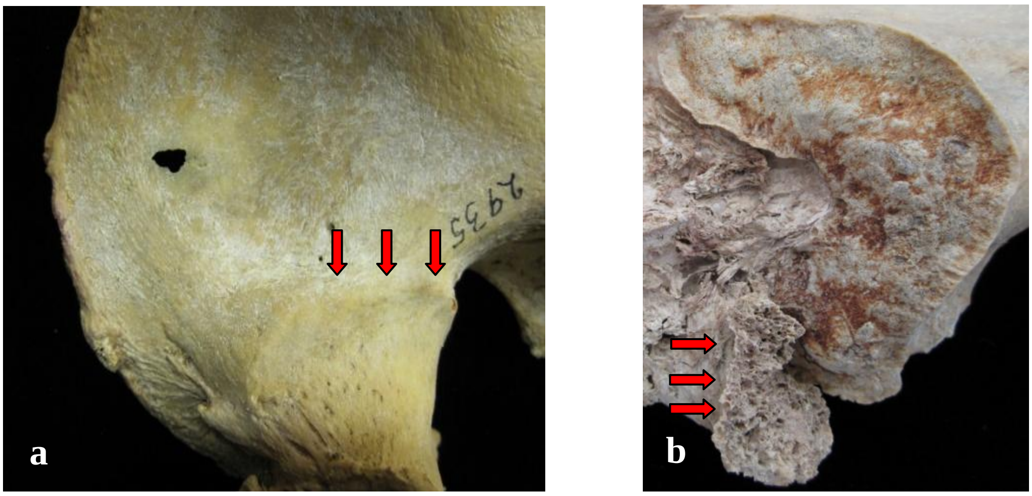


Figure 5.20a-b: *Criteria for used for assessment sacro-iliac joint ankylosis. a) ankylosis at the superior demiface; b) ankylosis at the inferior demiface.*

5.3.4 ILIAC CREST

Criteria used to qualify morphological alterations focused entirely on the amount of osteophyte development (lipping) observed on the lateral surface of the iliac crest, specifically at the attachment for the external oblique muscles. A non-metric five point scale of none, minimal, slight, moderate and severe (Figure 5.21) was employed.

Figure 5.21a-f: *Differing degrees of severity recorded for iliac crest osteophytes. a) none; b) minimal; c) slight; d) moderate; e) severe; f) pathological.*

5.3.5 ISCHIUM

Three traits were recorded on the upper, or superior aspect of the ischium. This upper portion of the ischial tuberosity (Figure 5.22a) is separated from the inferior aspect (Figure 5.22b), by the transverse ridge. The ischium does not articulate with any other bone. The superior aspect of the ischial tuberosity is the site of attachment for semi-membranosus and the semi-tendinosus and long head of biceps. The lower part of the ischial tuberosity is the attachment for adductor magnus.

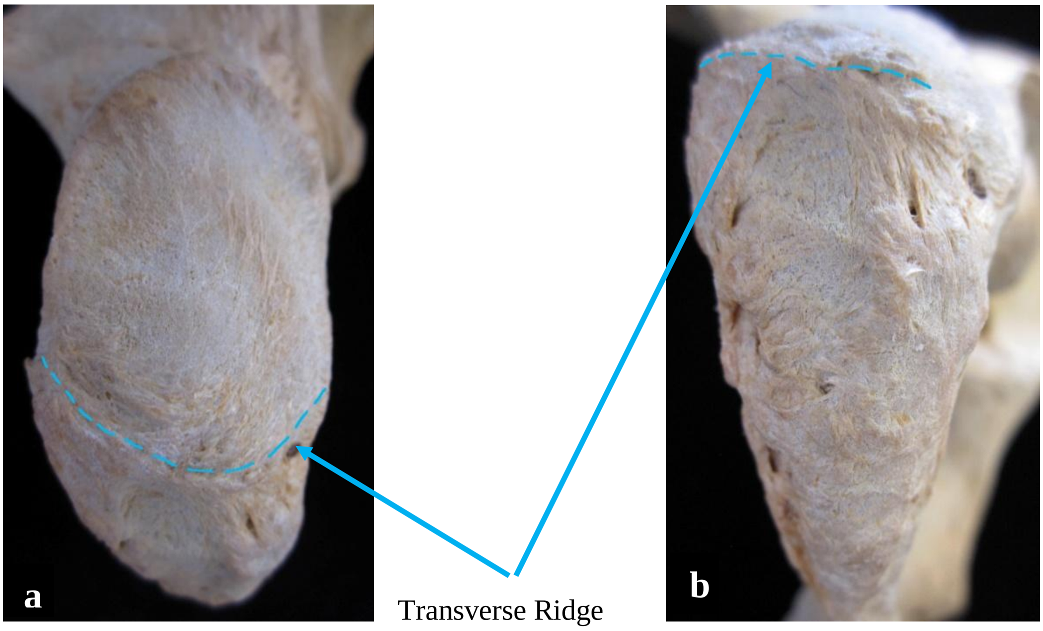


Figure 5.22a-b: *Anatomy of the ischium. a) upper or superior aspect; b) lower or inferior aspect (not recorded).*

Criteria used in this portion of the study focused on qualifying and quantifying the degree of degenerative changes to the upper and lower parts (including the longitudinal ridge). Surface topography, including the surface texture (i.e. slight or coarse granulation) and surface contour change (smooth, nodules of new bone formation, billowing), porosity (micro- and macroporosity) and osteophyte formation or lipping (i.e. none, minimal, slight, moderate, severe) were all recorded (Table 5.9). Photographic examples of trait expression on the upper part of the ischial tuberosity are presented in Figure 5.23.

Table 5.9: *Ischium scoring system.*

Score	Topography	Porosity	Osteophytes
0	-	no porosity	none
1	smooth	microporosity present	minimal
2	coarse granulation	macroporosity present	slight
3	rugged/nodules	-	moderate
4	surface breakdown/ highly irregular surface	-	severe

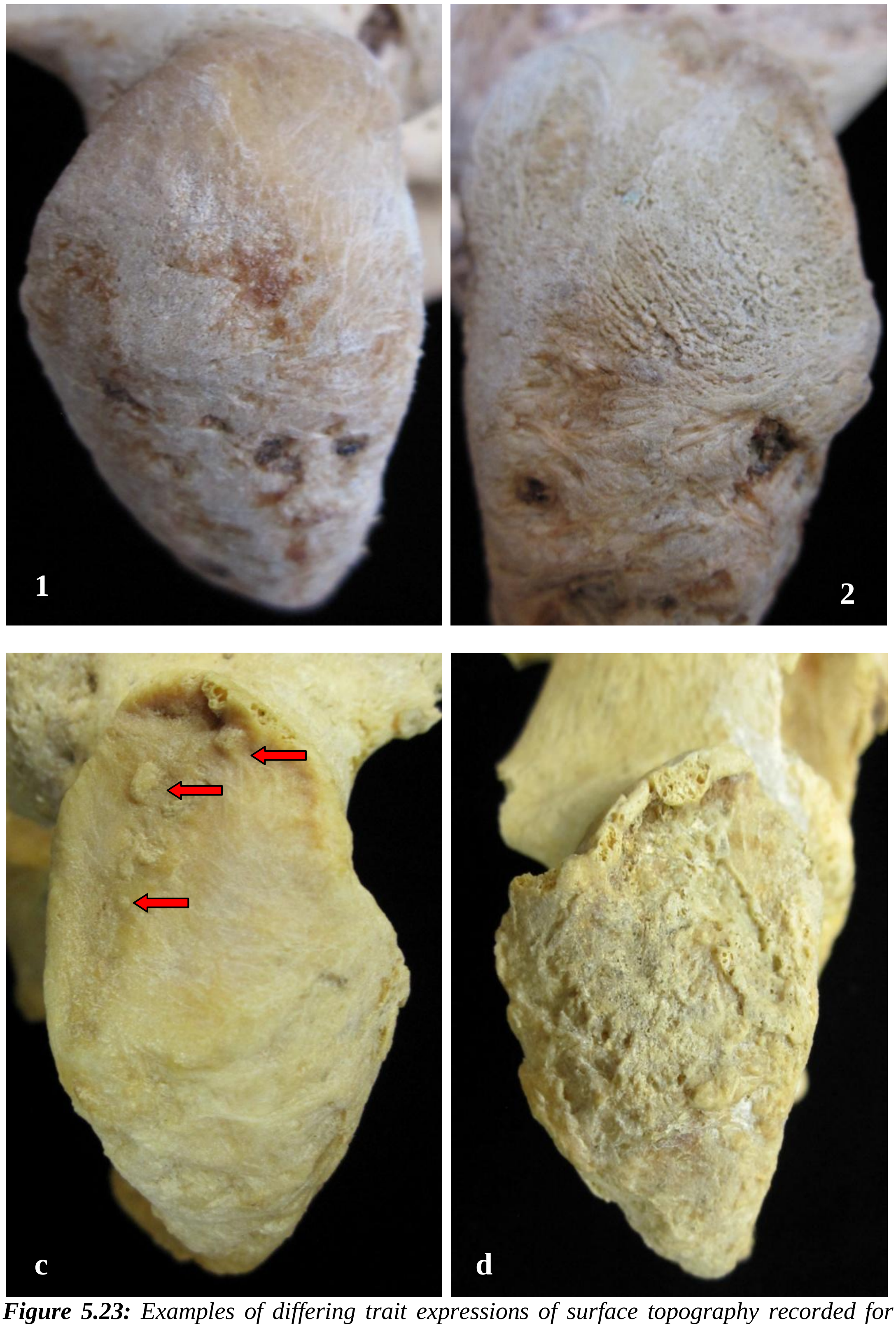


Figure 5.23: *Examples of differing trait expressions of surface topography recorded for the upper part of the ischial tuberosity.*

5.4 DIFFUSE IDIOPATHIC SKELELTAL HYPEROSTOSIS (DISH)

Presence of DISH was recorded for later comparison with trait expression of the pelvis. Diagnosis of DISH was made using criteria by Rogers and Waldron (2001:362-363): hyperostosis of the spine (right-hand side of thoracic vertebrae) affecting at least three vertebrae. Rogers and Waldron (2001:363) also suggest that "evidence of extra-spinal calcification or ossification of extra-spinal ligaments and/or enthuses" is also a major criterion for diagnosing DISH. Common sites of ossifications are attachment sites on the iliac crest, ischium, the proximal femur, patella, calcaneus and ulna. The severity of entheses was recorded for the iliac crest and ischial tuberosity in all individuals, not only those with DISH (see sections 5.3.4 and 5.3.5).

5.5 BLIND TEST METHOD

The blind test of the above observed techniques was undertaken using established methodology (Falys et al., 2005; Falys et al., 2006). The test sample was comprised of adult individuals, over the age of 40 years from Christ Church, Spitalfields. This population was chosen due to its pre-modern date (i.e. 18th–19th centuries). Observations for each individual were recorded with no prior knowledge of age-at-death. Sex was known, as the boxes of female individuals in the Spitalfields collection are marked as such. As many individuals were assessed as possible within the one-week period for which access was granted. It was attempted to record an equivalent number of males and females, however, time constraints inhibited this.

The methods tested, where sufficiently preserved, were: degeneration of the cervical vertebrae, lateral and sternal ends of the clavicle, clavicular notch of the manubrium, fusion of the manubriosternal joint, degeneration of the articular facet for the sternum on the distal manubrium, fusion of the xiphisternal joint, osteophyte formation on the iliac crest, auricular surface, pubic symphysis and degeneration of the ischial tuberosity. Once all observations had been recorded, the trait scores, composite scores, and surface age stages were entered into a database, and cross referenced with known age.

5.6 STATISTICAL METHODS

5.6.1 ESTABLISHED METHODS

The established methods were assessed for their accuracy (or inaccuracy) and precision (bias) to predict the true age. To test the ability for established ageing methods to predict documented age (i.e. Suchey-Brooks pubic symphysis and Lovejoy et al.'s auricular surface), bias and inaccuracy were calculated using the following equations:

Inaccuracy = $\Sigma|\text{estimated age} - \text{real age}|/N$ Bias = $\Sigma(\text{estimated age} - \text{real age}/N)$

5.6.2 DEVELOPED METHODS

Developed methods were all created following a similar structure (i.e. quantifying qualitative individual trait scores, which were most commonly combined to form a composite score). As a result, similar statistical analyses were performed on each reference collection for each method. All analyses were undertaken using the computer statistical package GenStat 13th edition.

The statistical tests performed:

1. Differences between state of degeneration recorded for left and right elements were determined using a paired *t*-test, for all individuals that had both elements present for analysis.

2. Differences in trait expression between male and female individuals were determined using standard unpaired (two-sample, two-tailed) *t*-tests. Males and females displaying the same trait score or composite score were compared.

3. Spearman's rank correlation statistics were applied to identify relationships between individual trait expression(s) and the derived composite score (combination of trait scores) with documented age.

4. Descriptive statistics were used to describe each composite score: mean age, standard deviation, median age, actual range of observed known ages.

5. Statistically distinct surface degeneration age stages were developed using standard unpaired (two-sample, two-tailed) *t*-tests to determine which consecutive composite scores were most appropriate to combine into independent stages of degeneration (i.e. age stages).

6. Descriptive statistics were also applied to the distinct surface stages, to identify the mean age, standard deviation, and 95% confidence interval. To compensate for the variability of the ageing process (i.e. trait expression), broad age ranges (i.e. age phases) were also proposed for each distinct surface age stage.

5.6.3 INTRAOBSERVER ERROR

Each method was assessed for intraobserver error by comparison of trait and composite scores of a small subsample of the elements from all reference collections, which were recorded twice. Intraobserver error was assessed by comparing the two recorded observations using a paired *t*-test.

5.6.4 BLIND TEST

In the blind test, age estimates were presented in age stages composed of one or more composite scores to account for trait expression variability between individuals and the ageing process. Each age stage was stated with a mean age, 95% confidence interval and a suggested broad age range. As ages for the developed methods were estimated with a range, and exact ages (i.e. 60 years) were not supplied, the use of the bias and inaccuracy equations (as used in the established methods) were determined to be not entirely representative of the result (i.e. bias (Σ(estimated age – real age/N)); inaccuracy (i.e. Σ|estimated age – real age|/N)). Instead, accuracy calculations were performed to test whether the known age fell within the 95% confidence interval of the recorded surface degenerative stage, and/or within the broader suggested age range ("age phase"). An accuracy of the method was determined by the overall percentage of individuals correctly aged using the given criteria. If the documented age fell outside of either range, bias was determined based on whether the known age was underaged by being allotted to the age stage, or overaged.

CHAPTER SIX

RESULTS

Given the amount of data recorded in the course of the research, and the set length of time in which this study had to be completed, it was not feasible to adequately analyse the obtained information for all skeletal regions for inclusion in the final thesis. For preservation reasons, aspects of the skull (i.e. button osteoma, ectocranial suture fusion, HFI, dentition), first rib, ossification of costal cartilage and acetabulum were not included in the rest of this study. The following sections will detail the results of statistical analyses of the arachnoid granulations, cervical vertebrae, clavicle, manubrium, sternum and xiphoid process, ilium (iliac crest and auricular surface), pubic symphysis, and ischium. Organized by skeletal region, the recorded raw data is provided in Appendix 4, results of each individual study sample are located in Appendix 5, and the raw data and age estimation derived on the blind test sample are provided in Appendix 6.

Information recorded using established ageing methods were investigated for the degree of accuracy between the estimated age and the documented age, as well as any bias (i.e. under- or overageing) of the age estimate. If additional morphological traits were observed during the research which could potentially improve the establish methodology in identifying older age ranges, these traits were also investigated for their relationship with documented age. Revised versions of established osteological techniques were proposed wherever possible. The results are presented in anatomical order, beginning with the cranium (i.e. arachnoid granulations), followed by the neck and thorax (i.e. cervical spine, clavicle, manubrium/sternum/xiphoid process), and concludes with the pelvis (i.e. iliac crest, auricular surface, pubic symphysis, and ischium).

To evaluate the morphological criteria developed on new regions of the skeleton, the observed trait expressions were investigated for differences between the sides of the body (where applicable), and differences between the sexes. Each individual surface trait was also investigated for its relationship with the composite score and documented age. Descriptive statistics for composite scores, produced by combining two or more surface traits, were then assessed for similar age distributions, to discern the ability of the traits to form distinctive surface stages, and whether these surface stages of progressive degeneration may be useful in adult age estimation. If similar patterns were observed across all four study samples, the collections were combined to assess the applicability of the method as a universal measure of age (using the same methods outlined above). Ultimately, ageing criteria were developed using age stages, and included mean ages and 95% confidence intervals. As will be apparent in the following sections, the 95% confidence intervals found to be very narrow ranges in all cases. Although very precise, it was not felt that such estimates allowed adequate expression of variability between individuals of equivalent ages to be demonstrated. As a result, for each age stage, a sufficiently broad age range (i.e. age phase) was also suggested, which was derived by taking into account the wider spectrum of ages which demonstrated the same degenerative traits (age stages). It is important to note that these broader age ranges are not necessarily statistically robust, as they were derived from somewhat subjective means. Although providing less precision (i.e. commonly spanned ranges of 15 years or more), these age phases would likely be more accurate with respect to assessing the true age of the target individual, as they enable inter-personal variation in ageing to be acknowledged.

Blind tests were carried out for each method to evaluate the accuracy of the 95% confidence intervals of age stages and the proposed age phases. The raw data recorded for each individual from each of the four study samples is provided in Appendix 4, the statistical results of each study sample for each method are presented in Appendix 5, and the results of the combined study samples and blind tests are presented in Appendix 6.

6.1 RESULTS: ARACHNOID GRANULATIONS

The accuracy and bias of estimated ages derived using the regression equation **[age = 43.7 + 4.45*(total score of pits and depressions)]** were assessed in each of the study samples. As suggested by Barber (1997), the total number of pits and depressions present on the left and right parietals were counted and recorded (Appendix 4.1). The two totals were then added to form the final score (i.e. total number of pits and depressions present on the parietal bones of each individual). This total score was used to provide an age estimate, through inclusion in the above regression equation. Males and females were combined for analysis, as Barber (1997) found criteria were not sexually dimorphic. Inaccuracy was calculated using the equation Σ|predicted age-known age|/N. Bias was assessed using the equation Σ(predicted age – known age)/N. The statistical results of each study sample are presented in this section.

6.1.1 ARACHNOID GRANULATIONS RESULTS: HTH SAMPLE

This study was performed on the endocranial surface of the parietal bones of 158 individuals from the Hamann-Todd Human Osteological Collection (HTH). The sample comprised 94 males with age-at-death ranging from 42-96 years (mean age, 68.2 years) and 64 females, ranging between 41-93 years (mean age, 65.9 years) (Table 6.1).

Table 6.1: *Arachnoid granulations: age composition of HTH study sample.*

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	9	19	19	24	23	**94**
Female	10	12	15	13	14	**64**
Total	**19**	**31**	**34**	**37**	**37**	**158**

A scatter plot of the total arachnoid granulation score compared with documented age for all individuals (males and females combined) is provided in Figure 6.1. A regression line is also provided to assess the relationship between arachnoid granulation count and known age.

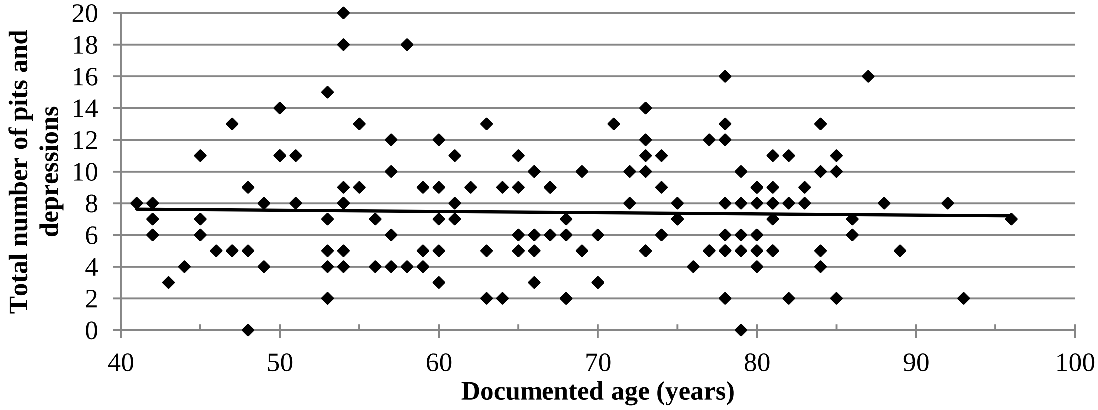


Figure 6.1: *Scatter plot of total score of arachnoid granulations against documented age in the HTH sample.*

As Figure 6.1 displays, there does not appear to be a positive relationship between arachnoid granulation score and increasing age, as the regression line's slope is decreasing, indicating a negative correlation.

6.1.1.1 Inaccuracy and Bias

Accuracy was assessed based on the ability of the equation to correctly estimate age within 5 years, 10 years, and 20 years of the documented age (Table 6.2). Of the 158 individuals, 22.8% were aged within 5 years of the known age, and 67.7% within 20 years. On average, this method provided a bias towards overageing by 9.5 years (Table 6.3).

Table 6.2: *Percent accuracy of age estimation based on arachnoid granulation counts in the HTH sample.*

Estimated age	Number of individuals	% Accuracy
± 5 years	36	22.8
± 10 years	57	36.1
± 10–20 years	50	31.6
± 20 years	107	67.7
Total	**158**	-

Table 6.3: *Inaccuracy and bias of age estimations (in years) based on the total arachnoid granulation count in the HTH study sample.*

Known age	Age group (years)					All ages (40+ years)
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Inaccuracy (years)	27.1	27.5	13.7	13.4	12.6	17.7
Bias (years)	26.6	27.5	9.7	2.2	-7.5	9.5

6.1.2 ARACHNOID GRANULATION RESULTS: PBC SAMPLE

This study was performed on the endocranial surface of the parietal bones of 149 individuals from the Pretoria Bone Collection (PBC). The sample comprised 92 males with age-at-death ranging from 47-94 years (mean age, 71.9 years) and 57 females, ranging between 42-94 years (mean age, 73.5 years) (Table 6.4).

Table 6.4: *Arachnoid granulations: age composition of PBC study sample.*

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	2	13	16	38	23	**92**
Female	3	3	11	22	18	**57**
Total	**5**	**16**	**27**	**60**	**41**	**149**

A scatter plot of the total arachnoid granulation score compared with documented age for all individuals (males and females combined) is provided in Figure 6.2. A regression line is also provided to assess the relationship between arachnoid granulation count and known age.

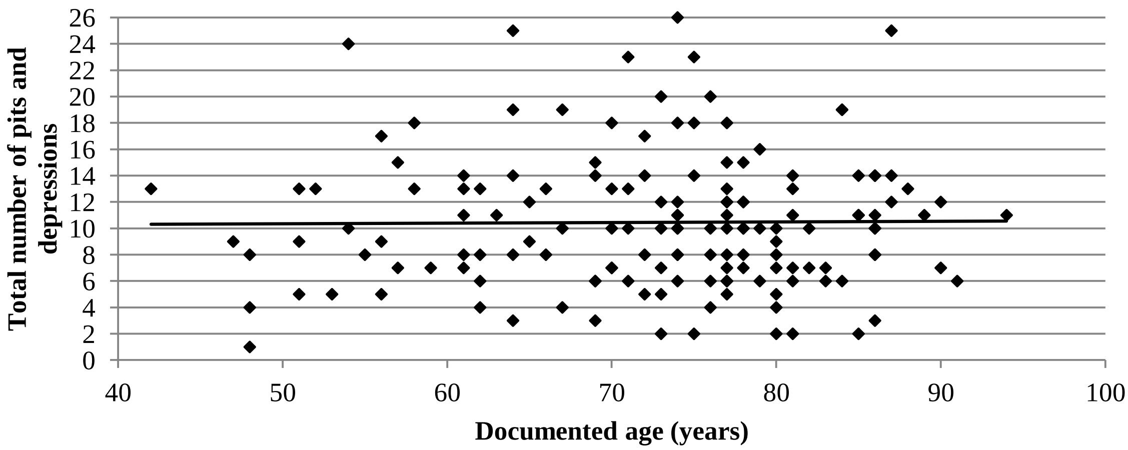


Figure 6.2: *Scatter plot of total score of arachnoid granulations against documented age in the PBC sample.*

As Figure 6.2 displays, there is not a strong positive relationship between arachnoid granulation score and increasing age, as the regression line's slope is only vaguely increasing.

6.1.2.1 Inaccuracy and Bias

Accuracy was assessed based on the ability of the equation to correctly estimate age within 5 years, 10 years, and 20 years of the documented age (Table 6.5). Inaccuracy results are presented in Table 6.6. Of the 149 individuals, 15.4% were aged within 5 years of the known age, and 59.7% within 20 years. On average, this method provided a bias towards overageing by 17.7 years.

Table 6.5: *Percent accuracy of age estimation based on arachnoid granulation counts (PBC sample).*

Estimated age	Number of individuals	% Accuracy
± 5 years	23	15.4
± 10 years	49	32.9
± 10–20 years	40	26.8
± 20 years	89	59.7
Total	**194**	-

Table 6.6: *Inaccuracy and bias of age estimations (in years) based on the total arachnoid granulation count in the PBC study sample.*

Known age	Age group (years)					All ages (40+ years)
	40-49	50-59	60-69	70-79	80+	
Inaccuracy (years)	28.3	38.3	27.6	21.9	15.5	23.2
Bias (years)	28.3	38.3	25.8	17.9	2.6	17.7

6.1.3 ARACHNOID GRANULATIONS RESULTS: SB SAMPLE

This study was performed on the endocranial surface of the parietal bones of 9 individuals from the St Bride's Documented Skeletal Collection (SB). The sample comprised 5 males with age-at-death ranging from 41-65 years (mean age, 50.0 years) and 4 females, ranging between 55-83 years (mean age, 66.0 years) (Table 6.7).

Table 6.7: *Arachnoid granulations: age composition of SB study sample.*

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	2	2	1	0	0	**5**
Female	0	2	1	0	1	**4**
Total	**2**	**4**	**2**	**0**	**1**	**9**

A scatter plot of the total arachnoid granulation score compared with documented age for all individuals (males and females combined) is provided in Figure 6.3. A regression line is also provided to assess the relationship between arachnoid granulation count and known age.

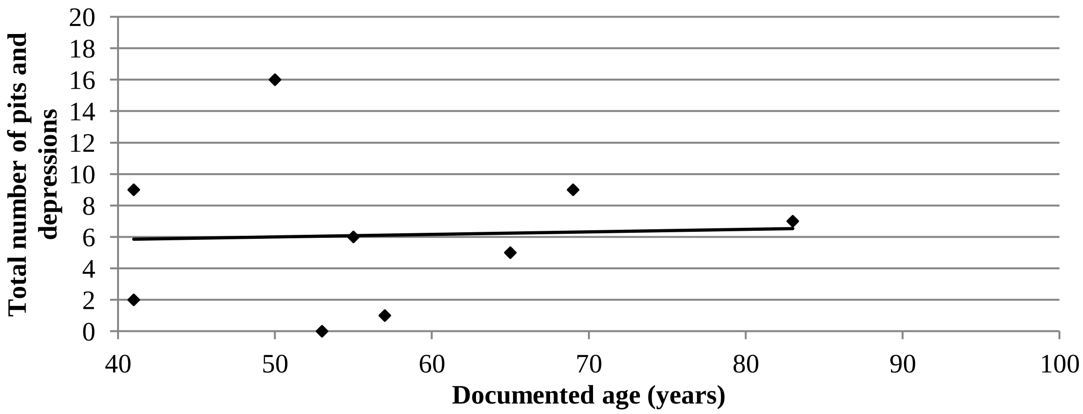


Figure 6.3: *Scatter plot of total score of arachnoid granulations against documented age in the SB sample.*

As Figure 6.3 displays, there is not a strong positive relationship between arachnoid granulation score and increasing age, as the regression line's slope is only vaguely increasing.

6.1.3.1 Inaccuracy and Bias

Accuracy was assessed based on the ability of the equation to correctly estimate age within 5 years, 10 years, and 20 years of the documented age. The results are summarised in Table 6.8, and inaccuracy and bias in Table 6.9. Of the 9 individuals, 11.1% were aged within 5 years of the known age, and 77.7% within 20 years. On average, this method provided a bias towards overageing by 13.8 years.

Table 6.8: *Percent accuracy of age estimation based on arachnoid granulations counts in the SB sample.*

Estimated age	Number of individuals	% Accuracy
± 5 years	1	11.1
± 10 years	4	44.4
± 10-20 years	3	33.3
± 20 years	7	77.7
Total	**9**	-

Table 6.9: *Inaccuracy and bias of age estimations (in years) based on the total arachnoid granulation count in the SB study sample.*

Known age	Age group (years)					All ages (40+ years)
	40-49	50-59	60-69	70-79	80+	
Inaccuracy (years)	27.2	24.6	7.9	-	8.0	19.6
Bias (years)	27.2	15.5	7.9	-	-8.0	13.8

As the results from the HTH, PBC, and SB collections did not provide support for arachnoid granulation counts to provide an accurate assessment of known age, no further analyses were undertaken (e.g. combining study samples to produce ageing criteria).

6.2 RESULTS: CERVICAL SPINE

Four aspects of the cervical spine are discussed in the following order: dens facet of the atlas, dens process of the axis, bodies of the third to the seventh cervical vertebrae, and articular facets of the third to the seventh cervical vertebrae. All raw data is presented in Appendices 4.2 to 4.4, and the statistical analyses of each study sample are provided in Appendix 5.1 for the atlas, and Appendix 5.2 for the axis. The bodies and facet of the third through seventh cervical vertebrae are provided in Appendix 5.3 and 5.4, respectively. The results presented are of the combined study sample, and the blind test (Appendices 6.1 to 6.10).

Before the results are presented for the cervical spine, it is important to note the pattern of degenerative changes of all aspects of the cervical vertebrae of the SB individuals differed from those recorded in the other study samples. The most significant differences are highlighted in each of the results sections below. Although the possible reasons for this discrepancy are presented in the discussion chapter (section 8.3.2), the most apparent contrasts between study samples was the SB assemblage was of poorer preservation, provided a smaller sample size, and dated to an earlier time period in history.

Although the general degenerative pattern differed in this sample, the SB individuals were not removed from the combined study sample. Each cervical spine provides information on the variation of the ageing process. Although removal of these individuals would have increased the accuracy and precision of the developed techniques, the full range of skeletal variation would not be represented.

6.2.1 CERVICAL SPINE: DENS FACET OF THE ATLAS

The individual trait scores recorded for each surface feature of the dens facet (i.e. presence of porosity, eburnation and osteophyte formation) were combined to form a composite score, ranging from 3 to 8 points (i.e. porosity, scored between 1 and 3; osteophyte formation, scored between 1 and 3; eburnation, scored from 1 to 2). This composite score was used to assess degenerative differences between males and females.

6.2.1.1 Dens Facet of First Cervical Vertebra: Combined Sample

As three of the four skeletal samples demonstrated very similar patterns of cervical vertebral body degeneration (i.e. no differences between the sexes, roughly equivalent age stages), the results were combined to assess the true variation in trait expression. In the SB sample, female traits had a non-significant correlation with age-at-death. Expression of osteophyte formation and eburnation were also found to be not significantly correlated with documented age in SB males and females. To assess the true extent of the degenerative processes of the dens facet of the atlas of all collections were combined (Figure 6.4). The total sample size of first cervical vertebra was 571 individuals (mean age, 67.2 years), 322 male individuals (mean age, 66.8 years) and 249 females (mean age, 67.7 years) (Table 6.10).

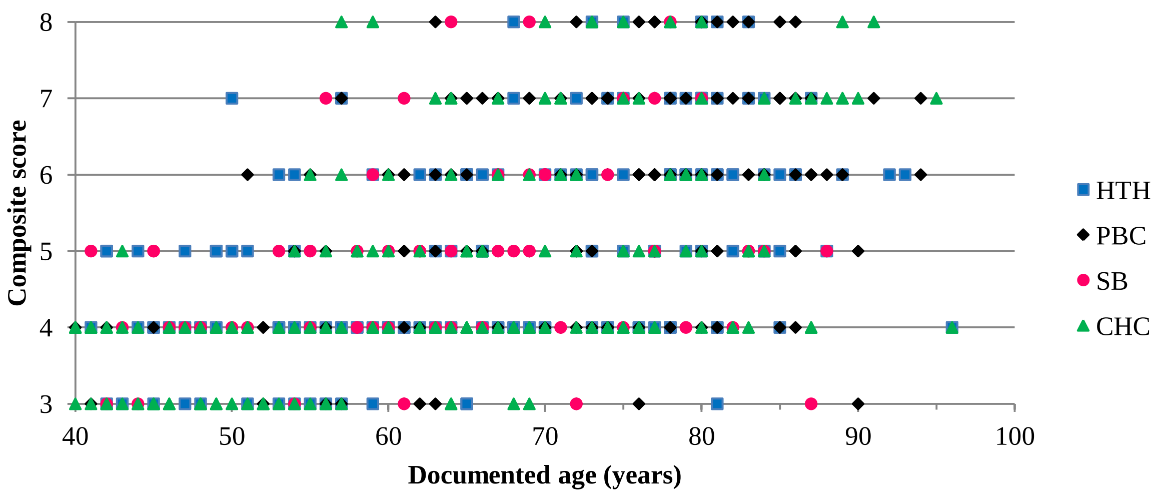


Figure 6.4: *Dens facet of the atlas: scatter plot of composite scores against age for all individuals in the combined study sample.*

Table 6.10: *Dens facet of the atlas: age construction of combined study sample.*

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	39	62	70	94	57	**322**
Female	32	38	59	61	59	**249**
Total	**71**	**100**	**129**	**155**	**116**	**571**

6.2.1.1.1 Male Versus Female

The ages were plotted against composite scores for males and females in a scatter plot, with a regression line for both sets of data (Figure 6.5). The regression lines indicate that there was little difference between sexes (males, $r_s = 0.574$, $P < 0.001$; females, $r_s = 0.522$, $P < 0.001$).

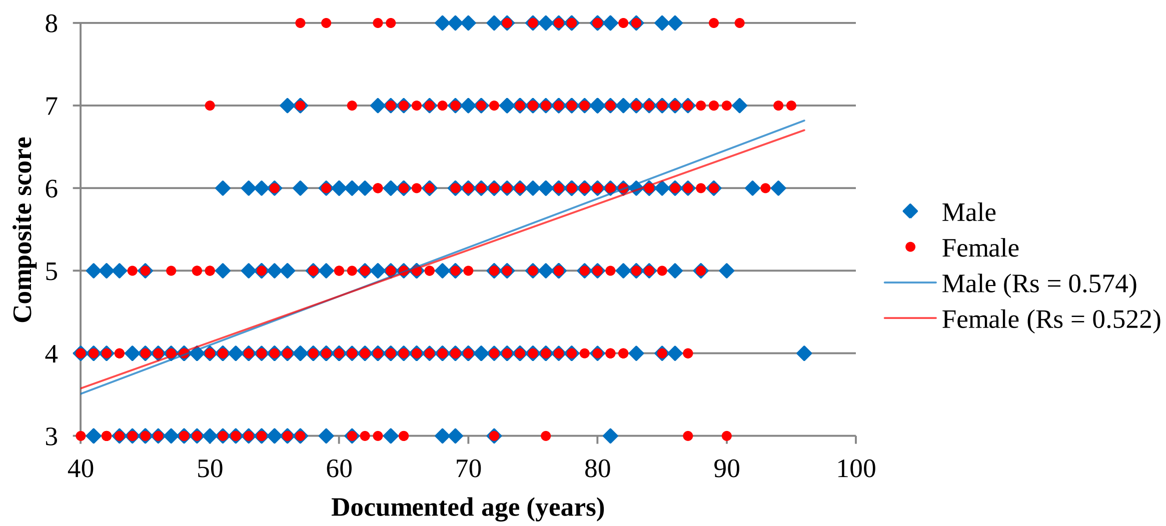


Figure 6.5: *Dens facet of the atlas: scatter plot of composite scores against age for the combined study sample. Spearman's rank correlation coefficients of composite score against age for males and females are provided.*

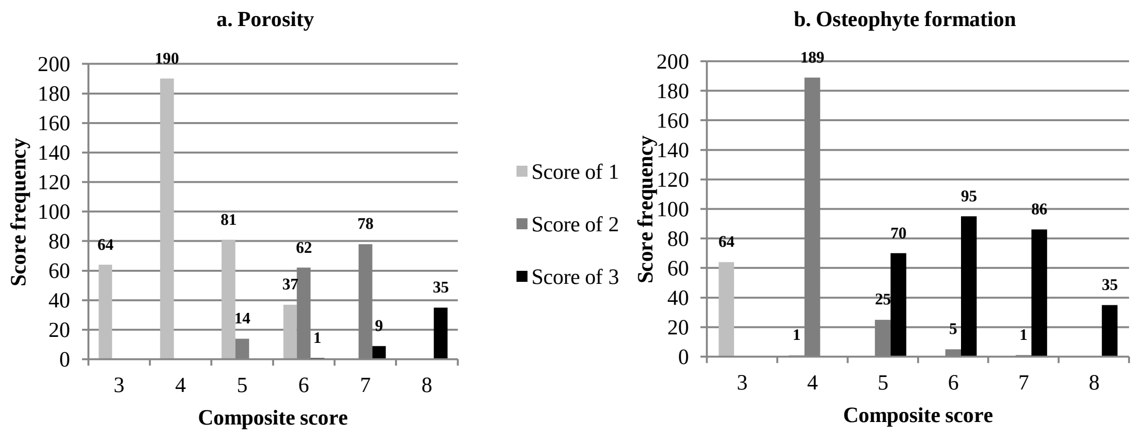
A standard unpaired (two-sample, two-tailed) *t*-test was also carried out to test for significant differences between males and females for each composite score. Although a wide spread of *P*-values resulted, no statistically significant differences were identified at the 95% confidence level between ages for males and females ($P > 0.05$; see Table 6.11). The sample size for the remaining statistically analyses was 571 (male, N = 322; female, N = 249).

Table 6.11: *Dens facet of the atlas: independent two-tailed t-tests between males and females for each composite score.*

Composite score	*t*	df	*P*
3	-0.31	62	0.757
4	-0.65	188	0.514
5	-0.26	93	0.795
6	-1.20	98	0.232
7	-0.50	85	0.622
8	0.58	27	0.566

6.2.1.1.2 Individual Trait Scores, Composite Scores and Age-at-Death

The frequencies of trait score within each composite score were plotted (Figure 6.6). The scores assigned to individual traits displayed a positive relationship with composite scores. That is, trait expressions (scores) with a higher score were generally found to cluster within the range of higher composite scores (see Figure 6.6).



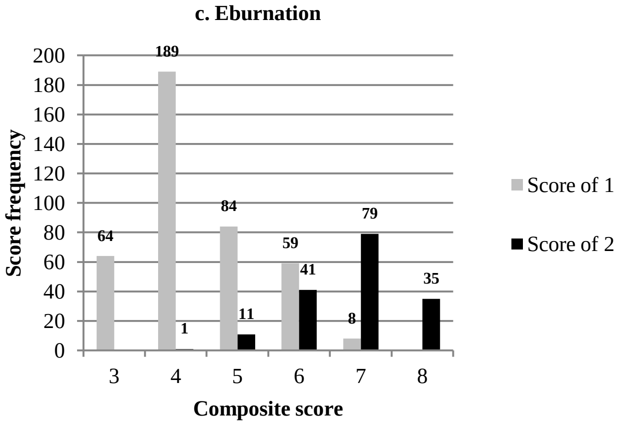


Figure 6.6a-c: *Dens facet of the atlas: number of observations of trait scores recorded in the combined study sample.*

Individual trait expressions were investigated as to their association with age-at-death. Scatter plots of trait scores were plotted against age-at-death (Figure 6.7).

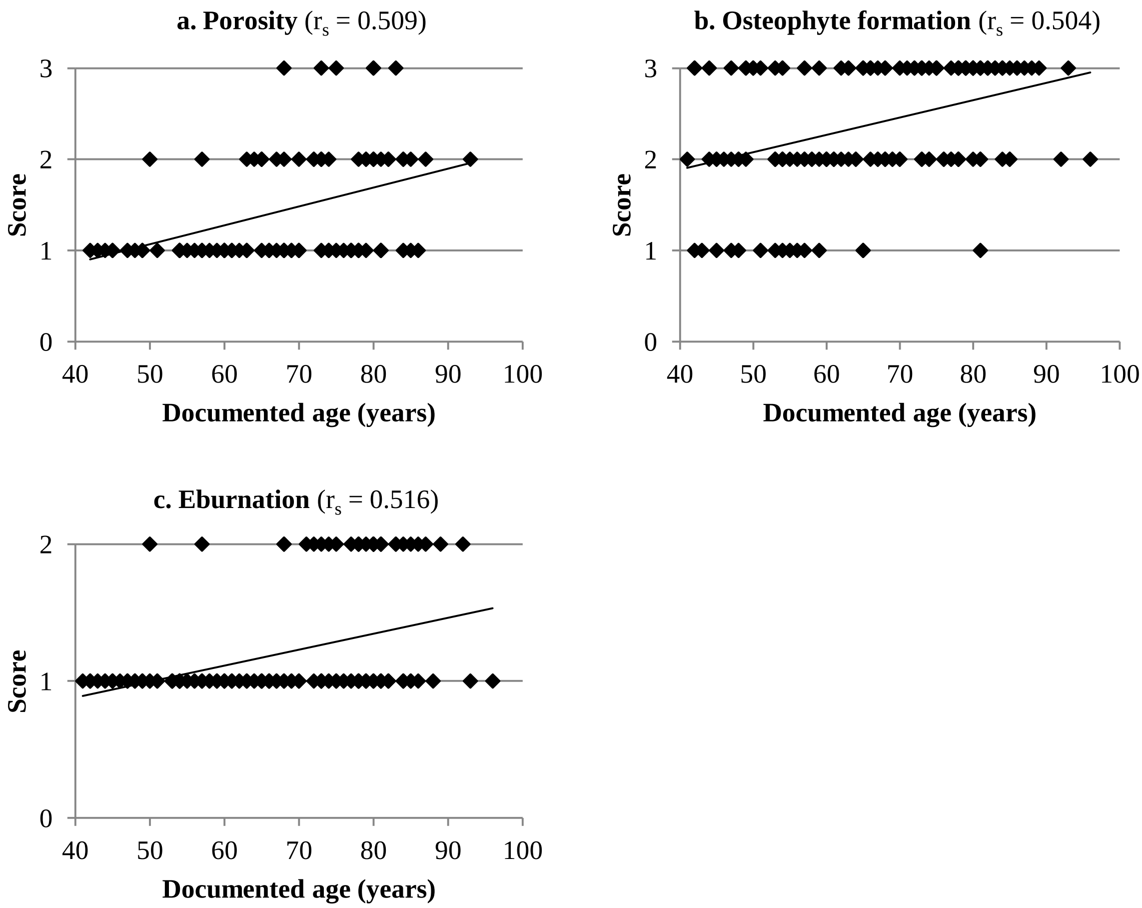


Figure 6.7a-c: *Dens facet of the atlas: scatter plots of trait scores against age-at-death. Spearman's rank correlation coefficients of trait score against age are provided.*

To test whether each feature is correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. Individual trait expressions were found to be significantly correlated with age-at-death (Table 6.12). The higher the score assigned to a particular trait expression, the more frequently it was associated with older age. This correlation was strongest with the presence of eburnation (r_s = 0.516, P < 0.001).

Table 6.12: *Dens facet of the atlas: Spearman's rank correlation between age and trait expression of features.*

Feature	**r_s**	***P***
Porosity	0.509	< 0.001
Osteophyte formation	0.504	< 0.001
Eburnation	0.516	< 0.001
Composite score	**0.549**	**< 0.001**

A Spearman's rank correlation coefficient was also calculated for the derived composite with age. As was found with each individual feature, the combination of scores for surface porosity, osteophyte formation and presence of eburnation also produced a significant correlation with documented age (r_s = 0.549, P < 0.001) (Table 6.12, Figure 6.8).

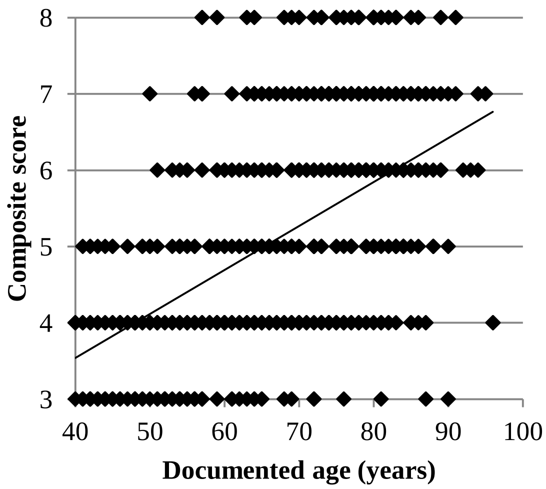


Figure 6.8: *Dens facet of the atlas: association between composite scores and documented age; r_s = 0.549.*

The descriptive statistics of age variation within composite scores (Table 6.13) revealed the overall trend of increasing age with increasing composite score.

Table 6.13: *Dens facet of the atlas: descriptive statistics for documented ages-at-death found to possess same composite scores of the combined study sample (N = 571).*

Composite score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
3	64	54.4	11.1	52	40–90
4	190	62.1	12.5	62	40–96
5	95	67.4	12.7	67	41–90
6	100	73.8	9.7	74	51–94
7	87	76.2	9.1	77	50–95
8	35	76.4	7.7	78	57–91

Several composite scores were found to provide similar age ranges, mean ages, and median ages. These similar scores were then combined to produce surface age stages (Table 6.14). In addition to the 95% confidence interval, a broader range (age phase) with which to estimate age was also provided for each age stage.

Table 6.14: *Dens facet of the atlas: age estimates from composite scores and age stages.*

Composite score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
3	I	64	54.4	11.1	51–57	< 70 years
4–5	II	285	63.9	12.8	62–65	45+ years
6–8	III	222	75.1	9.2	73–76	55+ years

Unpaired *t*-tests were employed to test for statistically significant differences between the stages (Table 6.15). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.15: *Dens facet of the atlas: results of t-tests between age stages.*

Stages compared	*t*	df	*P*
I vs II	-5.47	347	< 0.001
II vs III	-11.53	502	< 0.001

6.2.1.1.3 Intraobserver Error

A subsample (5 males and 5 females) from each of the four skeletal collections were re-recorded to test for intraobserver error (N = 40). Paired *t*-tests were used to determine any significant differences in the two occasions (Table 6.16), which found no significant variation between the trait scores and composite scores (i.e. $P > 0.05$).

Table 6.16: *Dens facet of the atlas: intraobserver error paired t-test results (N = 40).*

Trait	*t*	df	*P*
Porosity	-1.00	39	0.323
Osteophyte formation	-1.78	39	0.083
Eburnation	1.43	39	0.160
Composite score	**-1.36**	**39**	**0.183**

6.2.1.2 Dens Facet of First Cervical Vertebra: Blind Test

A blind test was performed on the dens facet of the first cervical vertebrae of 71 randomly chosen individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The sample comprised 40 males with age-at-death ranging from 40-91 years (mean age, 63.4 years) and 31 females, ranging between 45-89 years (mean age, 64.4 years) (Table 6.17).

Table 6.17: *Dens facet of the atlas, blind test: age construction of the CCS sample.*

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	4	11	11	11	3	**40**
Female	5	8	8	5	5	**31**
Total	**9**	**19**	**19**	**16**	**8**	**71**

As sexually dimorphic criteria were not required, males and females were analysed together. Individual trait scores for porosity, osteophyte formation and eburnation were combined to form a composite score, which is ultimately used to estimate age-at-death. Composite scores range from 3 to 8 points.

The resultant composite scores were allocated into corresponding surface age stages (between I and III) (Figure 6.9). It is these surface age stages that were used to estimate age. The developed ageing criteria for each stage was applied to each CCS individual and compared with documented age.

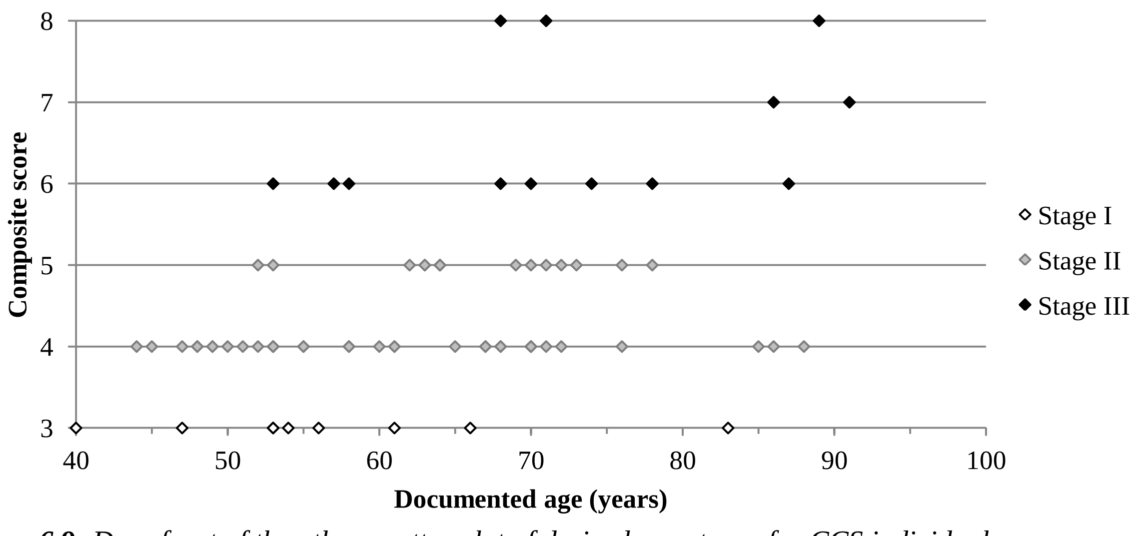


Figure 6.9: *Dens facet of the atlas: scatter plot of derived age stages for CCS individuals.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.10). Age estimations were made using a range(s) derived from the 95%

confidence interval unique to each age stage. The 95% confidence interval is denoted by two green vertical lines. As the 95% confidence intervals were commonly too narrow to display adequate variation in the ageing process, the proposed generalized age range (minimum and/or maximum values) was also blind tested, and is demarcated by one or two black vertical lines and a grey shaded area. Outliers are highlighted as orange circles and indicated where the known age for the individual fell out of the age range for that particular stage.

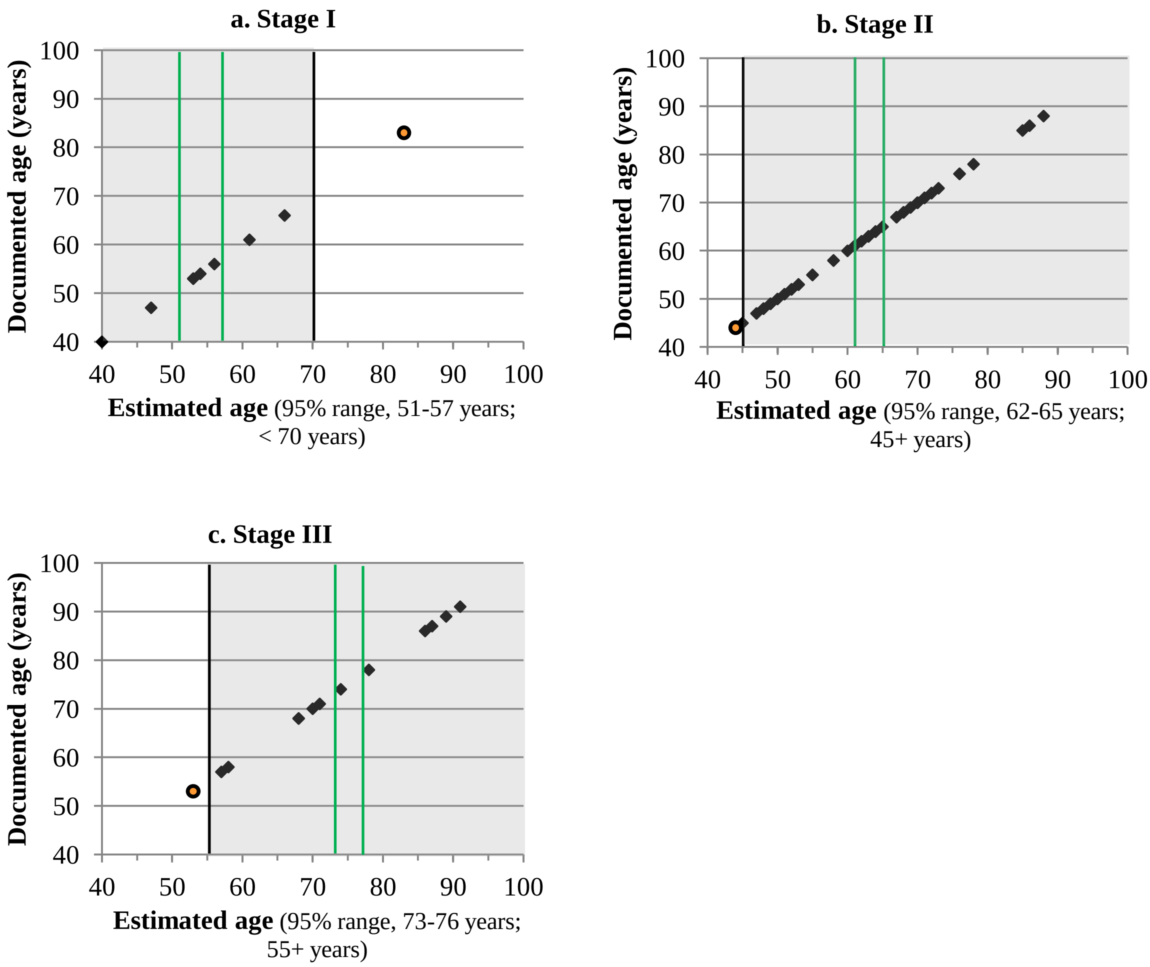


Figure 6.10a-c: *Dens facet of the atlas, blind test: observed age stages (estimated age; 95% confidence interval, age phase) for CCS individuals, compared with documented ages.*

The raw data for each CCS individual is present in Appendix 6.1. As Table 6.18 summarizes the frequency (i.e. the accuracy) at which the documented age fell within the 95% confidence interval for each age stage, and within the suggested general stated range (age phase). Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.18: ***Dens facet of the atlas, blind test: age estimations based on the appearance of the dens facet of the atlas.***

Stage of appearance	**N**	**Actual age range of individuals (years)**	**Estimated age** (ranges in years)						**Inaccuracy**		
			Within 95% confidence interval			**Within age phase**			**Under- or overaged**		
			Range	**N**	**%**	**Range**	**N**	**%**	**N**	%	**Bias**
I	9	40–83	51–57	4	44.4	< 70	8	88.9	1	11.1	underaged
II	49	44–88	62–65	7	14.3	45+	48	97.8	1	2.0	overaged
III	13	53–91	73–76	1	7.7	55+	12	92.3	1	7.7	overaged
Total	71	-	-	12	**16.9**	-	68	**95.8**	1	**1.4**	**underaged**
									2	**2.8**	**overaged**

Of the 71 individuals, only 16.9% fell within the 95% confidence interval based on this method, and 95.8% fell within the age phase.

6.2.1.1.1 Additional Analyses

To confirm the relationship between age and composite score of the dens facet of the atlas, a Spearman's rank correlation was calculated. Both were found to be highly statistically significant ($r_s = 0.469$; $P < 0.001$). The results are plotted in Figure 6.11.

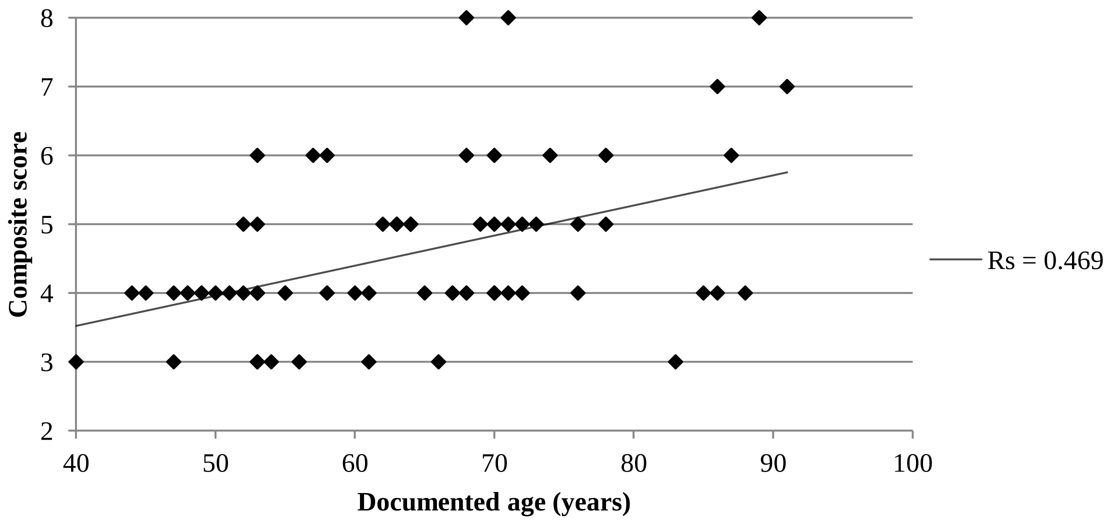


Figure 6.11: *Dens facet of the atlas, blind test: scatter plot of composite scores against age for individuals in the CCS sample. Spearman's rank correlation coefficient of score against age is provided.*

Comparison of the descriptive statistics of age variation within each age stage between the developed criteria and the CCS blind test sample is presented in Table 6.19.

Table 6.19: *Dens facet of the atlas, blind test: age estimates from composite scores and age stages for the developed criteria and the CCS sample.*

Age stage	**Composite score**	**Developed criteria**			**CCS blind test sample**			
		Mean age (years)	**Standard deviation**	**95% confidence interval (years)**	**N**	**Mean age (years)**	**Standard deviation**	**95% confidence interval (years)**
I	3	54.4	11.1	51–57	9	57.0	12.3	47–66
II	4–5	63.9	12.8	62–65	49	62.6	11.0	59–66
III	6–8	75.1	9.2	73–76	13	73.1	12.6	65–81

6.2.2 CERVICAL SPINE RESULTS: DENS PROCESS OF THE AXIS

The individual trait scores recorded for each surface feature of the dens process (i.e. presence of porosity, eburnation and osteophyte formation) were combined to form a composite score, ranging between 3 and 8 points (i.e. porosity, scored between 1 and 3; osteophyte formation, scored between 1 and 3; eburnation, scored from 1 to 2). This composite score was used to assess degenerative differences between males and females.

6.2.2.1 Dens Process on Second Cervical Vertebra: Combined Sample

The results of the four assessed study samples were combined to assess the true variation in trait expression. As sexually dimorphic criteria were required in both the PBC and SB collections, the combined results were assessed for males and females separately. It is noted that three skeletal samples demonstrated very similar patterns of dens degeneration (i.e. roughly equivalent age stages). The exception to this was again the SB sample, where male composite score was significantly correlated with known age despite the expression of all three individual traits displaying no relationship to documented age. To assess the true extent of the degenerative processes of the dens of the axis of males in all collections were combined (Figure 6.12), as were the females (Figure 6.13). The total sample size used to develop this method was the second cervical vertebrae of 583 individuals (mean age, 67.1 years), 331 males (mean age, 66.6 years) and 252 females (mean age, 67.8 years) (Table 6.20).

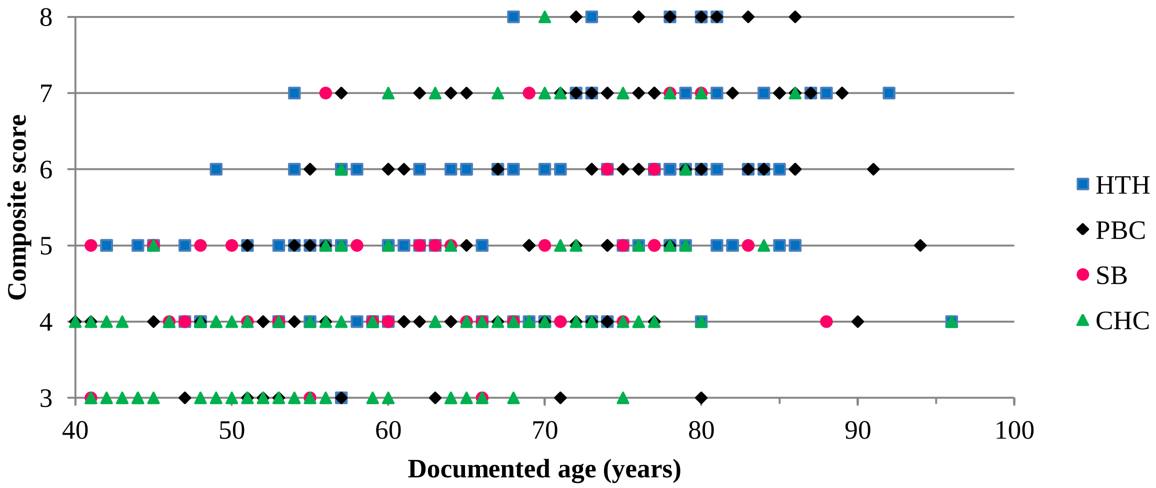


Figure 6.12: *Dens facet of the axis: scatter plot of composite scores against age for males in the combined study sample.*

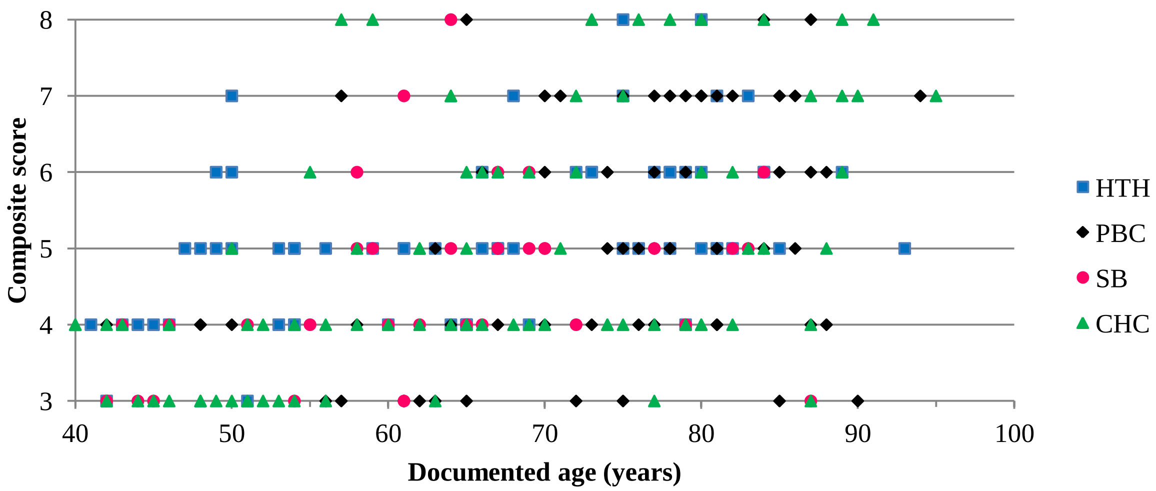


Figure 6.13: *Dens facet of the axis: scatter plot of composite scores against age for females in the combined study sample.*

Table 6.20: *Dens facet of the axis: age construction of combined study sample.*

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	41	64	73	95	58	**331**
Female	32	39	60	59	62	**252**
Total	**73**	**103**	**133**	**154**	**120**	**583**

6.2.2.1.1 Male Versus Female

The ages were plotted against composite scores for males and females in a scatter plot, with a regression line for both sets of data (Figure 6.14). The regression lines indicate that there was little difference between sexes (males, $r_s = 0.530$, $P < 0.001$; females, $r_s = 0.473$, $P < 0.001$).

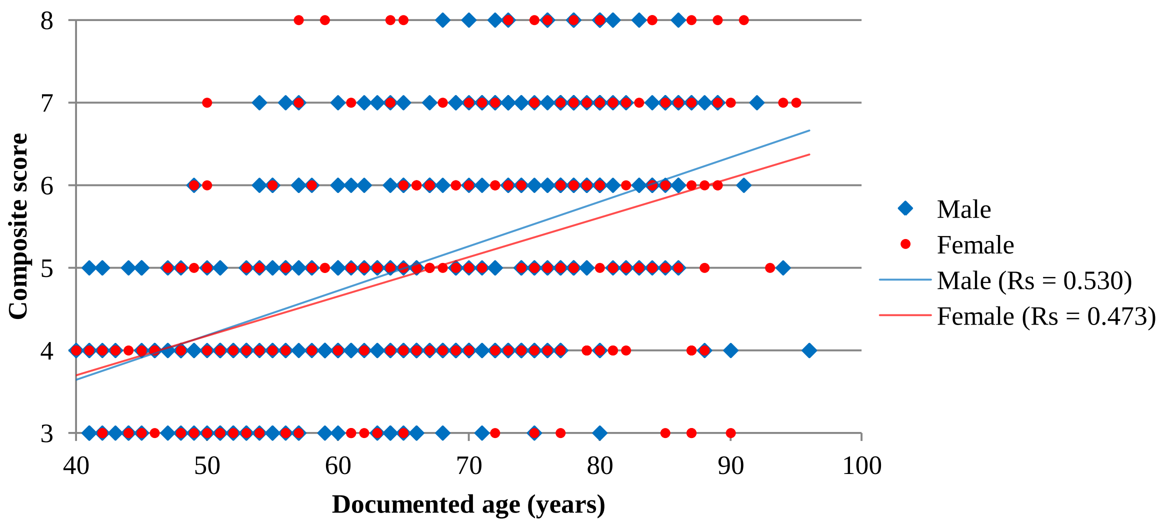


Figure 6.14: *Dens facet of the axis: scatter plot of composite scores against age for the combined study sample. Spearman's rank correlation coefficients of composite score against age for males and females are provided.*

A standard unpaired (two-sample, two-tailed) *t*-test was also carried out to test for significant differences between males and females for each composite score. A statistically significant difference was identified at the 95% confidence level between composite score 5 for males and females ($P < 0.05$; see Table 6.21). This suggests the sexes must be separated, making the sample size of 331 males and 252 females for the remaining analyses.

Table 6.21: *Dens facet of the axis: independent two-tailed t-tests between males and females for each composite score.*

Composite score	*t*	df	*P*
3	-1.10	69	0.274
4	0.13	174	0.899
5	2.10	129	0.038*
6	-0.59	91	0.554
7	-0.45	78	0.655
8	0.47	24	0.645

*Key: * result is significant at the 95% confidence level (P < 0.05).*

6.2.2.1.2 Individual Trait Scores, Composite Scores and Age-at-Death

The frequencies of trait score within each composite score were plotted (Figure 6.15). The scores assigned to individual traits displayed a positive relationship with composite scores. That is, trait expressions (scores) with higher individual scores were generally found to cluster within the range of higher composite scores (see Figure 6.15).

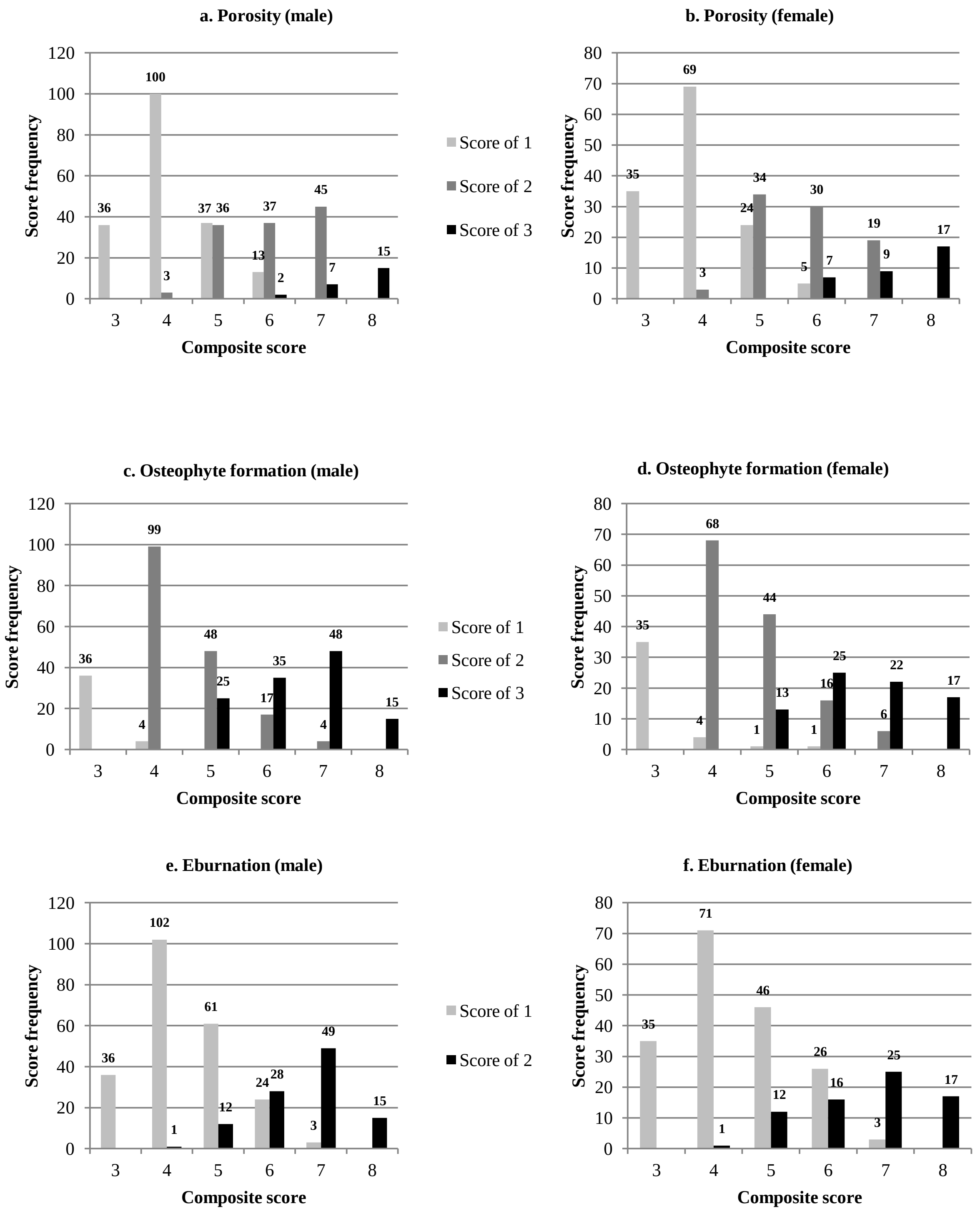


Figure 6.15a-f: *Dens facet of the axis: number of observations of trait scores recorded in the combined study sample.*

Individual trait expressions were investigated as to their association with age-at-death. Scatter plots of trait scores were plotted against age-at-death (Figure 6.16).

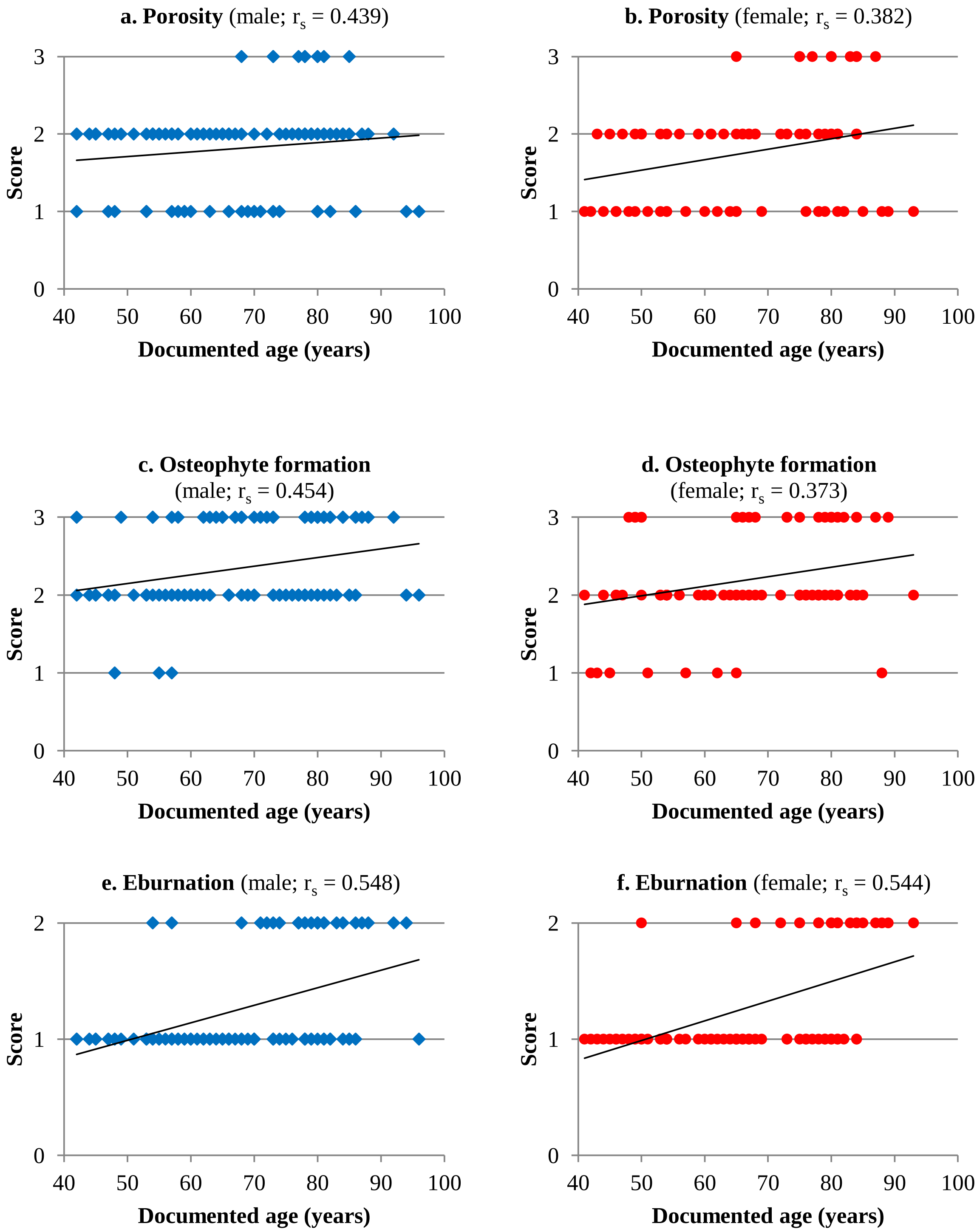


Figure 6.16a-f: *Dens facet of the axis: scatter plots of trait scores against age-at-death. Spearman's rank correlation coefficients of trait score against age are provided for males and females.*

To test whether each feature is correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. Individual trait expressions were found to be significantly correlated with age-at-death (Table 6.22). The higher the score assigned to a particular trait expression, the more frequently it was

associated with older age. This correlation was strongest with the presence of eburnation in males and females (male, $r_s = 0.548$, $P < 0.001$; female, $r_s = 0.544$, $P < 0.001$).

Table 6.22: *Dens facet of the axis: Spearman's rank correlation between age and trait expression of features.*

Feature	**Male**		**Female**	
	r_s	***P***	r_s	***P***
Porosity	0.439	< 0.001	0.382	< 0.001
Osteophyte formation	0.454	< 0.001	0.373	< 0.001
Eburnation	0.548	< 0.001	0.544	< 0.001
Composite score	**0.530**	**< 0.001**	**0.473**	**< 0.001**

A Spearman's rank correlation coefficient was also calculated for the derived composite with age. As was found with each individual feature, the combination of scores for surface porosity, osteophyte formation and presence of eburnation also produced a significant correlation with documented ages-at-death (male, $r_s = 0.530$, $P < 0.001$; female, $r_s = 0.473$, $P = 0.001$) (Table 6.22, Figure 6.17).

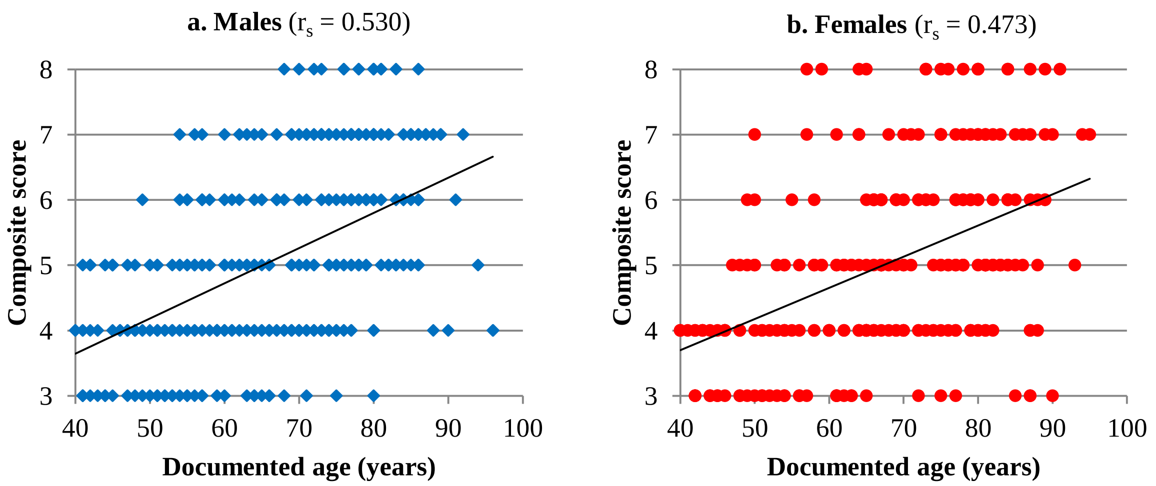


Figure 6.17a-b: *Dens facet of the axis: association between composite scores and documented age. Spearman's rank correlation coefficients of composite score against age are provided.*

The descriptive statistics of age variation within composite scores for males (Table 6.23) and females (Table 6.24) revealed the overall trend of increasing age with increasing composite score.

Table 6.23: *Dens facet of the axis: descriptive statistics for documented ages-at-death found to possess same composite scores of male individuals in combined sample.*

Composite score	**N**	**Mean age (years)**	**Standard deviation**	**Median age (years)**	**Observed range (years)**
3	36	55.1	10.1	53	41–80
4	103	62.4	12.2	63	40–96
5	73	65.4	13.1	64	41–94
6	52	72.4	10.4	75	49–91
7	52	75.7	9.0	77	54–92
8	15	77.5	5.0	78	68–86

Table 6.24: *Dens facet of the axis: descriptive statistics for documented ages-at-death found to possess same composite scores of female individuals in the combined sample.*

Composite score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
3	35	58.2	13.9	54	42–90
4	72	62.0	13.6	64	40–88
5	58	70.0	11.8	70	47–93
6	42	73.6	9.9	73	49–89
7	28	76.8	10.9	78	50–95
8	17	76.2	10.1	78	57–91

Several composite scores were found to provide similar age ranges, mean ages, and median ages. These scores were then combined to surface age stages for males and females (Tables 6.25 and 6.26, respectively). In addition to the 95% confidence interval, a broader range (age phase) with which to estimate age was also provided for each age stage.

Table 6.25: *Dens facet of the axis: age estimates from composite scores and age stages (males).*

Composite score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
3	I	36	55.1	10.1	51–59	< 70 years
4–5	II	176	63.6	12.7	61–66	< 80 years
6–8	III	119	74.5	9.4	72–76	55+ years

Table 6.26: *Dens facet of the axis: age estimates from composite scores and age stages (females).*

Composite score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
3–4	I	107	60.8	13.8	58–63	< 80 years
5	II	58	70.0	11.8	66–73	50–80 years
6–8	III	87	75.1	10.3	72–77	65+ years

Unpaired *t*-tests were employed to test for statistically significant differences between the stages (Table 6.27). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.27: *Dens facet of the axis: results of t-tests between age stages.*

Stages compared	Male			Female		
	t	df	*P*	*t*	df	*P*
I vs II	-3.81	210	< 0.001	-4.32	163	< 0.001
II vs III	8.46	290	< 0.001	2.76	143	0.007

6.2.2.2 Dens Process on Second Cervical Vertebra: Blind Test

A blind test was performed on the dens process of the second cervical vertebrae of 72 randomly chosen individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The sample comprised 42 males with age-at-death ranging from 40-91 years (mean age, 64.5 years) and 30 females, ranging between 45-89 years (mean age, 64.9 years) (Table 6.28).

Table 6.28: *Dens facet of the axis, blind test: age construction of the CCS sample.*

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	5	10	11	10	6	**42**
Female	4	8	8	5	5	**30**
Total	**9**	**18**	**19**	**15**	**11**	**72**

As sexually dimorphic criteria were required, males and females were analysed separately. Individual trait scores for porosity, osteophyte formation and eburnation were combined to form a composite score, which is ultimately used to estimate age-at-death. Composite scores range from 3 to 8 points.

6.2.2.2.1 Male

A total of 42 males provided suitably preserved articular facet on the dens processes for examination. The resultant composite scores were allocated into corresponding surface age stages (ranging between I and III) (Figure 6.18). It is the surface age stage that will provide an estimate of age. The developed ageing criteria for each stage was applied to each male CCS individual and compared with documented age.

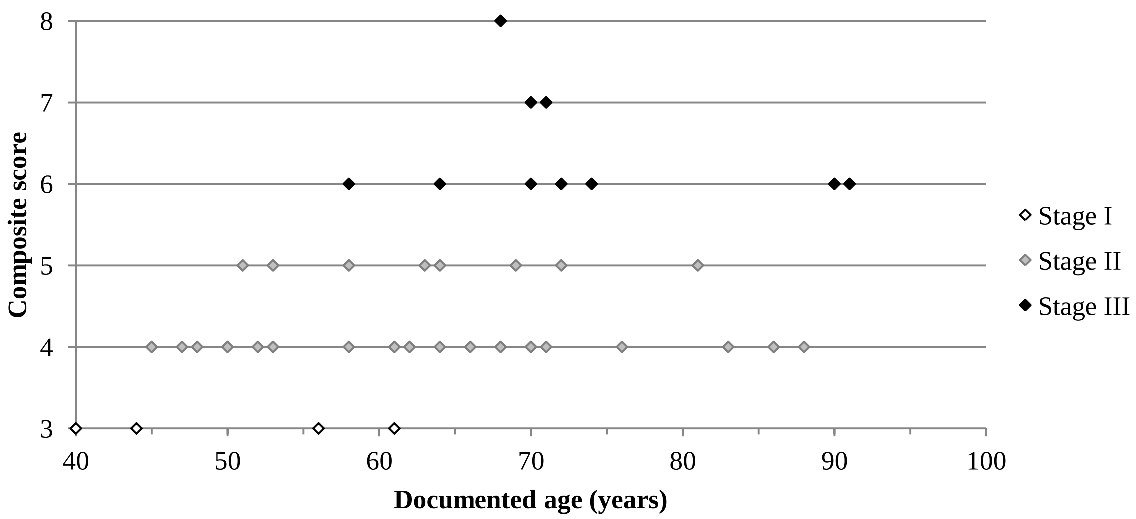


Figure 6.18: *Dens facet of the axis, blind test: scatter plot of derived age stages for males.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.19).

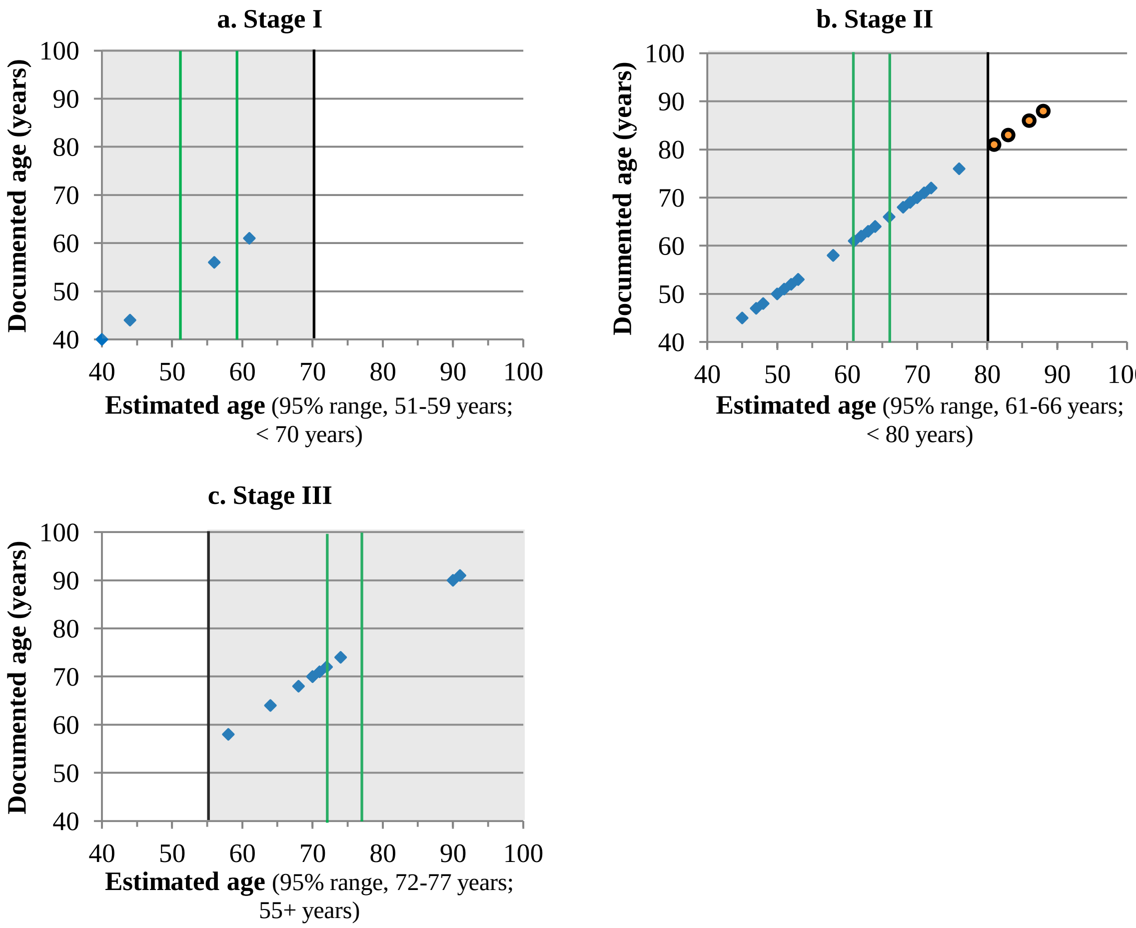


Figure 6.19a-c: *Dens facet of the axis, blind test: observed age stages (estimated age) for CCS male individuals, compared with documented ages. Outliers are highlighted as orange circles.*

Table 6.29 summarizes the frequency (i.e. accuracy) that the documented age fell within the 95% confidence interval for each age stage, and within the suggested general stated range (age phase). Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.29: *Dens facet of the axis, blind test: age estimations based on the appearance of the dens of the axis in males.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	4	40–61	51–59	1	25.0	< 70	4	100.0	0	0	no bias
II	28	45–88	61–66	7	25.0	< 80	24	85.7	4	14.3	underaged
III	10	58–91	72–77	2	20.0	55+	10	100.0	0	0	no bias
Total	42	-	-	10	**23.8**	-	38	**90.5**	4	**9.5**	**underaged**

Of the 42 individuals, only 23.8% fell within the 95% confidence interval based on this method, and 90.5% fell within the age phase.

6.2.2.2.2 Female

A total of 30 females provided suitably preserved articular facet on the dens processes for analysis. The resultant composite scores were allocated into corresponding surface age stages (between I and III) (Figure 6.20). It is the surface age stage that will provide an estimate of age. The developed ageing criteria for each stage was applied to each female CCS individual and compared with documented age.

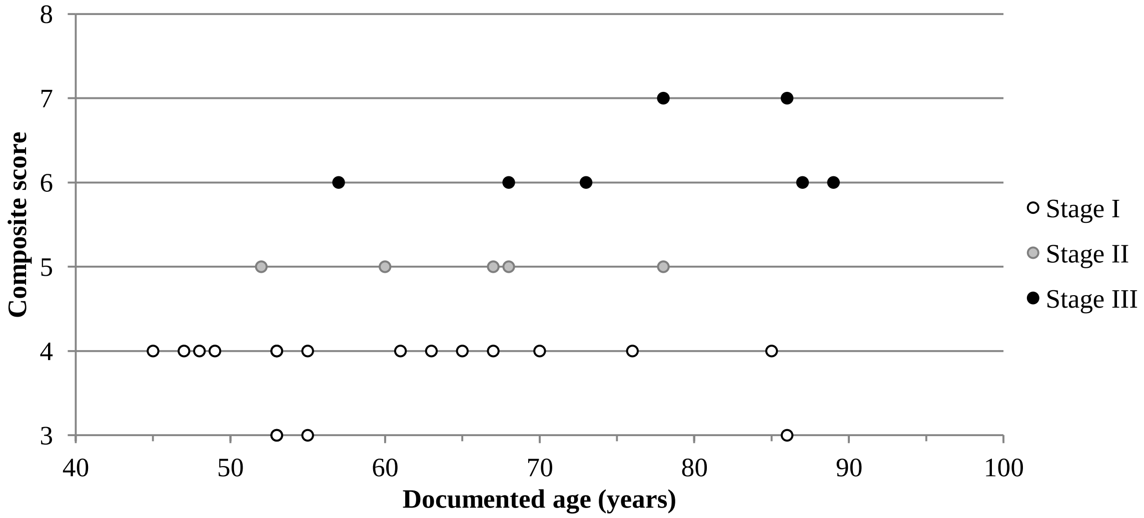
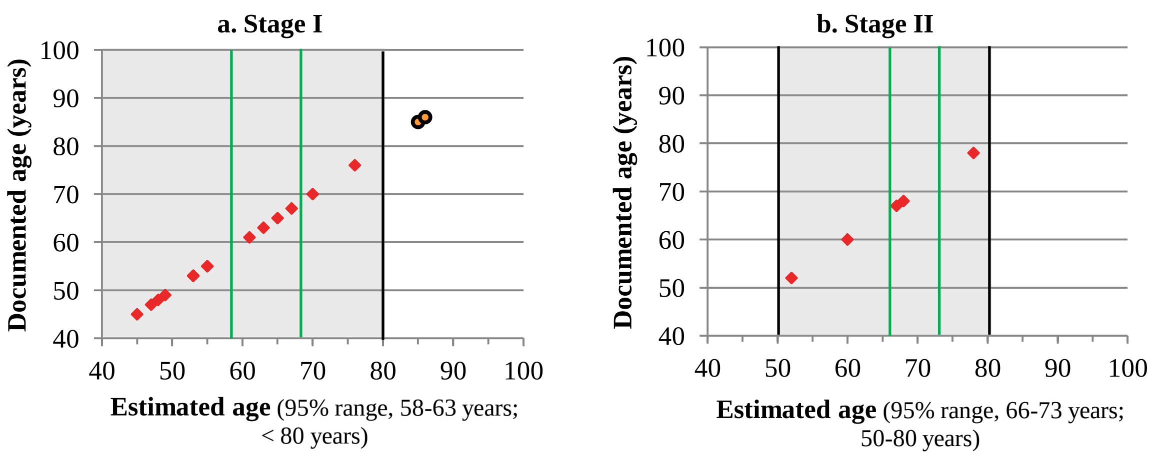


Figure 6.20: *Dens facet of the axis, blind test: scatter plot of derived age stages for females.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.21).



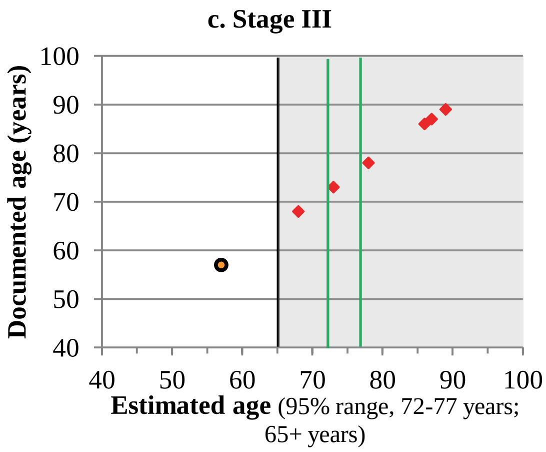


Figure 6.21a-c: *Dens facet of the axis, blind test: observed age stages (estimated age) for CCS female individuals, compared with documented ages.*

Table 6.30 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested general age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.30: *Dens facet of the axis, blind test: age estimations based on the appearance of the dens of the axis in females.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age: Within 95% confidence interval			Estimated age: Within age phase			Inaccuracy: Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	18	45–86	58–63	2	11.1	< 80	16	88.9	2	11.1	underaged
II	5	52–78	66–73	2	40.0	50–80	5	100.0	0	0	no bias
III	7	57–89	72–77	1	14.3	65+	6	85.7	1	14.3	overaged
Total	30	-	-	5	**16.7**	-	27	**90.0**	2	**6.7**	**underaged**
									1	**3.3**	**overaged**

Of the 30 females blind tested, only 16.7% fell within the 95% confidence interval based on this method, and 90.0% fell within the age phase.

6.2.2.2.3 Additional Analyses

To confirm the relationship between age and composite score of the anterior facet on the dens process of the second cervical vertebrae, a Spearman's rank correlation was calculated for males and females. Both were found to be highly statistically significant (male, $r_s = 0.475$; $P = 0.004$; female, $r_s = 0.496$; $P = 0.009$). The results are plotted in Figure 6.22.

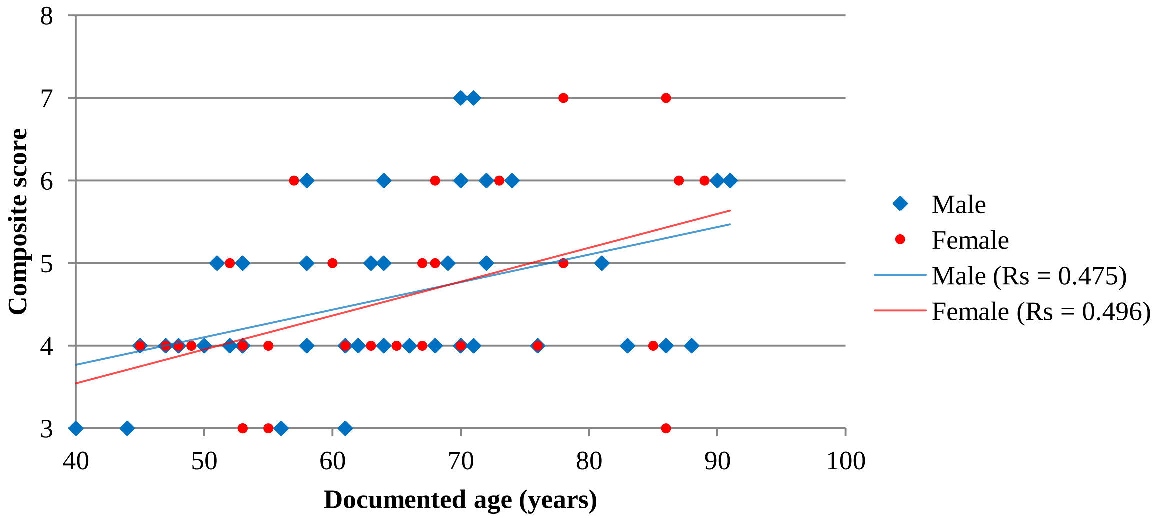


Figure 6.22: *Dens facet of the axis, blind test: scatter plot of composite scores against age for all individuals in the CCS sample. Spearman's rank correlation coefficients of score against age for males and females are provided.*

Comparison of the descriptive statistics of age variation within each age stage for males and females between the developed criteria and the CCS blind test sample are presented in Table 6.31.

Table 6.31: *Dens facet of the axis: age estimates from composite scores and age stages for the developed criteria and the CCS blind test sample.*

Age stage	Composite score	Developed criteria			CCS blind test sample			
		Mean age (years)	Standard deviation	95% confidence interval (years)	N	Mean age (years)	Standard deviation	95% confidence interval (years)
Males								
I	3	55.1	10.1	51–59	4	50.3	9.9	*
II	4–5	63.6	12.7	61–66	28	63.6	12.1	59–68
III	6–8	74.5	9.4	72–76	10	72.8	10.4	65–80
Female								
I	3–4	60.8	13.8	58–63	18	60.2	12.5	54–66
II	5	70.0	11.8	66–73	5	65.0	9.7	*
III	6–8	75.1	10.3	72–77	7	76.9	11.7	66–88

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.2.3 COMBINED RESULTS FOR DENS FACET OF ATLAS AND DENS PROCESS OF AXIS

In attempt to gain an overall view of the dens facet degeneration, the composite scores recorded for the dens facet on the atlas and the facet on the dens process of the axis were added together to for a summary score. This value was assessed for its correlation with documented age using Spearman's rank correlation coefficients. The Spearman's rank r_s value for the summary score was compared against each score found for composite scores, to determine whether the summary score was more highly correlated with age. The results for all study samples and the combined assemblage are presented below.

6.2.3.1 Combined Results for Dens Facets of the Atlas and the Axis: HTH Sample

A total of 156 individuals from the HTH sample had both the first and second cervical vertebrae for assessment. The combination of the composite scores for both the dens facet and dens itself resulted in a statistically significant correlation with documented age (r_s = 0.522, P < 0.001) (Table 6.32).

Table 6.32: *Combined results of the dens facets of the atlas and axis: Spearman's rank correlation between age and composite scores in the HTH sample.*

Feature	r_s	P
Atlas composite score	0.524	< 0.001
Axis composite score	0.460	< 0.001
Atlas and axis summary score	**0.522**	**< 0.001**

6.2.3.2 Combined Results for Dens Facets of the Atlas and the Axis: PBC Sample

As the degeneration of the facet of the dens process of the axis differed between the sexes, males and females were separated for analysis. A total of 109 males and 65 females from the PBC sample had both the first and second cervical vertebrae for assessment. The combination of the composite scores for both the dens facet and dens itself resulted in a statistically significant correlation with documented age in both males and females (male, r_s = 0.551, P < 0.001; female, r_s = 0.421, P < 0.001) (Table 6.33).

Table 6.33: *Combined results of the dens facets of the atlas and axis: Spearman's rank correlation between age and composite scores in the PBC sample for males and females.*

Feature	Male		Female	
	r_s	P	r_s	P
Atlas composite score	0.529	< 0.001	0.422	< 0.001
Axis composite score	0.536	< 0.001	0.383	0.002
Atlas and axis summary score	**0.551**	**< 0.001**	**0.421**	**< 0.001**

6.2.3.3 Combined Results for Dens Facets of the Atlas and the Axis: SB Sample

This was not possible as only males demonstrated a significant relationship between composite score and documented age for the dens facet of the atlas (C1), and only females showed this relationship on the dens process of the axis (C2).

6.2.3.4 Combined Results for Dens Facets of the Atlas and the Axis: CHC sample

A total of 163 individuals from the CHC sample had both the first and second cervical vertebrae for assessment. The combination of the composite scores for both the dens facet and dens itself resulted in a statistically significant correlation with documented age (r_s = 0.611, P < 0.001) (Table 6.34).

__Table 6.34:__ Combined results of the dens facets of the atlas and axis: Spearman's rank correlation between age and composite scores in the CHC sample.

Feature	$\mathbf{r_s}$	***P***
Atlas composite score	0.619	< 0.001
Axis composite score	0.558	< 0.001
Atlas and axis summary score	**0.611**	**< 0.001**

6.2.3.5 Combined Results for Dens Facets of the Atlas and the Axis: Combined Sample

To assess whether the combination of composite scores for the dens facet (atlas) and the dens itself (axis) has the ability to estimate age better than evaluating each element separately, the composite scores of the atlas and axis of 555 individuals (mean age, 67.1 years) were combined together to form a summary score (a value between 6 and 16 points). The sample included 315 male individuals (mean age, 66.7 years) and 240 females (mean age, 67.6 years) (Table 6.35).

__Table 6.35:__ Combined results of the dens facets of the atlas and axis: age construction of combined study sample.

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	39	61	68	92	55	**315**
Female	31	38	56	57	58	**240**
Total	**70**	**99**	**124**	**149**	**113**	**555**

The ages were plotted against summary scores for males and females in a scatter plot, with a regression line for both sets of data (Figure 6.23). The regression lines indicate that there was some difference between sexes (males, $r_s = 0.574$, $P < 0.001$; females, $r_s = 0.525$, $P < 0.001$).

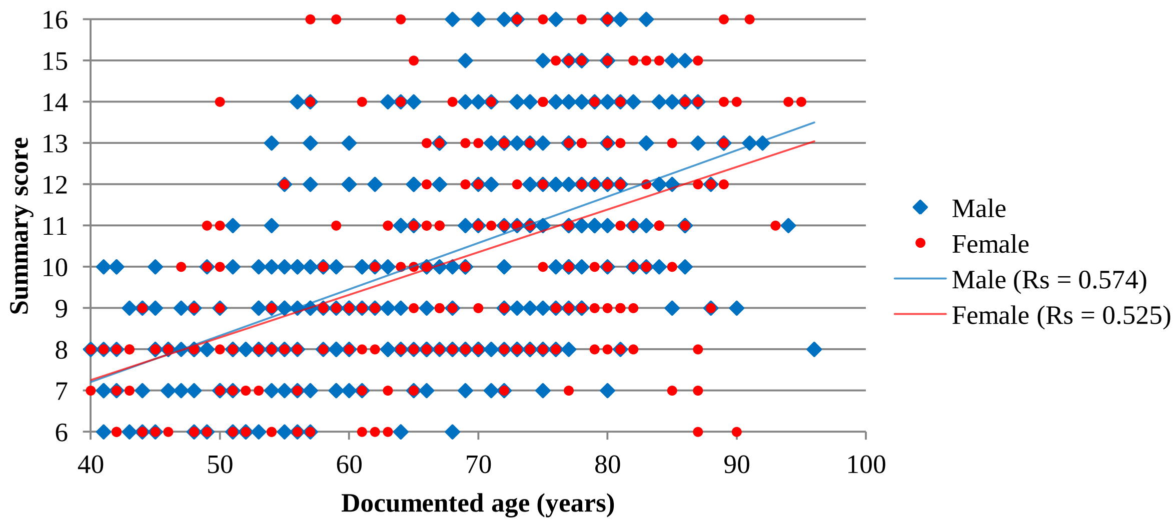


__Figure 6.23:__ Combined results of the dens facets of the atlas and axis: scatter plot of atlas and axis summary score against documented age. Spearman's rank correlation coefficients of summary score against age are provided.

To test whether the summary score was more correlated with age-at-death and each separate composite score, a Spearman's rank correlation coefficient was calculated (Table 6.36). The higher the score assigned to a particular trait expression, the more frequently it was associated with older age. This correlation was strongest with the atlas composite score in males (r_s = 0.581, P < 0.001) and the summary score in females (r_s = 0.525, P < 0.001).

Table 6.36: *Combined results of the dens facets of the atlas and axis: Spearman's rank correlation between age, composite and summary scores.*

Score	**Male**		**Female**	
	$\mathbf{r_s}$	***P***	$\mathbf{r_s}$	***P***
Atlas composite score	0.581	< 0.001	0.524	< 0.001
Axis composite score	0.524	< 0.001	0.477	< 0.001
Summary score	**0.574**	**< 0.001**	**0.525**	**< 0.001**

The descriptive statistics of age variation within composite scores for males (Table 6.37) and females (Table 6.38) each revealed the general trend of increasing age with increasing composite score.

Table 6.37: *Combined results of the dens facets of the atlas and axis: descriptive statistics for documented ages-at-death found to possess same summary scores of male individuals in combined sample.*

Summary score	**N**	**Mean age (years)**	**Standard deviation**	**Median age (years)**	**Observed range (years)**
6	16	52.6	7.8	52	41–68
7	25	56.8	11.1	56	41–80
8	72	61.6	12.3	63	40–96
9	37	62.9	12.3	60	43–90
10	37	64.0	12.6	63	41–86
11	26	74.6	10.0	77	51–94
12	28	73.0	9.1	74	55–88
13	22	75.9	10.7	76	54–92
14	32	75.5	8.1	77	56–87
15	11	78.7	4.6	78	69–86
16	9	76.0	5.5	76	68–83

Table 6.38: *Combined results of the dens facets of the atlas and axis: descriptive statistics for documented ages-at-death found to possess same summary scores of female individuals in the combined sample.*

Summary score	**N**	**Mean age (years)**	**Standard deviation**	**Median age (years)**	**Observed range (years)**
6	21	54.1	13.2	51	42–90
7	16	60.1	14.5	58	40–87
8	52	60.4	12.8	61	40–87
9	32	67.3	11.6	67	44–88
10	21	69.3	11.9	69	47–85
11	27	72.3	10.9	71	49–93
12	18	77.8	8.8	79	55–89
13	14	75.6	6.8	75	66–89
14	18	75.6	13.2	75	50–95
15	9	79.1	6.4	80	65–87
16	12	74.9	10.7	76	57–91

Several composite scores were found to provide similar age ranges, mean ages, and median ages. These scores were then combined to produce surface age stages for males and females (Tables 6.39 and 6.40, respectively). In addition to the 95% confidence interval, a broader range (age phase) with which to estimate age was also provided for each age stage.

Table 6.39: *Combined results of the dens facets of the atlas and axis: age estimates from summary scores and age stages (males).*

Summary score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
6	I	16	52.6	7.9	48–57	< 60 years
7–10	II	171	61.7	12.3	59–64	45+ years
11–16	III	128	75.2	8.8	73–77	60+ years

Table 6.40: *Combined results of the dens facets of the atlas and axis: age estimates from summary scores and age stages (females).*

Summary score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
6–8	I	89	58.9	13.3	56–62	< 65 years
9–11	II	80	69.5	11.5	66–72	50–80 years
12–16	III	71	76.5	9.7	74–79	65+ years

Unpaired *t*-tests were employed to test for statistically significant differences between the stages (Table 6.41). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.41: *Combined results of the dens facets of the atlas and axis: results of t-tests between age stages.*

Stages compared	Male			Female		
	t	**df**	***P***	***t***	**df**	***P***
I vs II	-4.15	23	< 0.001	-5.50	167	< 0.001
II vs III	11.01	297	< 0.001	4.01	149	< 0.001

6.2.3.5.1 Intraobserver Error

A subsample (5 males and 5 females) from each of the four skeletal collections were re-recorded to test for intraobserver error (N = 40). Paired *t*-tests were used to determine any significant differences in the two occasions (Table 6.42), which found no significant variation between the trait scores and composite scores (i.e. $P > 0.05$).

Table 6.42: *Combined results of the dens facets of the atlas and axis: intraobserver error paired t-test results (N = 40).*

Trait	*t*	df	*P*
Porosity	-1.40	39	0.168
Osteophyte formation	-1.14	39	0.262
Eburnation	1.00	39	0.323
Composite score	**-1.48**	**39**	**0.147**

6.2.3.6 Combined Results for Dens Facets of the Atlas and the Axis: Blind Test

A total of 67 individuals from the CCS collection provided both the dens facets of the atlas and the dens process of the axis to be combined in the blind test. The sample comprised 37 males with age-at-death ranging from 40-91 years (mean age, 63.5 years) and 30 females, ranging between 45-89 years (mean age, 64.9 years) (Table 6.43).

Table 6.43: *Combined results of the dens facets of the atlas and axis, blind test: age construction of the CCS sample.*

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	4	9	11	10	3	**37**
Female	4	8	8	5	5	**30**
Total	**8**	**17**	**19**	**15**	**8**	**67**

As sexually dimorphic criteria were required, males and females were analysed separately. Individual trait scores for porosity, osteophyte formation and eburnation for each element were combined to form a composite score. Combined composite scores (i.e. summary score) range from 6 to 16 points were formed, which were ultimately used to estimate age-at-death.

6.2.3.6.1 Male

A total of 37 males provided suitably preserved articular facet on the dens processes for examination. The resultant combined composite scores were allocated into corresponding surface age stages (ranging between I and III) (Figure 6.24). It is the surface age stage that will provide an estimate of age. The developed ageing criteria for each stage was applied to each male CCS individual and compared with documented age.

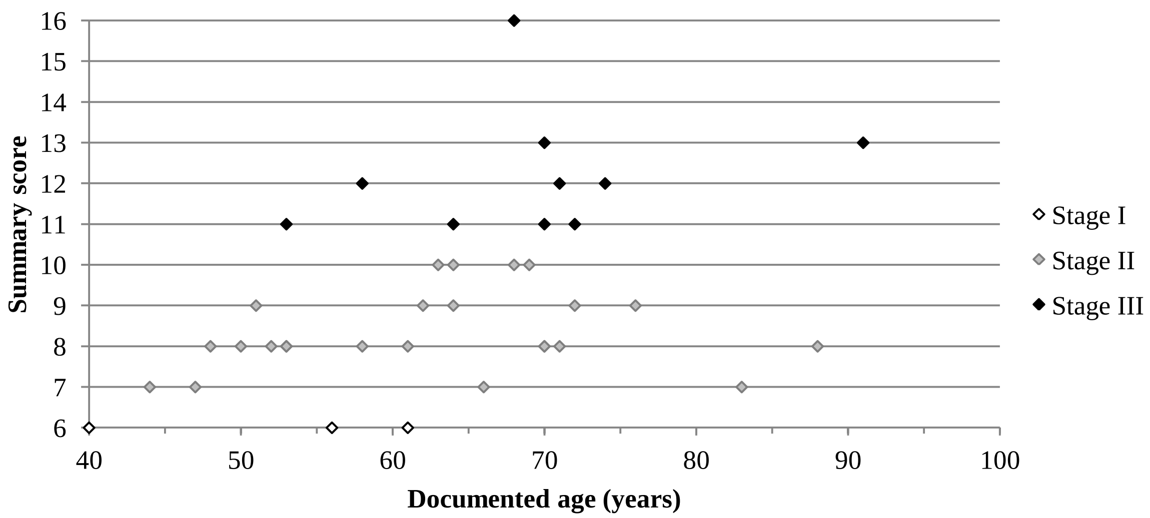


Figure 6.24: *Combined results of the dens facets of the atlas and axis, blind test: scatter plot of derived age stages for males.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.25).

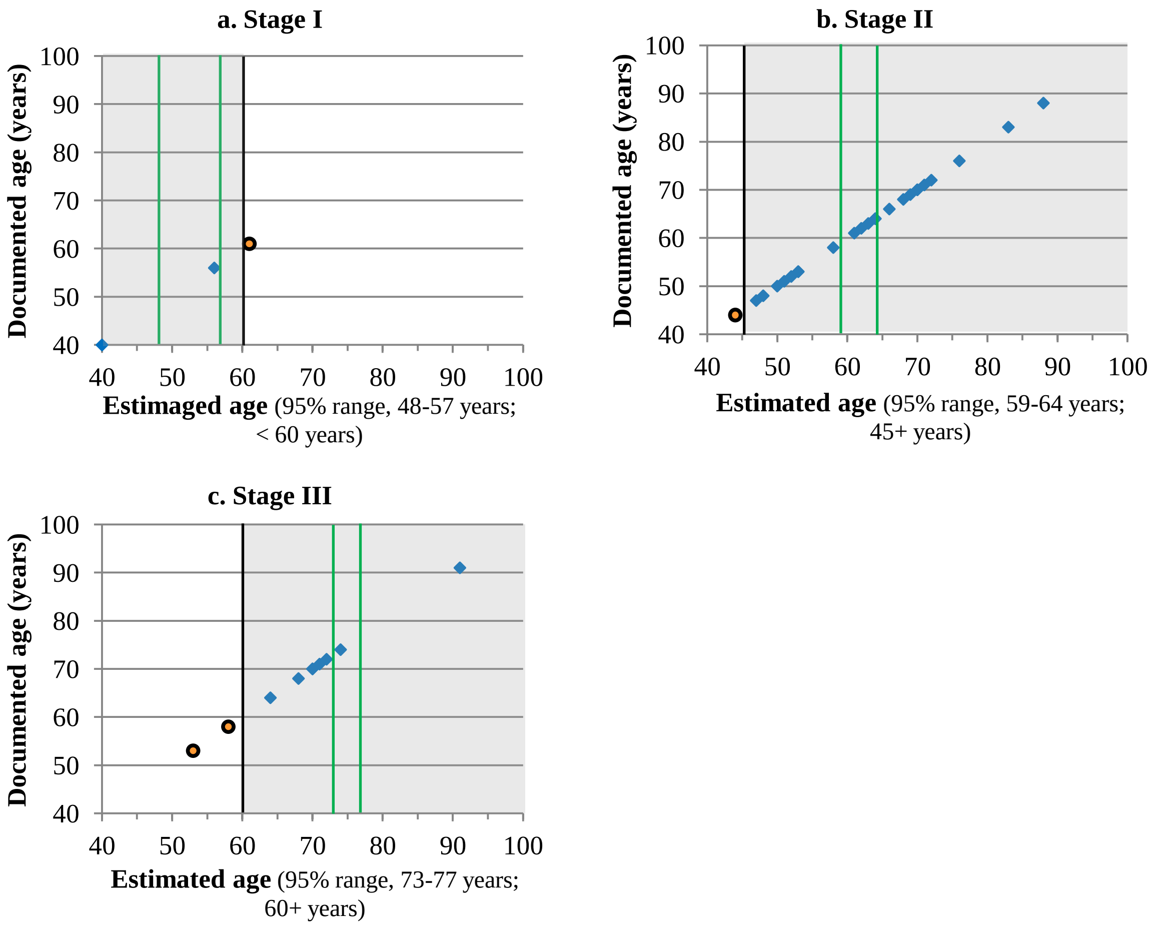


Figure 6.25a-c: *Combined results of the dens facets of the atlas and axis, blind test: observed age stages (estimated age) for CCS males, compared with documented ages.*

Table 6.44 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested general age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.44: *Combined results of the dens facets of the atlas and axis, blind test: age estimations based on the combined appearance of the dens facets in males.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age (ranges in years)						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range	N	%	Range	N	%	N	%	Bias
I	3	40–61	48–57	1	33.3	< 60	2	66.7	1	33.3	underaged
II	24	44–88	59–64	5	20.8	45+	23	95.8	1	4.7	overaged
III	10	53–91	73–77	1	10.0	60+	8	80.0	2	20.0	overaged
Total	37	-	-	7	**18.9**	-	33	**89.2**	1	**2.7**	**underaged**
									3	**8.1**	**overaged**

Of the 37 male individuals, only 18.9% fell within the 95% confidence interval based on this method, and 89.2% fell within the age phase.

6.2.3.6.2 Female

A total of 30 females provided suitably preserved dens articular facet on the atlas and dens processes of the axis for analysis. The resultant composite scores were allocated into corresponding surface age stages (between I and III) (Figure 6.26). It is the surface age stage that will provide an estimate of age. The developed ageing criteria for each stage was applied to each female CCS individual and compared with documented age.

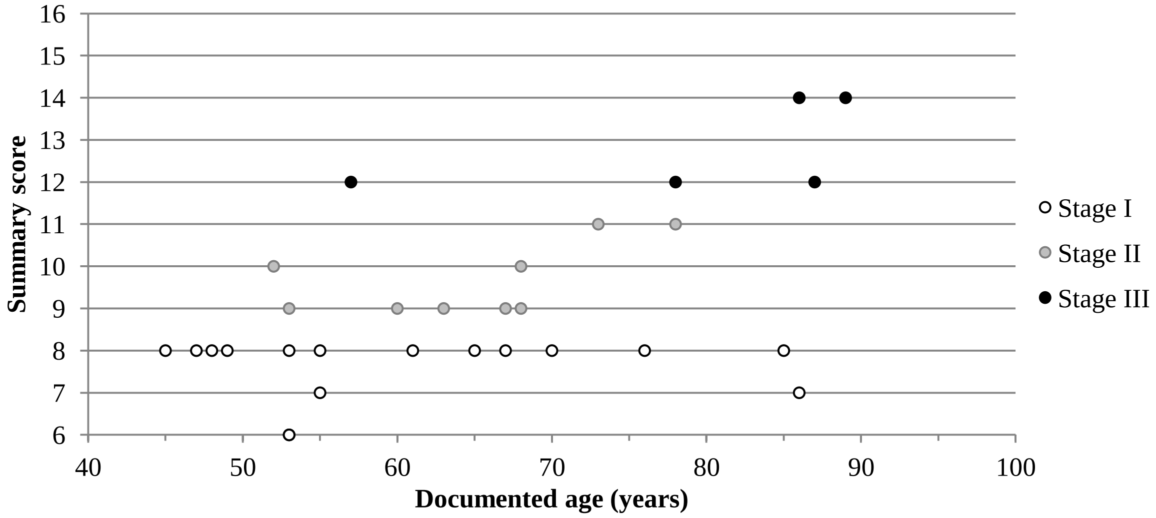
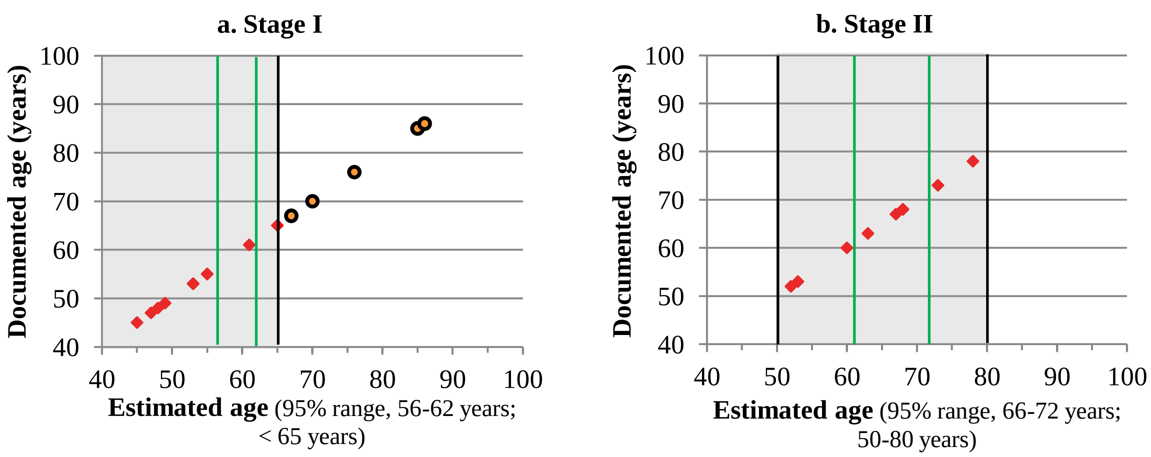


Figure 6.26: *Combined results of the dens facets of the atlas and axis, blind test: scatter plot of derived age stages for females.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.27).



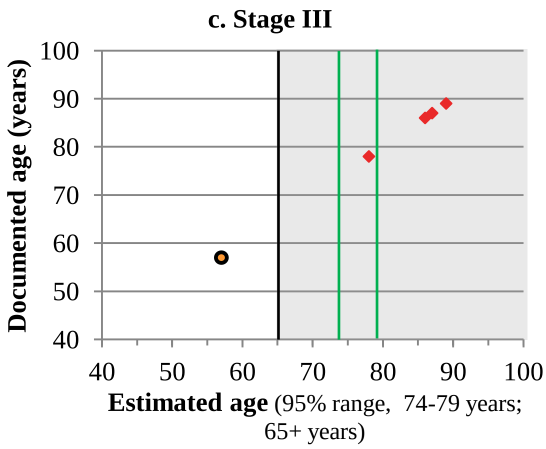


Figure 6.27a-c: *Combined results of the dens facets of the atlas and axis, blind test: observed age stages (estimated age) for CCS females, compared with documented ages.*

Table 6.45 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested general age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.45: *Combined results of the dens facets of the atlas and axis, blind test: age estimations based on the combined appearance of the dens facets in females.*

Stage of appearance	N	Actual age range of individuals (years)	**Estimated age** (ranges in years)						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range	N	%	Range	N	%	N	%	Bias
I	16	45–86	56–62	1	6.3	< 65	11	68.8	5	31.2	underaged
II	9	52–78	66–72	3	33.3	50–80	9	100.0	0	0	no bias
III	5	57–89	74–79	1	20.0	65+	4	80.0	1	20.0	overaged
Total	30	-	-	5	**16.7**	-	24	**80.0**	5	**16.7**	**underaged**
									1	**3.3**	**overaged**

Of the 30 female individuals, only 16.7% fell within the 95% confidence interval based on this method, and 80.0% fell within the age phase.

6.2.3.6.3 Additional Analyses

To confirm the relationship between age and summary score of the dens facet of the atlas and the dens process of the axis, a Spearman's rank correlation was calculated for males and females. This relationship was found to be highly statistically significant in males and females (males, $r_s = 0.446$; $P = 0.007$; females, $r_s = 0.485$; $P = 0.009$). The results are plotted in Figure 6.28.

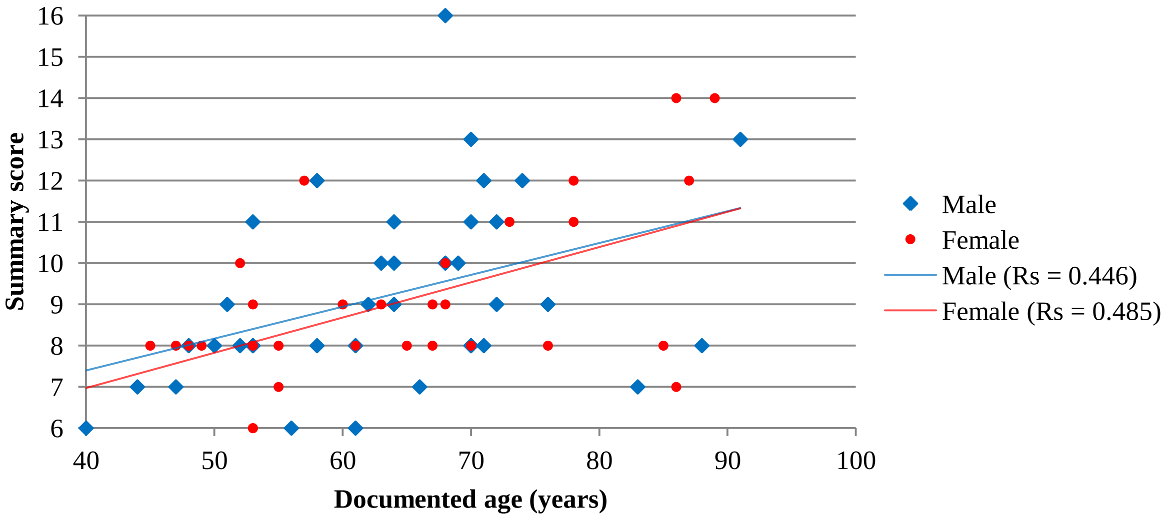


Figure 6.28: *Combined results of the dens facets of the atlas and axis, blind test: scatter plot of summary scores against age for all individuals in the CCS sample. Spearman's rank correlation coefficients of score against age for males and females are provided.*

Comparison of the descriptive statistics of age variation within each age stage for males and females between the developed criteria and the CCS blind test sample are presented in Table 6.46.

Table 6.46: *Combined results of the dens facets of the atlas and axis, blind test: comparison of age estimates for the developed criteria and the CCS blind test sample.*

Age stage	Summary score	Developed criteria			CCS blind test sample			
		Mean age (years)	Standard deviation	95% confidence interval (years)	N	Mean age (years)	Standard deviation	95% confidence interval (years)
Males								
I	6	52.6	7.9	48–57	3	52.3	11.0	*
II	7–10	61.7	12.3	59–64	24	62.6	11.4	57–68
III	11–16	75.2	8.8	73–77	10	69.1	10.2	61–76
Females								
I	6–8	58.9	13.3	56–62	16	60.5	13.1	53–68
II	9–11	69.5	11.5	66–72	9	64.7	8.6	58–71
III	12–16	76.5	9.7	74–79	5	79.4	13.2	*

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.2.4 CERVICAL VERTEBRAL BODIES

The general observations for individual trait scores recorded for the bodies of the third to seventh cervical vertebral bodies (i.e. presence of porosity, osteophyte formation, eburnation and surface bone formation) were combined to form a composite score. It was common for the expression of degenerative traits to vary greatly from one vertebra to the next (i.e. the lower vertebrae commonly displayed more severe changes than the upper), and as a result, the most severe recorded trait expression was used in the final composite score production. In the event that two or more of the cervical vertebrae were fused together, a score of 4 was assigned to three of the four traits (porosity, osteophyte formation, and eburnation). Composite scores ranged between 4 and 14 points (i.e. porosity, scored between 1 and 4 (fused vertebrae); osteophyte formation, scored between 1 and 4 (fused vertebrae); eburnation, scored 1, 2 or 4 (fused vertebrae); surface bone formation, scored 1 or 2). The composite score was used to assess degenerative differences between males and females.

6.2.4.1 Cervical Vertebrae Body Results: Combined Sample

To assess the true extent of the degenerative processes of the cervical vertebral bodies, all four collections were combined (Figure 6.29). Again the SB sample differed from the other three, as differences were found between males and females. Eburnation was also found to not be significantly correlated with documented age. The total sample size used to develop this method was the cervical spine of 610 individuals (mean age, 67.3 years), 341 male individuals (mean age, 66.8 years) and 269 female clavicles (mean age, 68.0 years) (Table 6.47).

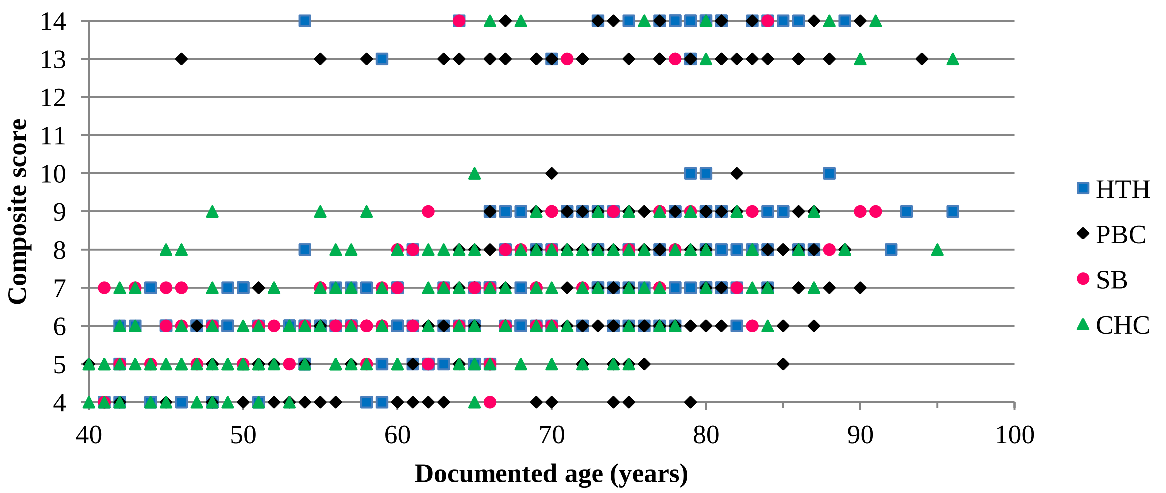


Figure 6.29: *Cervical vertebrae bodies: scatter plot of composite scores against age for all individuals in the combined study sample.*

Table 6.47: Cervical vertebrae bodies: age construction of combined study sample.

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	40	66	76	98	61	**341**
Female	33	41	64	67	64	**269**
Total	**73**	**107**	**140**	**165**	**125**	**610**

Development of the cervical vertebrae ageing technique will re-assess the expression between males and females, as well as the distribution of trait expression of the larger combined sample. Composite scores ranged between 4 and 14 points (i.e. porosity, scored between 1 and 4 (fused vertebrae); osteophyte formation, scored between 1 and 4 (fused vertebrae); eburnation, scored 1, 2 or 4 (fused vertebrae); surface bone formation, scored 1 or 2). This composite score was used to assess degenerative differences between males and females.

6.2.4.1.1 Male Versus Female

The ages were plotted against composite scores for males and females in a scatter plot, with a regression line for both sets of data (Figure 6.30). The regression lines indicate that there was some difference between sexes (males, $r_s = 0.614$, $P < 0.001$; females, $r_s = 0.557$, $P < 0.001$).

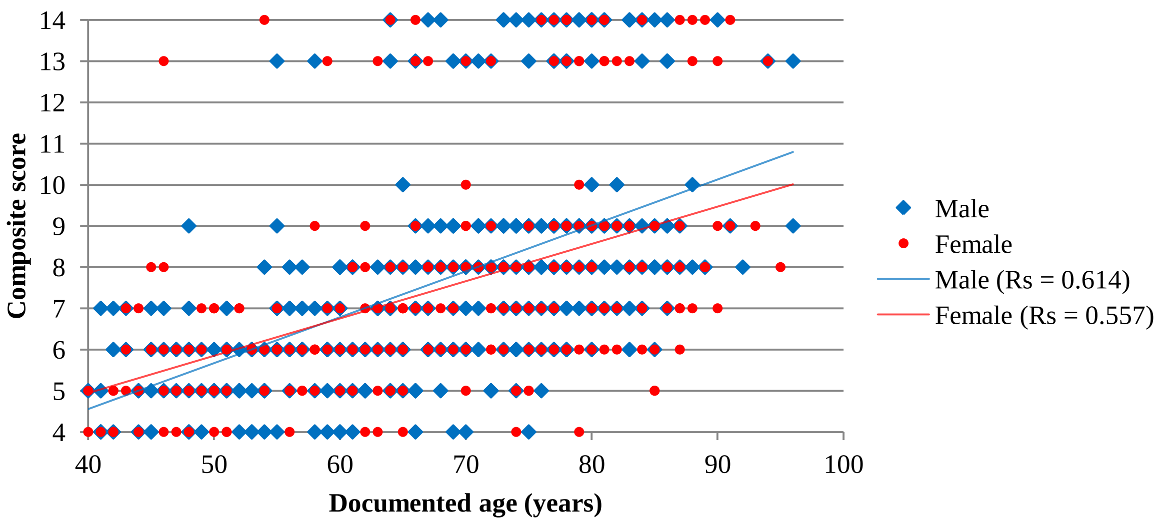


Figure 6.30: *Cervical vertebrae bodies: scatter plot of composite scores against known age for the combined study sample. Spearman's rank correlation coefficients of composite score against age for males and females are provided.*

A standard unpaired (two-sample, two-tailed) *t*-test was also carried out to test for significant differences between males and females for each composite score. It is noted a minimum of two males and two females were required to perform a *t*-test. Although a wide spread of *P*-values resulted, no statistically significant differences were identified at the 95% confidence level between ages for males and females ($P > 0.05$; see Table 6.48). The sample size for the remaining statistically analyses was 610 (male, N = 341; female, N = 269).

***Table 6.48:** Cervical vertebrae bodies: two-tailed t-tests between males and females for each composite score.*

Composite score	*t*	df	*P*
4	0.30	40	0.767
5	-0.30	78	0.766
6	-1.20	142	0.232
7	1.45	99	0.149
8	-0.44	93	0.661
9	-1.06	63	0.294
10	0.54	4	0.616
11	none observed		
12	none observed		
13	0.13	37	0.899
14	-0.06	21	0.952

6.2.4.1.2 Individual Trait Scores, Composite Scores and Age-at-Death

The frequencies of trait score within each composite score were plotted (Figure 6.31). The scores assigned to individual traits displayed a positive relationship with composite scores. That is, trait expressions with a higher individual score clustered within the range of higher composite scores (see Figure 6.31).

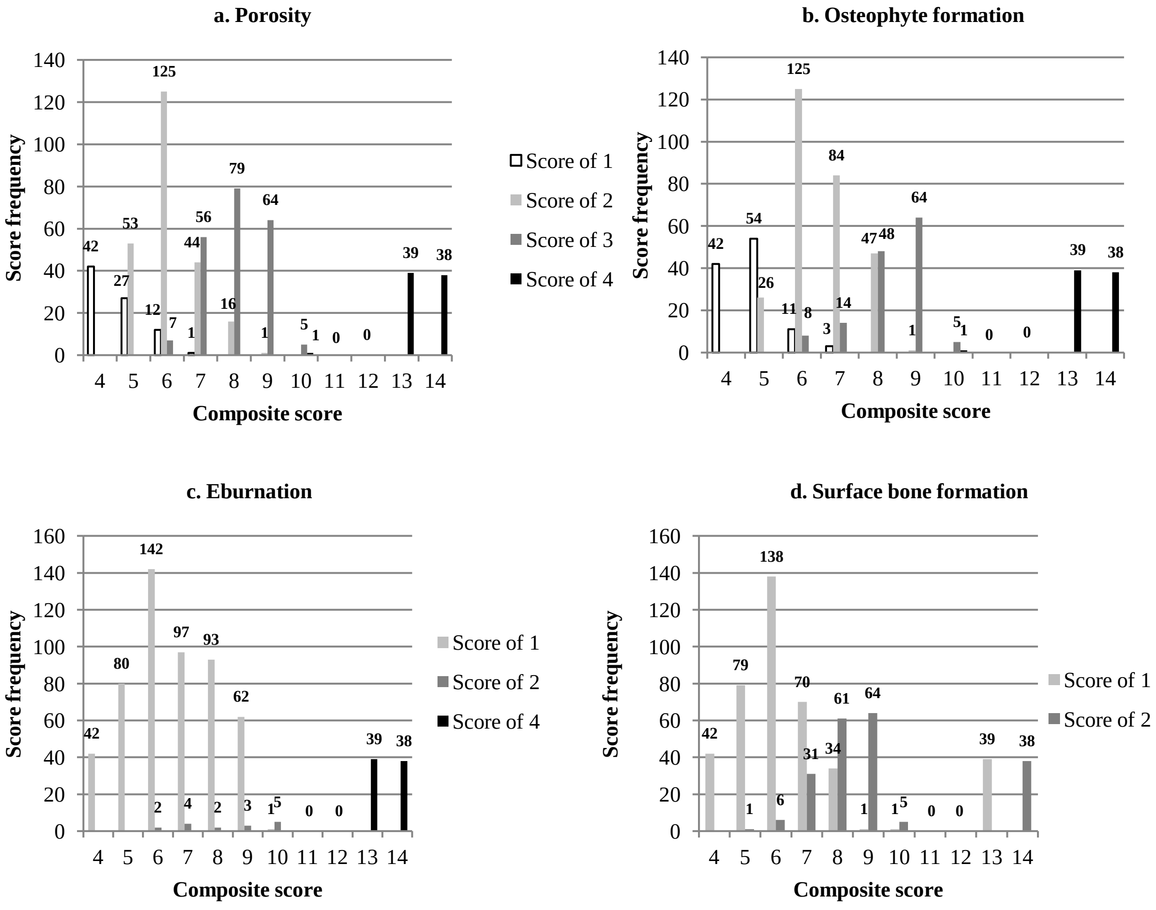


***Figure 6.31a-d:** Cervical vertebrae bodies: number of observations of trait scores recorded in the combined study sample.*

Individual trait expressions were investigated as to their association with age-at-death. Scatter plots of trait scores were plotted against age-at-death (Figure 6.32).

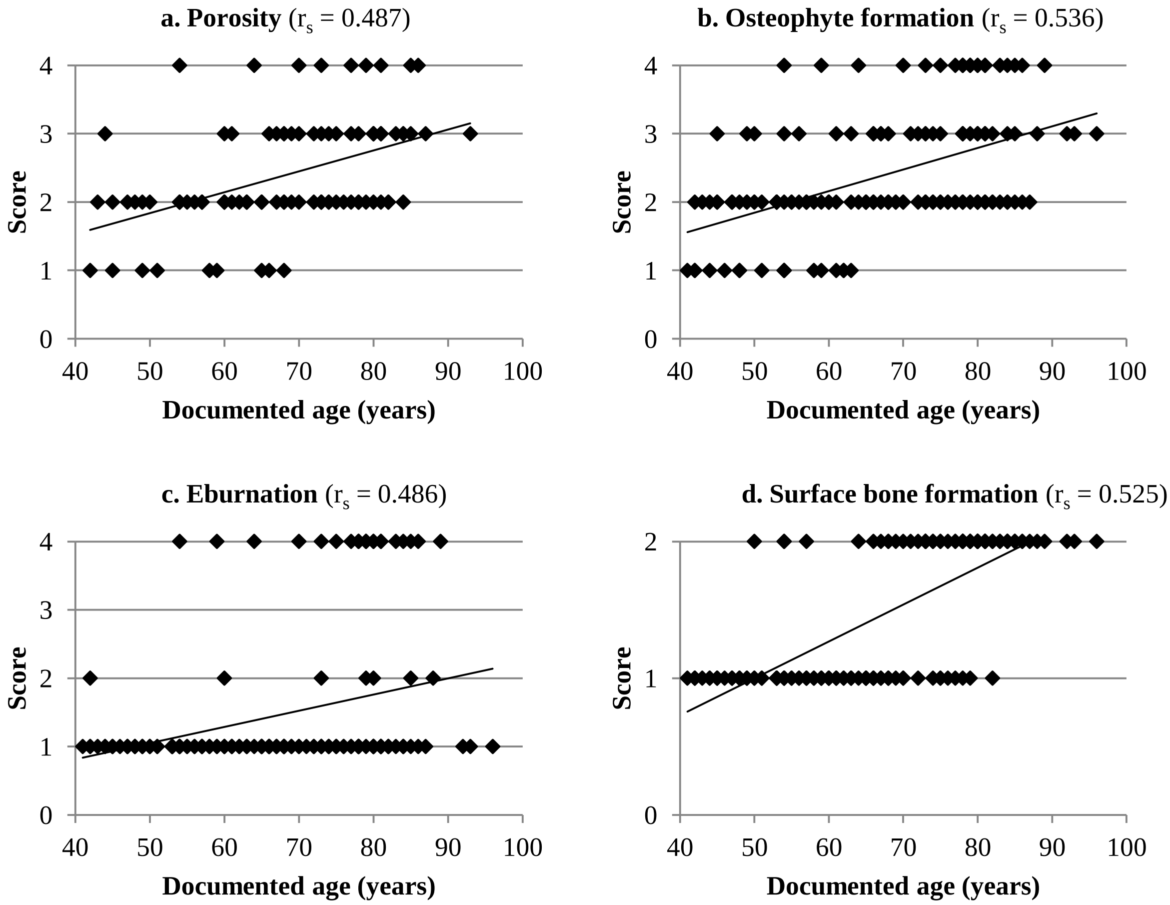


Figure 6.32a-d: *Cervical vertebrae bodies: scatter plots of trait scores against age-at-death. Spearman's rank correlation coefficients of trait score against age are provided.*

To test whether each feature is correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. Individual trait expressions were found to be significantly correlated with age-at-death (Table 6.49). The higher the score assigned to a particular trait expression, the more frequently it was associated with older age. This correlation was strongest with osteophyte formation ($r_s = 0.535$, $P < 0.001$).

Table 6.49: *Cervical vertebrae bodies: Spearman's rank correlation between age and trait expression of features.*

Feature	r_s	***P***
Porosity	0.487	< 0.001
Osteophyte formation	0.536	< 0.001
Eburnation	0.486	< 0.001
Surface bone formation	0.525	< 0.001
Composite score	**0.587**	**< 0.001**

A Spearman's rank correlation coefficient was also calculated for the derived composite with age. As was found with each individual feature, the combination of scores for surface porosity, osteophyte formation and presence of eburnation also produced a significant correlation with documented age (r_s = 0.587, $P < 0.001$) (Table 6.49, Figure 6.33).

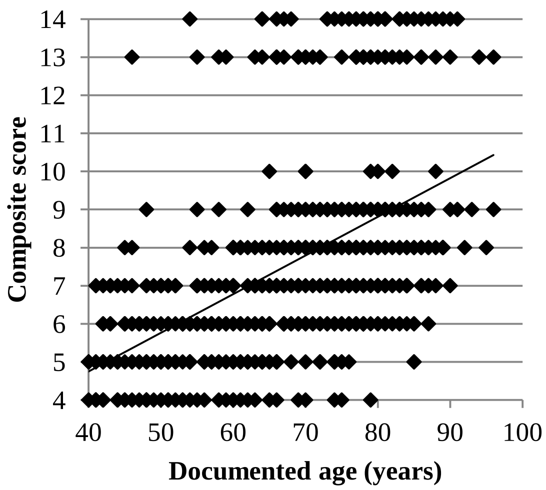


Figure 6.33: *Cervical vertebrae bodies: association between composite scores and documented age;* $r_s = 0.587$.

The descriptive statistics of age variation within composite scores (Table 6.50) revealed the general trend of increasing age with increasing composite score.

Table 6.50: *Cervical vertebrae bodies: descriptive statistics for documented ages-at-death found to possess same composite scores of the combined study sample (N = 610).*

Composite score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
4	42	53.3	10.5	51	40–79
5	80	56.8	10.9	55	40–85
6	144	63.0	11.3	62	42–87
7	101	67.7	12.4	68	41–90
8	95	73.9	10.1	74	45–95
9	65	76.9	8.7	78	48–96
10	6	77.3	8.4	79	65–88
11	0	-	-	-	-
12	0	-	-	-	-
13	39	75.0	11.1	77	46–96
14	38	78.2	7.9	79	54–91

Several composite scores were found to provide similar age ranges, mean ages, and median ages. These scores were then combined to produce surface age stages (Table 6.51). In addition to the 95% confidence interval, a broader range (age phase) with which to estimate age was also provided for each age stage.

Table 6.51: *Cervical vertebrae bodies: age estimates from composite scores and age stages.*

Composite score	**Age stage**	**N**	**Mean age (years)**	**Standard deviation**	**95% confidence interval (years)**	**Age estimate (age phase)**
4–5	I	122	55.6	10.9	53–58	< 70 years
6–7	II	245	65.0	12.0	63–67	45–80 years
8–14	III	243	75.6	9.6	74–77	65+ years

Unpaired *t*-tests were employed to test for statistically significant differences between the stages (Table 6.52). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.52: *Cervical vertebrae bodies: results of t-tests between age stages.*

Stages compared	***t***	**df**	***P***
I vs II	-7.27	365	< 0.001
II vs III	10.87	466	< 0.001

6.2.4.1.3 Intraobserver Error

A subsample (5 males and 5 females) from each of the four skeletal collections were re-recorded to test for intraobserver error (N = 40). Paired *t*-tests were used to determine any significant differences in the two occasions (Table 6.53), which found no significant difference between the trait scores and composite scores (i.e. $P > 0.05$).

Table 6.53: *Cervical vertebrae bodies: intraobserver error paired t-test results (N = 40).*

Trait	***t***	**df**	***P***
Porosity	1.43	39	0.160
Osteophyte formation	-1.00	39	0.323
Eburnation	-1.00	39	0.323
Surface growth	-1.00	39	0.323
Composite score	**0.26**	**39**	**0.800**

6.2.4.1.4 Other Observations

In all four collections, it was noted that the severity of trait expression of the vertebral bodies were not uniform throughout the cervical spine. The bodies of the lower vertebrae (i.e. the fifth, sixth and seventh cervical vertebrae) were the first to show degenerative change, and were commonly more severe than the upper cervical vertebral bodies.

6.2.4.2 Cervical Vertebrae Body Results: Blind Test

A blind test was performed on the bodies of the third through seventh cervical vertebrae (or any cervical bodies present) of 78 randomly chosen individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The sample comprised 44 males with age-at-death ranging from 40-91 years (mean age, 64.5 years) and 34 females, ranging between 44-89 years (mean age, 63.8 years) (Table 6.54).

Table 6.54: *Cervical vertebrae bodies, blind test: age construction of the CCS sample.*

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	4	12	12	10	6	**44**
Female	5	10	8	6	5	**34**
Total	**9**	**22**	**20**	**16**	**11**	**78**

As sexually dimorphic criteria were not required, males and females were analysed together. The most severe expressions of the individual trait scores for porosity, osteophyte formation and eburnation were combined to form a composite score, which is ultimately used to estimate age-at-death. Composite scores range from 4 to 14 points.

The resultant composite scores were allocated into corresponding surface age stages (ranging between I and III) (Figure 6.34). The developed ageing criteria for each stage was applied to each CCS individual and compared with documented age, as depicted in Figure 6.35.

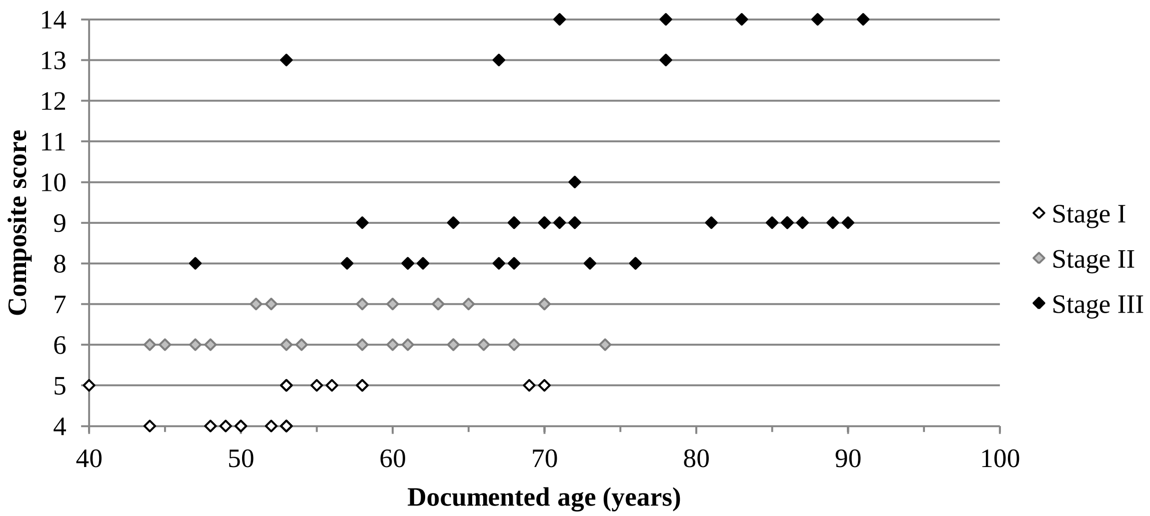


Figure 6.34: *Cervical vertebrae bodies, blind test: scatter plot of derived age stages for CCS individuals.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.35).

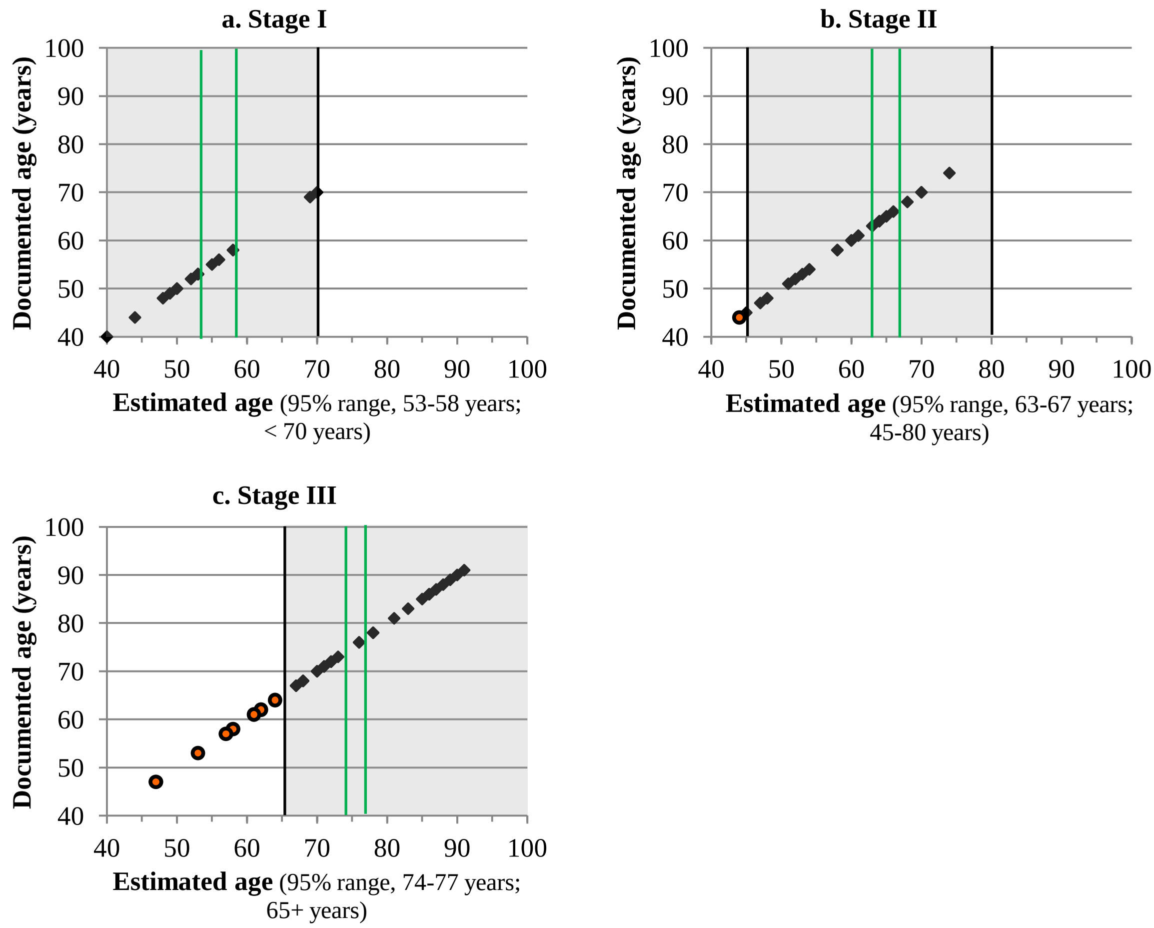


Figure 6.35a-c: *Cervical vertebrae bodies, blind test: observed age stages (estimated age) for CCS individuals, compared with documented ages.*

Table 6.55 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested general age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.55: *Cervical vertebrae bodies, blind test: age estimations based on the appearance of the bodies of the third to seventh cervical vertebrae.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	19	40–70	53–58	10	52.6	< 70	19	100.0	0	0	no bias
II	23	44–74	63–67	6	26.1	45–80	22	95.7	1	4.3	overaged
III	36	47–91	74–77	2	5.6	65+	28	77.8	8	22.2	overaged
Total	78	-	-	18	**23.1**	-	69	**88.5**	9	**11.5**	**overaged**

Of the 78 individuals, only 23.1% fell within the 95% confidence interval based on this method, and 88.5% fell within the age phase.

6.2.4.2.1 Additional Analyses

To confirm the relationship between age and composite score of the cervical vertebral bodies, a Spearman's rank correlation was calculated. The result was found to be highly statistically significant ($r_s = 0.727$; $P < 0.001$). The results are plotted in Figure 6.36.

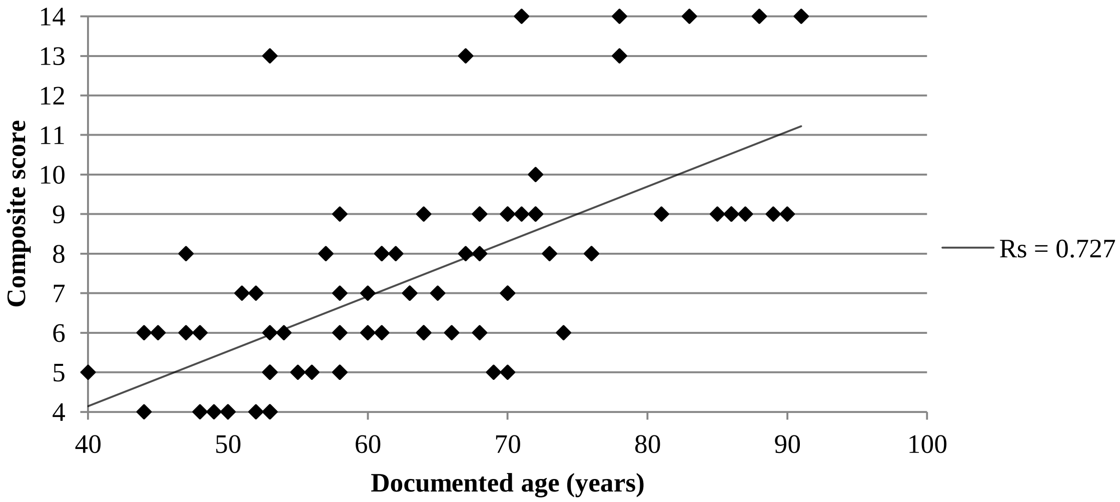


Figure 6.36: *Cervical vertebrae bodies, blind test: scatter plot of composite scores against age for all individuals in the CCS sample. Spearman's rank correlation coefficient of score against age is provided.*

Comparison of the descriptive statistics of age variation within each age stage between the developed criteria and the CCS blind test sample is presented in Table 6.56.

Table 6.56: *Age estimates from composite scores and age stages for the developed criteria and the CCS blind test sample.*

Age stage	Composite score	Developed criteria			CCS blind test sample			
		Mean age (years)	Standard deviation	95% confidence interval (years)	N	Mean age (years)	Standard deviation	95% confidence interval (years)
I	4–5	55.6	10.9	53–58	19	53.5	7.1	50–57
II	6–7	65.0	12.0	63–67	23	59.0	8.5	55–63
III	8–14	75.6	9.6	74–77	36	73.1	11.2	69–77

6.2.5 CERVICAL VERTEBRAE: ARTICULAR FACETS

The same procedure was followed as the dens facet of the atlas (section 6.2.1). It was common for the expression of degenerative traits to vary greatly from one vertebra to the next (i.e. the lower vertebrae commonly displayed more severe changes than the upper), and as a result, the most severe recorded trait expression was used in the final composite score production. As with the dens facet, composite scores ranged between 3 and 8 points (i.e. porosity, scored between 1 and 3; osteophyte formation, scored between 1 and 3; eburnation, scored 1 or 2). This composite score was used to assess degenerative differences between males and females.

6.2.5.1 Cervical Vertebrae Facet Results: Combined Results

Two of the four skeletal samples demonstrated very similar patterns of cervical vertebral body degeneration (i.e. no differences between males and females, all traits statistically significant). The other two samples, PBC and SB, had differences between the sexes, and traits that were not correlated with documented age (i.e. PBC, eburnation; SB, eburnation and porosity). The total sample size used to develop this method was the cervical spine of 612 individuals (mean age, 67.2 years) (Table 6.57), 342 male individuals (mean age, 66.7 years) (Figure 6.37) and 270 females (mean age, 67.9 years) (Figure 6.38).

Table 6.57: *Cervical vertebrae facets: age construction of combined study sample.*

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	41	66	78	96	61	**342**
Female	34	41	64	67	64	**270**
Total	**75**	**107**	**142**	**163**	**125**	**612**

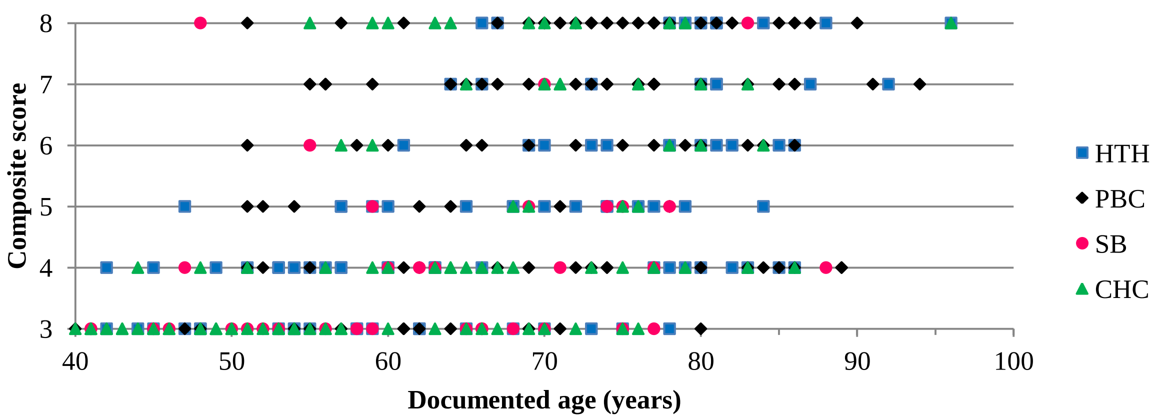


Figure 6.37: *Cervical vertebrae facets: scatter plot of composite scores against age for males in the combined study sample.*

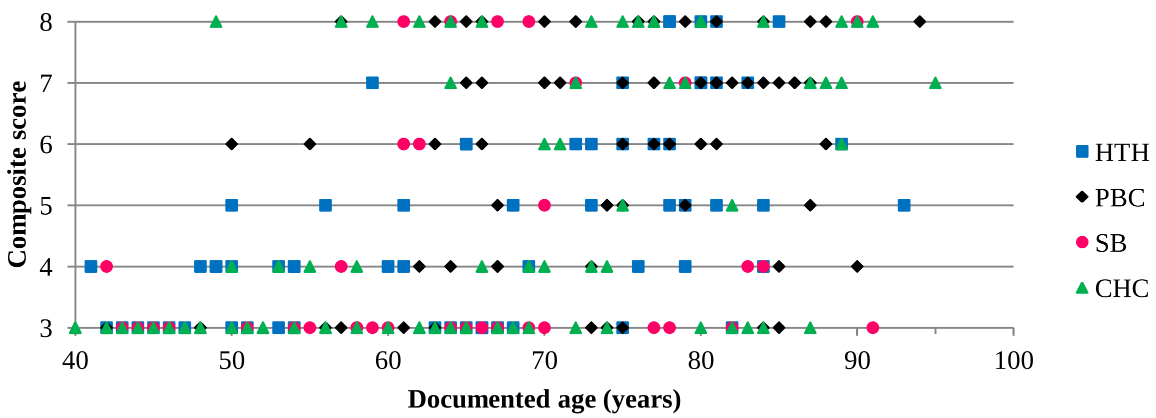


Figure 6.38: *Cervical vertebrae facets: scatter plot of composite scores against age for females in the combined study sample.*

Development of the cervical vertebrae facet ageing technique will re-assess the expression between males and females, as well as the distribution of trait expression of the larger combined sample. Composite scores ranged between 3 and 8 points (i.e. porosity, scored between 1 and 3; osteophyte formation, scored between 1 and 3; eburnation, scored 1 or 2). This composite score was used to assess degenerative differences between males and females.

6.2.5.1.1 Male Versus Female

The ages were plotted against composite scores for males and females in a scatter plot, with a regression line for both sets of data (Figure 6.39). The regression lines indicate that there was little difference between sexes (males, $r_s = 0.552$, $P < 0.001$; females, $r_s = 0.518$, $P < 0.001$).

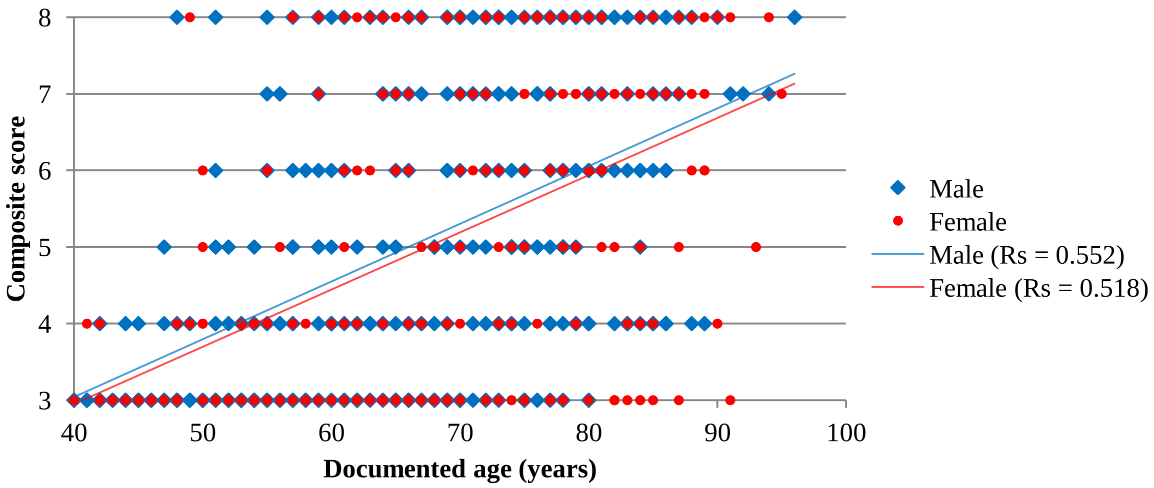


Figure 6.39: *Cervical vertebrae facets: scatter plot of composite scores against age for combined study sample. Spearman's rank correlation coefficients of composite score against age for males and females are provided.*

A standard unpaired (two-sample, two-tailed) *t*-test was also carried out to test for significant differences between males and females for each composite score. Statistically significant differences were identified at the 95% confidence level between ages for males and females in composite scores 3, 5 and 7 ($P < 0.05$; see Table 6.58). The sample size for the remaining statistically analyses was 342 males and 270 females, as the sexes display different ages in the noted composite scores.

Table 6.58: *Cervical vertebrae facets: independent two-tailed t-tests between males and females for each composite score.*

Composite score	*t*	df	*P*
3	-2.27	194	0.024*
4	1.21	106	0.229
5	-2.08	51	0.043*
6	0.29	56	0.772
7	-2.61	84	0.011*
8	0.07	101	0.944

*Key: * result is significant at the 95% confidence level (P < 0.05).*

6.2.5.2.2 Individual Trait Scores, Composite Scores and Age-at-Death

The frequencies of trait score within each composite score were plotted (Figure 6.40).

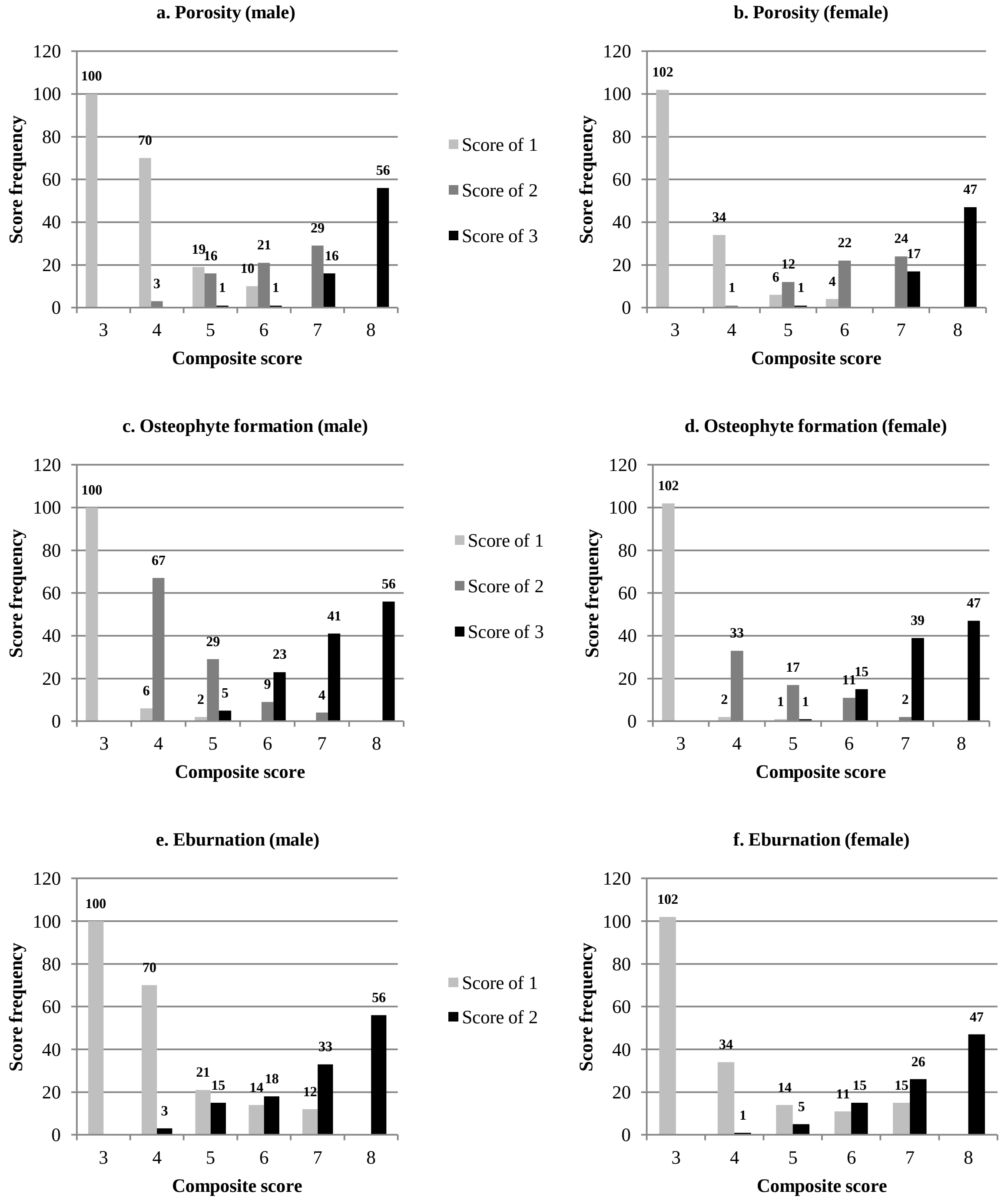


Figure 6.40a-f: *Cervical vertebrae facets: number of observations of trait scores recorded in the combined study sample.*

Individual trait expressions were investigated as to their association with age-at-death. Scatter plots of trait scores were plotted against age-at-death (Figure 6.41).

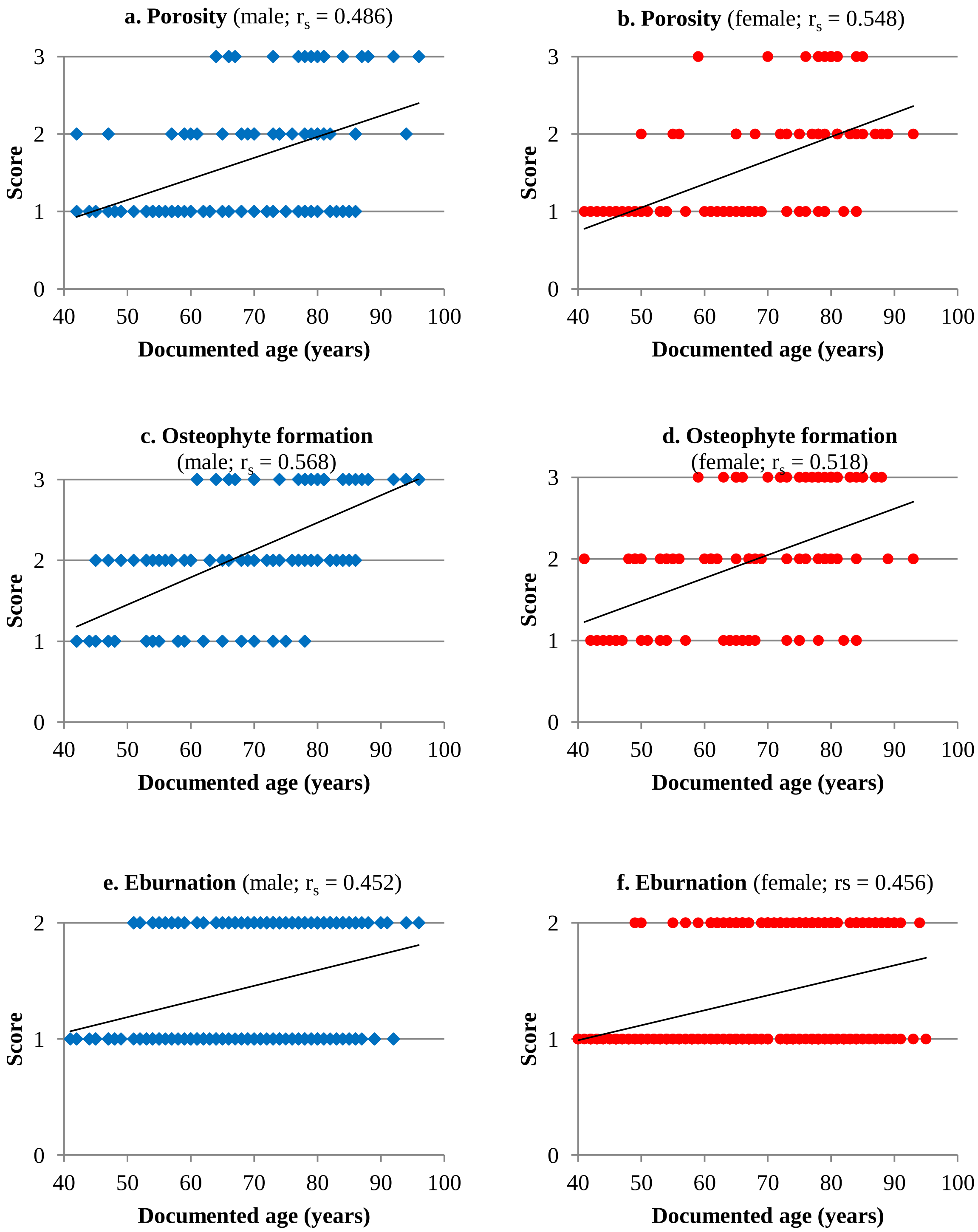


Figure 6.41a-f: *Cervical vertebrae facets: scatter plots of trait scores against age-at-death. Spearman's rank correlation coefficients of trait score against age are provided.*

To test whether each feature is correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. Individual trait expressions were found to be significantly correlated with age-at-death (Table 6.59). The higher the score assigned to a particular trait expression, the more frequently it was

associated with older age. This correlation was strongest with osteophyte formation in males (r_s = 0.568, $P < 0.001$), and porosity in females (r_s = 0.548, $P < 0.001$).

Table 6.59: *Cervical vertebrae facets: Spearman's rank correlation between age and trait expression of features.*

Feature	**Male**		**Female**	
	r_s	***P***	**r_s**	***P***
Porosity	0.486	< 0.001	0.548	< 0.001
Osteophyte formation	0.568	< 0.001	0.518	< 0.001
Eburnation	0.452	< 0.001	0.456	< 0.001
Composite score	**0.552**	**< 0.001**	**0.518**	**< 0.001**

A Spearman's rank correlation coefficient was also calculated for the derived composite with age. As was found with each individual feature, the combination of scores for surface porosity, osteophyte formation and presence of eburnation also produced a significant correlation with documented ages-at-death (male, r_s = 0.552, $P < 0.001$; female, r_s = 0.518, $P < 0.001$) (Table 6.59, Figure 6.42).

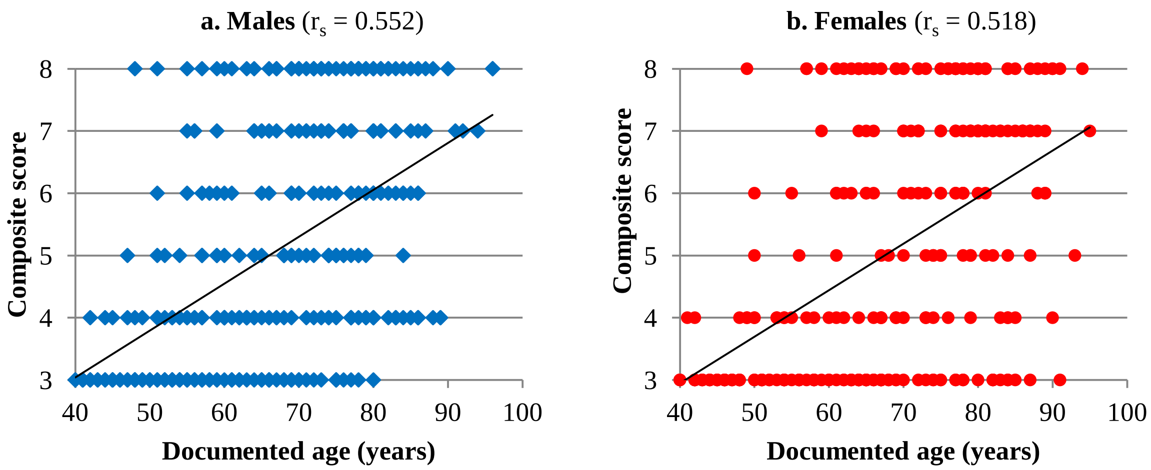


Figure 6.42: *Cervical vertebrae facets: association between composite scores and documented age. Spearman's rank correlation coefficients of composite score against age are provided.*

The descriptive statistics of age variation within composite scores for males and females (Tables 6.60 and 6.61, respectively) revealed the very general trends of increasing age with increasing composite score.

Table 6.60: *Cervical vertebrae facets: descriptive statistics for documented ages-at-death found to possess same composite scores of male individuals in the combined study sample (N = 342).*

Composite score	**N**	**Mean age (years)**	**Standard deviation**	**Median age (years)**	**Observed range (years)**
3	100	56.0	10.6	54	40–80
4	73	67.1	12.7	65	42–89
5	36	68.4	9.2	70	47–84
6	32	73.0	10.2	76	51–86
7	45	74.0	9.4	74	55–94
8	56	74.6	10.1	76	48–96

Table 6.61: *Cervical vertebrae facets: descriptive statistics for documented ages-at-death found to possess same composite scores of female individuals in the combined study sample (N = 270).*

Composite score	**N**	**Mean age (years)**	**Standard deviation**	**Median age**	**Observed range (years)**
3	102	59.8	13.0	58	40–91
4	35	63.9	13.0	64	41–90
5	19	74.0	10.5	75	50–93
6	26	72.2	10.1	74	50–89
7	41	78.9	7.6	80	59–95
8	47	74.5	10.4	76	49–94

Almost all composite scores were found to provide similar age ranges, mean ages, and median ages, making the production of distinct surface age stages problematic (Tables 6.62 and 6.63). For both males and females, a composite score of 3 was found to be statistically significantly different from the remaining composite scores. In addition to the 95% confidence interval, a broader range (age phase) with which to estimate age was also provided for each age stage.

Table 6.62: *Cervical vertebrae facets: age estimates from composite scores and age stages (males).*

Composite score	**Age stage**	**N**	**Mean age (years)**	**Standard deviation**	**95% confidence interval (years)**	**Age estimate (age phase)**
3	I	100	56.0	10.6	53–58	< 70 years
4–5	II	109	67.5	11.6	65–70	50–80 years
6–8	III	133	74.0	9.8	72–76	60+ years

Table 6.63: *Cervical vertebrae facets: age estimates from composite scores and age stages (females).*

Composite score	**Age stage**	**N**	**Mean age (years)**	**Standard deviation**	**95% confidence interval (years)**	**Age estimate (age phase)**
3–4	I	137	60.8	13.1	58–63	< 80 years
5–8	II	133	75.3	9.8	73–77	60+ years

Unpaired *t*-tests were employed to test for statistically significant differences between the stages (Table 6.64).

Table 6.64: *Cervical vertebrae facets: results of t-tests between age stages.*

Stages compared	**Male**			**Female**		
	t	**df**	***P***	***t***	**df**	***P***
I vs II	-7.49	207	< 0.001	-10.34	252	< 0.001
II vs III	4.71	240	< 0.001	-	-	-

6.2.5.1.3 Intraobserver Error

A subsample (5 males and 5 females) from each of the four skeletal collections were re-recorded to test for intraobserver error (N = 40). Paired *t*-tests were used to determine any significant differences in the two occasions (Table 6.65), which found no significant variation between the trait scores and composite scores (i.e. $P > 0.05$).

Table 6.65: *Cervical vertebrae facets: intraobserver error paired t-test results (N = 40).*

Trait	***t***	**df**	***P***
Porosity	1.00	39	0.323
Osteophyte formation	-1.78	39	0.083
Eburnation	1.00	39	0.323
Composite score	**-0.57**	**39**	**0.570**

6.2.5.1.4 Other Observations

In all four collections, it was noted that the severity of trait expression of the articular facets were not uniform throughout the cervical spine. The facets of the upper vertebrae (i.e. the third, fourth and fifth cervical vertebrae) were most frequently the first to display degenerative change, and the most severe trait expression.

6.2.5.2 Cervical Vertebrae Facet Results: Blind Test

A blind test was performed on the facets of the third through seventh cervical vertebrae (or any cervical vertebrae present) of 76 randomly chosen individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The sample comprised 43 males with age-at-death ranging from 40-91 years (mean age, 64.9 years) and 33 females, ranging between 45-89 years (mean age, 63.9 years) (Table 6.66).

Table 6.66: *Cervical vertebrae facets, blind test: age construction of the CCS sample.*

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	3	12	12	10	6	**43**
Female	4	11	8	5	5	**33**
Total	**7**	**23**	**20**	**15**	**11**	**76**

As sexually dimorphic criteria were required, males and females were analysed separately. The most severe expressions of the individual trait scores for porosity, osteophyte formation and eburnation were combined to form a composite score, which is ultimately used to estimate age-at-death. Composite scores range from 3 to 8 points.

6.2.5.2.1 Male

A total of 43 males provided suitably preserved articular facets on the third to seventh cervical vertebrae for examination. The resultant composite scores were allocated into corresponding surface age stages (ranging between I and III) (Figure 6.43). It is the surface stages that will provide an estimate of age. The developed ageing criteria for each stage was applied to each male CCS individual and compared with documented age.

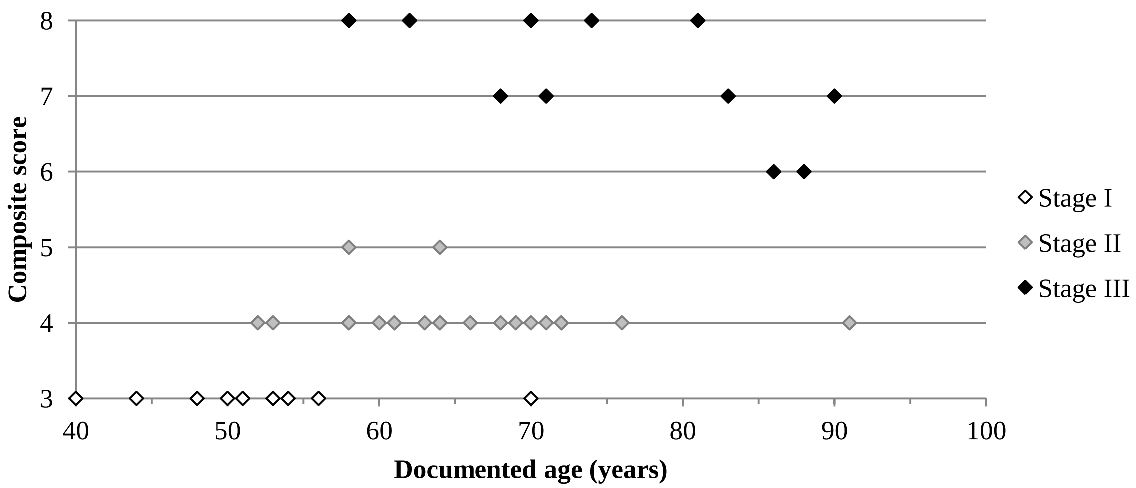


Figure 6.43: *Cervical vertebrae facets, blind test: scatter plot of derived age stages for male individuals.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.44).

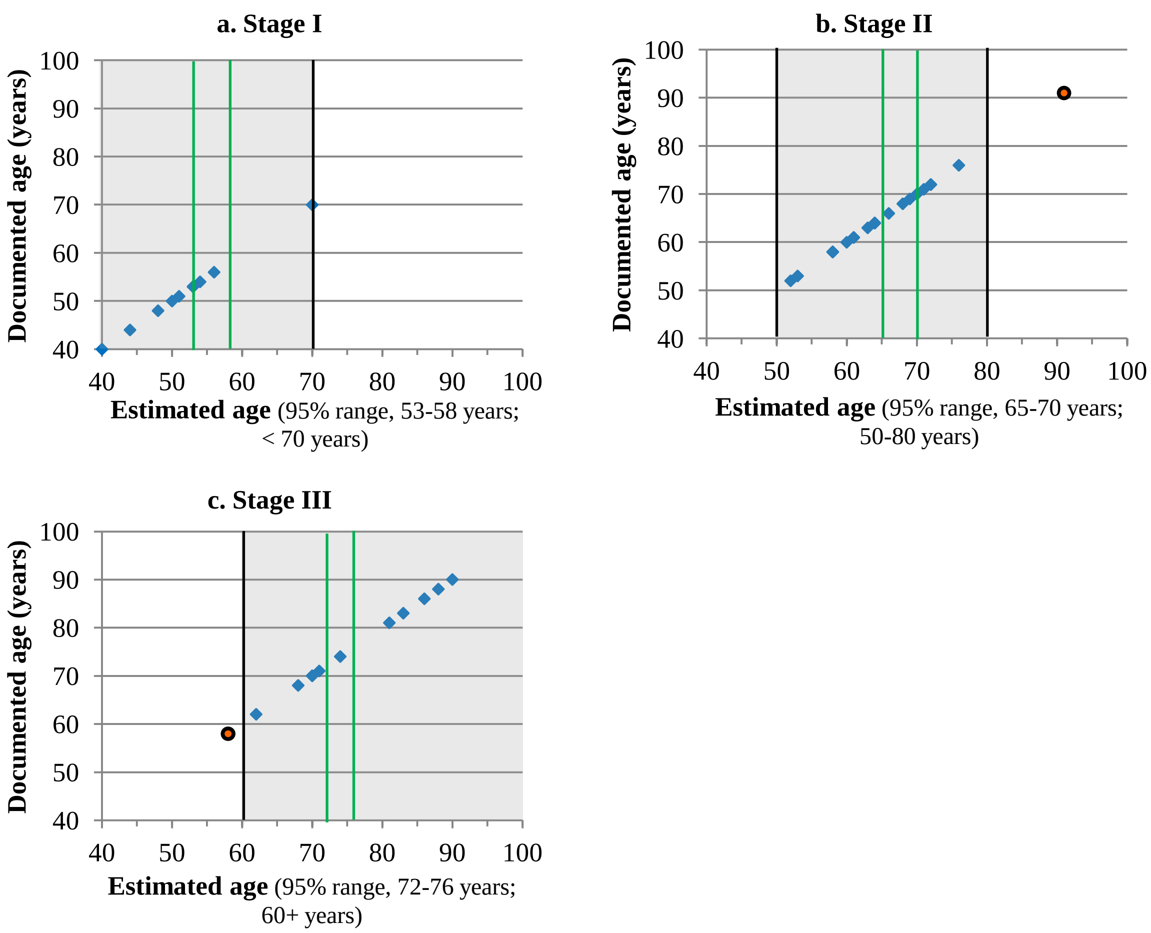


Figure 6.44a-c: *Cervical vertebrae facets, blind test: observed age stages (estimated age) for the CCS males, compared with documented ages.*

Table 6.67 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.67: *Cervical vertebrae facets, blind test: age estimations based on the appearance of the facets of the third to seventh cervical vertebrae in males.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age: Within 95% confidence interval			Estimated age: Within age phase			Inaccuracy: Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	10	40–70	53–58	4	40.0	< 70	10	100.0	0	0	no bias
II	21	52–91	65–70	4	19.0	50–80	20	95.2	1	4.8	underaged
III	12	58–90	72–76	1	8.3	60+	11	91.7	1	8.3	overaged
Total	43	-	-	9	**20.9**	-	41	**95.3**	1	**2.3**	**underaged**
									1	**2.3**	**overaged**

Of the 43 males blind tested, only 20.9% fell within the 95% confidence interval based on this method, and 95.3% fell within the age phase.

6.2.5.2.2 Female

A total of 33 females provided suitably preserved articular facets of the cervical vertebrae for analysis. The resultant composite scores were allocated into corresponding surface age stages (I or II) (Figure 6.45). It is the surface stage that will provide an estimate of age. The developed ageing criteria for each stage was applied to each female CCS individual and compared with documented age.

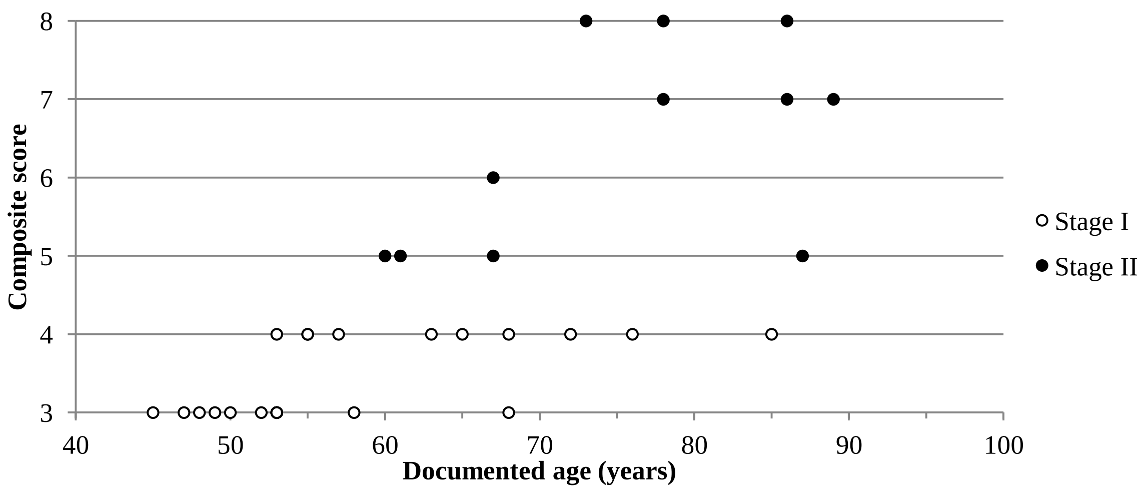


Figure 6.45: *Cervical vertebrae facets, blind test: scatter plot of derived age stages for female individuals.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.46).

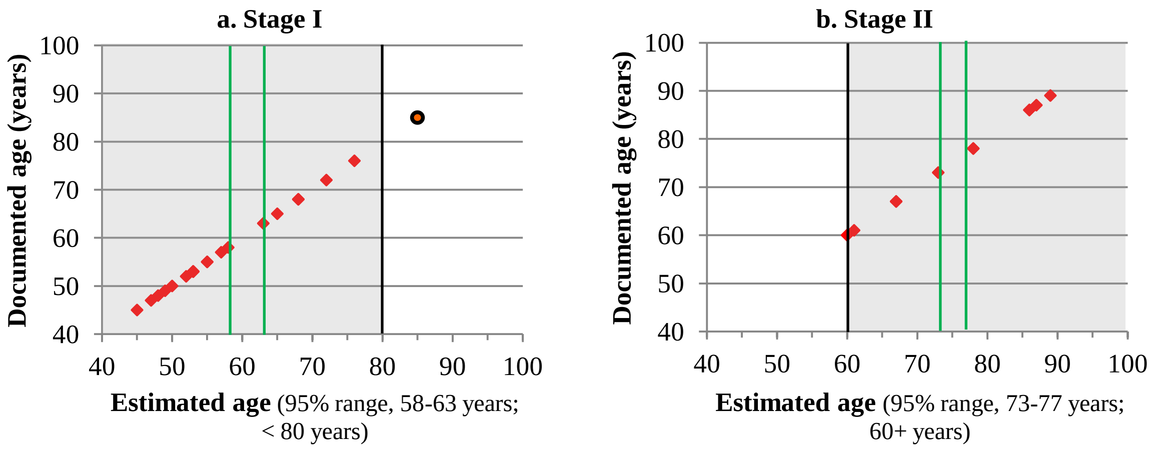


Figure 6.46a-b: *Cervical vertebrae facets, blind test: observed age stages (estimated age) of the CCS females, compared with documented ages.*

Table 6.68 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested general age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.68: *Cervical vertebrae facets, blind test: age estimations based on the appearance of the facets of the third to seventh cervical vertebrae in females.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	22	45–85	58–63	2	9.1	< 80	21	95.5	1	4.5	underaged
II	11	60–89	73–77	1	9.1	60+	11	100.0	0	0	no bias
Total	33	-	-	3	**9.1**	-	32	**96.7**	1	**3.3**	**underaged**

Of the 33 females blind tested, only 9.1% fell within the 95% confidence interval based on this method, and 96.7% fell within the age phase.

6.2.5.6.3 Additional Analyses

To confirm the relationship between age and composite score of the articular facets of the cervical vertebrae, a Spearman's rank correlation was calculated for males and females. Both were found to be highly statistically significant (male, $r_s = 0.635$; $P < 0.001$; female, $r_s = 0.805$; $P < 0.001$). The results are plotted in Figure 6.47.

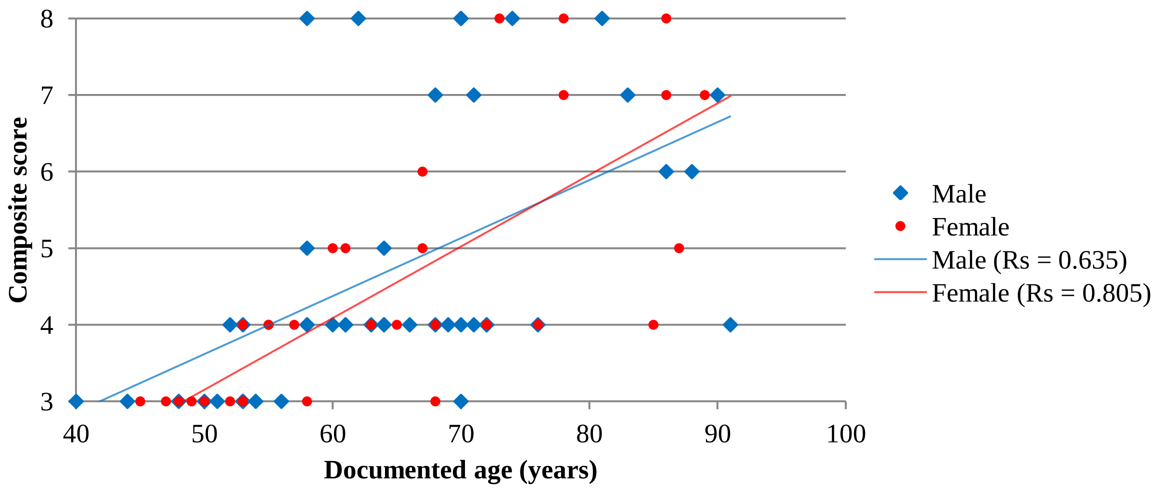


Figure 6.47: *Cervical vertebrae facets, blind test: scatter plot of composite scores against age for all individuals in the CCS sample. Spearman's rank correlation coefficients of score against age for males and females are provided.*

Comparison of the descriptive statistics of age variation within each age stage for males and females between the developed criteria and the CCS blind test sample is presented in Table 6.69.

Table 6.69: *Cervical vertebrae facets, blind test: comparison of age estimates from composite scores and age stages for the developed criteria and the CCS blind test sample.*

Age stage	**Composite score**	**Developed criteria**			**CCS blind test sample**			
		Mean age (years)	**Standard deviation**	**95% confidence interval (years)**	**N**	**Mean age (years)**	**Standard deviation**	**95% confidence interval (years)**
Males								
I	3	56.0	10.6	53–58	10	51.9	8.0	46–58
II	4–5	67.5	11.6	65–70	21	65.3	8.7	61–69
III	6–8	74.0	9.8	72–76	12	75.1	10.4	68–82
Females								
I	3–4	60.8	13.1	58–63	22	58.1	10.3	53–63
II	5–8	75.3	9.8	73–77	11	75.6	10.7	68–83

6.2.6 COMBINED CERVICAL VERTEBRAE BODY AND FACET SCORES

This study assessed whether the combination of composite scores for the bodies and facets of the third to seventh cervical vertebrae improved the correlation of composite scores with age. The composite scores for the cervical vertebral bodies and facets were combined to form a "Summary Score" for these individuals, ranging in value between 7 and 22 points.

6.2.6.1 Cervical Vertebrae Body and Facet: Combined Sample

A total of 608 individuals that had one or more of the cervical vertebrae present were used in this analysis. The sample comprised 339 males with age-at-death ranging from 40-96 years (mean age, 66.8 years) and 269 females, ranging between 40-95 years (mean age, 68.0 years) (Table 6.70).

Table 6.70: Cervical vertebrae bodies and facets: age composition of the combined study sample.

	Age category (years)					Total
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	39	66	76	97	61	**339**
Female	33	41	64	67	64	**269**
Total	**72**	**107**	**140**	**164**	**125**	**608**

The sexes were assessed separately, as the degeneration of the facets showed statistically significant differences between males and females. Plots of "Summary Score" against documented age for all individuals in the study sample are presented in Figure 6.48.

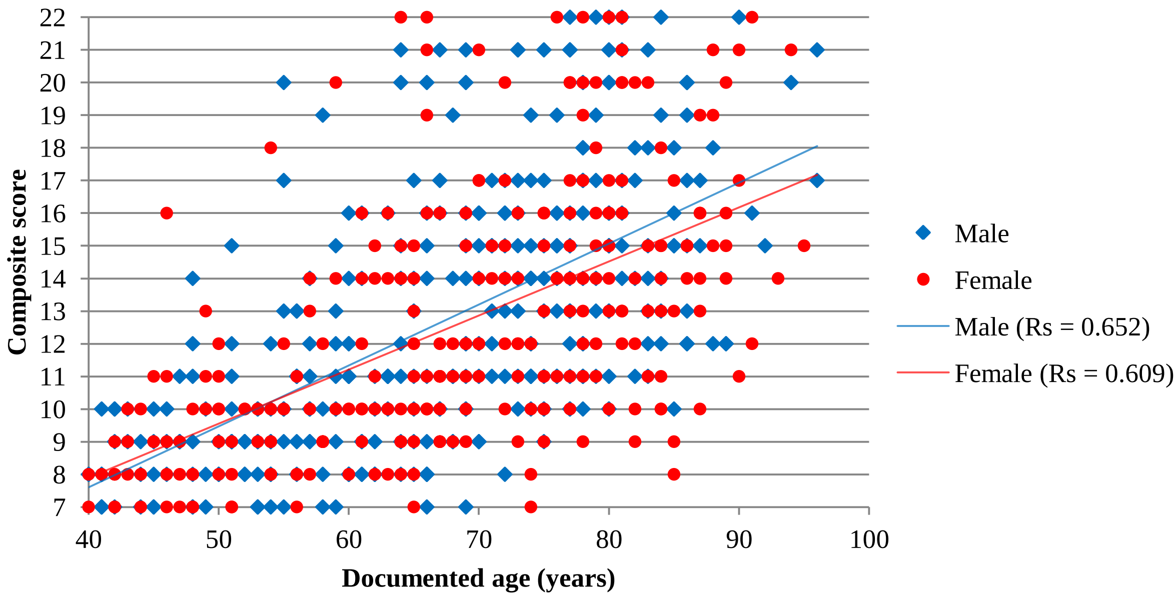


Figure 6.48: *Scatter plot of combined composite scores for cervical vertebral bodies and facets against documented age for males (N = 339) and females (N = 269). Spearman's rank correlation coefficient of score against age is provided.*

To test whether each the combination of scores was more highly correlated with age-at-death than assessing each aspect of the vertebrae separately (i.e. bodies and facets), a Spearman's rank correlation coefficient was calculated (Table 6.71). The higher the score (r_s) assigned to a composite/summary score, the more frequently it was associated with older age. For males and females this correlation was strongest with the summary score, indicating the combination of composite scores increased the correlation of techniques with documented age.

Table 6.71: *Spearman's rank correlation between age, cervical vertebrae body and facet composite scores and summary scores for males and females in the combined study sample.*

Feature	All males (N = 339)		All females (N = 269)	
	r_s	*P*	r_s	*P*
Body CS	0.613	<0.001	0.556	<0.001
Facet CS	0.548	<0.001	0.514	<0.001
Summary score	**0.652**	**<0.001**	**0.609**	**<0.001**

The descriptive statistics of age variation within composite scores for males and females (Tables 6.72 and 6.73, respectively) revealed the overall trend of increasing age with increasing composite score.

Table 6.72: *Cervical vertebrae bodies and facets: descriptive statistics for documented ages-at-death found to possess same summary scores for males individuals in the combined study sample.*

Summary score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
7	18	50.6	8.5	48	41–69
8	32	55.0	8.9	55	40–72
9	37	55.3	8.5	53	42–75
10	38	61.4	12.3	59	41–85
11	39	67.1	9.5	68	47–83
12	24	71.6	12.7	72	48–89
13	20	72.7	9.6	75	55–86
14	27	70.7	8.8	73	48–84
15	26	75.4	9.1	76	51–92
16	21	73.2	7.9	72	60–91
17	16	76.2	9.7	76	55–96
18	6	82.3	3.9	82	78–88
19	7	75.0	9.6	76	58–86
20	10	75.8	12.0	79	55–94
21	12	76.3	8.4	76	64–96
22	6	81.8	4.6	77	77–90

Table 6.73: *Cervical vertebrae bodies and facets: descriptive statistics for documented ages-at-death found to possess same summary scores for females individuals in the combined study sample.*

Summary score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
7	13	50.3	9.7	48	40–74
8	25	53.8	10.9	54	40–85
9	30	60.4	11.7	59	42–85
10	39	63.0	11.6	62	43–87
11	24	68.2	12.1	68	45–90
12	20	70.5	9.7	71	50–91
13	13	75.5	11.5	80	49–87
14	27	73.9	9.7	76	57–93
15	19	78.4	9.3	80	62–95
16	19	73.8	10.6	75	46–89
17	9	78.1	6.8	78	70–90
18	3	72.3	16.1	79	54–84
19	4	79.8	10.2	82	66–88
20	11	78.0	7.6	79	59–89
21	6	81.5	11.3	84	66–94
22	7	76.6	9.2	78	64–91

The summary scores found to provide similar age ranges, mean ages, and median ages were combined to produce surface age stages (Tables 6.74 and 6.75). In addition to the 95% confidence interval, a broader range (age phase) with which to estimate age was also provided for each age stage.

Table 6.74: *Cervical vertebrae bodies and facets: age estimates from composite scores and age stages (males).*

Summary score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
7	I	18	50.6	8.5	46–55	< 60 years
8–10	II	107	57.4	10.5	55–59	45–70 years
11–17	III	173	71.8	10.0	70–73	60+ years
18–22	IV	41	77.6	8.9	74–80	70+ years

Table 6.75: *Cervical vertebrae bodies and facets: age estimates from composite scores and age stages (females).*

Summary score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
7	I	13	50.3	9.7	44–56	< 60 years
8–10	II	94	59.7	11.9	57–62	45–70 years
11–16	III	122	73.1	10.8	71–75	55+ years
17–22	IV	40	78.1	9.0	75–81	65+ years

Unpaired *t*-tests were employed to test for statistically significant differences between the stages (Table 6.76).

Table 6.76: *Cervical vertebrae bodies and facets: results of t-tests between age stages.*

Stages compared	Male			Female		
	t	**df**	***P***	***t***	**df**	***P***
I vs II	-2.61	123	0.010	-2.72	105	0.008
II vs III	11.48	278	< 0.001	8.61	214	< 0.001
III vs IV	-3.45	212	< 0.001	-2.63	160	0.009

6.2.6.2 Combined Cervical Vertebrae Body and Facet: Blind Test

A blind test was performed on the bodies and facets of the third through seventh cervical vertebrae (or any cervical vertebrae present) of 75 randomly chosen individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The sample comprised 43 males with age-at-death ranging from 40-91 years (mean age, 64.9 years) and 32 females, ranging between 45-89 years (mean age, 64.2 years) (Table 6.77).

Table 6.77: *Cervical vertebrae bodies and facets, blind test: age construction of the CCS sample.*

	Age category (years)					Total
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	3	12	12	10	6	**43**
Female	4	10	8	5	5	**32**
Total	**7**	**22**	**20**	**15**	**11**	**75**

As sexually dimorphic criteria were required, males and females were analysed separately. The most severe expressions of the individual trait scores for porosity, osteophyte formation and eburnation affecting the bodies and facets were combined to form a summary score, which is ultimately used to estimate age-at-death. Summary scores ranged from 7 to 22 points.

6.2.6.2.1 Male

A total of 43 males provided suitably preserved bodies and articular facets on the third to seventh cervical vertebrae for examination. The resultant composite scores were allocated into corresponding surface age stages (ranging between I and IV) (Figure 6.49). The developed ageing criteria for each stage was applied to each male CCS individual and compared with documented age.

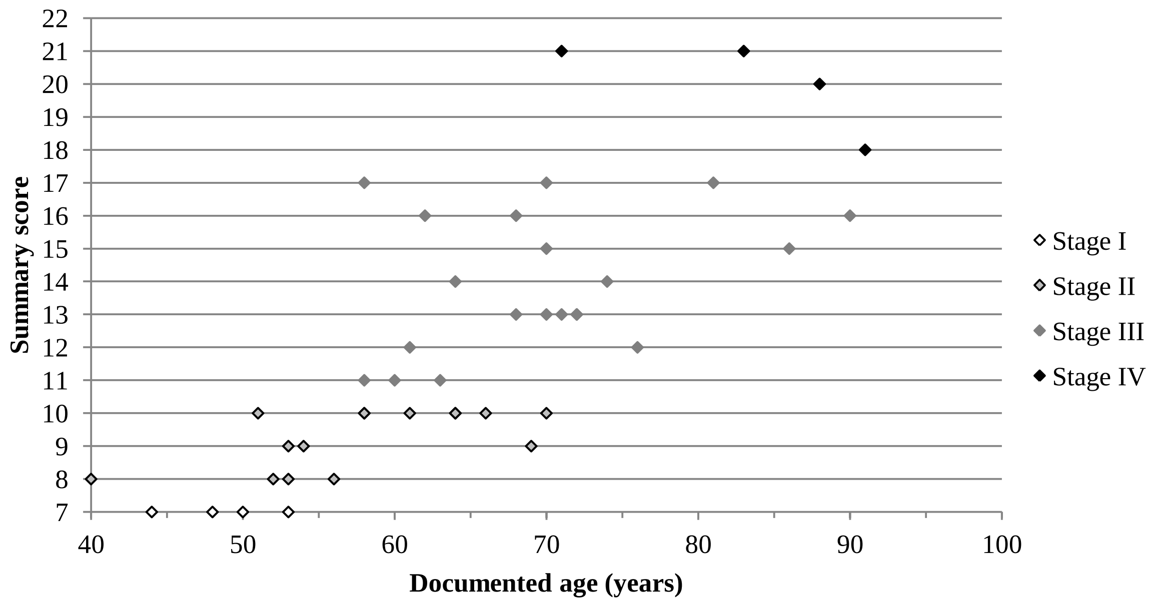
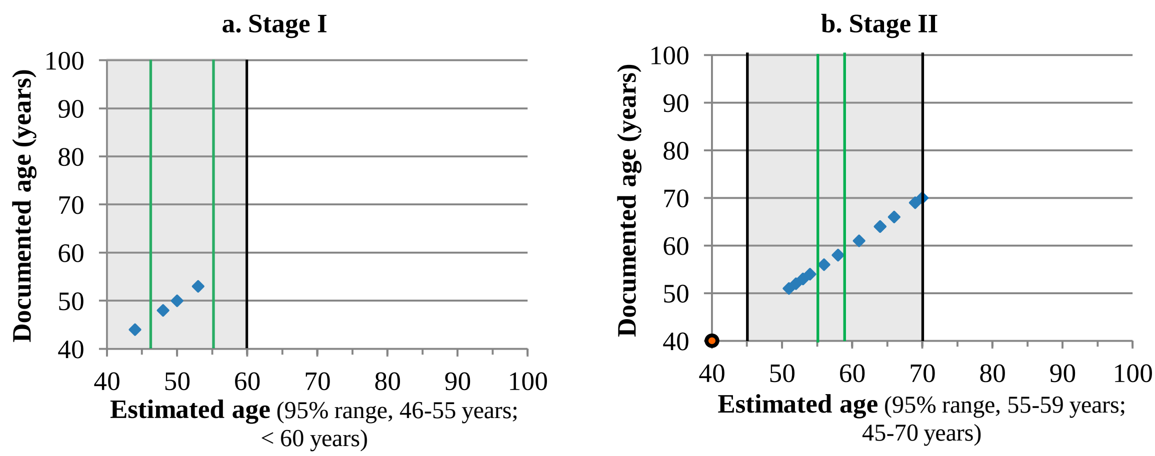


Figure 6.49: *Cervical vertebrae bodies and facets, blind test: scatter plot of derived age stages for male individuals.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.50).



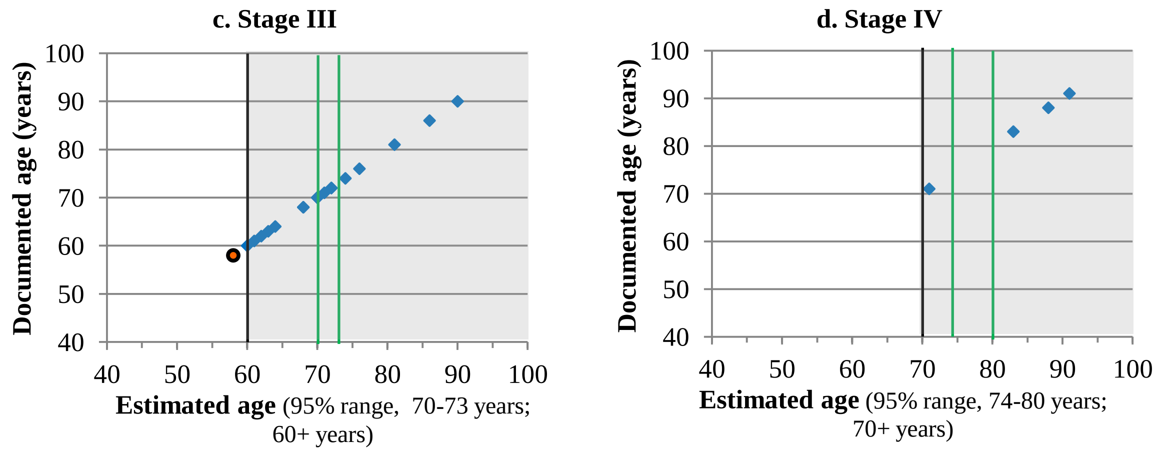


Figure 6.50a-d: *Cervical vertebrae bodies and facets, blind test: observed age stages (estimated age) for CCS males, compared with documented ages.*

Table 6.78 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested general age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.78: *Age estimations based on the combined appearance of the bodies and facets of the third to seventh cervical vertebrae in males in the blind test sample.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	4	44–53	46–55	3	75.0	< 60	4	100.0	0	0	no bias
II	15	40–70	55–59	3	20.0	45–70	14	93.3	1	6.7	overaged
III	20	58–90	70–73	6	30.0	60+	18	90.0	2	10.0	overaged
IV	4	71–91	74–80	0	0	70+	4	100.0	0	0	no bias
Total	43	-	-	12	**27.9**	-	40	**93.0**	3	**7.0**	**overaged**

Of the 43 males, 27.9% fell within the 95% confidence interval based on this method, and 93.0% fell within the age phase.

6.2.6.2.2 Female

A total of 32 females provided suitably preserved bodies and articular facets of the cervical vertebrae for analysis. The resultant composite scores were allocated into corresponding surface age stages (between I and IV) (Figure 6.51). The developed ageing criteria for each stage was applied to each female CCS individual and compared with documented age.

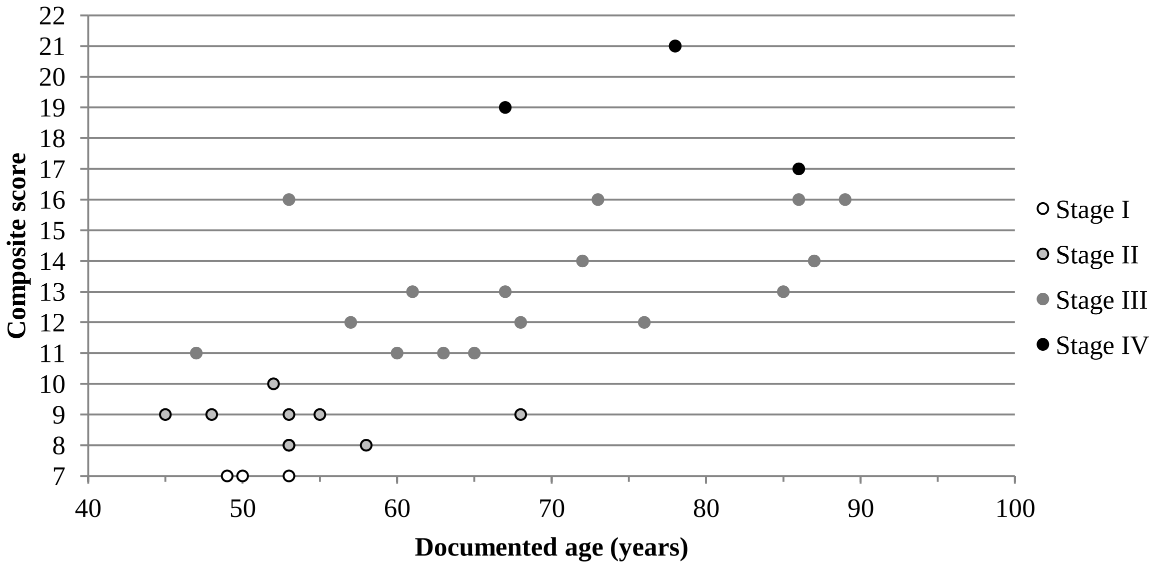


Figure 6.51: *Cervical vertebrae bodies and facets, blind test: scatter plot of derived age stages for female individuals.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.52).

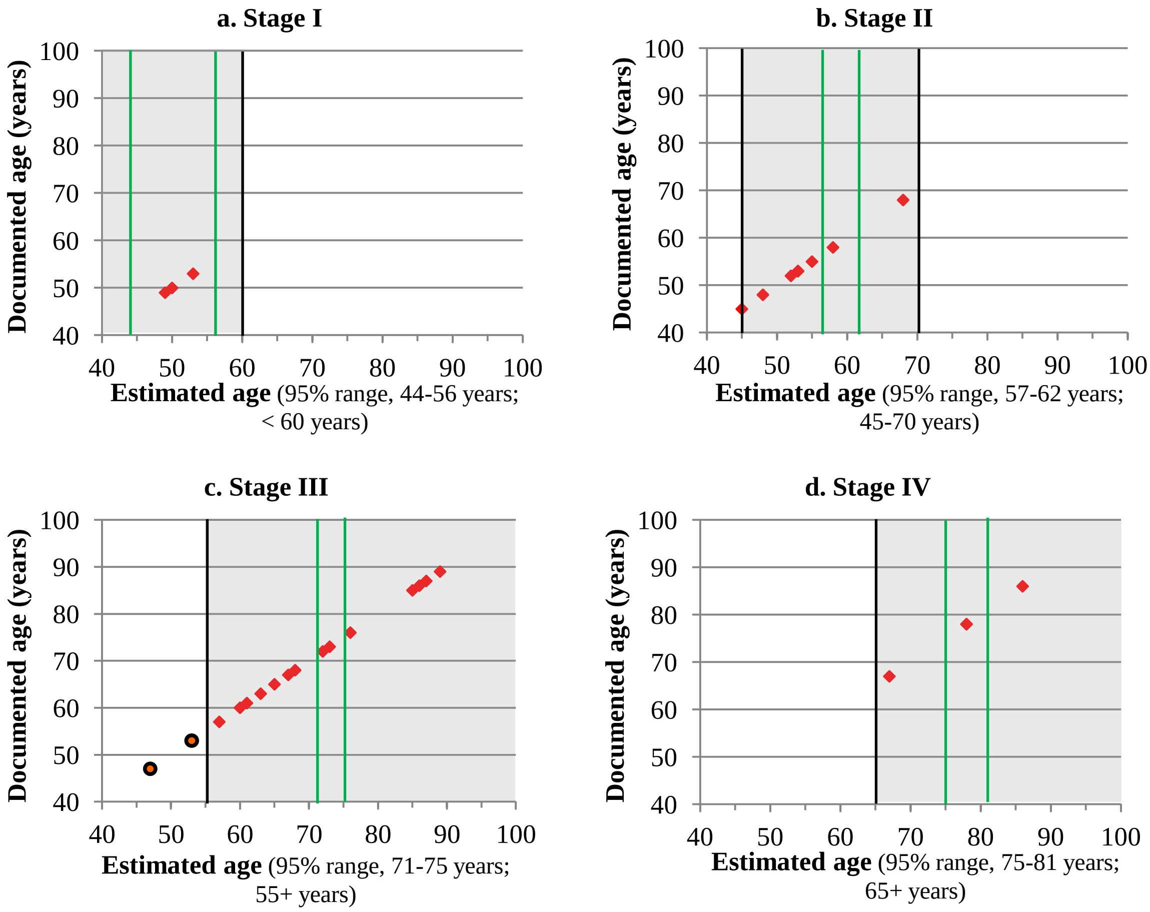


Figure 6.52a-b: *Cervical vertebrae bodies and facets, blind test: observed age stages (estimated age) for CCS females, compared with documented ages.*

Table 6.79 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.79: *Age estimations based on the combined appearance of the bodies and facets of the third to seventh cervical vertebrae in females in the blind test sample.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	bias
I	3	49–53	44–56	3	100.0	< 60	3	100.0	0	0	no bias
II	9	45–68	57–62	1	11.1	45–70	9	100.0	0	0	no bias
III	16	47–89	71–75	2	12.5	55+	14	87.5	2	12.5	overaged
IV	4	67–86	75–81	2	50.0	65+	4	100.0	0	0	no bias
Total	32	-	-	8	**25.0**	-	30	**93.8**	2	**6.2**	**overaged**

Of the 32 females blind tested, 25.0% fell within the 95% confidence interval based on this method, and 93.8% fell within the age phase.

6.2.6.2.3 Additional Analyses

To confirm the relationship between age and composite score of the articular facets of the cervical vertebrae, a Spearman's rank correlation was calculated for males and females. Both were found to be highly statistically significant (male, $r_s = 0.799$; $P < 0.001$; female, $r_s = 0.747$; $P < 0.001$). The results are plotted in Figure 6.53.

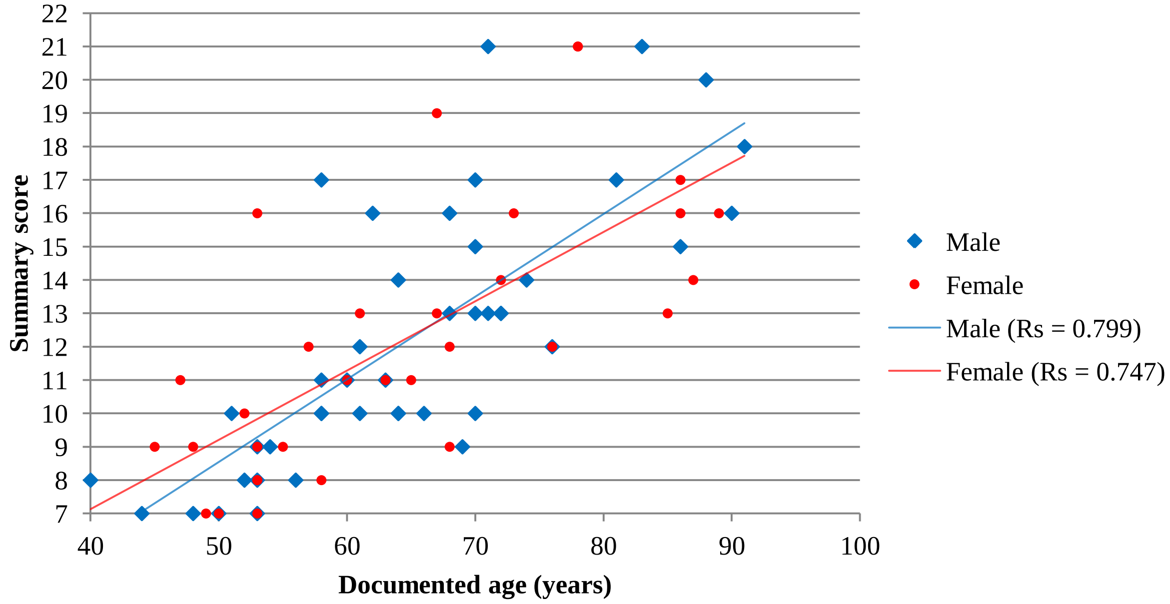


Figure 6.53: *Cervical vertebrae bodies and facets, blind test: scatter plot of summary scores against age for all individuals in the CCS sample. Spearman's rank correlation coefficients of score against age for males and females are provided.*

Comparison of the descriptive statistics of age variation within each age stage for males and females between the developed criteria and the CCS blind test sample is presented in Table 6.80.

Table 6.80: *Comparison of age estimates from cervical vertebrae summary scores and age stages for the developed criteria and the CCS blind test sample.*

Age stage	**Summary score**	**Developed male criteria**			**CCS blind test sample (male)**			
		Mean age (years)	**Standard deviation**	**95% confidence interval (years)**	**N**	**Mean age (years)**	**Standard deviation**	**95% confidence interval (years)**
Males								
I	7	50.6	8.5	46–55	4	48.8	3.8	*
II	8–10	57.4	10.5	55–59	15	57.9	8.0	53–62
III	11–17	71.8	10.0	70–73	20	69.7	8.8	65–74
IV	18–22	77.6	8.9	74–80	4	83.3	8.8	*
Females								
I	7	50.3	9.7	44–56	3	50.7	2.1	*
II	8–10	59.7	11.9	57–62	9	53.9	6.5	48–59
III	11–16	73.1	10.8	71–75	16	69.3	12.7	62–76
IV	17–22	78.1	8.96	75–81	4	77.3	7.81	*

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.3 RESULTS: CLAVICLE

This results section presents the findings of recorded degenerative traits of three aspects of the clavicle: the lateral surface, the sternal surface, and the manubrium facet located on the inferior surface of the sternal clavicle. A combination of the lateral and sternal surfaces of the clavicle is also provided for its use in age estimation. The raw data recorded from the study samples is provided in Appendices 4.5 to 4.7, and the individual analysis of each study sample is presented in Appendix 5.5 for the lateral surface, and Appendices 5.6 and 5.7 for the sternal end. The analysis of the combined study sample and subsequent blind test (Appendices 6.11 to 6.17) of the developed criteria is provided in this section.

6.3.1 LATERAL SURFACE OF THE CLAVICLE

The individual trait scores recorded for each surface feature of the lateral clavicle (i.e. surface topography, porosity and osteophyte formation) were combined to form a composite score, ranging between 3 and 16 points (i.e. surface topography, scored between 1 and 6; porosity, scored between 1 and 6; osteophyte formation, scored between 1 and 4). This composite score was used to assess degenerative differences between males and females.

6.3.1.1 Lateral Surface of the Clavicle Results: Combined Sample

To assess the true extent of the degenerative processes of the lateral end of the clavicle, all four study samples were combined (Figure 6.54). This was justified because each collection demonstrated very similar patterns of degeneration of the lateral clavicle articular surface. As there were no significant differences between left and right elements, the left clavicle was substituted in absence of the right side. The total sample size used to develop this method was 534 lateral clavicles (mean age, 66.9 years), including 302 male individuals (mean age, 66.4 years) and 232 female clavicles (mean age, 67.5 years) (Table 6.81).

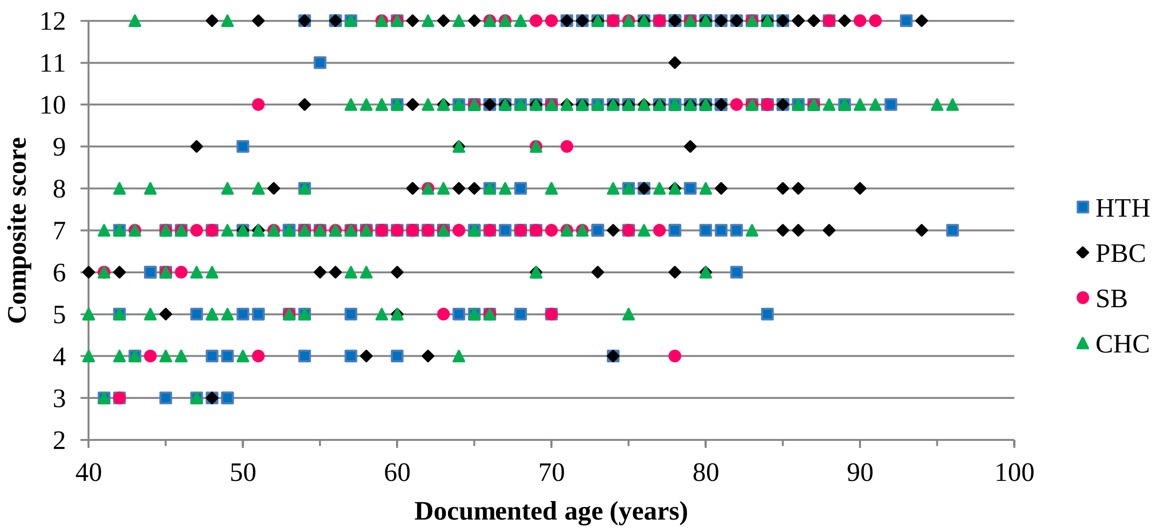


Figure 6.54: *Clavicle, lateral surface: scatter plot of composite scores against age for all individuals in the combined study sample.*

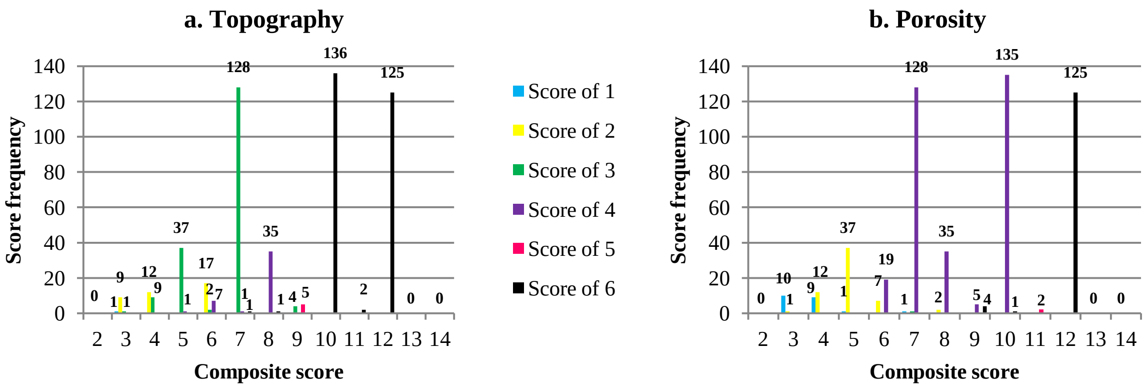
Table 6.81: *Clavicle, lateral surface: age construction of combined study sample.*

	Age category (years)					Total
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	38	59	68	84	53	**302**
Female	32	37	54	53	56	**232**
Total	**70**	**96**	**122**	**137**	**109**	**534**

Development of the lateral end of the clavicle ageing technique will re-assess the distribution of trait expression of the larger combined sample. Three of the four populations showed a non-significant correlation between degree of osteophyte formation and documented age (excluding CHC). Therefore, surface topography and porosity are the only two features from the composite score that will be related to age-at-death.

6.3.1.1.1 Individual Trait Scores, Composite Scores and Age-at-Death

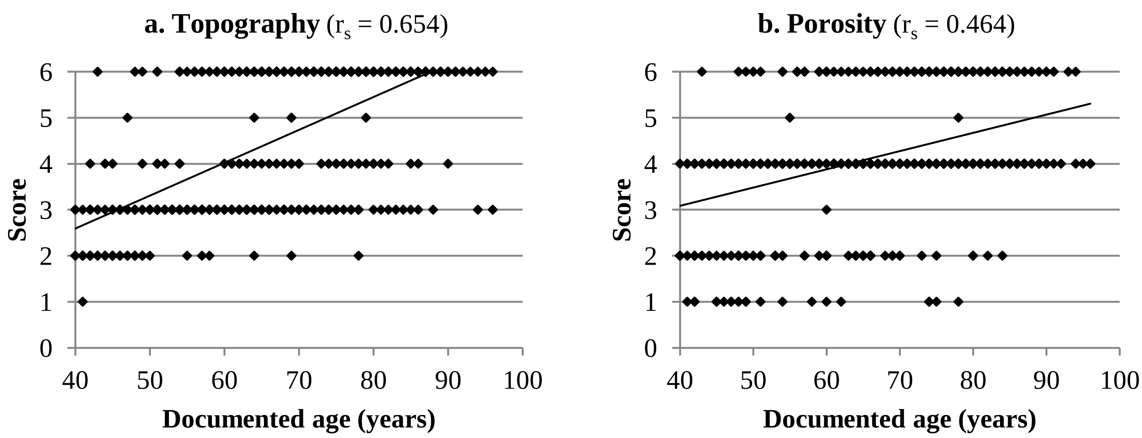
The scores assigned to individual traits displayed a positive relationship with composite scores (Figure 6.55).



Figures 6.55a-b: *Number of observations of trait scores recorded for the lateral surface of the clavicle in the combined study sample.*

Both surface features possessed observable morphological differences, which altered their expression over an age range represented by each composite score.

Individual trait expressions were investigated as to their association with age-at-death. Scatter plots of trait scores were plotted against age-at-death (Figure 6.56). These figures display a wide variation in the age of trait expression (score) of each of the features (e.g. topography and porosity).



Figures 6.56a-b: *Clavicle, lateral surface: scatter plots of trait score against documented age. Spearman's rank correlation coefficients of trait score against age are provided.*

To test whether each feature is correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. Individual trait expressions were found to be significantly correlated with age-at-death (Table 6.82). The higher the score assigned to a particular trait expression, the more frequently it was associated with older age. The correlation was strongest with surface topography (r_s = 0.654, $P < 0.001$).

Table 6.82: *Clavicle, lateral surface: Spearman's rank correlation between age and trait expression of features.*

Feature	r_s	*P*
Surface topography	0.654	<0.001
Porosity	0.464	<0.001
Composite score	**0.583**	**<0.001**

A Spearman's rank correlation coefficient was also calculated for the derived composite with age. As was found with each individual feature, the combination of scores for surface topography, porosity and osteophyte formation also produced a significant correlation with documented ages-at-death (r_s = 0.583; *P* < 0.001) (Table 6.82, Figure 6.57).

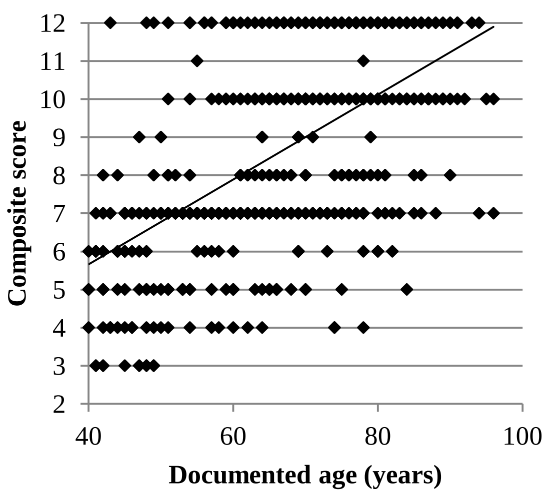


Figure 6.57: *Clavicle, lateral surface: scatter plot comparing documented age with recorded composite score; r_s = 0.583.*

The descriptive statistics of age variation within composite scores (Table 6.83) revealed that despite the overall trend of increasing age with increasing composite score, there was some variation leading to non-linear progression in the highest composite scores.

Table 6.83: *Clavicle, lateral surface: descriptive statistics for documented ages-at-death found to possess same composite scores in the combined study sample.*

Composite score	N	Mean age (years)	Standard deviation	Median age (years)	Observed Range (years)
2	0	-	-	-	-
3	11	45.4	3.3	47	41–49
4	21	53.7	11.4	50	40–78
5	38	56.9	10.5	55	40–84
6	26	56.0	51.5	51	40–82
7	130	60.5	11.4	58	41–96
8	36	66.7	12.4	66	42–90
9	9	64.7	10.2	69	47–79
10	136	74.9	9.3	75	51–96
11	2	66.5	16.3	66	55–78
12	125	74.4	10.3	77	43–94

Several composite scores were found to provide similar age ranges, mean ages, and median ages. To simplify the method, these scores were then combined to produce surface age stages (Table 6.84, Figure 6.58). In addition to the 95% confidence interval, a broader range (age phase) with which to estimate age was also provided for each age stage.

Table 6.84: *Clavicle, lateral surface: age estimates from composite scores and age stages.*

Composite score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
2–3	I	11	45.4	3.3	43–48	< 50 years
4–7	II	215	58.7	11.8	57–60	< 65 years
8–12	III	308	73.4	10.5	72–75	60+ years

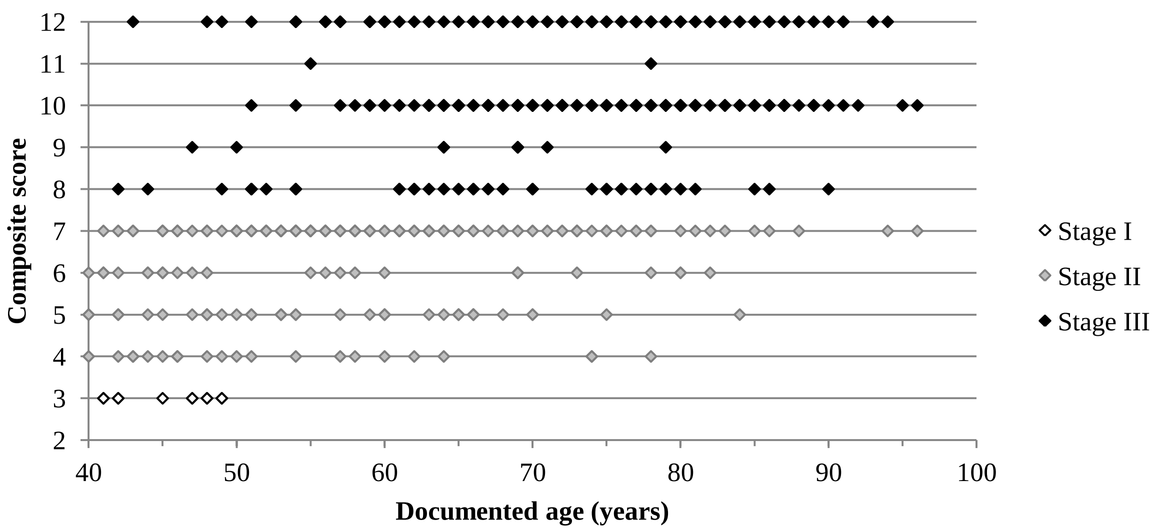


Figure 6.58: *Clavicle, lateral surface: scatter plot of derived age stages for all individuals.*

Unpaired *t*-tests were employed to test for statistically significant differences between the stages (Table 6.85). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.85: *Clavicle, lateral surface: results of t-tests between age stages.*

Stages compared	*t*	df	*P*
I vs II	10.46	27	< 0.001
II vs III	-15.00	521	< 0.001

6.3.1.5.2 Intraobserver Error

A subsample (10 males and 10 females) from each of the four skeletal collections were re-recorded to test for intraobserver error (N = 80). Paired *t*-tests were used to determine any significant differences in the two occasions (Table 6.86), which found no significant variation between the trait scores and composite scores (i.e. $P > 0.05$).

Table 6.86: *Clavicle, lateral surface: intraobserver error paired t-test results (N = 80).*

Trait	*t*	df	*P*
Surface topography	-0.90	79	0.373
Porosity	-0.55	79	0.582
Composite score	**-0.83**	**79**	**0.411**

6.3.1.2 Lateral Surface of the Clavicle Results: Blind Test

A blind test was performed on the lateral surface of the right clavicle of 67 individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The left side was substituted if the right was absent. The sample comprised 34 males with age-at-death ranging from 40-91 years (mean age, 63.8 years) and 33 females, ranging between 44-89 years (mean age, 62.3 years) (Table 6.87).

Table 6.87: *Clavicle, blind test of lateral surface: age construction of the CCS sample.*

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	4	10	8	7	5	**34**
Female	6	11	6	5	5	**33**
Total	**10**	**21**	**14**	**12**	**10**	**67**

As sexually dimorphic differences in trait expression were not identified while developing the ageing criteria, males and females were analysed together. Individual trait scores for surface topography and porosity were combined to form a composite score, which is ultimately used to estimate age-at-death. Composite scores range from 2 to 12 points. The resultant composite scores were allocated to corresponding surface age stages (between I and III) (Figure 6.59). The developed ageing criteria for each stage was applied to each CCS individual and compared with the documented age (Figure 6.59).

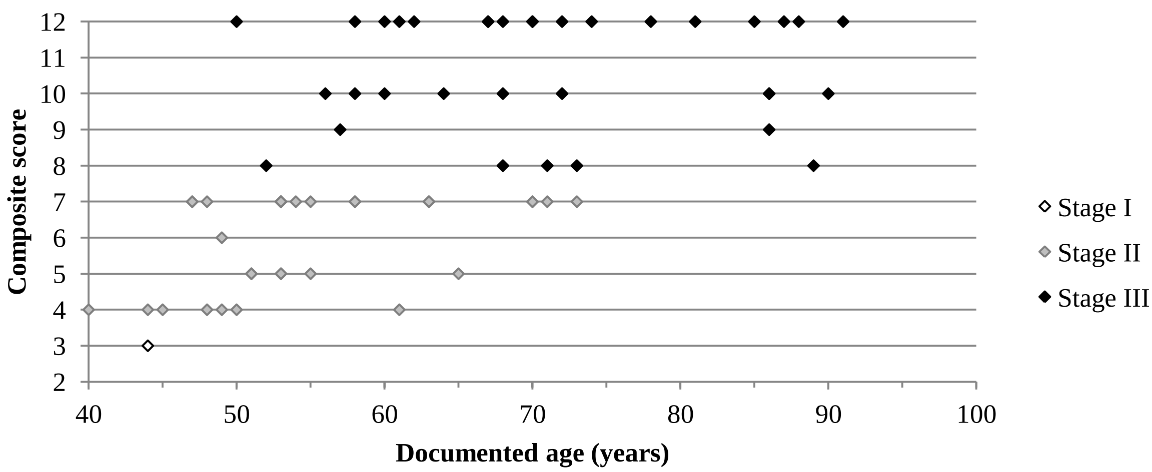


Figure 6.59: *Clavicle, blind test of lateral surface: scatter plot of composite scores against known age for all individuals in the CCS sample.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.60). The formats of the figures follow that of the cervical vertebrae.

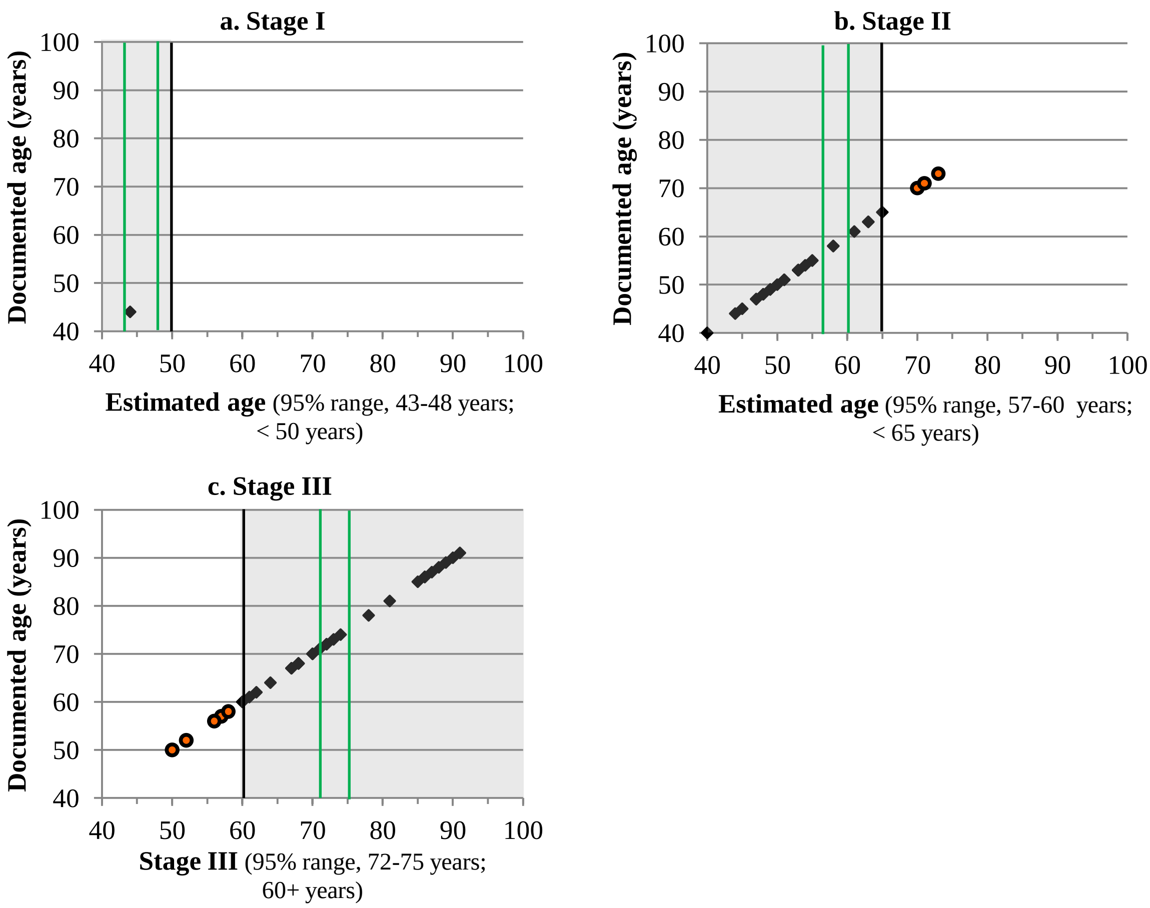


Figure 6.60a-c: *Observed lateral clavicle surface age stages (estimated age; 95% confidence interval and suggested age range) for CCS individuals, compared against known age.*

Table 6.88 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested general age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.88: *Age estimations based on the appearance of the lateral surface of the clavicle in the blind test sample.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	1	44	43–48	1	100.0	< 50	1	100.0	0	0	no bias
II	32	40–73	57–60	2	6.3	< 65	28	87.5	4	12.5	underaged
III	34	50–91	72–75	1	2.9	60+	28	82.4	6	17.6	overaged
Total	67	-	-	4	**6.0**	-	57	**85.1**	4	**6.0**	**underaged**
									6	**9.0**	**overaged**

Of the 67 individuals, only 6.0% fell within the 95% confidence interval based on this method, and 85.1% fell within the age phase.

6.3.1.2.1 Additional Analyses

To confirm the relationship between age and composite score of the lateral surface of the clavicle, a Spearman's rank correlation (r_s) was calculated. Both were found to be highly statistically significant (r_s = 0.669; $P < 0.001$). The results are plotted in Figure 6.61.

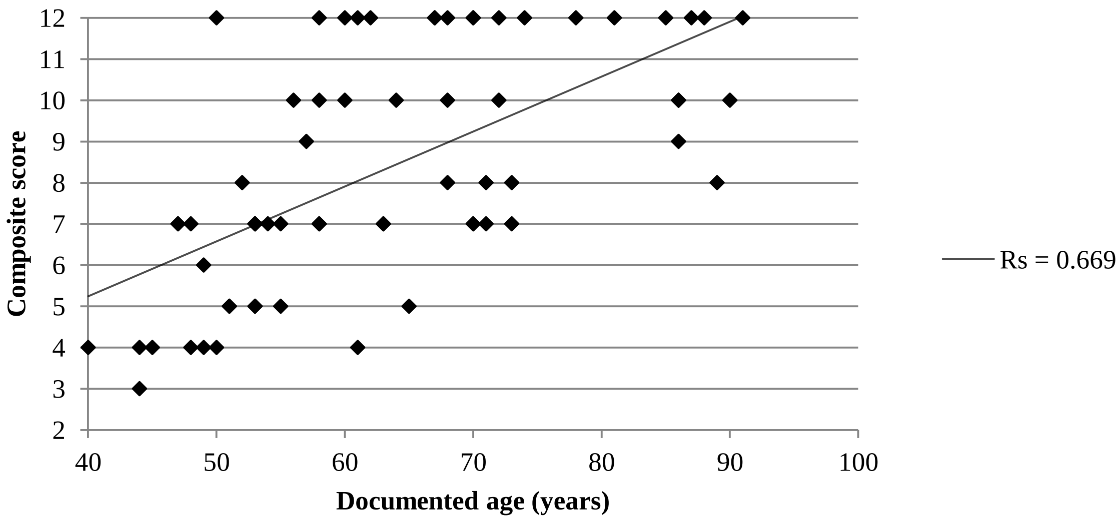


Figure 6.61: *Clavicle, blind test of lateral surface: scatter plot of composite scores against age for individuals in the CCS sample. Spearman's rank correlation coefficient of score against age for is provided.*

Comparison of the descriptive statistics of age variation within each age stage (Table 6.89) revealed similar patterns of mean age, standard deviation and 95% confidence intervals between the developed criteria and the CCS blind test sample.

Table 6.89: *Comparison of age estimates from composite scores and age stages between the developed criteria and the CCS blind test sample.*

Age stage	Composite scores	Developed criteria			CCS blind test sample			
		Mean age (years)	Standard deviation	95% confidence interval (years)	N	Mean age (years)	Standard deviation	95% confidence interval (years)
I	2–3	45.4	3.3	43–48	1	44.0	-	-
II	4–7	58.7	11.8	57–60	32	54.9	8.3	51–58
III	8–12	73.4	10.5	72–75	34	71.3	12.0	67–76

6.3.2 STERNAL SURFACE OF THE CLAVICLE

The individual trait scores recorded for each surface feature of the sternal surface of the clavicle (i.e. surface topography, porosity and osteophyte formation) were combined to form a composite score, ranging between 3 and 16 points (i.e. surface topography, scored between 1 and 6; porosity, scored between 1 and 6; osteophyte formation, scored between 1 and 4). This composite score was used to assess degenerative differences between males and females.

6.3.2.1 Sternal Surface of the Clavicle Results: Combined Sample

When the results of the four study samples were assessed, each collection demonstrated a similar pattern of degeneration of the sternal clavicle articular surface. There were no differences between left and right elements, with the exception of the CHC sample, and as a result the left clavicle was not substituted in absence of the right side. Differences were identified between males and females (Figures 6.62 and 6.63).

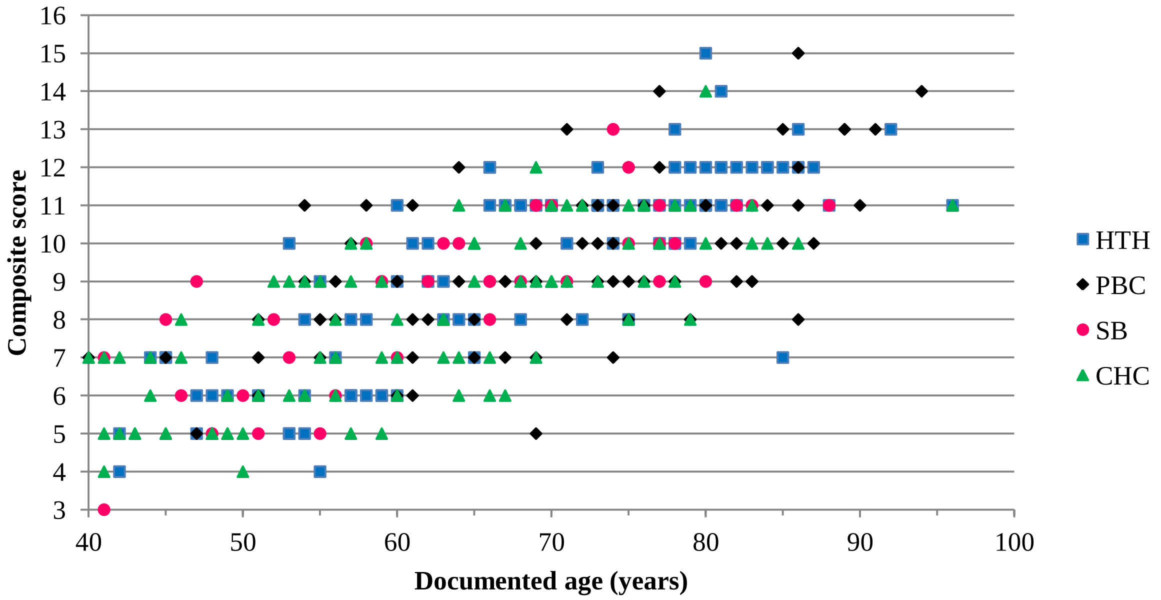


Figure 6.62: *Clavicle, sternal surface: Scatter plot of composite scores against age for males in the combined study sample.*

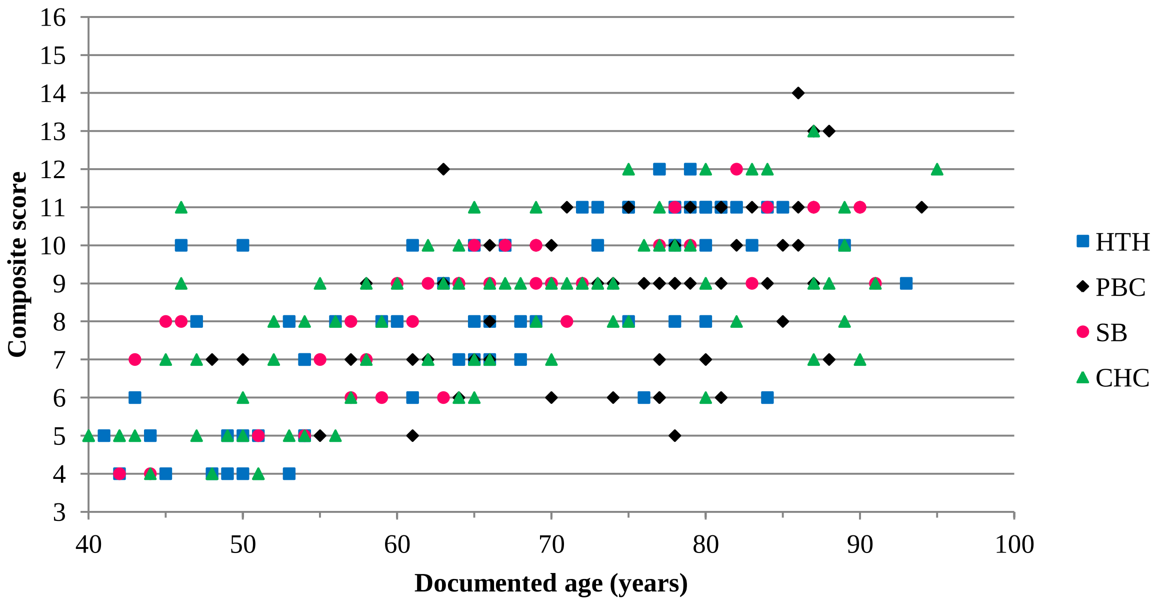


Figure 6.63: *Clavicle, sternal surface: Scatter plot of composite scores against age for females in the combined study sample.*

To assess the true extent of the degenerative processes of the sternal end of the clavicle, all four collections were combined. The total sample sizes used develop this method were 318 right sternal clavicles from male individuals (mean age, 66.6 years) and 246 female clavicles (mean age, 67.9 years) (Table 6.90).

Table 6.90: *Clavicle, sternal surface: age construction of the combined study sample.*

	Age category (years)					Total
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	40	62	71	87	58	**318**
Female	30	39	59	61	57	**246**
Total	**70**	**101**	**130**	**148**	**115**	**564**

Surface topography, porosity and osteophyte formation are the surface features that form the resultant composite score, which ultimately will be investigated for relationship with age-at-death. Composite scores range from 3 to 16 points.

6.3.2.1.1 Individual Trait Scores, Composite Scores and Age-at-Death

The scores assigned to individual traits displayed a positive relationship with composite scores. That is, traits with a higher individual score were generally found to cluster within the range of higher composite scores (Figure 6.64).

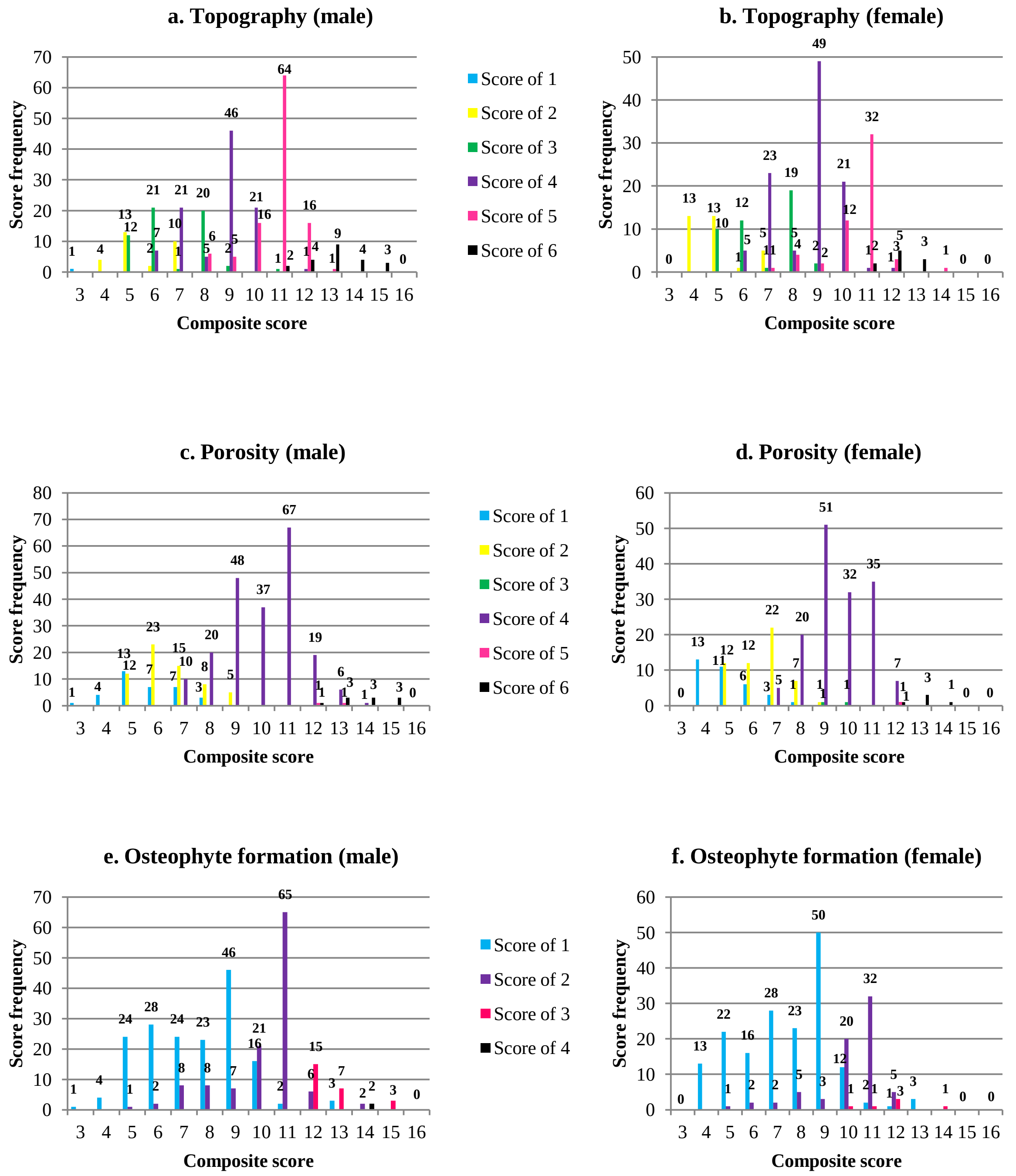


Figure 6.64a-f: *Number of observations of trait scores recorded for the sternal surface in the combined study sample.*

Individual trait expressions were investigated for their association with age-at-death. Scatter plots of trait scores were plotted against age-at-death (Figure 6.65). These figures display a wide variation in the age of trait expression (score) of each of the features.

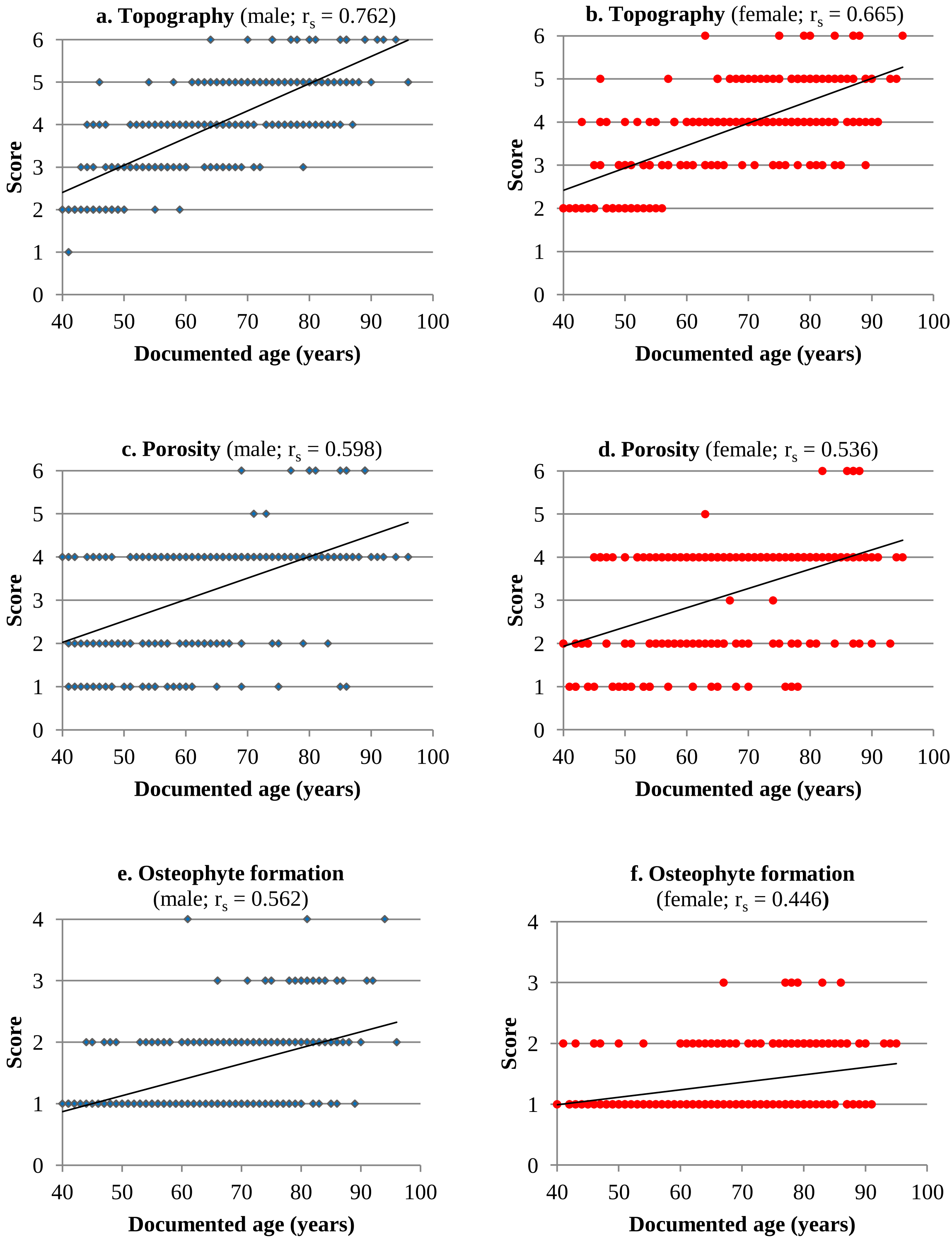


Figure 6.65a-f: *Clavicle, sternal surface: scatter plots of trait score against documented age. Spearman's rank correlation coefficients of trait score against age are provided.*

To test whether each feature is correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. Individual trait expressions were found to be significantly correlated with age-at-death (Table 6.91). The higher the score assigned to a particular trait expression, the more frequently it was

associated with older age. This correlation was strongest with surface topography in both males and females (male, $r_s = 0.762$, $P < 0.001$; female, $r_s = 0.665$; $P < 0.001$).

Table 6.91: *Clavicle, sternal surface: Spearman's rank correlation between age and trait expression of features.*

Feature	Male		Female	
	r_s	*P*	r_s	*P*
Surface topography	0.762	< 0.001	0.665	< 0.001
Porosity	0.598	< 0.001	0.536	< 0.001
Osteophyte formation	0.562	< 0.001	0.446	< 0.001
Composite score	**0.755**	**< 0.001**	**0.644**	**< 0.001**

A Spearman's rank correlation coefficient was also calculated for the derived composite with age. As was found with each individual feature, the combination of scores also produced a significant correlation with documented ages-at-death (male, $r_s = 0.755$; $P < 0.001$; female, $r_s = 0.644$; $P < 0.001$) (Table 6.91, Figure 6.66).

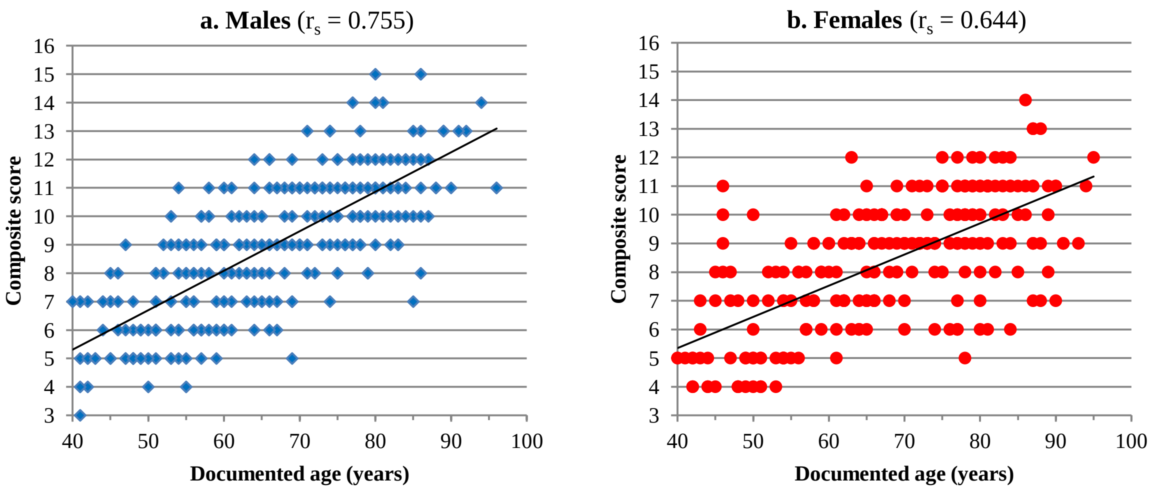


Figure 6.66a-b: *Clavicle, sternal surface: scatter plot comparing documented age with recorded composite score. Spearman's rank correlation coefficients are provided.*

The descriptive statistics of age variation within composite scores for males and females are presented in Tables 6.92 and 6.95, respectively. While the males revealed the overall trend of increasing age with increasing composite score, the females revealed that despite the overall trend of increasing age with increasing composite score, there was some variation leading to non-linear progression. Results for males and females are presented separately.

6.3.2.1.2 Male

Table 6.92: *Clavicle, sternal surface: descriptive statistics for documented ages-at-death found to possess same composite scores in the male study sample.*

Composite score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
3	1	41.0	-	41	41
4	4	47.0	6.7	46	41–55
5	25	49.4	6.3	48	41–69
6	30	54.9	5.9	55	44–67
7	32	55.4	11.5	55	40–85
8	31	62.8	10.1	63	45–86
9	53	67.3	9.0	68	47–83
10	37	72.5	9.3	75	53–87
11	67	75.2	8.0	75	54–96
12	21	78.1	7.1	80	64–87
13	10	82.9	7.9	85	71–92
14	4	83.0	7.5	80	77–94
15	3	84.0	3.5	86	80–86
16	0	-	-	-	-

Several composite scores were found to provide similar age ranges, mean ages, and median ages. These scores were combined together to produce surface age stages (Table 6.93, Figure 6.67). In addition to the 95% confidence interval, a broader range (age phase) with which to estimate age was also provided for each age stage.

Table 6.93: *Clavicle, sternal surface: age estimates from composite scores and age stages for males (N = 318).*

Composite score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
3–5	I	30	48.8	6.3	46–51	< 60 years
6–7	II	62	55.2	9.1	52–58	45–65 years
8–9	III	84	65.7	9.6	63–68	50–80 years
10–12	IV	125	74.9	8.4	73–76	60–90 years
13–16	V	17	83.1	6.9	79–87	70+ years

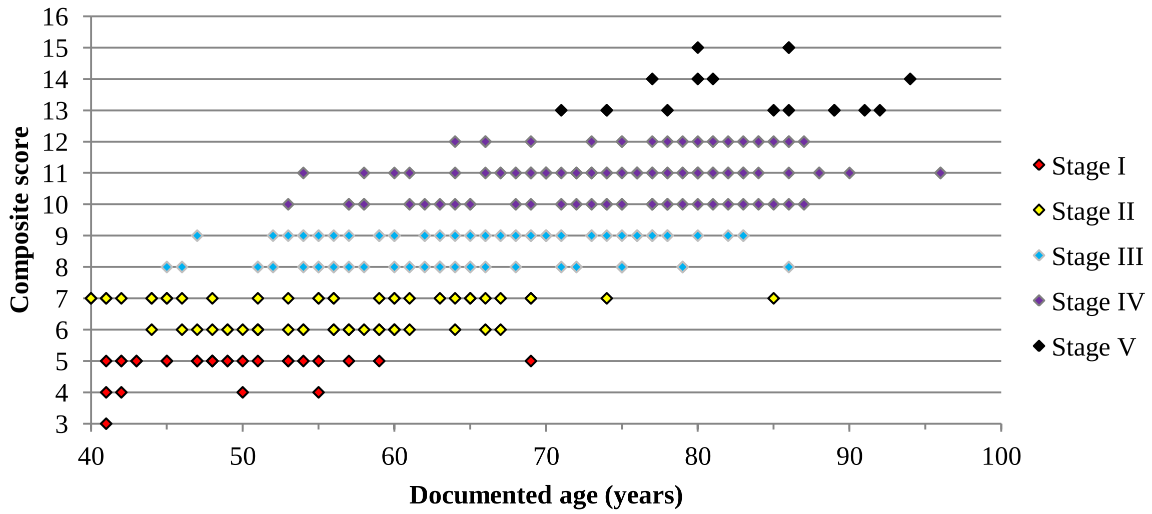


Figure 6.67: *Clavicle, sternal surface: scatter plot of derived age stages for males.*

Unpaired *t*-tests were employed to test for statistically significant differences between the stages (Table 6.94). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.94: *Clavicle, sternal surface: results of t-tests between age stages.*

Stages compared	Male			Female		
	t	**df**	***P***	***t***	**df**	***P***
I vs II	-3.91	79	< 0.001	-8.45	104	< 0.001
II vs III	-6.69	144	< 0.001	-4.36	160	< 0.001
III vs IV	-7.32	207	< 0.001	4.19	128	< 0.001
IV vs V	-3.87	140	< 0.001	-5.77	45	< 0.001

6.3.2.1.3 Female

Table 6.95: *Clavicle, sternal surface: descriptive statistics for documented ages-at-death found to possess same composite scores in the female study sample (N = 246).*

Composite score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
3	0	-	-	-	-
4	13	47.3	3.6	48	42–53
5	23	50.4	8.4	50	40–78
6	18	66.8	11.4	64	43–84
7	30	62.8	12.2	62	43–90
8	28	64.9	12.0	65	45–89
9	53	71.9	9.8	72	46–93
10	33	72.1	10.1	70	46–89
11	35	79.2	8.5	80	46–94
12	9	79.8	8.5	80	63–95
13	3	87.3	0.6	87	87–88
14	1	86.0	-	86	86
15	0	-	-	-	-
16	0	-	-	-	-

Several composite scores in the female sample were found to provide similar age ranges, mean ages, and median ages. These scores were combined together to produce surface age stages (Table 6.96, Figure 6.68). In addition to the 95% confidence interval, a broader range with which to estimate age was also provided for each age stage.

Table 6.96: *Clavicle, sternal surface: age estimates from composite scores and age stages for females (N = 246).*

Composite score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
3–5	I	36	49.3	7.1	46–52	< 55 years
6–8	II	76	64.5	11.9	61–67	45–80 years
9–10	III	86	72.0	9.9	69–74	60+ years
11–12	IV	44	79.3	8.4	76–82	70+ years
13–16	V	4	87.0	0.8	85–88	85+ years

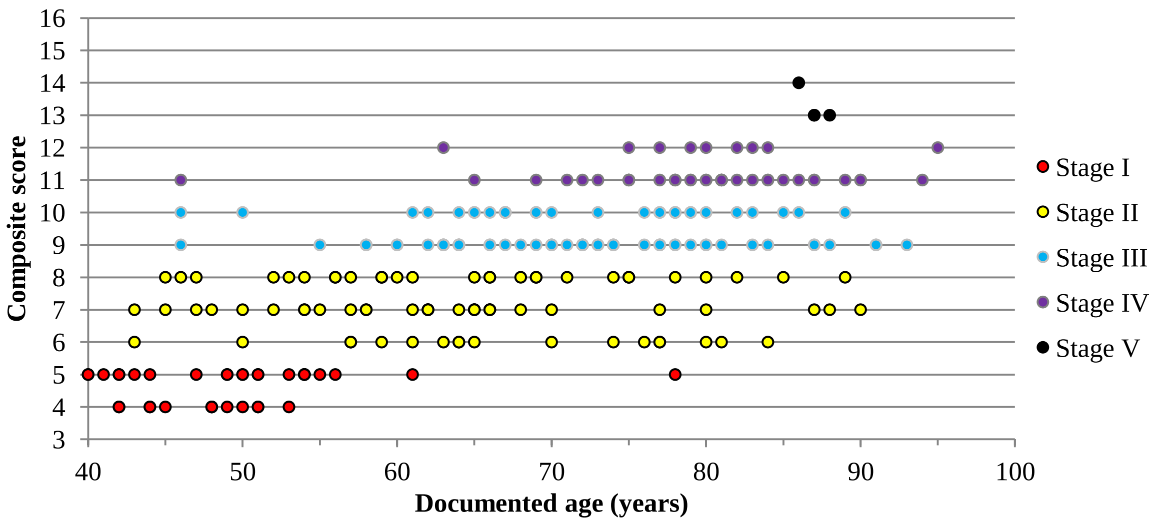


Figure 6.68: *Clavicle, sternal surface: scatter plot of derived age stages for females.*

6.3.2.1.4 Additional Observation

Although not quantified in this study, a general pattern was noted during the data collection phase. Small bodied females (i.e. individuals with notably gracile skeletal elements) in all study samples did not display the same range of trait expressions on the sternal end of the clavicle as observed in males and "normal-sized" females. The expressions were minimal to slight compared to the other members of the collections. This trend will be revisited in the discussion (section 8.2).

6.3.2.1.5 Intraobserver Error

A subsample (10 males and 10 females; N = 80) from each of the four skeletal collections were re-recorded to test for intraobserver error. Paired *t*-tests were used to determine any significant differences in the two occasions (Table 6.97), which found no significant variation between the trait scores and composite scores (i.e. $P > 0.05$).

Table 6.97: *Clavicle, sternal surface: intraobserver error paired t-test results (N = 80).*

Trait	***t***	**df**	***P***
Surface topography	-0.77	79	0.442
Porosity	-0.57	79	0.567
Osteophyte formation	0.81	79	0.418
Composite score	**-0.90**	**79**	**0.369**

6.3.2.2 Sternal Surface of the Clavicle Results: Blind Test

A blind test was performed on the sternal end of the right clavicle of 70 randomly chosen individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The left side was substituted if the right was absent. The sample comprised 35 males with age-at-death ranging from 40-

91 years (mean age, 63.2 years) and 35 females, ranging between 44-89 years (mean age, 63.7 years) (Table 6.98).

Table 6.98: *Clavicle, blind test of sternal surface: age construction of the CCS sample.*

	Age category (years)					Total
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	5	8	11	7	4	**35**
Female	5	11	7	7	5	**35**
Total	**10**	**19**	**18**	**14**	**9**	**70**

As sexually dimorphic differences in trait expression were identified while developing the ageing criteria, males and females were analysed separately. Individual trait scores for surface topography, porosity and osteophyte formation were combined to form a composite score, which was ultimately used to estimate age-at-death. Composite scores range from 3 to 16 points. The resultant composite scores were allocated to corresponding surface age stages (between I and V) (Figures 6.69 and 6.71, males and females respectively). The developed ageing criteria for each stage was applied to each CCS individual and compared with the documented age.

6.3.2.2.1 Male

A total of 35 males provided suitably preserved sternal clavicles for analysis. To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.69). As the 95% confidence intervals were all notably narrow (i.e. between 3 and 8 years), a broader age range (age phase) was also suggested during the development stage of this method.

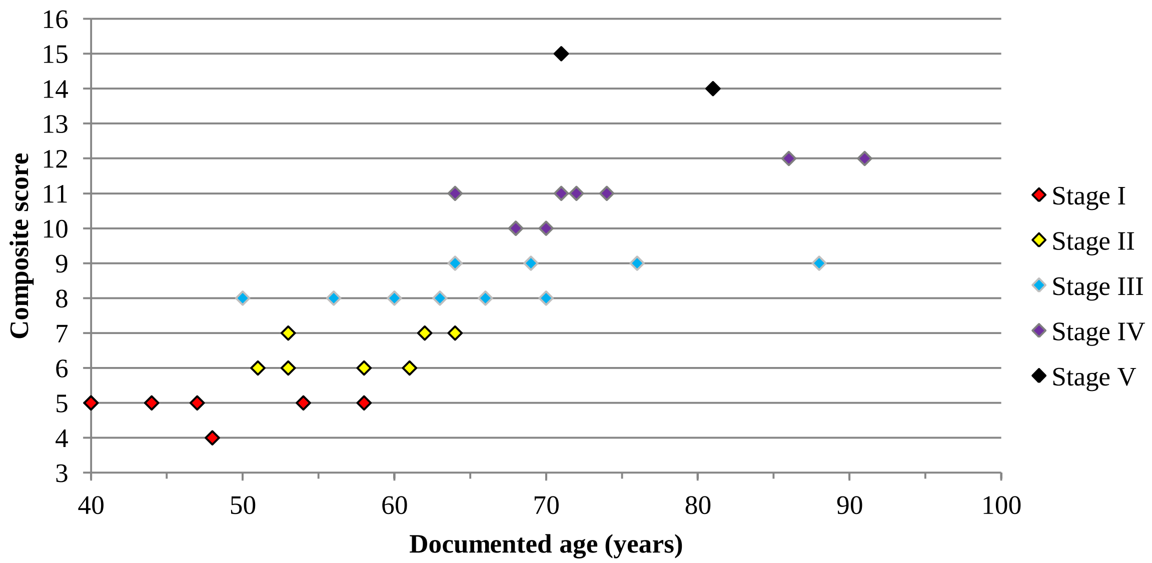


Figure 6.69: *Clavicle, blind test of sternal surface: scatter plot of composite scores and age stages against known age for males in the CCS sample.*

Age estimations were made using a range(s) unique to each age stage (Figure 6.70).

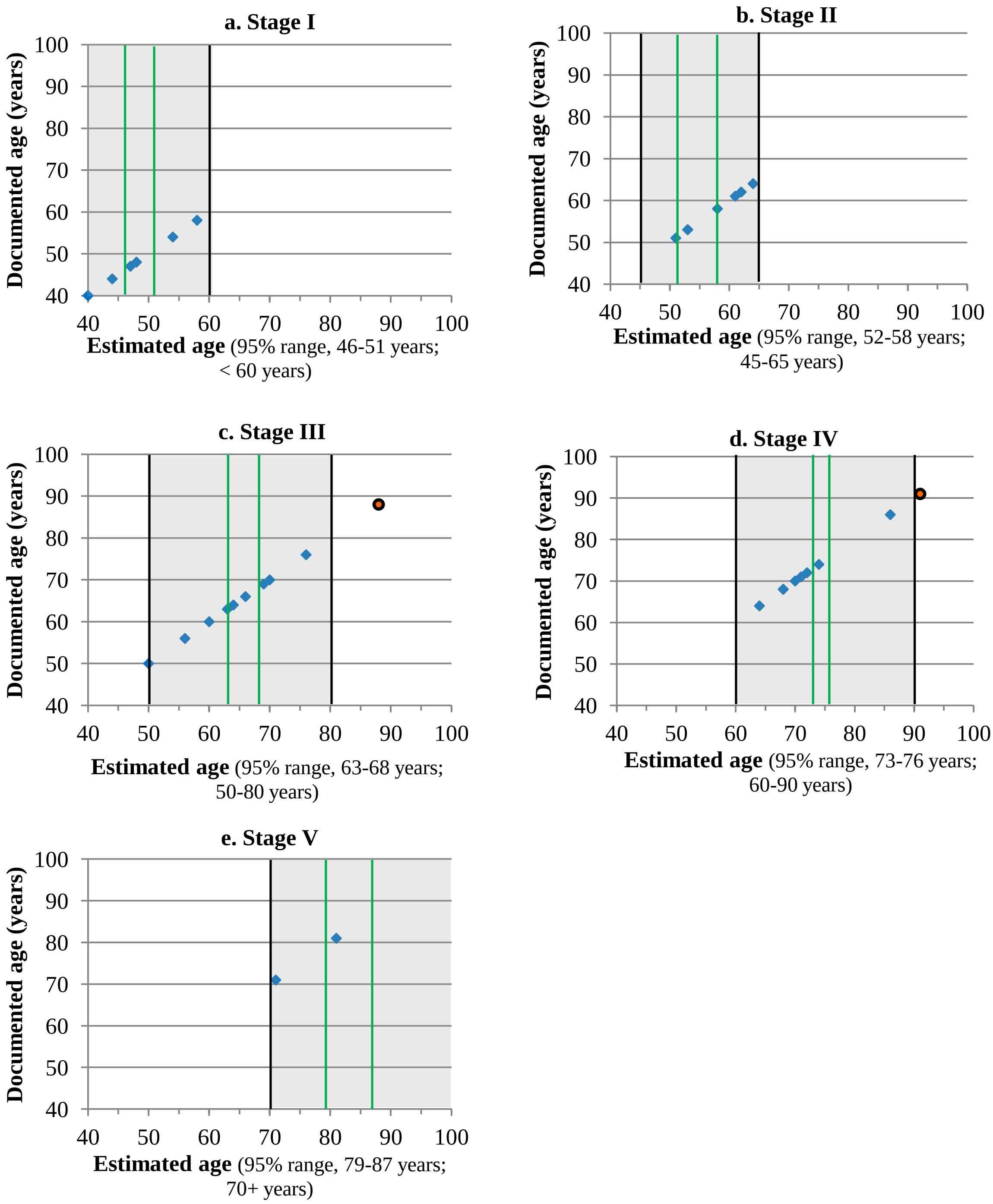


Figure 6.70a-e: *Observed age stages (estimated age; 95% confidence interval and age phase) of the sternal end of the clavicle for CCS males, compared with documented ages.*

Table 6.99 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested general age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.99: *Age estimations based on the appearance of the sternal surface of the clavicle in males in the blind test.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	7	40–58	46–51	2	28.6	< 60	7	100.0	0	0	no bias
II	7	51–64	52–58	3	42.9	45–65	7	100.0	0	0	no bias
III	10	50–88	63–68	3	30.0	50–80	9	90.0	1	10.0	underaged
IV	9	64–91	73–76	1	11.1	60–90	8	88.9	1	11.1	underaged
V	2	71 - 81	79–87	2	100.0	70+	2	100.0	0	0	no bias
Total	35	-	-	11	**31.4**	-	33	**94.3**	2	**5.7**	**underaged**

Of the 35 male individuals, 31.4% fell within the 95% confidence interval based on this method, and 94.3% fell within the age phase.

6.3.2.2.2 Female

A total of 35 females provided suitably preserved sternal clavicles for analysis. The resultant composite scores were allocated into corresponding surface age stages (between I to V) (Figure 6.71). The developed ageing criteria for each stage was applied to each female CCS individual and compared with documented age.

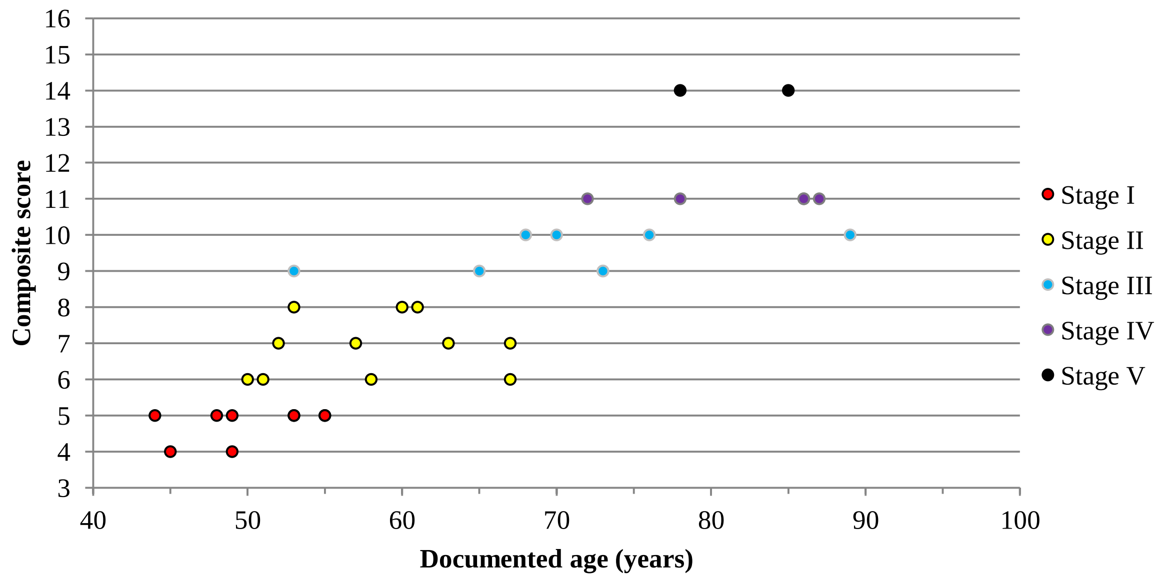


Figure 6.71: *Clavicle, blind test of sternal surface: scatter plot of composite scores and age stages against known age for females in the CCS sample.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.72).

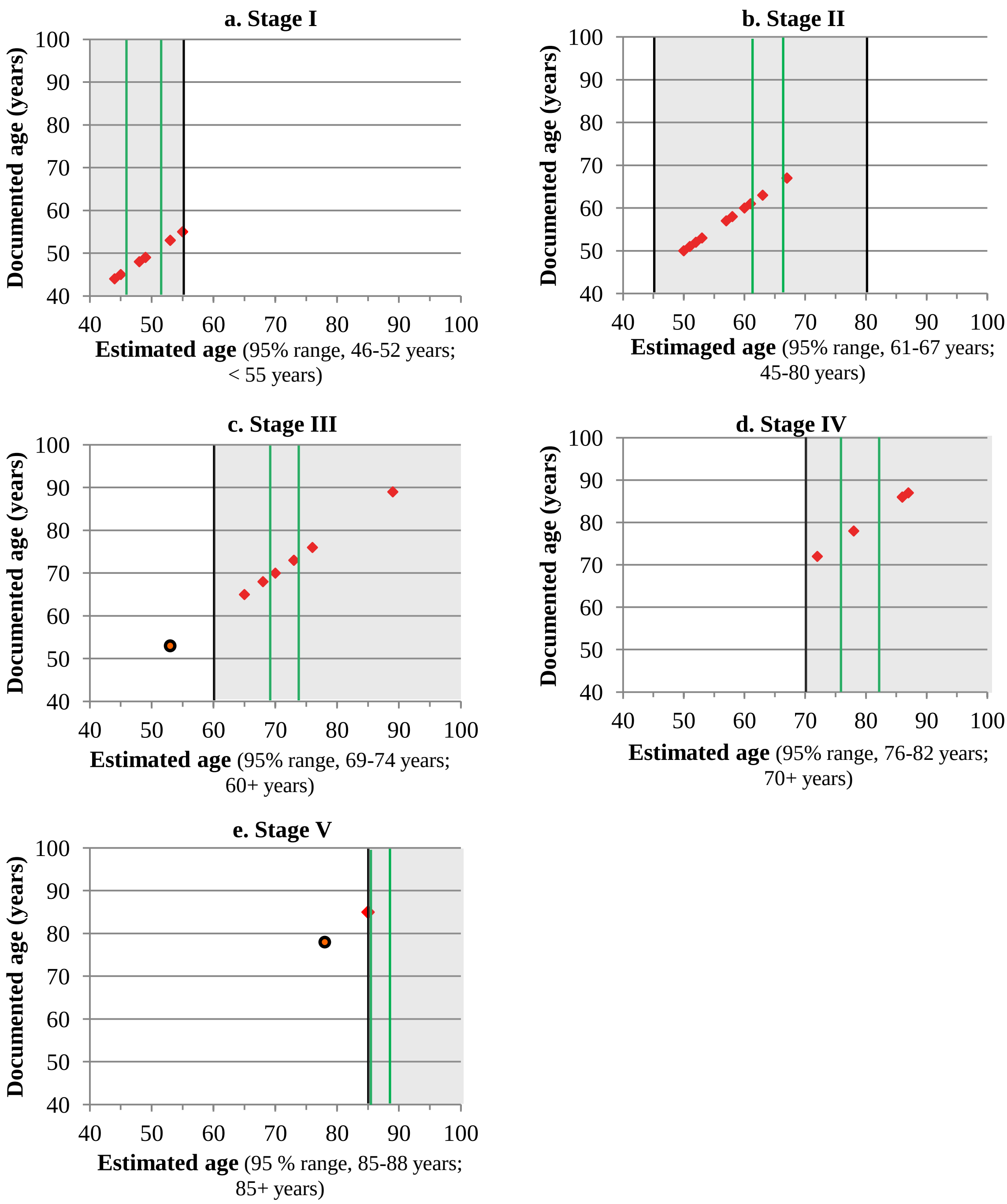


Figure 6.72a-e: *Observed age stages (estimated age) of the sternal end of the clavicle for CCS female individuals, compared with documented ages.*

Table 6.100 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

__Table 6.100:__ Age estimations based on the appearance of the sternal surface of the clavicle in females in the blind test sample.

Stage of appearance	**N**	**Actual age range of individuals (years)**	**Estimated age**						**Inaccuracy**		
			Within 95% confidence interval			**Within age phase**			**Under- or overaged**		
			Range (years)	**N**	**%**	**Range (years)**	**N**	**%**	**N**	**%**	**Bias**
I	9	44–55	46–52	3	33.3	< 55	9	100.0	0	0	no bias
II	11	50–67	61–67	4	36.4	45–80	11	100.0	0	0	no bias
III	8	53–89	69–74	3	37.5	60+	7	87.5	1	12.5	overaged
IV	5	72–87	76–82	1	20.0	70+	5	100.0	0	0	no bias
V	2	78–85	85–88	1	50.0	85+	1	50.0	1	50.0	overaged
Total	35	-	-	12	**34.3**	-	33	**94.3**	2	**5.7**	**overaged**

Of the 35 female individuals, 34.3% fell within the 95% confidence interval based on this method, and 94.3% fell within the age phase.

6.3.2.2.3 Additional Analyses

To confirm the relationship between age and composite score of the sternal surface of the clavicle, a Spearman's rank correlation was calculated for males and females. Both were found to be highly statistically significant (male, $r_s = 0.870$; $P < 0.001$; female, $r_s = 0.872$; $P < 0.001$). The results are plotted in Figure 6.73.

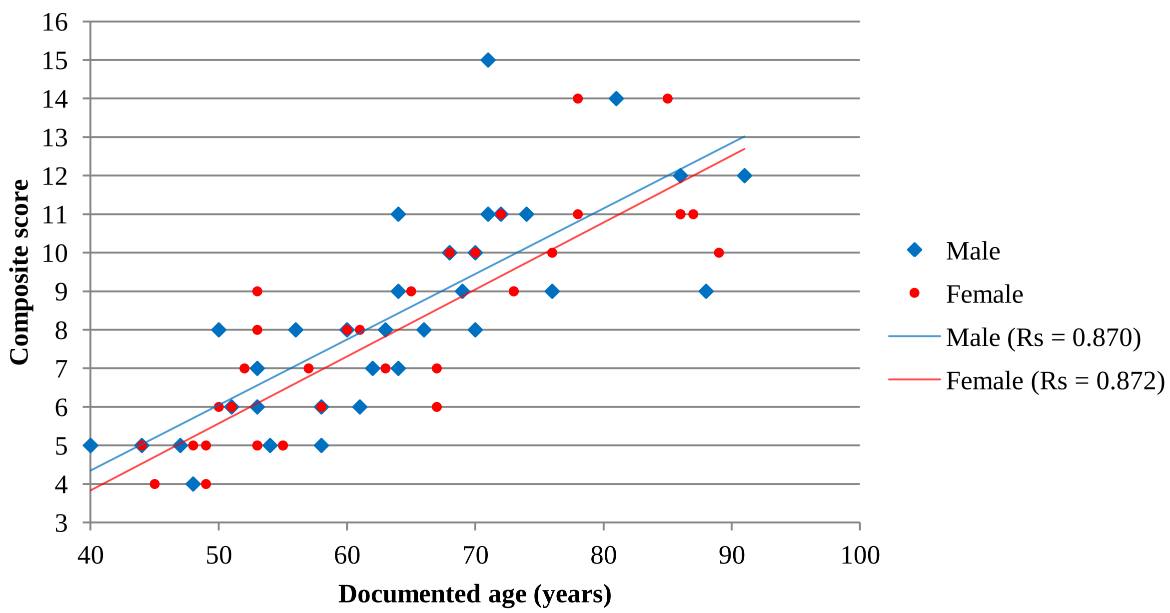


***Figure 6.73:** Clavicle, blind test of sternal surface: scatter plot of composite scores against age for all individuals in the CCS sample. Spearman's rank correlation coefficients of score against age for males and females are provided.*

Comparison of the descriptive statistics of age variation within each age stage for males and females (Table 6.101) revealed similar patterns of mean age, standard deviation and 95% confidence intervals between the developed criteria and the CCS blind test sample.

Table 6.101: *Comparison of age estimates from composite scores and age stages for the developed criteria and the CCS blind test sample.*

Age stage	Composite score	Developed criteria			CCS blind test sample			
		Mean age (years)	Standard deviation	95% confidence interval (years)	N	Mean age (years)	Standard deviation	95% confidence interval (years)
Males								
I	3–5	48.8	6.3	46–51	7	47.3	6.8	41–54
II	6–7	55.2	9.1	52–58	7	57.4	5.1	52–62
III	8–9	65.7	9.6	63–68	10	66.2	10.6	58–74
IV	10–12	74.9	8.4	73–76	9	73.8	8.9	66–81
V	13–16	83.1	6.9	79–87	2	76.0	7.1	*
Females								
I	3–5	49.3	7.1	46–52	9	50.1	4.1	47–53
II	6–8	64.5	11.9	61–67	11	58.1	6.1	54–62
III	9–10	72.0	9.9	69–74	8	70.1	10.2	62–79
IV	11–12	79.3	8.4	76–82	5	81.8	6.6	*
V	13–16	87.0	0.8	85–88	2	81.5	5.0	*

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.3.3 MANUBRIUM FACET OF THE STERNAL END OF THE CLAVICLE

As recorded for the two other clavicular surfaces, the individual trait scores for each surface feature of the manubrium facet on the sternal end of the clavicle were combined to form a composite score, ranging between 3 and 16 points (i.e. surface topography, scored between 1 and 6; porosity, scored between 1 and 6; osteophyte formation, scored between 1 and 4). This composite score was used to assess degenerative differences between left and right elements, as well as between males and females.

6.3.3.1 Manubrium Facet of the Sternal End of the Clavicle Results: Combined Sample

When the results of the four study samples were assessed, each collection demonstrated similar patterns of degeneration of the manubrium facet of the sternal end of the clavicle. There were no differences between left and right elements, and the need for sexually dimorphic criteria was suggested by the differences found in the Spearman’s rank correlation coefficients for relationship between composite score and age, with the exception of PBC females who rarely displayed severe degeneration. Composite scores were also found to have similar mean ages, standard deviations and ranges. The composite scores were plotted against known age for the males (Figure 6.74) and females (Figure 6.75) of all study samples.

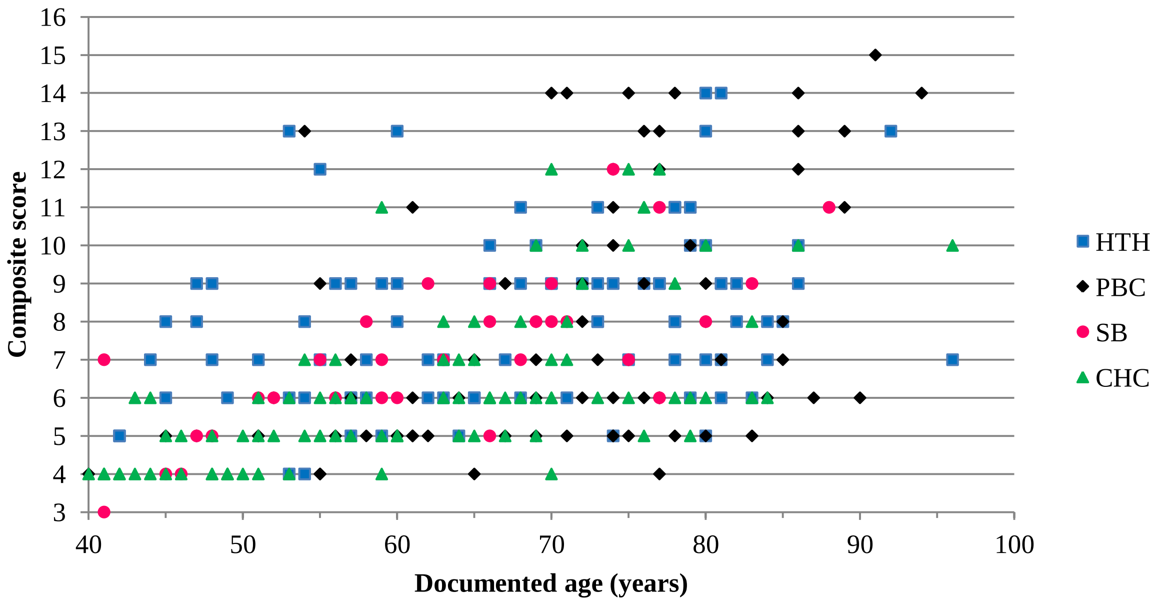


Figure 6.74: *Clavicle, manubrium facet: scatter plot of composite scores against known age for males in the combined sample.*

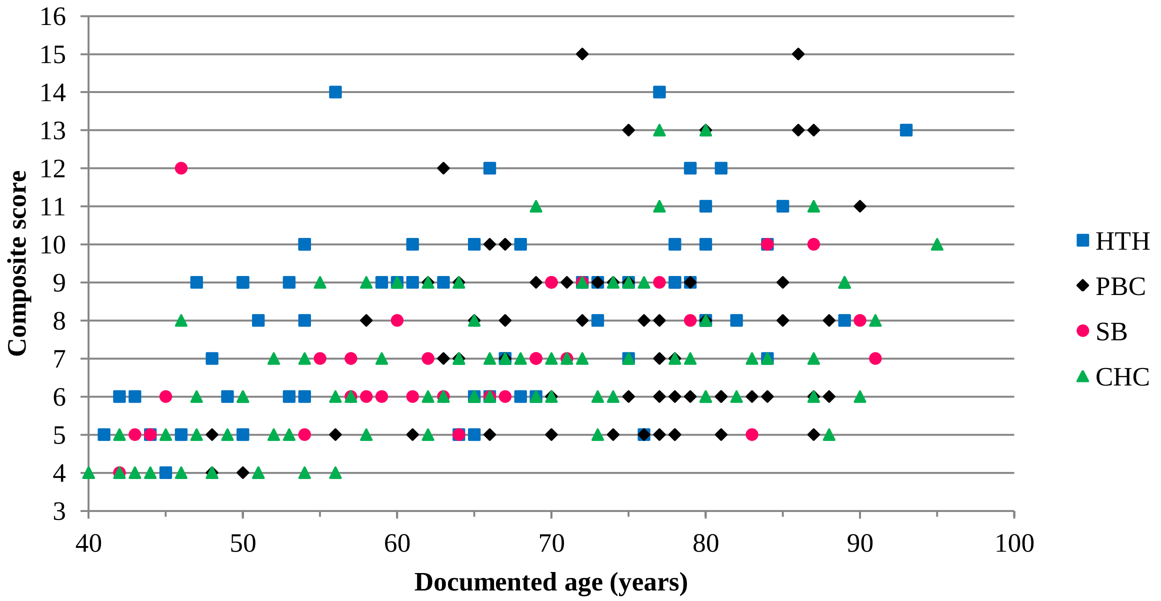


Figure 6.75: *Clavicle, manubrium facet: scatter plot of composite scores against known age of females in the combined sample.*

To assess the true extent of the degenerative processes of the manubrium facet of sternal end of the clavicle, all four collections were combined. The total sample sizes used to develop this method were 296 right sternal clavicles from male individuals (mean age, 66.0 years) and 232 female clavicles (mean age, 67.4 years) (Table 6.102).

Table 6.102: Clavicle, manubrium facet: age composition of the combined study sample.

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	40	59	68	80	49	**296**
Female	30	38	56	58	50	**232**
Total	**70**	**97**	**124**	**138**	**99**	**528**

6.3.3.1.1 Individual Trait Scores, Composite Scores and Age-at-Death

Plots of the frequency of trait score within each composite score for males and females are provided in Figure 6.76.

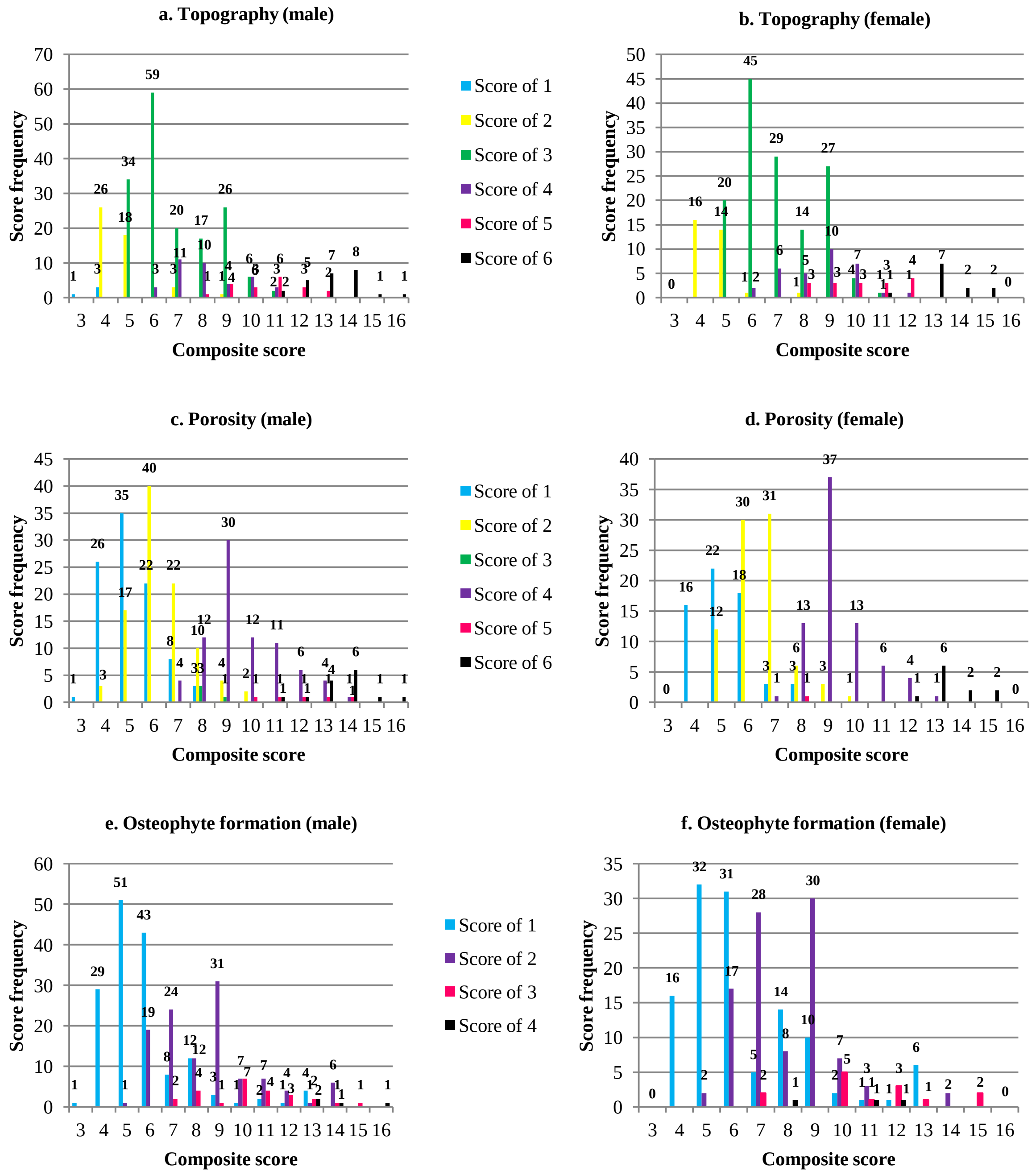


Figure 6.76a-f: *Number of observations of trait scores recorded for the manubrium facet of the sternal end of the clavicle in the combined study sample.*

Individual trait expressions were investigated as to their association with age-at-death. Scatter plots of trait scores were plotted against age-at-death (Figure 6.77). These figures display a wide variation in the age of trait expression of each of the features.

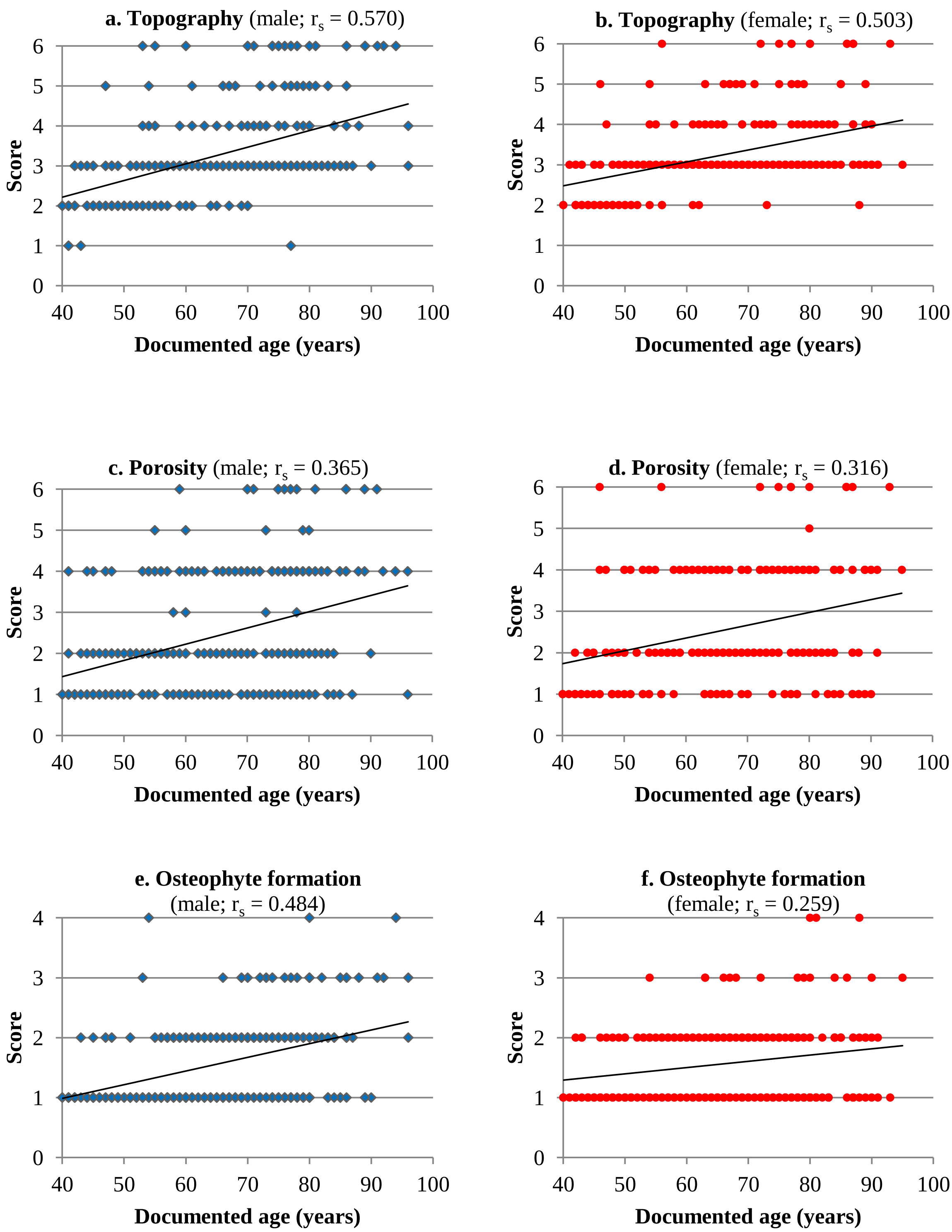


Figure 6.77a-f: *Clavicle, manubrium facet: scatter plots of trait scores against age-at-death. Spearman's rank correlation coefficients of trait score against age are provided.*

To test whether each feature is correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. Individual trait expressions were found to be significantly correlated with age-at-death (Table 6.103). The higher the score (r_s) assigned to a particular trait expression, the more frequently it was associated with older age. This correlation was strongest with surface topography for males and females (male, r_s = 0.570, P < 0.001; female, r_s = 0.503, P < 0.001). Although all surface features were correlated with age-at-death (i.e. P < 0.05).

Table 6.103: *Clavicle, manubrium facet: Spearman's rank correlation between age and trait expression of features.*

Feature	Male		Female	
	r_s	P	r_s	P
Surface topography	0.570	< 0.001	0.503	< 0.001
Porosity	0.365	< 0.001	0.316	< 0.001
Osteophyte formation	0.484	< 0.001	0.259	0.007
Composite score	**0.539**	**< 0.001**	**0.411**	**< 0.001**

A Spearman's rank correlation coefficient was also calculated for the derived composite with age. As was found with each individual feature, the combination of scores for surface topography, porosity and osteophyte formation also produced a significant correlation with documented ages-at-death (male, r_s = 0.539, P < 0.001; female, r_s = 0.411, P < 0.001) (Table 6.103, Figure 6.78).

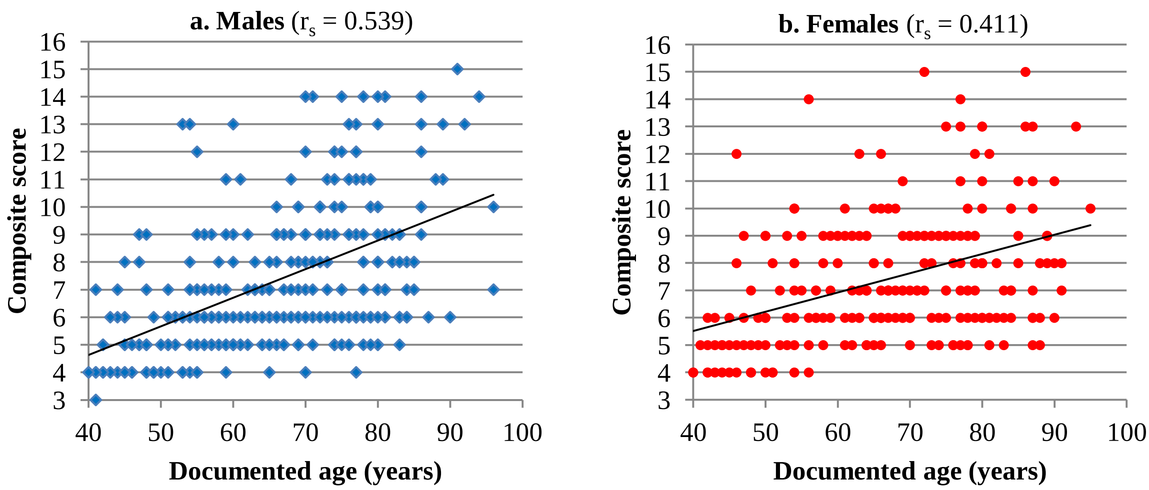


Figure 6.78a-b: *Clavicle, manubrium facet: association between composite scores and documented age. Spearman's rank correlation coefficients are provided.*

The descriptive statistics of age variation within composite scores (Tables 6.104 and 6.105, males and females respectively) revealed that despite the overall trend of increasing age with increasing composite score, there was considerable variation leading to non-linear progression, especially in females.

Table 6.104: *Clavicle, manubrium facet: descriptive statistics for documented ages-at-death found to possess same composite scores of males in the combined study sample.*

Composite score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
3	1	41.0	-	41	41
4	29	49.7	9.0	48	40–77
5	52	60.4	11.0	60	42–83
6	62	65.6	11.6	65	43–90
7	34	66.2	12.4	65	41–96
8	28	70.6	10.8	71	45–85
9	35	69.8	9.9	70	47–86
10	15	77.0	8.0	75	66–96
11	13	75.1	8.7	76	59–89
12	8	73.5	8.8	74	55–86
13	9	74.1	14.9	77	53–92
14	8	79.4	7.9	79	70–94
15	1	91.0	-	91	91
16	0	-	-	-	-

Table 6.105: *Clavicle, manubrium facet: descriptive statistics for documented ages-at-death found to possess same composite scores of females in the combined study sample.*

Composite score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
3	0	-	-	-	-
4	16	46.8	4.8	47	40–56
5	34	61.6	14.6	61	41–88
6	48	67.1	12.8	66	42–90
7	35	69.0	10.3	68	48–91
8	23	73.4	13.0	77	46–91
9	40	69.3	10.7	71	47–89
10	14	72.1	12.6	67	54–95
11	6	81.3	7.7	82	69–90
12	5	67.0	14.1	66	46–81
13	7	82.6	6.4	80	75–93
14	2	66.5	14.9	66	56–77
15	2	79.0	9.9	79	72–86
16	0	-	-	-	-

The descriptive statistics for male individuals were not found to demonstrate clear patterns of increasing age with larger composite scores. Composite scores for males and females were each able to be divided into three statistically significant stages (Tables 6.106 and 6.107). In addition to the 95% confidence interval, a broader range (age phase) with which to estimate age was also provided for each age stage.

Table 6.106: *Clavicle, manubrium facet: age estimates from composite scores and age stages (male).*

Composite score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
3–4	I	30	49.4	9.0	46–53	< 60 years
5–9	II	211	65.8	11.7	64–67	45+ years
10–16	III	54	76.2	9.7	73–79	60+ years

Table 6.107: *Clavicle, manubrium facet: age estimates from composite scores and age stages (female).*

Composite score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
3–4	I	16	46.8	4.8	44–49	< 60 years
5–10	II	194	68.0	12.7	66–70	50–90 years
11–16	III	22	76.9	11.4	71–82	70+ years

Unpaired *t*-tests were employed to test for statistically significant differences between the stages (Table 6.108). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.108: *Clavicle, manubrium facet: results of t-tests between age stages.*

Stages compared	Male			Female		
	t	**df**	***P***	***t***	**df**	***P***
I vs II	-7.38	239	< 0.001	-14.07	36	< 0.001
II vs III	6.01	263	< 0.001	3.14	214	0.002

6.3.3.2 Manubrium Facet of the Sternal End of the Clavicle Results: Blind Test

A blind test was performed on the sternal end of the right clavicle of 70 randomly chosen individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The left side was substituted if the right was absent. The sample comprised 35 males with age-at-death ranging from 40-91 years (mean age, 63.2 years) and 35 females, ranging between 44-89 years (mean age, 63.7 years) (Table 6.109).

Table 6.109: *Clavicle, blind test of manubrium facet: age construction of the CCS sample.*

	Age category (years)					Total
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	5	8	11	7	4	**35**
Female	5	11	7	7	5	**35**
Total	**10**	**19**	**18**	**14**	**9**	**70**

As sexually dimorphic differences in trait expression were identified while developing the ageing criteria, males and females were analysed separately. Individual trait scores for surface topography, porosity and osteophyte formation were combined to form a composite score, which was ultimately used to estimate age-at-death. Composite scores range from 3 to 16 points.

6.3.3.2.1 Male

A total of 35 males provided suitably preserved sternal clavicles for analysis. The resultant composite scores were allocated into corresponding surface age stages (ranging between I and III) (Figure 6.79). The developed ageing criteria for each stage was applied to each male CCS individual and compared with documented age.

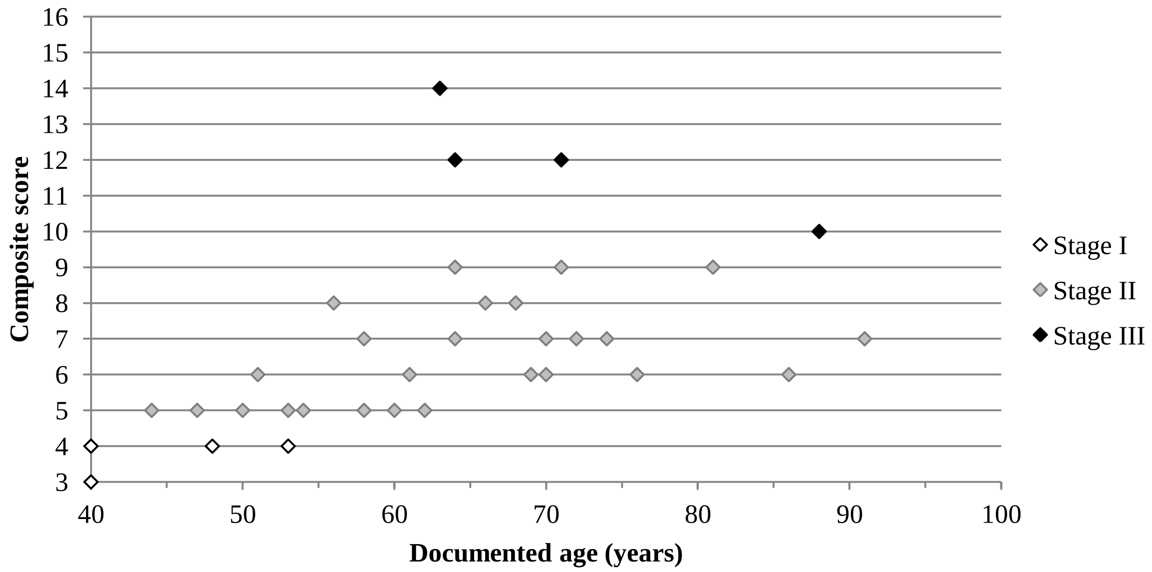


Figure 6.79: *Clavicle, blind test of manubrium facet: scatter plot of derived age stages for males.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.80). Age estimations were made using a range(s) unique to each age stage.

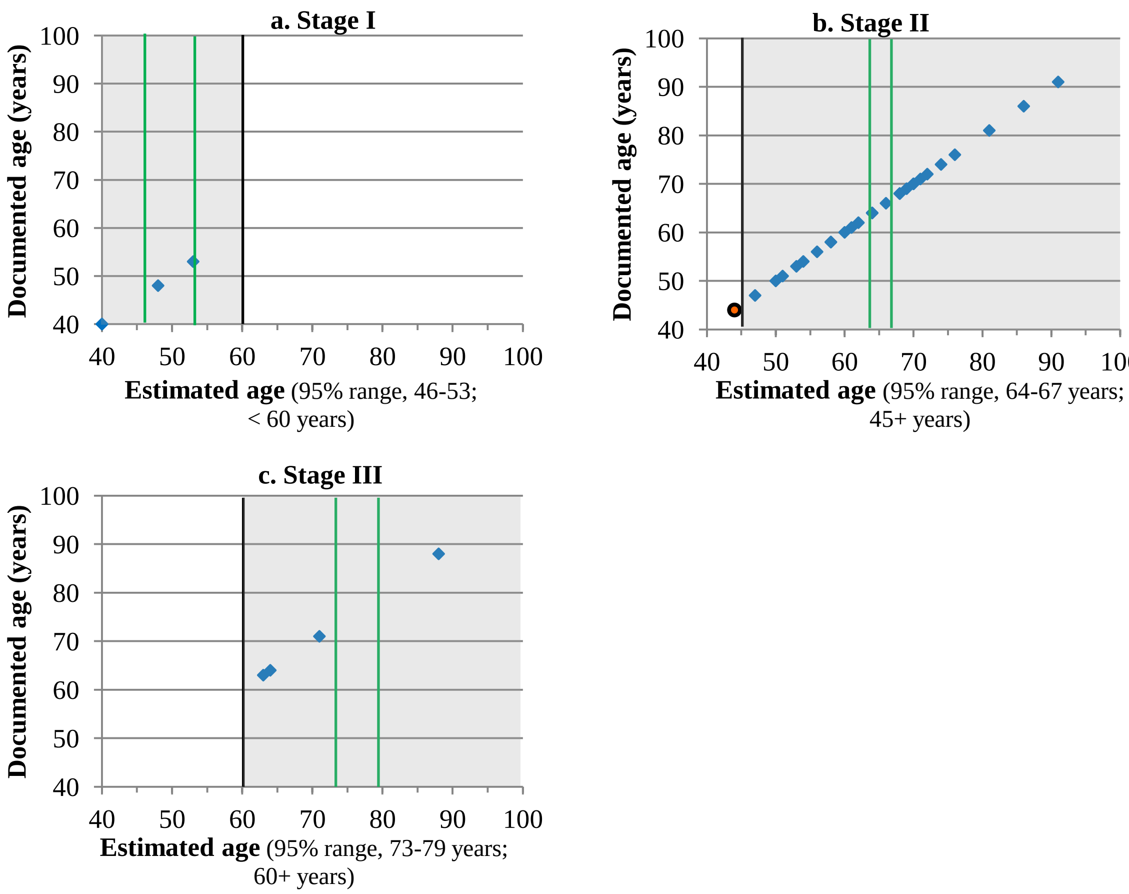


Figure 6.80a-c: *Observed age stages (estimated age) of the manubrium facet of the sternal end of the clavicle for CCS male individuals, compared with documented ages.*

Table 6.110 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.110: *Age estimations based on the appearance of the manubrium facet of the sternal end of the clavicle in males in the blind test sample.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	bias
I	4	40–53	46–53	2	50.0	< 60	4	100.0	0	0	no bias
II	27	44–91	64–67	3	11.1	45+	26	96.3	1	3.7	overaged
III	4	63–88	73–79	0	0	60+	4	100.0	0	0	no bias
Total	35	-	-	5	**14.3**	-	34	**97.1**	1	**2.9**	**overaged**

Of the 35 individuals, 14.3% fell within the 95% confidence interval based on this method, and 97.1% fell within the age phase.

6.3.3.2.2 Female

A total of 35 females provided suitably preserved sternal clavicles for analysis. The resultant composite scores were allocated into corresponding surface age stages (between I to III) (Figure 6.81). The developed ageing criteria for each stage was applied to each female CCS individual and compared with documented age.

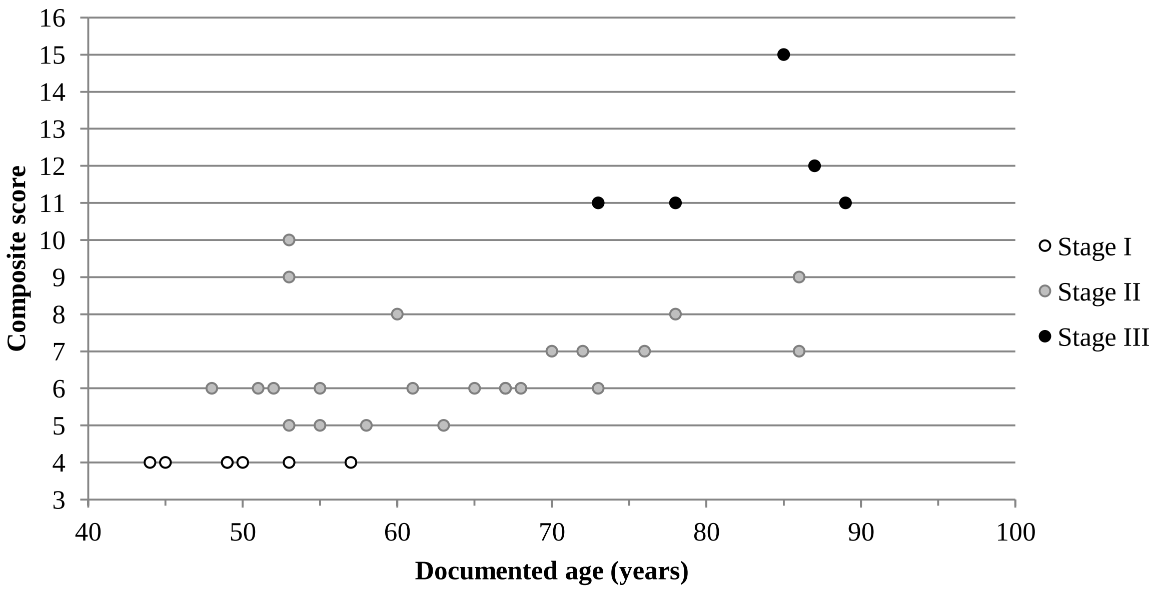


Figure 6.81: *Clavicle, blind test of manubrium facet: scatter plot of derived age stages for females.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.82). Age estimations were made using a range(s) unique to each age stage.

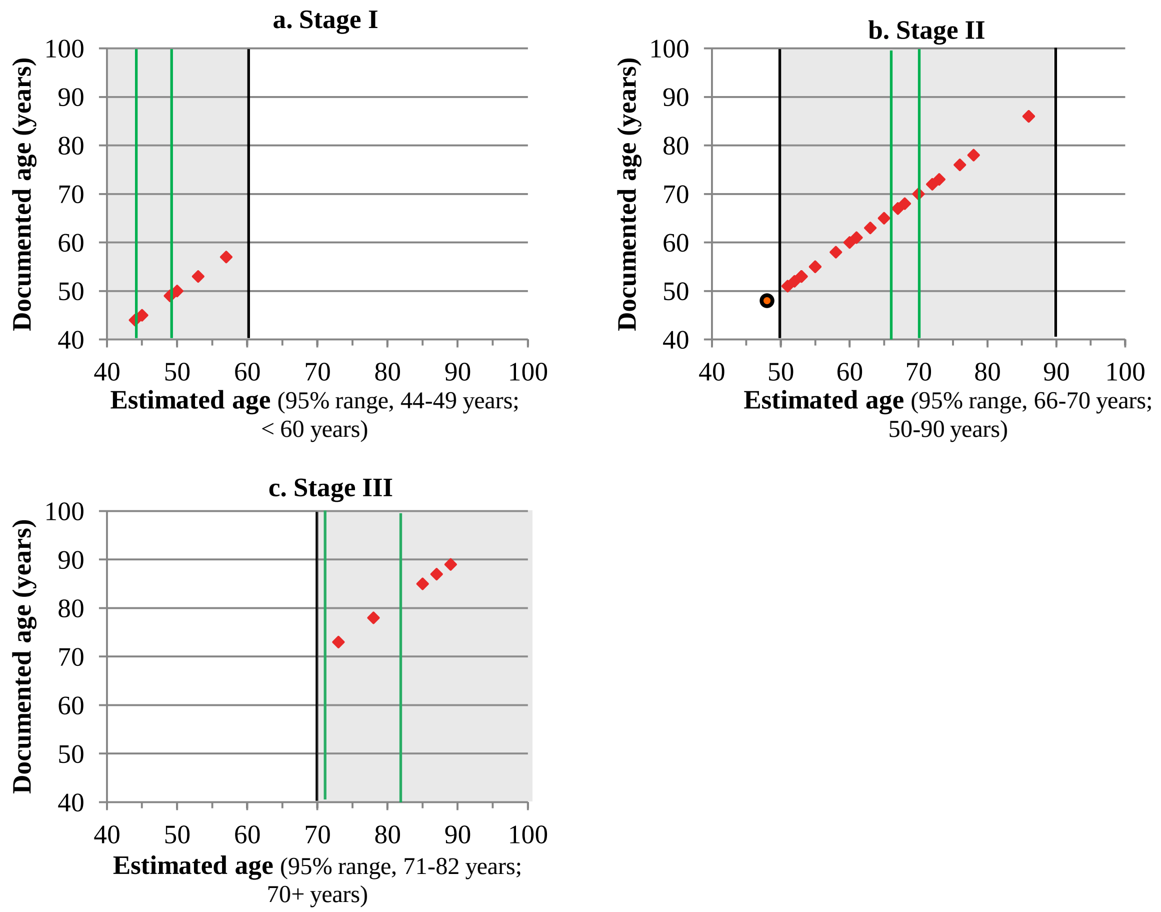


Figure 6.82a-c: *Observed age stages (estimated age) of the manubrium facet of the sternal end of the clavicle for CCS females, compared with documented ages.*

Table 6.111 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested general age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.111: *Age estimations based on the appearance of the manubrium facet of the sternal end of the clavicle in females in the blind test sample.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	bias
I	7	44–57	44–49	4	57.1	< 60	7	100.0	0	0	no bias
II	23	48–86	66–70	4	17.4	50–90	22	95.7	1	4.3	overaged
III	5	73–89	71–82	2	40.0	70+	5	100.0	0	0	no bias
Total	35	-	-	10	**28.6**	-	34	**97.1**	1	**2.9**	**overaged**

Of the 35 female individuals, 28.6% fell within the 95% confidence interval based on this method, and 97.1% fell within the age phase.

6.3.3.2.3 Additional Analyses

To confirm the relationship between age and composite score of the manubrium facet of the sternal surface of the clavicle, a Spearman's rank correlation was calculated for males and females. Both were found to be highly statistically significant (male, $r_s = 0.622$; $P < 0.001$; female, $r_s = 0.737$; $P < 0.001$). The results are plotted in Figure 6.83.

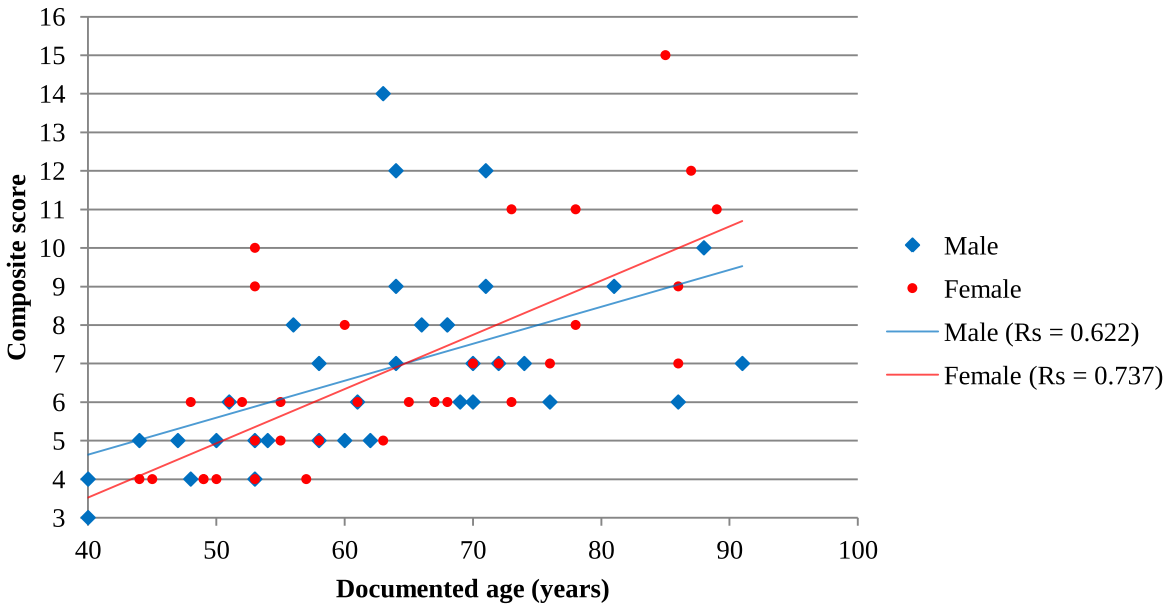


Figure 6.83: *Clavicle, blind test of manubrium facet: scatter plot of composite scores against age for all individuals in the CCS sample. Spearman's rank correlation coefficients of score against age for males and females are provided.*

Comparison of the descriptive statistics of age variation within each age stage (Table 6.112) revealed similar patterns of mean age, standard deviation and 95% confidence intervals between the developed criteria and the CCS blind test sample.

Table 6.112: *Comparison of age estimates from composite scores and age stages of the developed criteria and the CCS blind test sample.*

Age stage	Composite scores	Developed criteria			CCS blind test sample			
		Mean age (years)	Standard deviation	95% confidence interval (years)	N	Mean age (years)	Standard deviation	95% confidence interval (years)
Males								
I	3–4	49.4	9.0	46–53	4	45.3	6.4	*
II	5–9	65.8	11.7	64–67	27	64.6	11.5	60–69
III	10–16	76.2	9.7	73–79	4	71.5	11.7	*
Females								
I	3–4	46.8	4.8	44–49	7	49.6	4.5	45–54
II	5–10	68.0	12.7	66–70	23	63.9	11.0	59–69
III	11–16	76.9	11.4	71–82	5	82.4	6.7	*

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.3.4 COMBINATION OF LATERAL AND STERNAL CLAVICLE COMPOSITE SCORES

The composite scores for the lateral and sternal ends of the clavicle were combined to form a "Summary Score" for these individuals, ranging in value between 5 and 28 points. As the results for the sternal surface indicated the need for sexually dimorphic criteria, the sexes were assessed separately. Ageing criteria were made through the combination of all study samples, and the developed method was blind tested on the Christ Church Spitalfields collection.

6.3.4.1 Sternal and Lateral Clavicle Summary Score Results: Combined Sample

This study assessed whether the combination of composite scores for the lateral and sternal ends of the clavicle improved the correlation of composite scores with age. A total of 518 individuals that had both ends of the clavicle (right side) were present for use in this analysis. The sample comprised 293 males with age-at-death ranging from 40-96 years (mean age, 66.4 years) and 225 females, ranging between 40-95 years (mean age, 67.7 years) (Table 6.113).

Table 6.113: *Clavicle, summary score: age composition of the combined study sample.*

	Age category (years)					Total
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	37	57	66	82	51	**293**
Female	30	36	52	52	55	**225**
Total	**67**	**93**	**118**	**134**	**106**	**518**

Plots of "Summary Score" against documented age for males and females are presented in Figures 6.84 and 6.85, respectively.

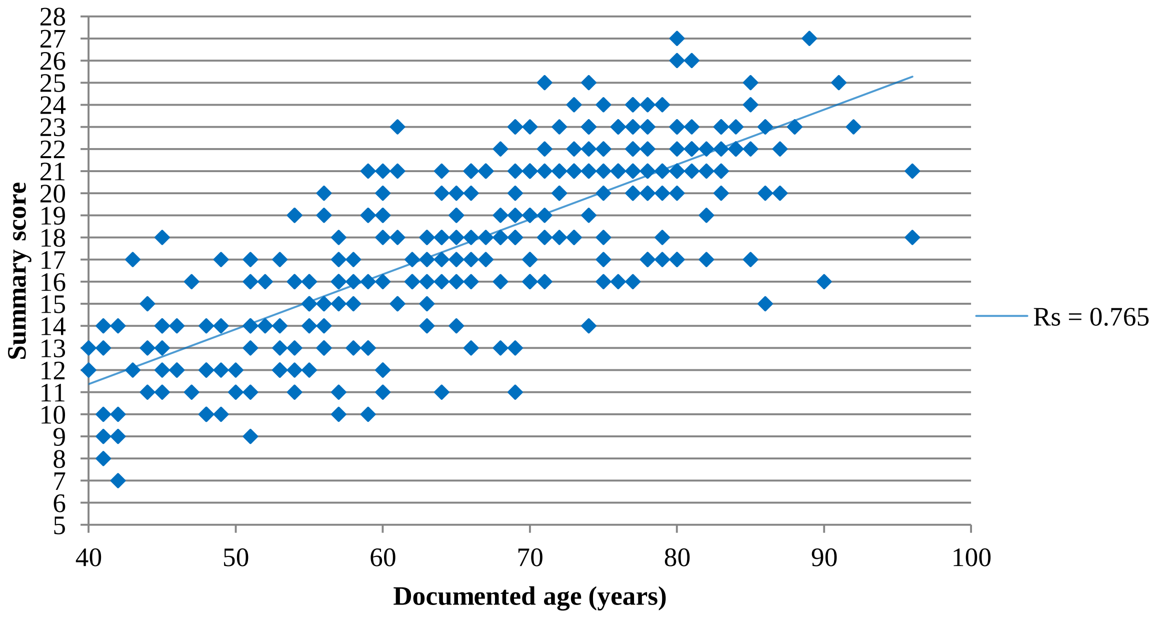


Figure 6.84: *Scatter plot of combined composite scores (i.e. summary score) for lateral and sternal surfaces of the clavicle against documented age for males (N = 293). Spearman's rank correlation coefficient of score against age for males is provided.*

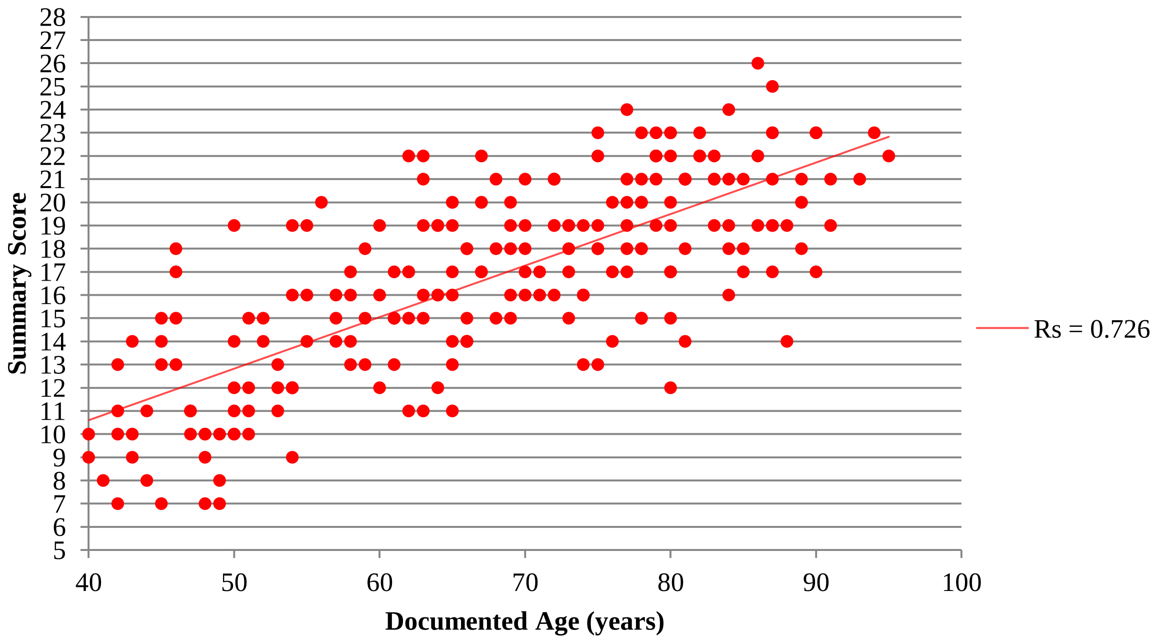


Figure 6.85: *Scatter plot of combined composite scores (i.e. summary score) for lateral and sternal surfaces of the clavicle against documented age for females (N = 225). Spearman's rank correlation coefficient of score against age for females is provided.*

To test whether each the combination of scores was more highly correlated with age-at-death than assessing each end separately, a Spearman's rank correlation coefficient was calculated (Table 6.114). Although the values varied between lateral and sternal ends and summary score, all were found to be highly statistically correlated with age (i.e. $P < 0.001$). The higher the score (r_s) assigned to a composite/summary score, the more frequently it was associated with older age. In the all males and all females categories, this correlation was strongest with the summary score (male, $r_s = 0.765$, $P < 0.001$; female, $r_s = 0.726$, $P < 0.001$) indicating the combination of composite scores increased the correlation of techniques with known age.

Table 6.114: *Clavicle, summary score: Spearman's rank correlation between age and composite scores for the combined sample.*

Feature	**Male**		**Female**	
	r_s	***P***	**r_s**	***P***
Lateral clavicle composite score	0.597	<0.001	0.625	<0.001
Sternal clavicle composite score	0.709	<0.001	0.647	<0.001
Lateral + sternal ends summary score	**0.765**	**<0.001**	**0.726**	**<0.001**

The descriptive statistics of age variation within composite scores for males and females (Tables 6.115 and 6.116, respectively) revealed the overall trend of increasing age with increasing composite score.

Table 6.115: *Descriptive statistics for documented ages-at-death found to possess same summary scores for males in the study sample (N = 293).*

Composite score	**N**	**Mean age (years)**	**Standard deviation**	**Median age (years)**	**Observed range (years)**
5	0	-	-	-	-
6	0	-	-	-	-
7	1	42.0	-	42	42
8	1	41.0	-	41	41
9	3	44.7	5.5	42	41–51
10	8	49.0	6.3	48	41–59
11	10	54.1	8.3	52	44–69
12	16	50.2	5.7	49	40–60
13	15	54.6	9.2	56	40–69
14	16	52.3	8.9	51	41–74
15	12	58.9	9.8	56	44–86
16	27	62.8	9.6	62	47–90
17	22	67.1	11.8	66	43–85
18	22	67.6	9.5	67	45–96
19	16	64.8	7.9	65	54–82
20	18	73.6	8.8	76	56–87
21	43	73.2	7.2	73	59–96
22	20	79.0	5.1	80	68–87
23	28	78.4	6.8	78	61–92
24	7	77.7	3.8	77	73–85
25	4	80.3	9.4	79	71–91
26	2	80.5	0.7	80	80–81
27	2	84.5	6.4	84	80–89
28	0	-	-	-	-

Table 6.116: *Descriptive statistics for documented ages-at-death found to possess same summary scores for all females in the study sample (N = 225).*

Composite score	**N**	**Mean age (years)**	**Standard deviation**	**Median age (years)**	**Observed range (years)**
5	0	-	-	-	-
6	0	-	-	-	-
7	4	46.0	3.2	46	42–49
8	3	44.7	4.0	44	41–49
9	4	46.3	6.1	45	40–54
10	10	46.8	3.8	48	40–51
11	10	52.4	8.2	50	42–65
12	10	57.4	9.0	54	50–80
13	10	57.8	11.5	58	42–75
14	15	62.3	12.8	65	43–88
15	18	62.8	10.4	61	45–80
16	16	65.9	8.2	64	54–84
17	18	70.9	11.3	70	46–90
18	17	72.9	10.4	75	46–89
19	26	72.9	11.3	73	50–91
20	14	73.9	9.4	76	56–89
21	22	79.6	7.6	81	63–93
22	13	77.9	9.3	79	62–95
23	11	83.8	6.1	82	75–94
24	2	80.5	5.0	80	77–84
25	1	87.0	-	87	87
26	1	86.0	-	86	86
27	0	-	-	-	-
28	0	-	-	-	-

Several composite scores were found to provide similar age ranges, mean ages, and median ages. These scores were combined together to produce surface age stages for males (Table 6.117, Figure 6.86) and females (Table 6.118, Figure 6.87). In addition to the 95% confidence interval, an age phase (broader range) with which to estimate age was also provided for each age stage.

Table 6.117: *Clavicle, summary score: age estimates from summary scores and age stages (male).*

Summary score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
7–9	I	5	43.4	4.3	38 - 49	< 50 years
10–14	II	65	52.2	7.9	50–54	< 60 years
15–19	III	99	64.7	10.1	62–67	50–75 years
20–21	IV	61	73.3	7.6	71–75	60+ years
22–28	V	63	78.9	6.0	77–80	70+ years

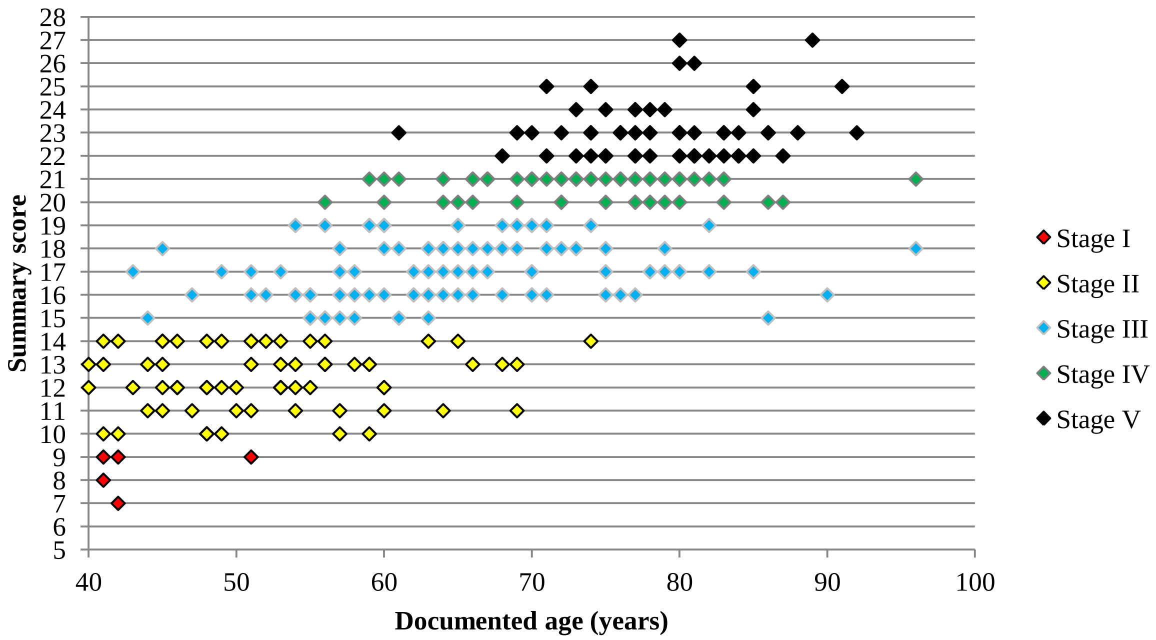


Figure 6.86: *Clavicle, summary score: scatter plot of age stages for males.*

Table 6.118*: Clavicle, summary score: age estimates from composite scores and age stages (female).*

Composite score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
7–10	I	21	46.2	4.0	44–48	< 55 years
11–16	II	79	60.7	10.8	58–63	45–70 years
17–20	III	75	72.6	10.6	70–75	55+ years
21–28	IV	50	80.4	7.8	78–83	65+ years

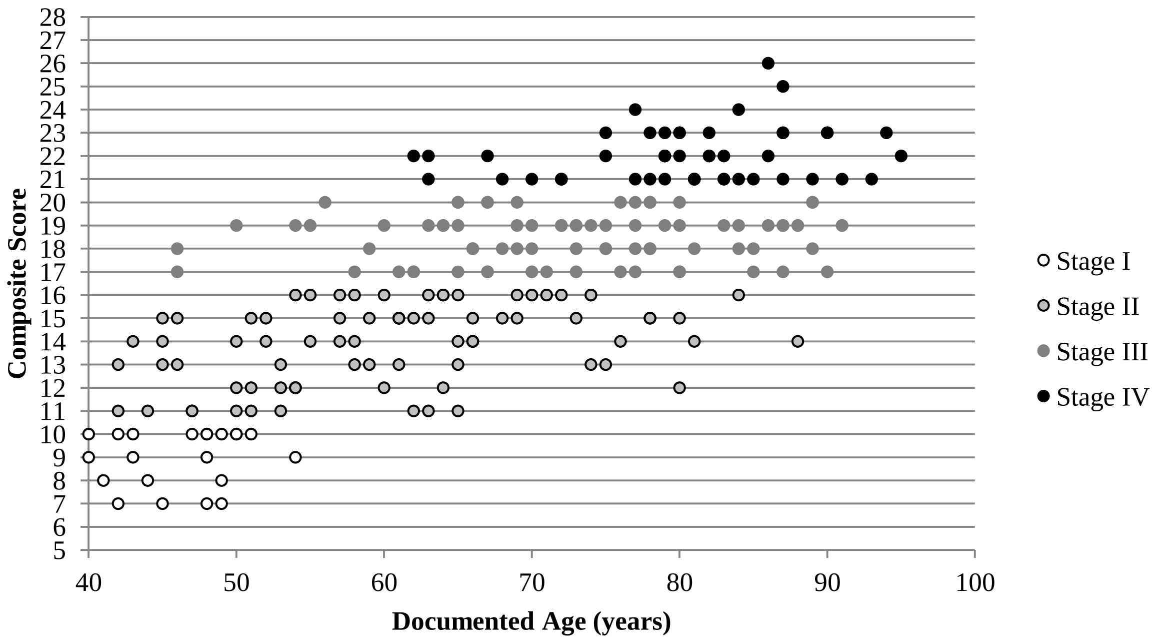


Figure 6.87: *Clavicle, summary score: scatter plot of age stages for females.*

Unpaired *t*-tests were employed to test for statistically significant differences between the stages (Table 6.119). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.119: *Clavicle, summary score: results of t-tests between age stages.*

Stages compared	Male			Female		
	t	df	*P*	*t*	df	*P*
I vs II	-2.43	68	0.018	-9.68	88	< 0.001
II vs III	-8.83	157	< 0.001	-6.91	152	< 0.001
III vs IV	6.14	152	< 0.001	-4.74	122	< 0.001
IV vs V	-4.55	122	< 0.001	-	-	-

6.3.4.2 Sternal and Lateral Clavicle Summary Score Results: Blind Test

A blind test was performed on the right clavicle of 60 randomly chosen individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The left side was substituted if the right was absent. The sample comprised 28 males with age-at-death ranging from 40-91 years (mean age, 62.9 years) and 32 females, ranging between 44-89 years (mean age, 62.8 years) (Table 6.120).

Table 6.120: *Clavicle, blind test of summary scores: age construction of the CCS sample.*

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	4	8	7	5	4	**28**
Female	5	11	6	5	5	**32**
Total	**9**	**19**	**13**	**10**	**9**	**60**

As sexually dimorphic differences in trait expression were identified while developing the ageing criteria, males and females were analysed separately. Individual trait scores for surface topography, porosity and osteophyte formation were combined to form a composite score, which was ultimately used to estimate age-at-death. Combined composite scores (i.e. summary scores) range from 5 to 28 points.

6.3.4.2.1 Male

A total of 28 males provided suitably preserved sternal clavicles for analysis. The resultant composite scores were allocated into corresponding surface age stages (ranging between I and V) (Figure 6.88). The developed ageing criteria for each stage was applied to each male CCS individual and compared with documented age.

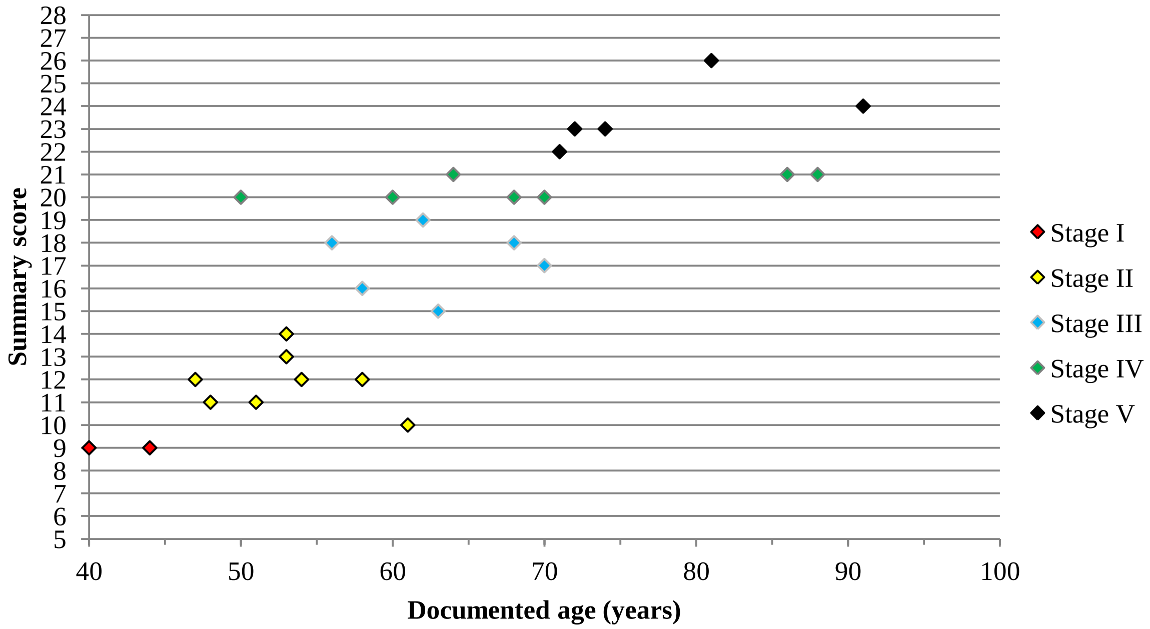


Figure 6.88: *Clavicle, blind test of summary scores: scatter plot of derived age stages for males.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.89). Age estimations were made using a range(s) unique to each age stage.

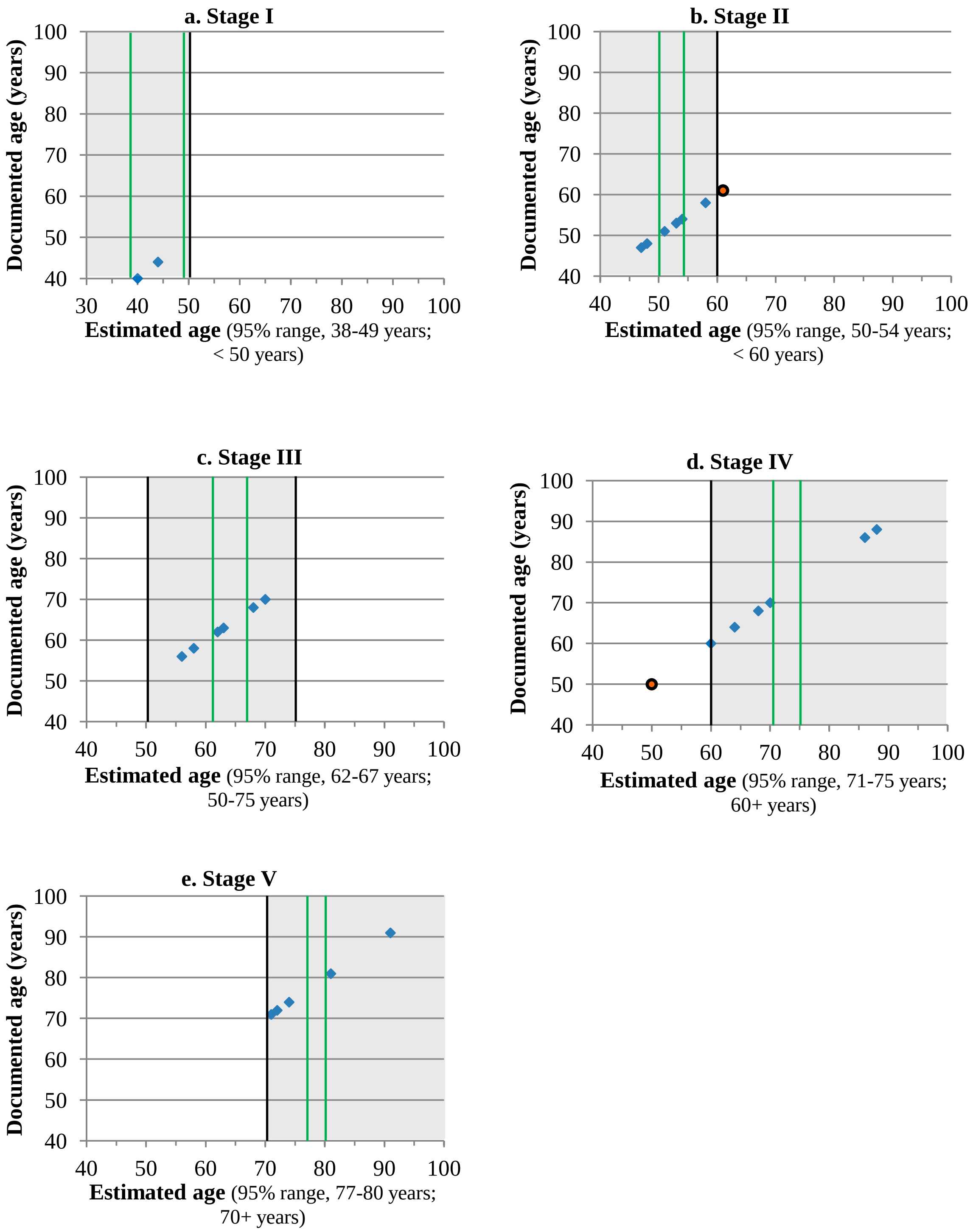


Figure 6.89a-e: *Clavicle, blind test of summary scores: observed age stages (estimated age) for CCS males, compared with documented ages.*

Table 6.121 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

__Table 6.121:__ Age estimations based on the combined appearance of the sternal and lateral surfaces of the clavicle in blind tested males.

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	2	40–44	38–49	2	100.0	< 50	2	100.0	0	0	no bias
II	8	47–61	50–54	4	50.0	< 60	7	87.5	1	12.5	underaged
III	6	56–70	62–67	2	33.3	50–75	6	100.0	0	0	no bias
IV	7	50–88	71–75	0	0	60+	6	85.7	1	14.3	overaged
V	5	71–91	77–80	0	0	70+	5	100.0	0	0	no bias
Total	28	-	-	8	**28.6**	-	26	**92.9**	1	**3.05**	**underaged**
									1	**3.05**	**overaged**

Of the 28 male individuals who had both ends of the clavicle present for examination, 28.6% fell within the 95% confidence interval based on this method, and 92.9% fell within the age phase.

6.3.4.2.2 Female

A total of 32 females provided suitably preserved sternal clavicles for analysis. The resultant composite scores were allocated into corresponding surface age stages (between I to IV) (Figure 6.90). The developed ageing criteria for each stage was applied to each female CCS individual and compared with documented age, and depicted in Figure 6.91.

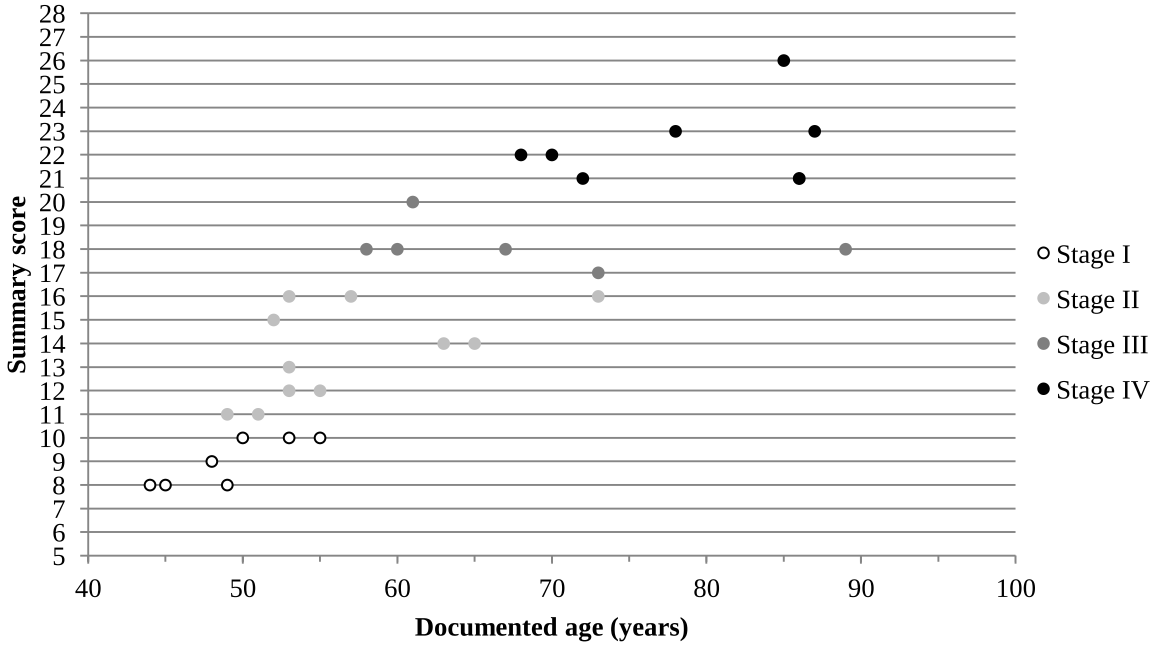


***Figure 6.90:** Clavicle, blind test of summary scores: scatter plot of derived age stages for females.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.91).

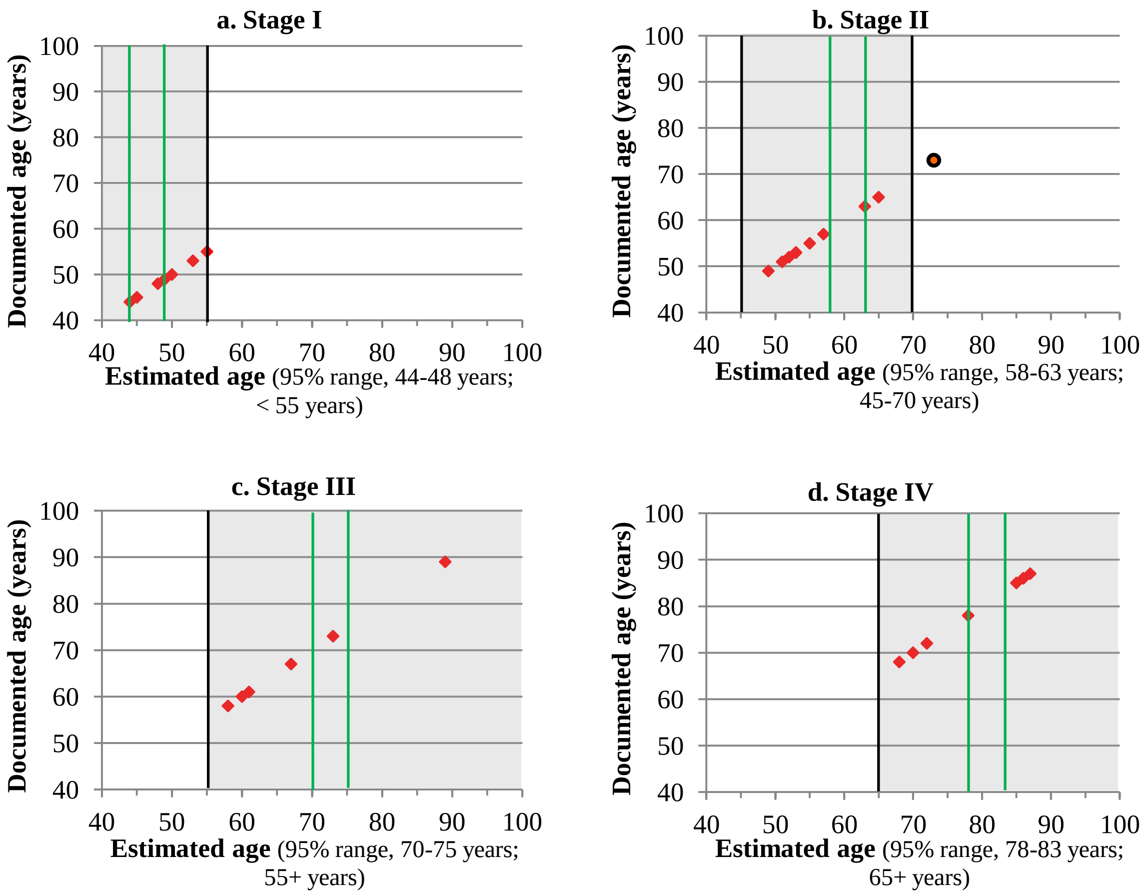


Figure 6.91a-e: *Clavicle, blind test of summary scores: observed age stages (estimated age) for CCS females, compared with documented ages.*

Table 6.122 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.122: *Age estimations based on the combined appearance of the sternal and lateral surfaces of the clavicle in blind tested females.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age (ranges in years)						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range	N	%	Range	N	%	N	%	Bias
I	7	44–55	44–48	3	42.8	< 55	7	100.0	0	0	no bias
II	11	45–70	58–63	1	9.1	45–70	10	90.9	1	9.1	underaged
III	6	58–89	70–75	1	16.7	55+	6	100.0	0	0	no bias
IV	8	68–87	78–83	1	12.5	65+	8	100.0	0	0	no bias
Total	32	-	-	6	**18.8**	-	31	**96.9**	1	**3.1**	**underaged**

Of the 32 female individuals blind tested, only 18.8% fell within the 95% confidence interval based on this method, and 96.9% fell within the age phase.

6.3.4.2.3 Additional Analyses

To confirm the relationship between age and composite score of the sternal surface of the clavicle, a Spearman's rank correlation was calculated for males and females. Both were found to be highly statistically significant (male, $r_s = 0.837$; $P < 0.001$; female, $r_s = 0.867$; $P < 0.001$). The results are plotted in Figure 6.92.

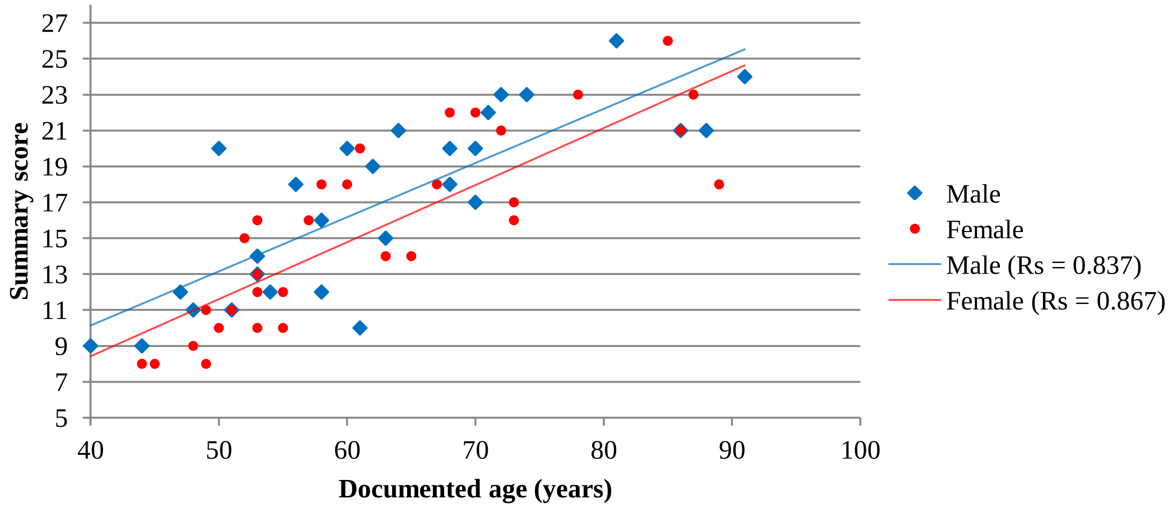


Figure 6.92: *Clavicle, blind test of summary scores: scatter plot of summary scores against age for all individuals in the CCS sample. Spearman's rank correlation coefficients of score against age for males and females are provided.*

Comparison of the descriptive statistics of age variation within each age stage for males and females (Table 6.123) revealed similar patterns of mean age, standard deviation and 95% confidence intervals between the developed criteria and the CCS blind test sample.

Table 6.123: *Comparison of age estimates from summary scores and age stages of the developed criteria and the CCS blind test sample.*

Age stage	Summary scores	Developed criteria			CCS blind test sample			
		Mean age (years)	Standard deviation	95% confidence interval (years)	N	Mean age (years)	Standard deviation	95% confidence interval (years)
Males								
I	7–9	43.4	4.3	38–49	2	42.0	2.8	*
II	10–14	52.2	7.9	50–54	8	53.1	4.7	49–57
III	15–19	64.7	10.1	62–67	6	62.8	5.5	57–69
IV	20–21	73.3	7.6	71–75	7	69.4	13.7	56–82
V	22–28	78.9	6.0	77–80	5	77.8	8.4	67–88
Females								
I	7–10	46.2	4.0	44–48	7	49.1	4.0	45–53
II	11–16	60.7	10.8	58–63	11	56.7	7.3	51–62
III	17–20	72.6	10.6	70–75	6	68.0	11.7	55–80
IV	21–28	80.4	7.8	78–83	8	79.0	8.0	72–86

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.4 RESULTS: MANUBRIUM, STERNUM AND XIPHOID PROCESS

Four aspects of the manubrium, sternum and xiphoid process were investigated for their relationship with advancing age. The clavicular notches on the proximal surface of the manubrium, as well as the articular surfaces between unfused manubria and sterna were assessed for degenerative traits. The fusion of the manubrium-sternum, and xiphoid process to the sternal body were also recorded. All raw data is provided in Appendix 4.8 and 4.9, the analysis of the individual study samples are in Appendix 5.8 and 5.9, and the blind test data is present in Appendix 6.18 and 6.19 (males and females, respectively).

6.4.1 MANUBRIUM CLAVICULAR NOTCH RESULTS

The individual trait scores recorded for each surface feature of the clavicular notches on the manubrium (i.e. surface topography, porosity and osteophyte formation) were combined to form a composite score, ranging between 3 and 16 points (i.e. surface topography, scored between 1 and 6; porosity, scored between 1 and 6; osteophyte formation, scored between 1 and 4). This composite score was used to assess degenerative differences between left and right elements, as well as between males and females.

6.4.1.1 Manubrium Clavicular Notch Results: Combined Sample

When the results of all four assessed skeletal collections were compared, each collection demonstrated very similar patterns of degeneration of the clavicle articular surfaces of the manubrium (i.e. composite scores had very similar mean ages, standard deviations and ranges and were commonly lower in females than males) (Figures 6.93 and 6.94). As three of the four collections found significant trait expressions between left and right elements (i.e. HTH found no difference between sides), only the right clavicular notch was used in the following analyses, which also allowed for comparison with the results obtained from the sternal surface of the clavicle. To assess the true extent of the degenerative processes of these notches of the manubrium, the males and the females (separately) of all study samples were combined.

The total sample size used to develop this method was 483 right clavicular notches of the manubrium (mean age, 67.2 years), including 275 male individuals (mean age, 67.0 years) and 208 female clavicles (mean age, 67.5 years) (Table 6.124).

Table 6.124: *Clavicular notch: age construction of combined study sample.*

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	30	54	64	76	51	**275**
Female	28	33	47	52	48	**208**
Total	**58**	**87**	**111**	**128**	**99**	**483**

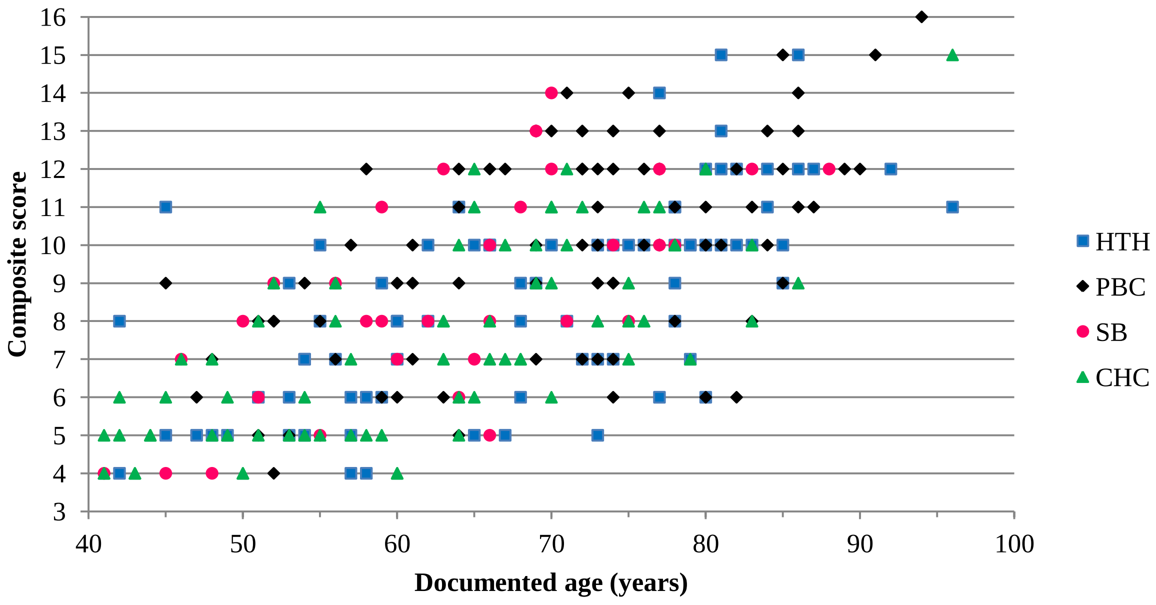


Figure 6.93: *Clavicular notch: scatter plot of composite scores against known age for males in the combined study sample.*

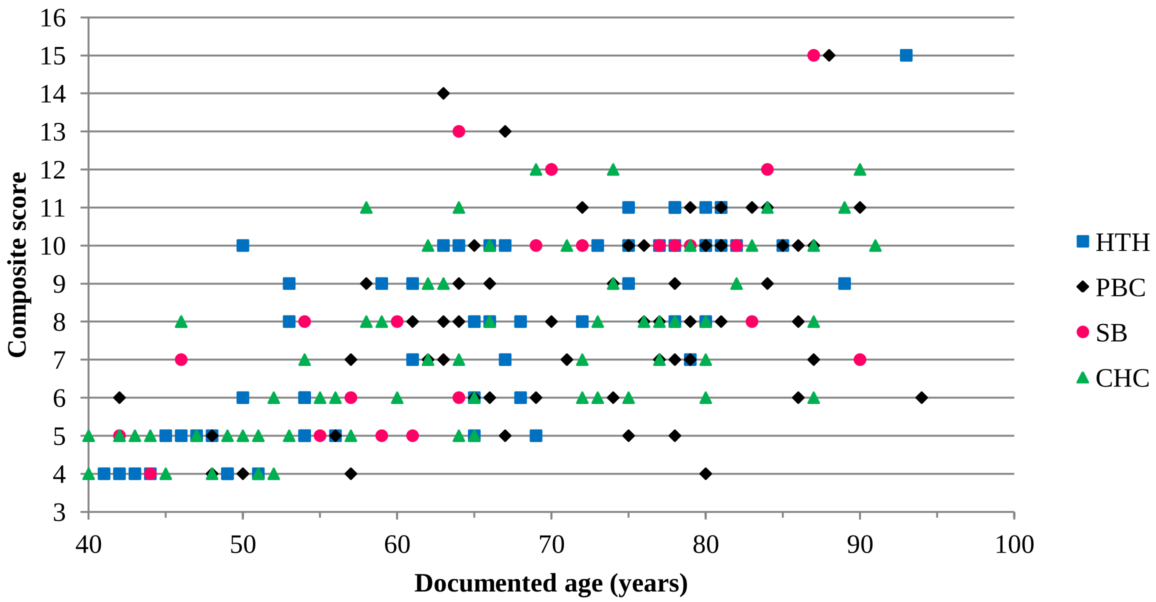


Figure 6.94: *Clavicular notch: scatter plot of composite scores against known age for females in the combined study sample.*

Development of the lateral end of the clavicle notch ageing technique will re-assess the distribution of trait expressions (i.e. surface topography, porosity and osteophyte formation) of the larger combined sample. These three traits that form the composite score will be related to age-at-death.

6.4.1.1.1 Individual Trait Scores, Composite Scores and Age-at-Death

The scores assigned to individual traits displayed a positive relationship with composite scores. That is, trait expressions (scores) of a higher individual score were generally found to cluster within the range of higher composite scores (Figure 6.95).

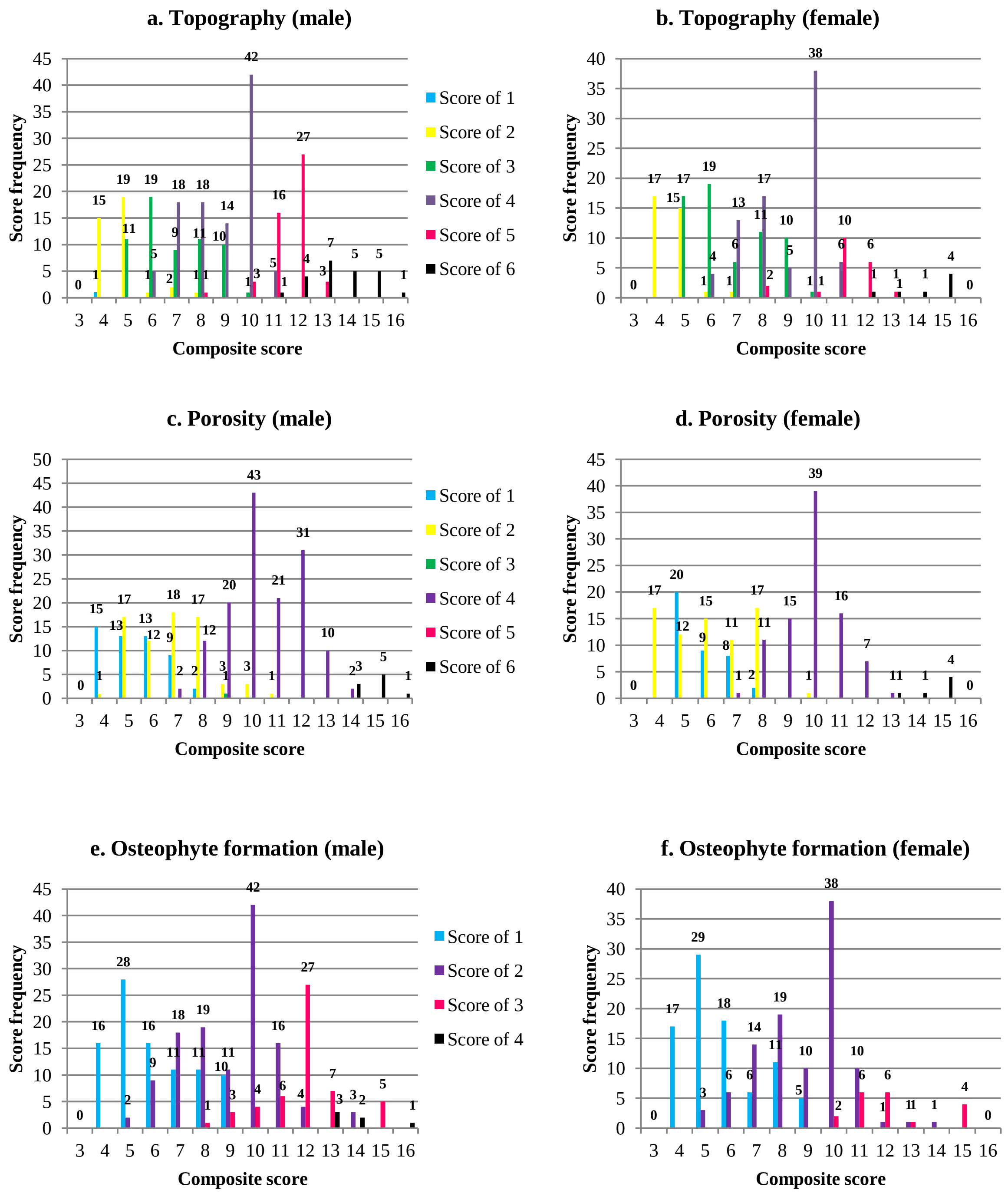


Figure 6.95a-f: *Number of observations of trait scores recorded for the clavicle notch of the manubrium in the combined study sample.*

Each surface feature had observable morphological differences, which altered their expression over an age range represented by each composite score.

Individual trait expressions were investigated as to their association with age-at-death. Scatter plots of trait scores were plotted against age-at-death (Figure 6.96). These figures display a wide variation in the age of trait expression of each feature.

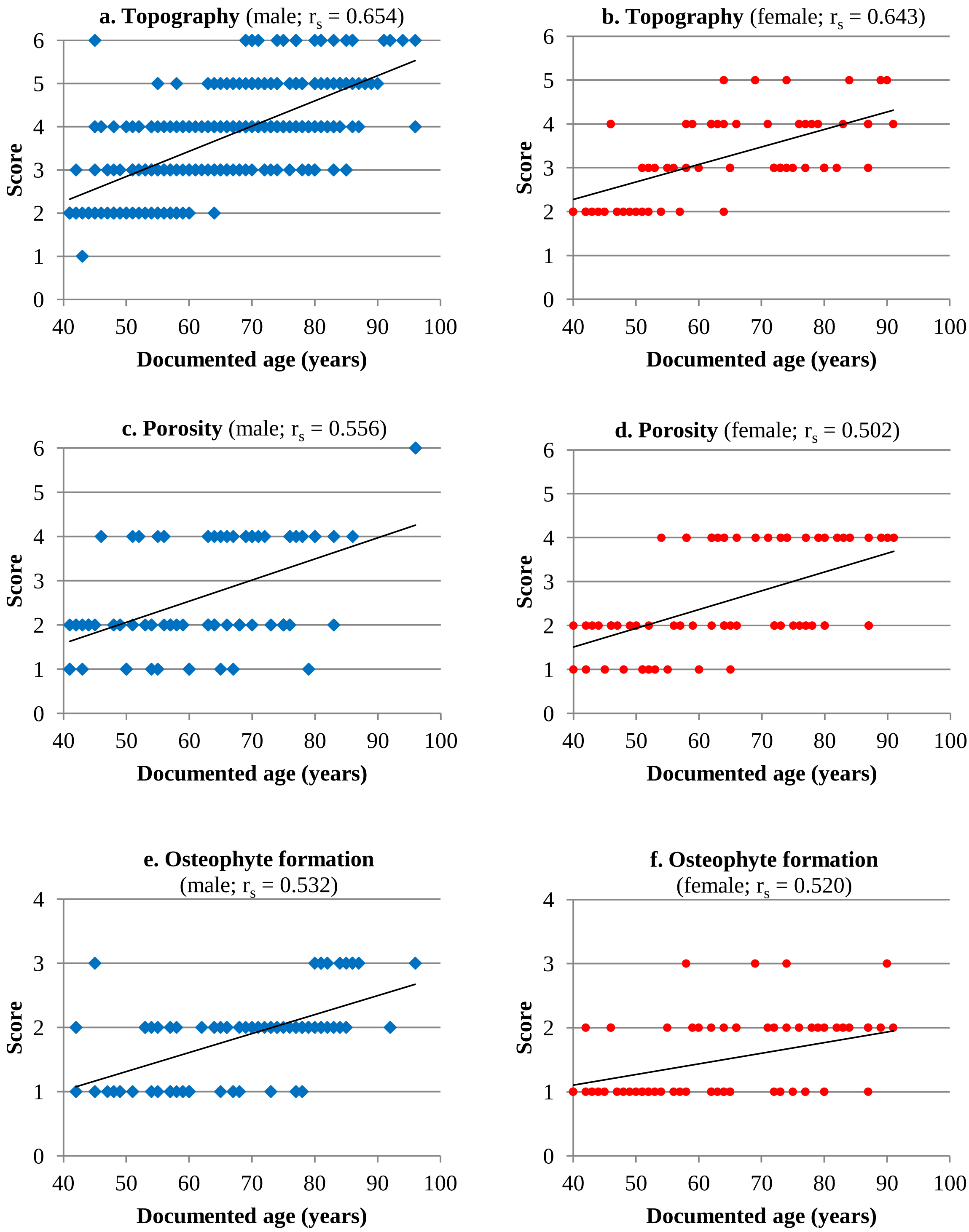


Figure 6.96a-f: *Clavicular notch: scatter plots of trait scores against age-at-death. Spearman's rank correlation coefficients of trait score against age are provided.*

To test whether each feature is correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. Individual trait expressions were found to be significantly correlated with age-at-death (Table 6.125). The higher the score assigned to a particular trait expression, the more frequently it was associated with older age. The correlation was strongest with surface topography (male, $r_s = 0.654$, $P < 0.001$; female, $r_s = 0.643$, $P < 0.001$).

***Table 6.125:** Clavicular notch: Spearman's rank correlation between age and trait expression of features.*

Feature	Male		Female	
	r_s	P	r_s	P
Surface topography	0.654	< 0.001	0.643	< 0.001
Porosity	0.556	< 0.001	0.502	< 0.001
Osteophyte formation	0.532	< 0.001	0.520	< 0.001
Composite score	**0.652**	**< 0.001**	**0.624**	**< 0.001**

A Spearman's rank correlation coefficient was also calculated for the derived composite with age. As was found with each individual feature, the combination of scores for surface topography, porosity and osteophyte formation also produced a significant correlation with documented ages-at-death (males, $r_s = 0.652$, $P < 0.001$; females, $r_s = 0.624$; $P < 0.001$) (Table 6.125, Figure 6.97).

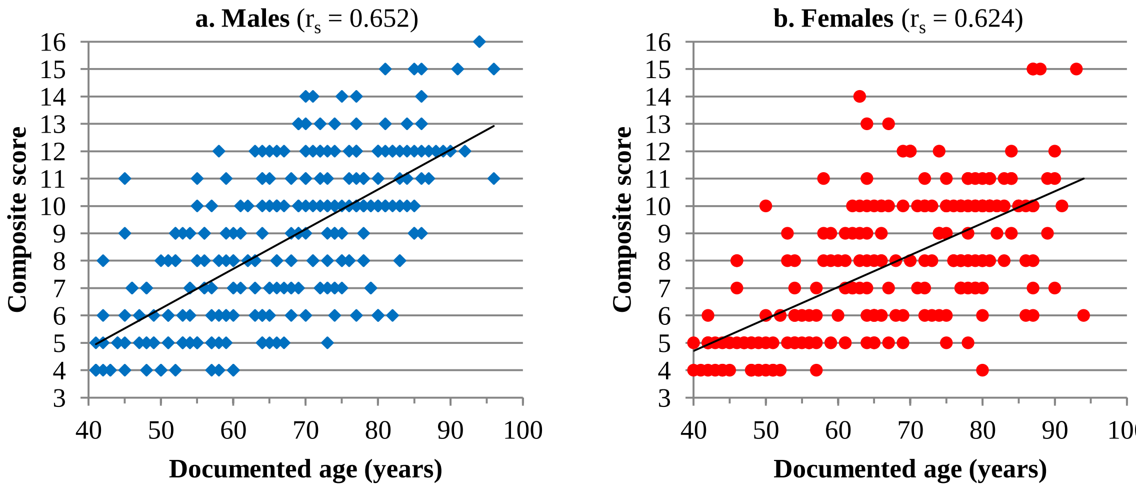


***Figure 6.97a-b:** Clavicular notch: association between composite scores and documented age. Spearman's rank correlation coefficients are provided.*

The descriptive statistics of age variation within composite scores (Tables 6.126 and 6.129) revealed the overall trend of increasing age with increasing composite score. Males and Females are discussed separately.

6.4.1.1.2 Male

Table 6.126: *Clavicular notch: descriptive statistics for documented ages-at-death of males possessing the same composite scores in the combined study sample.*

Composite score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
3	0	-	-	-	-
4	16	48.3	7.2	46	41–60
5	30	54.0	8.0	53	41–73
6	25	62.1	11.9	60	42–82
7	29	63.7	9.8	65	46–79
8	31	64.2	10.8	63	42–83
9	24	66.1	11.5	68	45–86
10	46	73.6	7.4	75	55–85
11	22	73.1	11.6	74	45–96
12	31	77.1	8.8	77	58–92
13	10	75.1	6.5	73	69–86
14	5	75.8	6.4	75	70–86
15	5	87.8	5.8	86	81–96
16	1	94.0	-	94	94

Several composite scores were found to provide similar age ranges, mean ages, and median ages. These scores were combined to produce surface age stages for males (Table 6.127 and Figure 6.98) and females (Table 6.130 and Figure 6.99). In addition to the 95% confidence interval, a broader range (age phase) with which to estimate age was also provided for each age stage.

Table 6.127: *Clavicular notch: age estimates from composite scores and age stages (males).*

Composite score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
3–5	I	46	52.0	8.1	49–54	< 65 years
6–9	II	109	64.0	10.9	61–66	50–70 years
10–14	III	114	74.7	8.7	73–76	60+ years
15–16	IV	6	88.8	5.8	82–95	75+ years

Unpaired *t*-tests were employed to test for statistically significant differences between the stages (Table 6.128). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.128: *Clavicular notch: results of t-tests between age stages.*

Stages compared	Male			Female		
	t	df	*P*	*t*	df	*P*
I vs II	-7.54	112	< 0.001	-8.30	136	< 0.001
II vs III	8.08	206	< 0.001	4.56	153	< 0.001
III vs IV	-3.95	118	< 0.001	-2.98	68	0.004

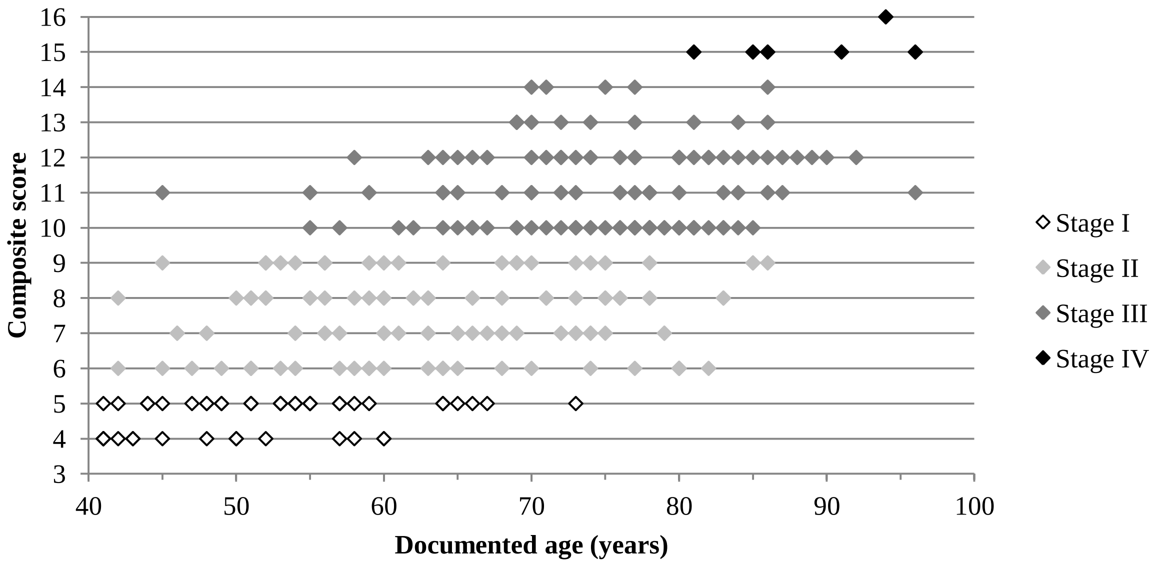


Figure 6.98: *Clavicular notch: scatter plot of derived age stages for males.*

6.4.1.1.3 Female

Table 6.129: *Clavicular notch: descriptive statistics for documented ages-at-death of females possessing the same composite scores in the combined study sample.*

Composite score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
3	0	-	-	-	-
4	17	49.1	9.2	48	40–80
5	32	54.2	10.0	53	40–78
6	24	66.0	12.7	65	42–94
7	20	70.2	11.4	71	46–90
8	30	69.4	11.3	71	46–87
9	15	69.5	10.8	66	53–89
10	40	76.0	8.4	77	50–91
11	16	78.6	8.3	80	58–90
12	7	75.3	8.3	70	69–90
13	2	65.5	2.1	65	64–67
14	1	63.0	-	63	63
15	4	88.8	2.9	87	87–93
16	0	-	-	-	-

Table 6.130*: Clavicular notch: age estimates from composite scores and age stages (females).*

Composite score	Age stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
3–5	I	49	52.4	9.9	49–55	< 65 years
6–9	II	89	68.7	11.6	66–71	50–80 years
10–14	III	66	76.0	8.5	73–78	65–90 years
15–16	IV	4	88.8	2.9	*	75+ years

*Key: * a sample size greater than five is required to produce a reliable 95% confidence interval.*

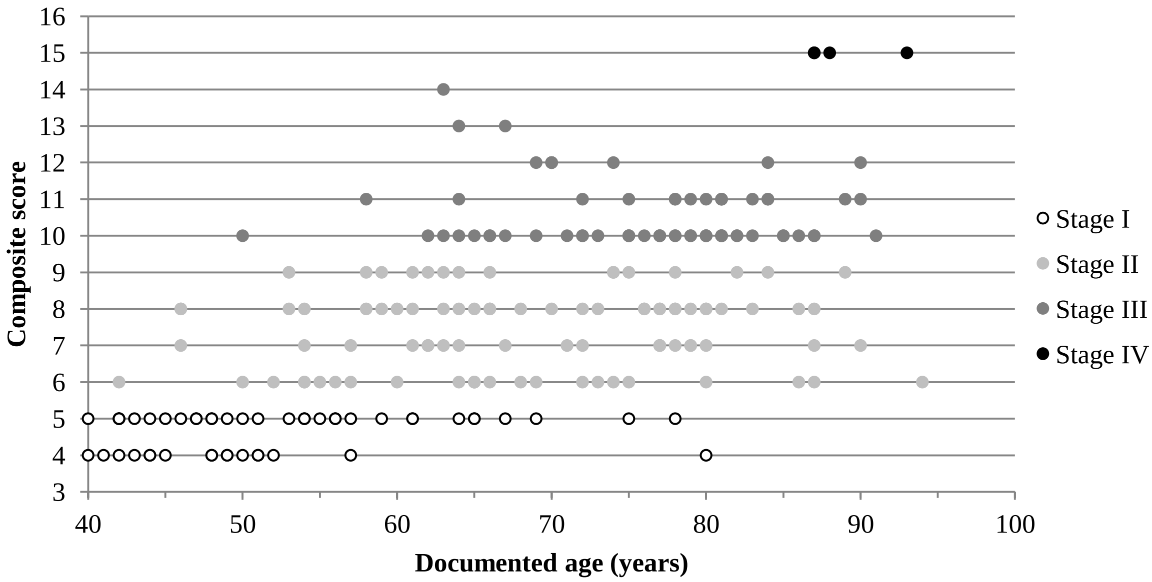


Figure 6.99: *Clavicular notch: scatter plot of derived age stages for females.*

6.4.1.1.4 Intraobserver Error

A subsample (5 males and 5 females) from each of the four skeletal collections were re-recorded to test for intraobserver error (N = 40). Paired *t*-tests were used to determine any significant differences in the two occasions (Table 6.131), which found no significant variation between the trait scores and composite scores (i.e. $P > 0.05$).

Table 6.131: *Clavicular notch: intraobserver error paired t-test results (N = 40).*

Trait	*t*	df	*P*
Surface topography	-1.22	39	0.230
Porosity	-1.00	39	0.323
Osteophyte formation	1.43	39	0.160
Composite score	**-1.11**	**39**	**0.275**

6.4.1.2 Manubrium Clavicular Notch Results: Blind Test

A blind test was performed on the right clavicle notch of the proximal manubrium of 50 randomly chosen individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The left side was substituted if the right was absent. The sample comprised 28 males with age-at-death ranging from 40-91 years (mean age, 64.3 years) and 22 females, ranging between 44-89 years (mean age, 62.1 years) (Table 6.132).

Table 6.132: *Clavicular notch, blind test: age construction of the CCS sample.*

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	4	6	9	4	5	**28**
Female	3	8	6	2	3	**22**
Total	**7**	**14**	**15**	**6**	**8**	**50**

As sexually dimorphic differences in trait expression were identified while developing the ageing criteria, males and females were analysed separately. Individual trait scores for surface topography, porosity and osteophyte formation were combined to form a composite score, which was ultimately used to estimate age-at-death. Composite scores range from 3 to 16 points.

6.4.1.2.1 Male

A total of 28 males provided suitably preserved clavicular notch present for analysis. The resultant composite scores were allocated into corresponding surface age stages (ranging between I and IV) (Figure 6.100). The developed ageing criteria for each stage was applied to each male CCS individual and compared with documented age.

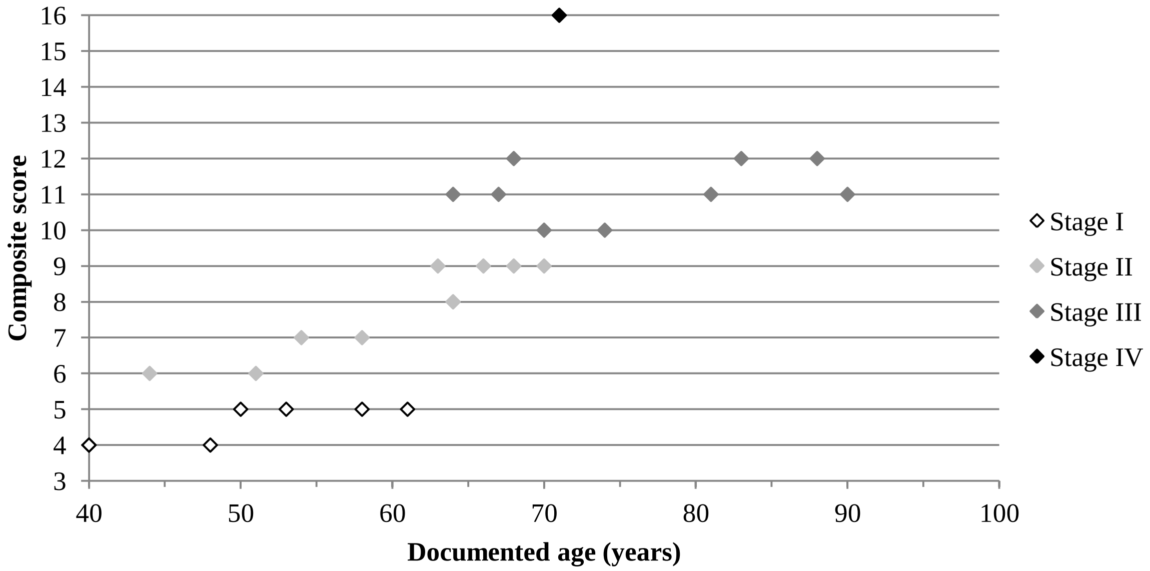
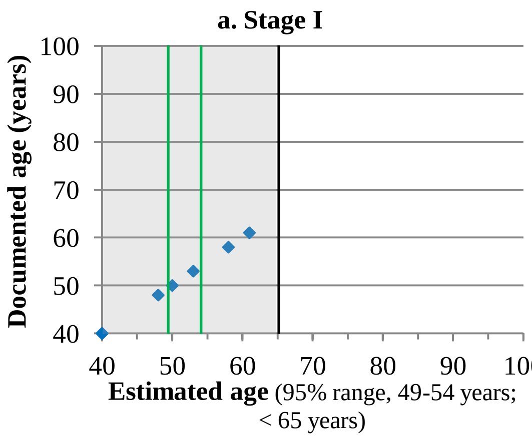
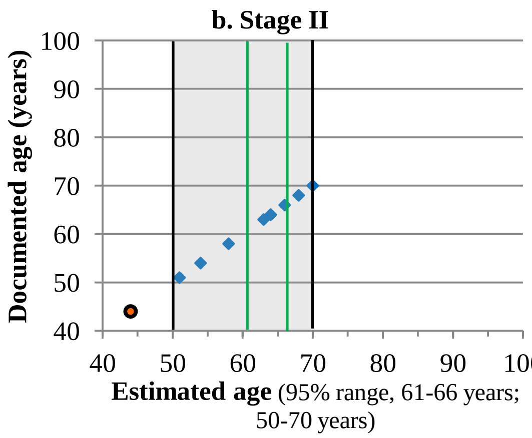


Figure 6.100: *Clavicular notch, blind test: scatter plot of derived age stages for males.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.101). Age estimations were made using a range(s) unique to each age stage.





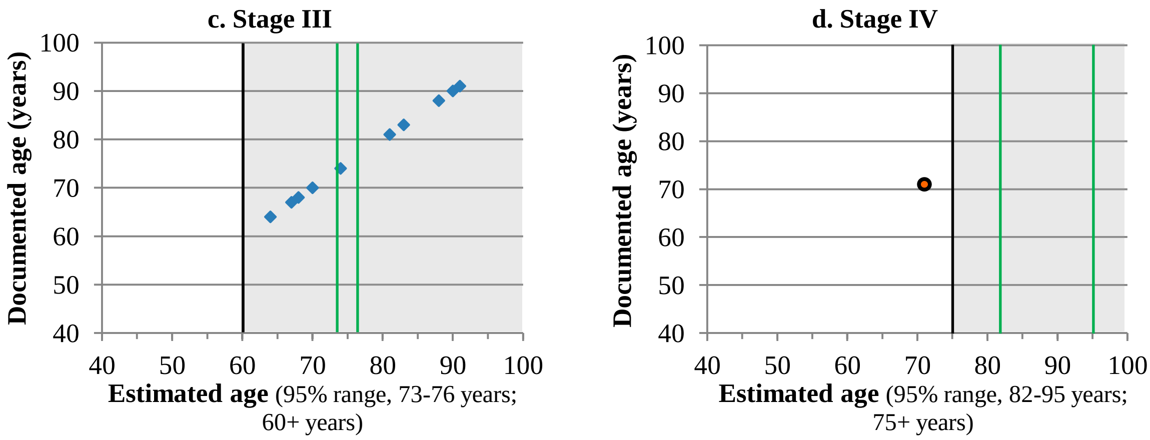


Figure 6.101a-d: *Observed age stages (estimated age) of the clavicular notch of the manubrium for CCS male individuals, compared with documented ages.*

Table 6.133 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.133: *Age estimations based on the appearance of the right clavicular notch of the manubrium of CCS males.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	7	40–61	49–54	2	28.6	< 65	7	100.0	0	0	no bias
II	10	44–70	61–66	4	40.0	50 - 70	10	100.0	0	0	no bias
III	10	64–91	73–76	1	10.0	60+	10	100.0	0	0	no bias
IV	1	71	82–95	0	0	75+	0	0	1	100.0	overaged
Total	28	-	-	7	**25.0**	-	27	**96.4**	1	**3.6**	**overaged**

Of the 28 males, only 25.0% fell within the 95% confidence interval based on this method, and 96.4% fell within the age phase.

6.4.1.2.2 Female

A total of 22 females provided suitably preserved manubrium clavicular notches for analysis. The resultant composite scores were allocated into corresponding surface age stages (between I to IV) (Figure 6.102). The developed ageing criteria for each stage was applied to each female CCS individual and compared with documented age.

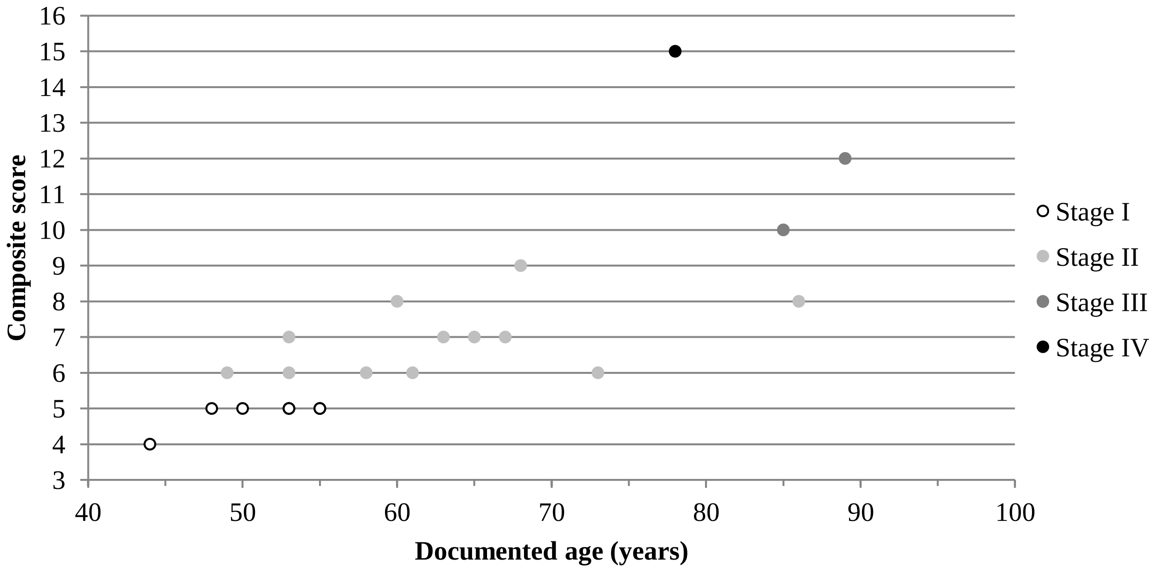


Figure 6.102: *Clavicular notch, blind test: scatter plot of derived age stages for females.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.103). Age estimations were made using a range(s) unique to each age stage.

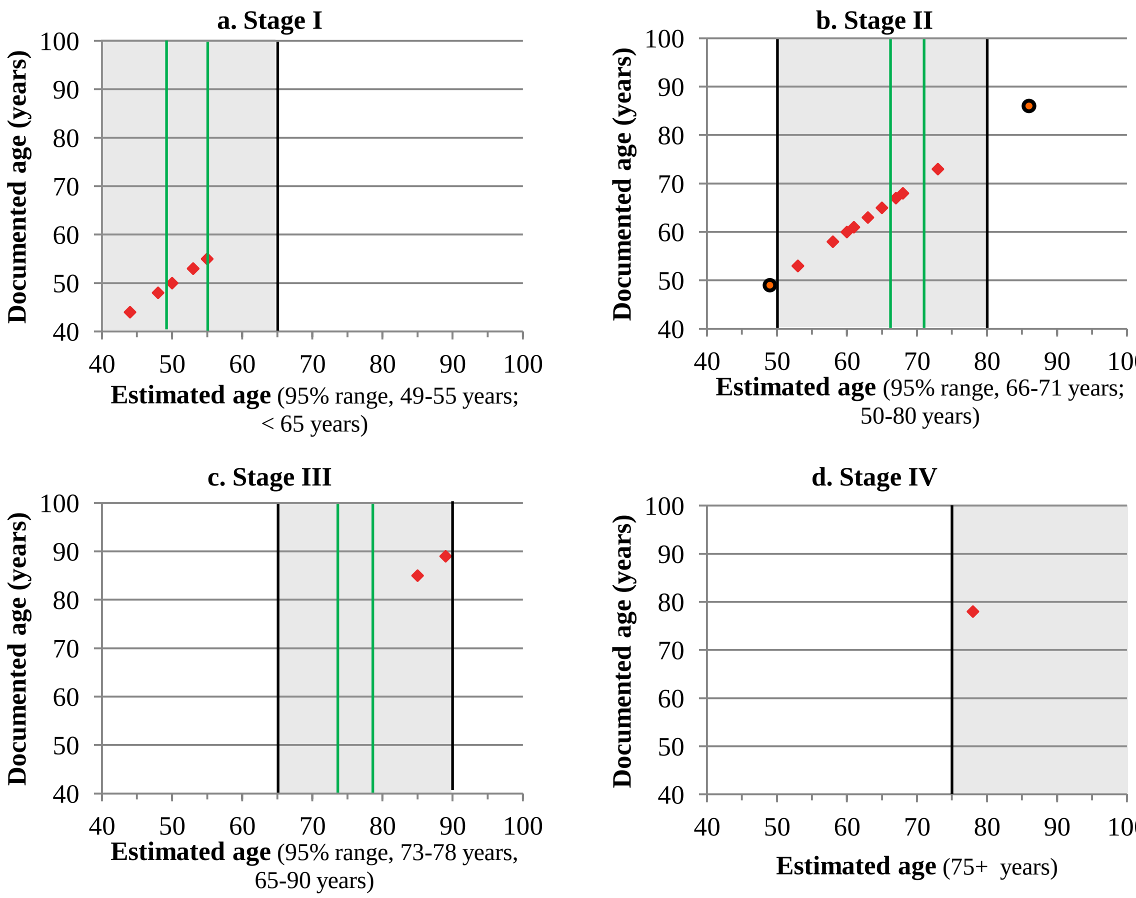


Figure 6.103a-d: *Observed age stages (estimated age) of the clavicular notch of the manubrium for CCS female individuals, compared with documented ages. Note, a 95% range could not be suggested for Stage IV, as the sample size was too small to accurately assess the confidence interval.*

Table 6.134 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.134: *Age estimations based on the appearance of the right clavicular notch of the manubrium in CCS females.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	7	44–55	49–55	5	71.4	< 65	7	100.0	0	0	no bias
II	12	49–86	66–71	2	16.7	50–80	10	83.3	2	16.7	both
III	2	85–89	73–78	0	0	65–90	2	100.0	0	0	no bias
IV	1	78	n/a	n/a	n/a	75+	1	100.0	0	0	no bias
Total	22	-	-	7	**31.8**	-	20	**90.9**	1	**4.55**	**underaged**
									1	**4.55**	**overaged**

Of the 22 female individuals, 31.8% fell within the 95% confidence interval based on this method, and 90.0% fell within the age phase.

6.4.1.2.3 Additional Analyses

To confirm the relationship between age and composite score of the clavicular notch of the manubrium, a Spearman's rank correlation was calculated for males and females. Both were found to be highly statistically significant (male, $r_s = 0.900$; $P < 0.001$; female, $r_s = 0.818$; $P < 0.001$). The results are plotted in Figure 6.104.

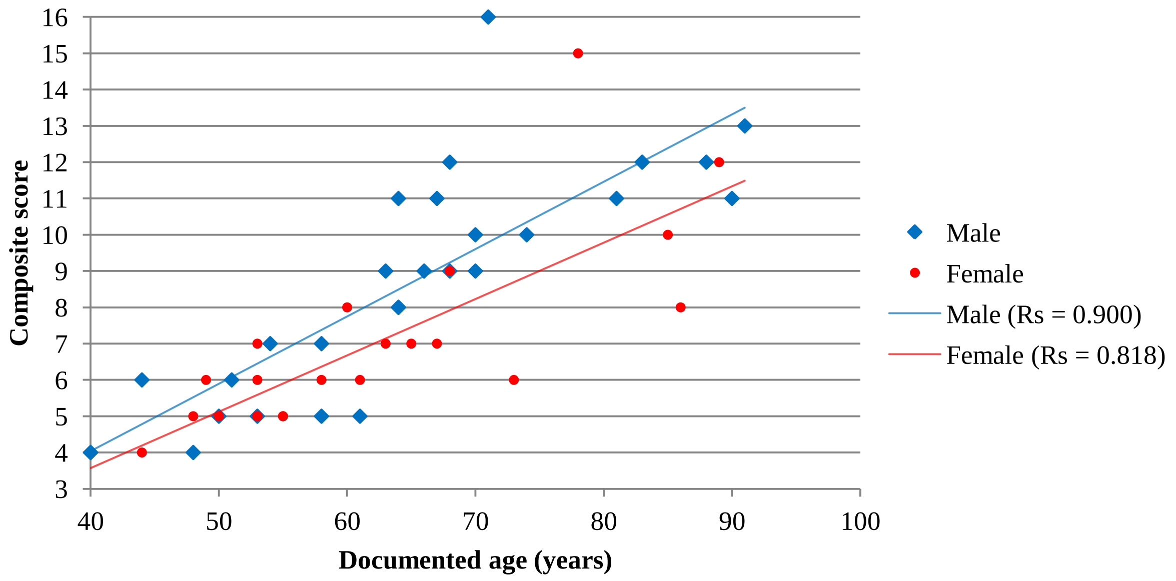


Figure 6.104: *Clavicular notch, blind test: scatter plot of composite scores against age for all individuals in the CCS sample. Spearman's rank correlation coefficients of score against age for males and females are provided.*

Comparison of the descriptive statistics of age variation within each age stage (Table 6.135) revealed generally similar patterns of mean age, standard deviation and 95% confidence intervals between the developed criteria and the CCS blind test sample.

Table 6.135: *Clavicular notch: age estimates from composite scores and age stages for the developed criteria and the CCS blind test sample.*

Age stage	Composite scores	Developed criteria			CCS blind test sample			
		Mean age (years)	**Standard deviation**	**95% confidence interval (years)**	**N**	**Mean age (years)**	**Standard deviation**	**95% confidence interval (years)**
Males								
I	3–5	52.0	8.1	49–54	7	50.0	8.2	42–58
II	6–9	64.0	10.9	61–66	10	60.2	8.3	54–66
III	10–14	74.7	8.7	73–76	10	77.6	10.2	70–85
IV	15–16	88.8	5.8	82–95	1	71.0	-	*
Females								
I	3–5	52.4	9.9	49–55	7	51.1	4.1	47–55
II	6–9	68.7	11.6	66–71	12	63.0	10.0	56–69
III	10–14	76.0	8.5	73–78	2	87.0	2.8	*
IV	15–16	88.8	2.9	*	1	78.0	-	*

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.4.2 MANUBRIUM, STERNUM, AND XIPHOID PROCESS RESULTS

Fusion of the manubrium, sternum and/or xiphoid process has previously been suggested as indicators of advanced age. In addition to ankylosis of one or both of these skeletal regions, degenerative traits of the sternum articular facet on the distal surface of manubrium was also recorded following the same criteria as the clavicular notches (section 6.4.1).

6.4.2.1 Ankylosis

General patterns of ankylosis were noted that were similar in all study samples. Fewer individuals displayed fusion of the manubrium and sternum (frequencies ranged between 9.6% and 22.7%) than the ossification of the xiphoid process to the sternal body (frequencies ranged from 51.2% to 59.3%). No relationship was found between the age of ankylosis of either location, with the exception of SB females, for whom age was identified as a significant factor in the fusion of the manubriosternal joint ($t = 2.62$, df = 26, $P = 0.014$). Age was also not correlated with ankylosis of all three skeletal elements, which occurred in between 11.1% and 14.0%.

6.4.2.2 Degeneration of the Sternum Articular Facet

Assessment of the degeneration of the manubriosternal joint of the distal manubrium provided varied results. Composite scores were found to be significantly correlated with age-at-death in males in the HTH and PBC samples, females in the SB assemblage, and both sexes in the CHC study sample. All three traits were found to be significantly correlated with age-at-death for individuals in the HTH and CHC samples, however, only porosity and osteophyte formation were related to age in the PBC and SB collections, respectively.

6.4.2.3 Manubrium, Sternum and Xiphoid Process Results: Combined Sample

No clear pattern of degeneration was observed between the collections, which does not justify the combination of skeletal samples to assess the degeneration of the manubrium-sternum joint. It does not lend support to any further analyses being undertaken, and no blind tests was preformed.

6.5 RESULTS: ILIAC CREST

The severity of the osteophyte development on the iliac crests was graded on a five-point scale from 0 (none) to 4 (severe) (Figure 5.22). The raw data for all study samples is presented in Appendix 4.10, the statistical analysis of each study sample in Appendix 5.10, and the blind test data in Appendices 6.20 and 6.21. The results of the combined study sample are presented in this section, and the blind test of the developed criteria.

6.5.1 ILIAC CREST RESULTS: COMBINED SAMPLE

Due to the differing results between left and right elements, and between males and females identified in the HTH sample, unlike the results of the PBC, SB, and CHC, the combined study analyses the sexes separately. As the degree of osteophyte formation was found to be correlated with age-at-death, the HTH individuals were not removed from the combined sample despite their differing pattern of trait expression, as these ilia also provide information regarding the variation observed in the ageing pattern between populations. For consistency, this study was performed on the left ilia of 619 individuals from all study samples (mean age, 67.1 years). The combined sample comprised 345 males with age-at-death ranging from 40-96 years (mean age, 66.6 years) and 274 females, ranging between 40-95 years (mean age, 67.7 years) (Table 6.136).

Table 6.136: *Iliac crest: age composition of the combined study sample.*

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	41	67	78	96	63	**345**
Female	36	42	64	69	63	**274**
Total	**77**	**109**	**142**	**165**	**126**	**619**

Plots of osteophyte score against known age for males and females in the combined sample are presented in Figure 6.105 and 6.106, respectively.

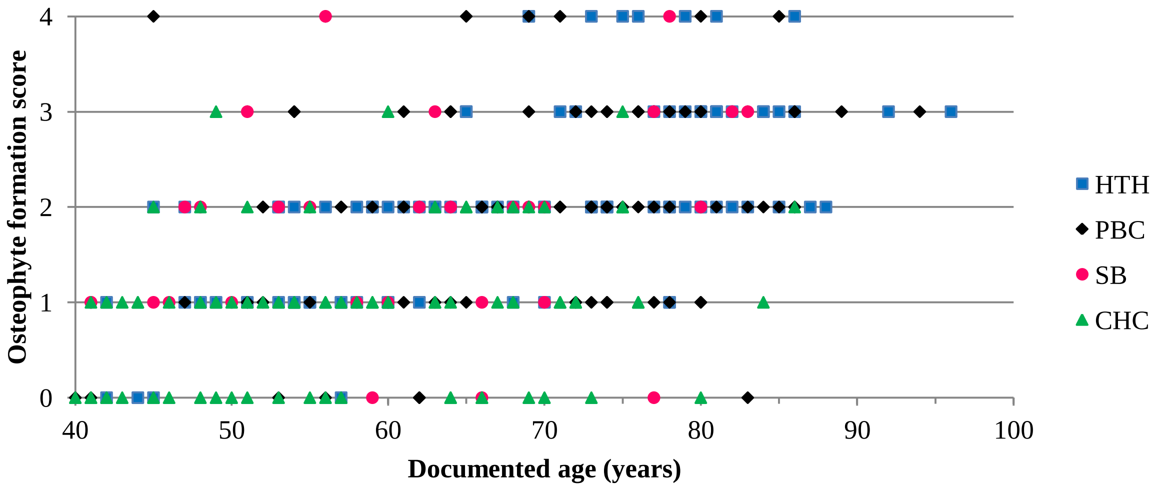


Figure 6.105: *Iliac crest: scatter plot of osteophyte development score against known age for males in the combined study sample.*

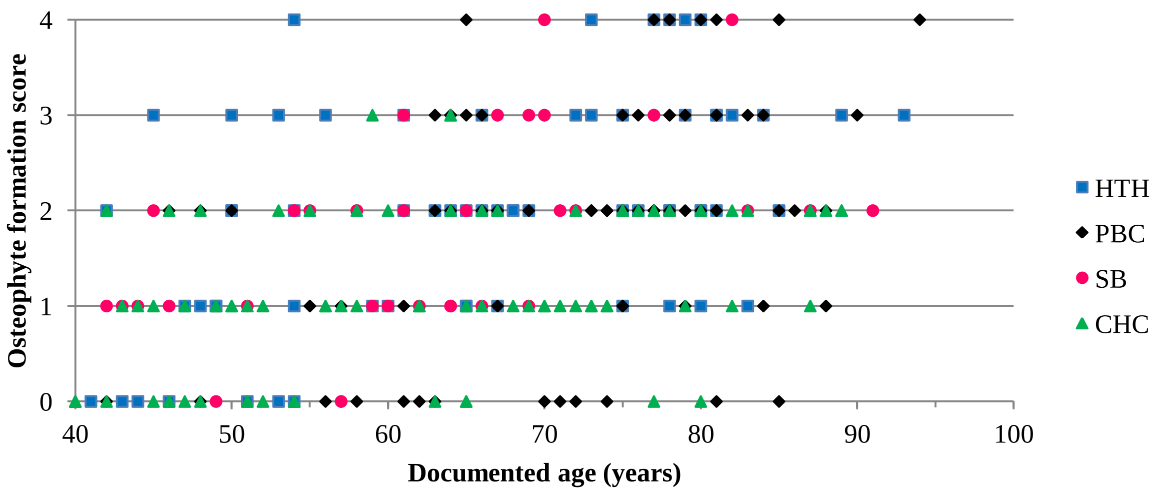


Figure 6.106: *Iliac crest: scatter plot of osteophyte development score against known age for females in the combined study sample.*

6.5.1.1 Osteophyte Score and Age-at-Death

The scores assigned to osteophyte formation displayed a positive relationship with generalized age group (Figure 6.107).

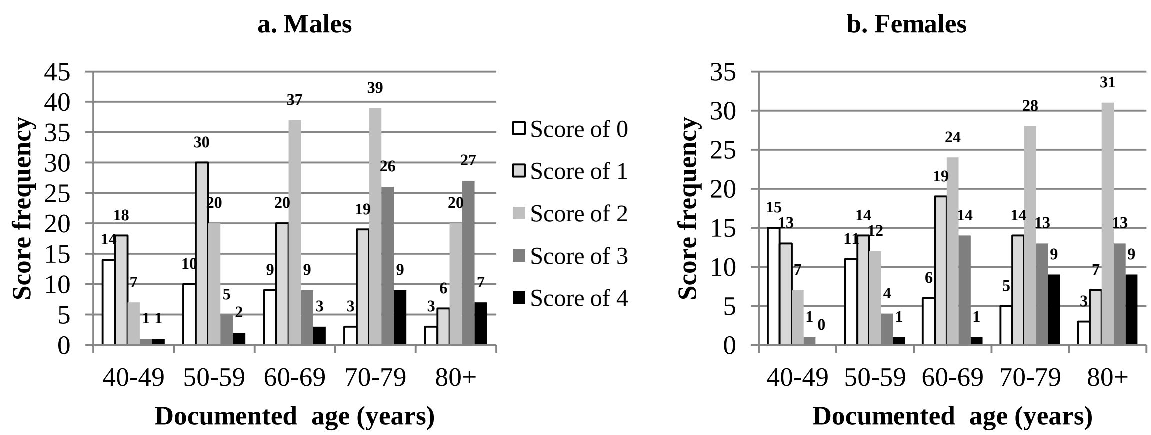


Figure 6.107a-b: *Number of observations of osteophyte scores recorded on the iliac crests in the combined study sample.*

The osteophyte formation thus possessed observable morphological differences (identified by observed trait score), which altered their expression over an age range. To further investigate this, osteophyte development expression with specific age-at-death was compared. A scatter plot of trait scores was plotted against age-at-death (Figure 6.108).

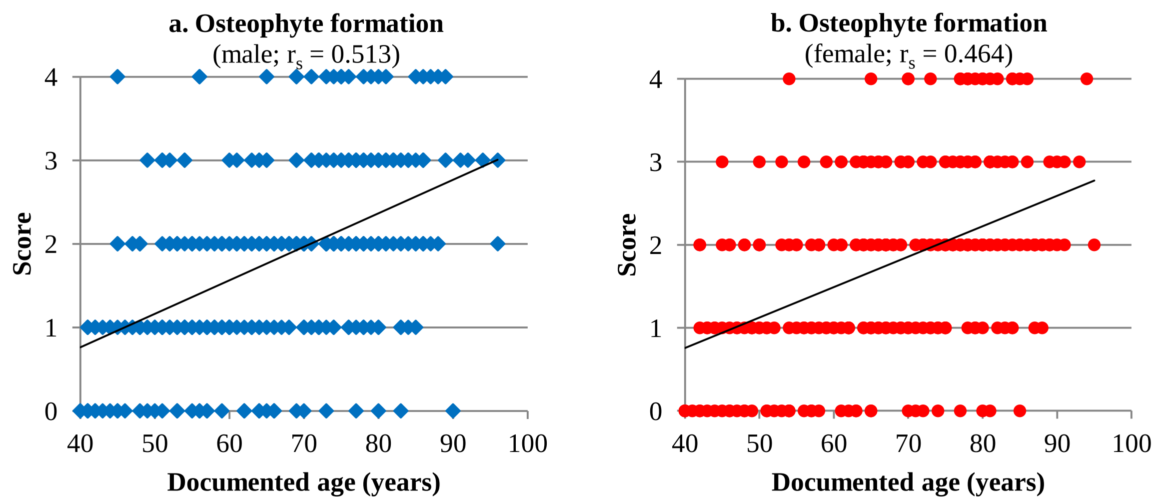


Figure 6.108: *Iliac crest: scatter plots of osteophyte score against age-at-death. Spearman's rank correlation coefficients of trait score against age are provided.*

To test whether osteophyte formation is correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. The result found osteophyte development to be significantly correlated with age-at-death (male, $r_s = 0.513$, $P < 0.001$; female, $r_s = 0.464$, $P < 0.001$).

The descriptive statistics of age variation within each score for males and females (Tables 6.137 and 6.138, respectively) revealed general patterns of increasing age with increasing composite score.

Table 6.137: *Iliac crest: descriptive statistics for males found to possess same osteophyte development scores in the combined study sample.*

Osteophyte score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
0	39	56.7	13.1	56	40–90
1	93	60.2	11.6	59	41–85
2	123	68.4	10.6	69	45–96
3	68	75.5	10.5	77	49–96
4	22	74.2	11.2	75	45–89

Table 6.138: *Iliac crest: descriptive statistics for females found to possess same osteophyte development scores in the combined study sample.*

Osteophyte score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)
0	40	56.2	12.6	54	40–85
1	67	62.9	12.4	62	42–88
2	102	71.4	12.7	74	42–95
3	45	72.4	11.2	73	45–93
4	20	77.8	8.5	78	54–94

Osteophyte scores that were found to provide similar distributions were combined to produce surface age stages (Tables 6.139 and 6.140, males and females respectively). In addition to the 95% confidence interval, a broader range (age phase) with which to estimate age was also provided for each age stage.

Table 6.139: *Iliac crest: age estimates from age stages (males).*

Osteophyte score	Stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
0–1	I	132	59.2	12.2	57–61	< 80 years
2	II	123	68.4	10.6	66–70	50+ years
3–4	III	90	75.1	10.6	72–77	65+ years

Table 6.140: *Iliac crest: age estimates from age stages (females).*

Osteophyte score	Stage	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
0–1	I	107	60.4	12.8	57–63	< 80 years
2–3	II	147	71.7	12.2	69–74	45+ years
4	III	20	77.8	8.5	73–82	65+ years

Unpaired *t*-tests were employed to test for statistically significant differences between the scores (i.e. to determine whether independent stages of degeneration were identifiable) (Table 6.141). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.141: *Iliac crest: results of t-tests between age stages.*

Stages compared	Male			Female		
	t	**df**	***P***	***t***	**df**	***P***
I vs II	-6.40	253	< 0.001	-7.18	252	< 0.001
II vs III	-4.60	211	< 0.001	-2.13	165	0.034

6.5.1.2 Additional Observation

Although not quantified in this study, a general pattern was noted during the data collection phase. Small bodied females (i.e. individuals with notably gracile skeletal elements) in all study samples did not display the same range of osteophyte formation as observed in males and "normal-sized" females. The most severe expressions were minimal to slight compared to the other members of the collections. This trend will be revisited in the discussion (section 8.2).

6.5.1.3 Intraobserver Error

A subsample (10 males and 10 females; N = 80) from each of the four skeletal collections were re-recorded to test the reproducibility of observation (i.e. intraobserver error). A paired *t*-test was used to determine any significant differences in the trait scores recorded between the two occasions. No statistically significant difference was found ($t = -1.78$, df = 39, $P = 0.083$).

6.5.1.4 Osteophyte Formation and DISH

To assess whether DISH significantly affected the severity of osteophyte formation of the iliac crest, the osteophyte scores of individuals displaying the osseous changes to the thoracic vertebrae were plotted against the scores of individuals that did not demonstrate signs of DISH (Figure 6.109). The HTH sample was not included in this analysis, as presence of DISH was not able to be confidently determined. This resulted from the fact that it was not possible to assess the entire skeleton during analysis due to the organization of skeletal remains at the HTH store-room. The results did not show any obvious trends towards more severe trait expression in individuals with DISH (i.e. the osteophyte scores recorded for individuals with DISH fell within the ranges of all other individuals), suggesting DISH is not a significant factor in the development of iliac crest osteophytes.

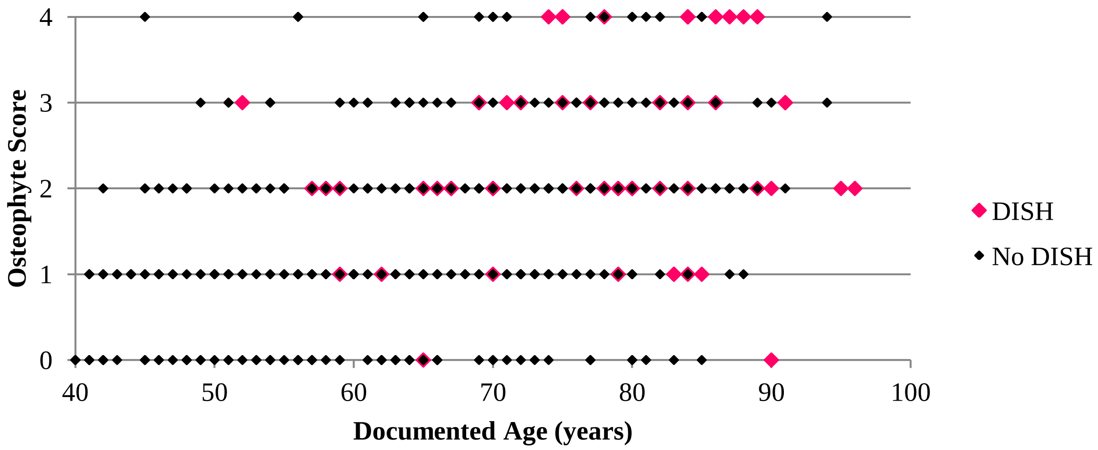


Figure 6.109: *Iliac crest: plot of osteophyte development score against known age for individuals with DISH against individuals without DISH in the combined study sample (excluding HTH).*

6.5.2 ILIAC CREST RESULTS: BLIND TEST

The blind test was performed on the left iliac crest of 84 individuals from the Christ Church Spitalfields documented collection (CCS). The right ilium substituted if the left was absent or poorly preserved. The sample comprised 44 males with age-at-death ranging from 40-91 years (mean age, 62.0 years) and 40 females, ranging between 44-89 years (mean age, 63.0 years) (Table 6.142).

Table 6.142: *Iliac crest, blind test: age composition of the CCS sample.*

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	6	13	11	10	4	**44**
Female	7	12	8	8	5	**40**
Total	**13**	**25**	**19**	**18**	**9**	**84**

As sexually dimorphic ageing criteria were found to be required, males and females were assessed separately. Plots of age stage and documented age are presented in Figures 6.110 and 6.111, respectively. The developed ageing criteria for each stage was applied to each CCS individual and compared with documented age.

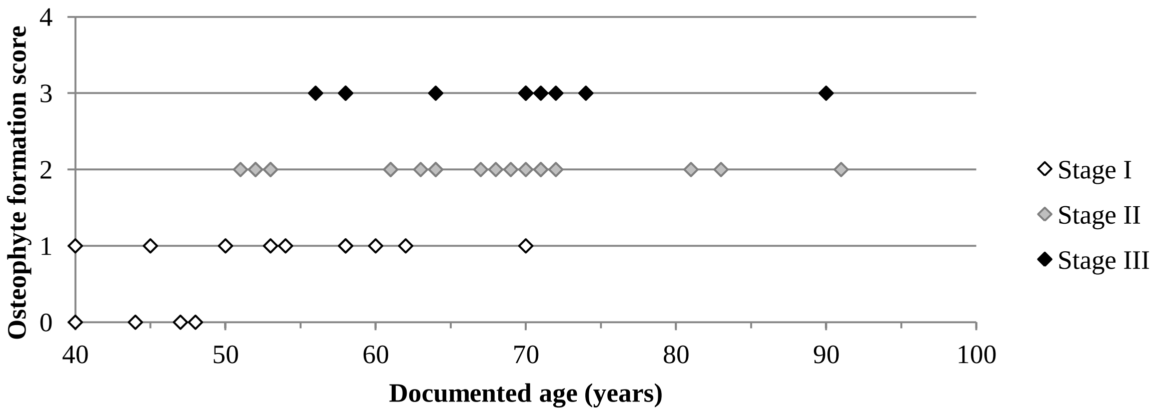


Figure 6.110: Iliac crest, blind test: scatter plot of osteophyte formation score against known age for males in the CCS sample.

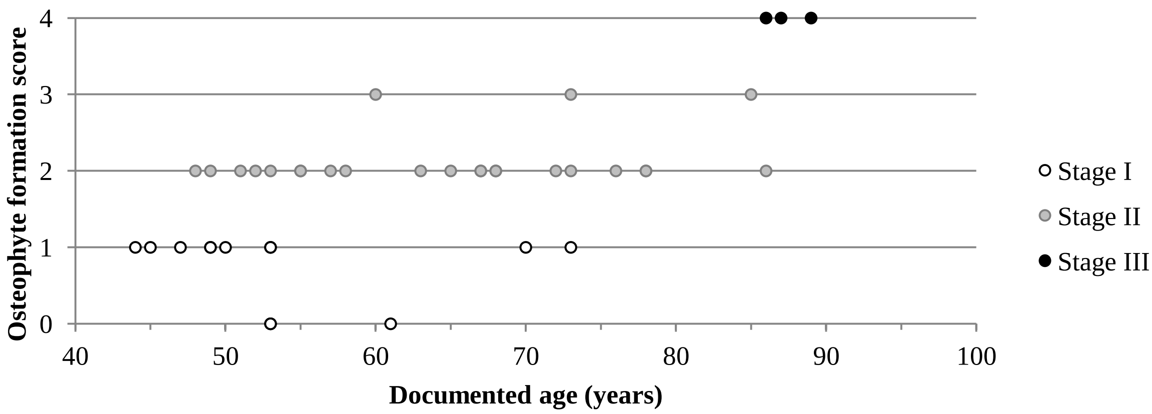
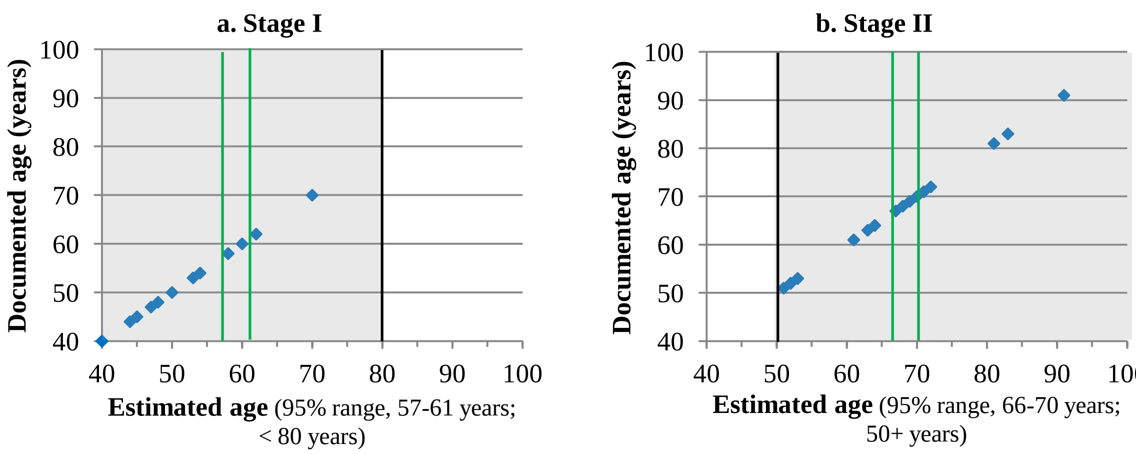


Figure 6.111: Iliac crest, blind test: scatter plot of osteophyte formation score against known age for females in the CCS sample.

6.5.2.1 Males

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.112). Age estimations were made using a range(s) unique to each age stage.



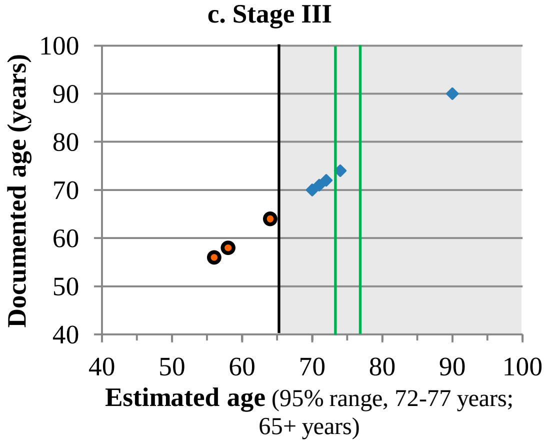


Figure 6.112 a-c: *Observed osteophyte development of the iliac crest age stages (estimated age) for male CCS individuals, compared with documented ages.*

Table 6.143 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.143: *Age estimations based on the appearance osteophytes on the iliac crest in CCS males.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	14	40–70	57–61	3	21.4	< 80	14	100.0	0	0	no bias
II	20	51–91	66–70	3	15.0	50+	20	100.0	0	0	no bias
III	10	56–90	72–77	2	20.0	65+	6	60.0	4	40.0	overaged
Total	44	-	-	8	**18.2**	-	40	**90.0**	4	**9.1**	**overaged**

Of the 44 individuals, only 18.2% fell within the 95% confidence interval based on this method, and 90.9% fell within the age phase.

6.5.2.2 Female

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.113). Age estimations were made using a range(s) unique to each age stage.

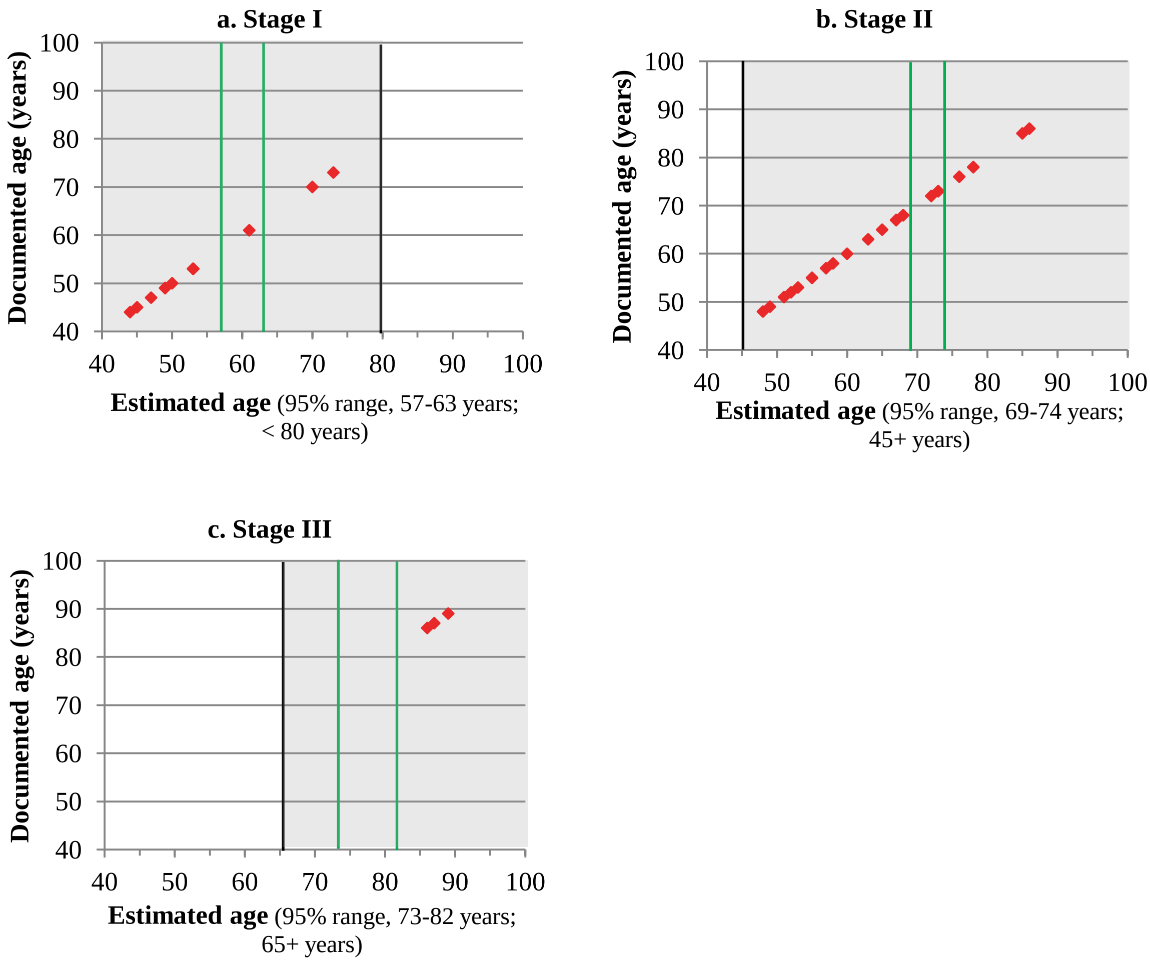


Figure 6.113 a-c: *Observed osteophyte development of the iliac crest age stages (estimated age) for female CCS individuals, compared with documented ages.*

Table 6.144 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.144: *Age estimations based on the appearance of the iliac crest of the ilium in CCS females.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	13	44–73	57–63	1	7.7	< 80	13	100.0	0	0	no bias
II	24	48–86	69–74	3	12.5	45+	24	100.0	0	0	no bias
III	3	86–89	73–82	0	0	65+	3	100.0	0	0	no bias
Total	40	-	-	4	**10.0**	-	40	**100.0**	0	**0**	**no bias**

Of the 40 individuals, only 10.0% fell within the 95% confidence interval based on this method, and 100.0% fell within the age phase.

6.5.6.3 Additional Analysis

To confirm the relationship between age and osteophyte formation score of the iliac crest, a Spearman's rank correlation (r_s) was calculated. The result was found to be highly statistically significant (male, r_s = 0.607; P < 0.001; female, r_s = 0.627; P < 0.001). The results are plotted in Figure 6.114.

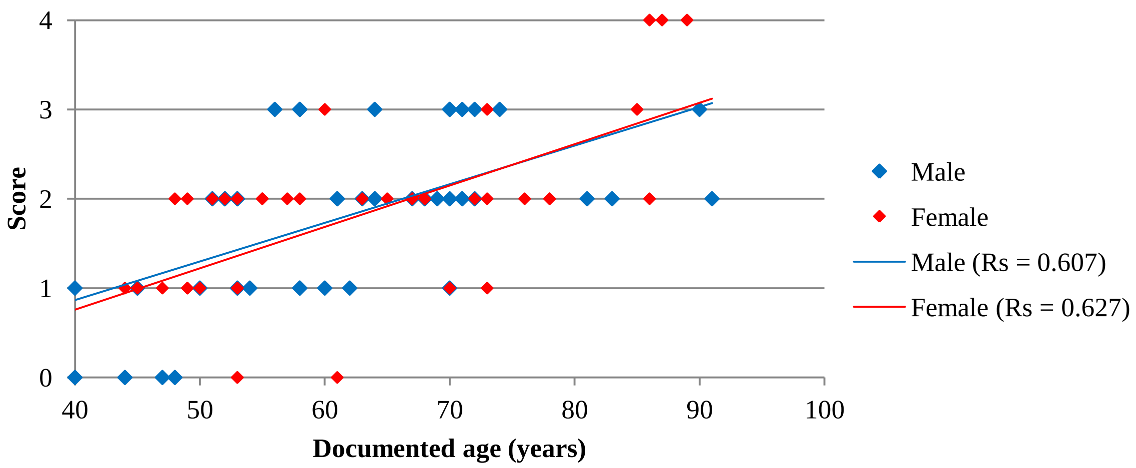


Figure 6.114: *Iliac crest, blind test: scatter plot of osteophyte score against known age-at-death for the CCS sample. Spearman's rank correlation coefficient of score against age is provided.*

Comparison of the descriptive statistics of age variation within each score (age stage) for males and females (Table 6.145) revealed the developed criteria was generally older than the ages observed in the CCS blind test sample (i.e. mean ages and confidence intervals provided older age estimates).

Table 6.145: *Comparison of descriptive statistics for iliac crest age stages between the combined study sample and blind test sample.*

Age stage	Osteophyte score	Developed criteria			CCS blind test sample			
		Mean age (years)	Standard deviation	95% confidence interval (years)	N	Mean age (years)	Standard deviation	95% confidence interval (years)
Males								
I	0–1	59.2	12.2	57–61	14	52.1	8.8	46–57
II	2	68.4	10.6	66–70	20	65.9	11.0	60–71
III	3–4	75.1	10.6	72–77	10	68.3	10.1	61–76
Females								
I	0–1	60.4	12.8	57–63	13	53.9	9.0	48–59
II	2–3	71.7	12.2	69–74	24	64.9	11.2	60–70
III	4	77.8	8.5	73–82	3	87.3	1.5	*

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.6 METAMORPHOSIS OF THE AURICULAR SURFACE OF THE ILIUM

This section presents the results of the three criteria recorded for each auricular surface, namely the Lovejoy et al. (1985b) method, a re-evaluation of the revised auricular surface technique proposed by Buckberry and Chamberlain (2002), and the development of ankylosis of the ilium and sacrum at the auricular surface. The accuracy and bias were investigated for the established methods, and revision to trait expressions were made where possible.

6.6.1 LOVEJOY ET AL. (1985b) AURICULAR SURFACE RESULTS

Each auricular surface was compared with written descriptions of the eight age stages of differing surface appearances (Lovejoy et al., 1985b:19-20). To test the applicability of the Lovejoy et al. (1985b) method to individuals aged 40+ years, the documented age-at-death was compared with published age ranges suggested by Lovejoy et al. (1985b:21-22, 26-27). It is noted that due to the tendency for the auricular surface to underage individuals (e.g. Saunders et al., 1992), in the event that the morphology of the surface demonstrated characteristics of two successive age stages, the "older" or "higher" age stage was used to estimate age (e.g. if the surface displayed features of both stages 6 or 7, stage 7 was chosen as the age estimation). For consistency, the left side was used for all subsequent analyses, the right side was substituted in the event the left was absent or damaged.

The raw data for each study sample is provided in Appendix 4.11, and the statistical analyses in Appendix 5.11. The revised criteria is investigated in the combined sample, as presented in this section, in addition to the blind test of the developed criteria and the original Lovejoy et al. (1985b) method (Appendices 6.22 and 6.23).

6.6.1.1 Lovejoy et al. (1985b) Auricular Surface Results: Combined Sample

It is acknowledged that Lovejoy et al. (1985b) developed their ageing criteria based on the Hamann-Todd skeletal collection, and as a result, it was expected that the HTH sample would have shown a very high correlation between surface metamorphosis and documented age. Spearman's rank correlation coefficient found the relationship between surface stage and known age to have a significant relationship ($r_s = 0.574$, $P < 0.001$), however, this correlation was even higher in the CHC sample ($r_s = 0.651$, $P < 0.001$). When the accuracy of the original Lovejoy et al. method (1985b) was tested in each of the four study samples, the HTH sample actually performed least well, with only 43.9% accurately aged, compared to other three samples that ranged between 53.3% and 61.8% accuracy. As the HTH collection did not display notably stronger association or more accurate results than the PBC, SB and CHC samples, no special considerations (i.e. placing less weight on the HTH data) were deemed necessary in the combined sample.

When the results of all four skeletal collections were assessed, each collection demonstrated similar patterns of degeneration of the auricular surface, no differences between left and right elements, and sexually dimorphic criteria were not required (with the exception of CHC), and revised phase scores (I–V) had vaguely similar descriptive statistics. Despite the sexually dimorphic differences identified in the CHC sample, they were not removed from the combined sample study. However, when the revised auricular surface phases for the combined sample were plotted against known age (Figure 6.115), inter-population differences were suggested as the HTH sample displayed lower phase scores than the PBC study sample.

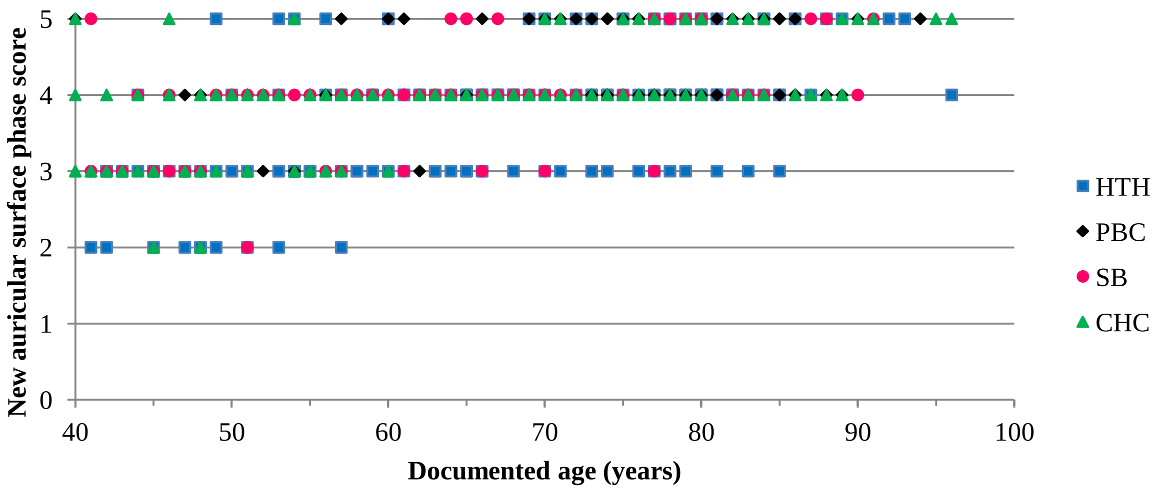


Figure 6.115: *Auricular surface, revised Lovejoy: scatter plot of composite scores against known age for all individuals in the combined study sample.*

As every auricular surface provides information regarding the ageing process, to assess the true extent of the variability of the auricular surface, all four collections were combined. The total sample sizes used to develop this method were the left auricular surfaces of 612 (mean age, 67.0 years); comprising 337 male individuals (mean age, 66.3 years) and 275 females (mean age, 67.9 years) (Table 6.146). The right side was substituted if the left was damaged or absent.

Table 6.146: *Auricular surface, revised Lovejoy: age composition of the combined study sample.*

	Age category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	41	67	79	92	58	**337**
Female	35	42	65	68	65	**275**
Total	**76**	**109**	**144**	**160**	**123**	**612**

To validate the combination of consecutive Lovejoy stage scores based on similar trait characteristics, the descriptive statistics for recorded stages are presented in Table 6.147.

Table 6.147: *Comparison of published Lovejoy et al. (1985b:27) age estimation ranges for the auricular surface age stage and recorded observations of the combined study sample (N = 612).*

Age stage	Lovejoy et al. (1985b) estimated age range (years)	N	Mean age (years)	Standard deviation	95% confidence interval (years)
1	20–24	0	-	-	-
2	25–29	0	-	-	-
3	30–34	1	47.0	-	-
4	35–39	12	48.2	4.6	45–51
5	40–44	64	52.1	10.4	49–55
6	45–49	41	58.1	11.6	54–62
7	50–59	133	64.4	11.3	62–66
8	60+	206	69.4	10.4	68–71
9	n/a	155	76.3	10.7	74–78

Unpaired *t*-tests were employed to test for statistically significant differences between the stages displaying similar surface characteristics (see table above) (Table 6.148). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.148: *Auricular surface, revised Lovejoy: results of t-tests between age stages.*

Stages compared	Phases compared	*t*	df	*P*
3 vs 4	I vs II	-	-	-
4 vs 5	II vs III	-3.89	36.6	< 0.001
5 vs 6				
6 vs 7	III vs IV	10.52	442	< 0.001
7 vs 8				
7+8 vs 9	IV vs V	-8.31	492	< 0.001

The ages were plotted against the revised auricular surface phase scores in a scatter plot (Figure 6.116). To test whether the new score was correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. The higher the score (r_s) assigned to a particular surface feature, the more frequently it was associated with older age. This correlation was found to be significant with age (r_s = 0.593, $P < 0.001$), and a stronger correlation with age than the original Lovejoy et al. (1985b) criteria (r_s = 0.553; $P < 0.001$).

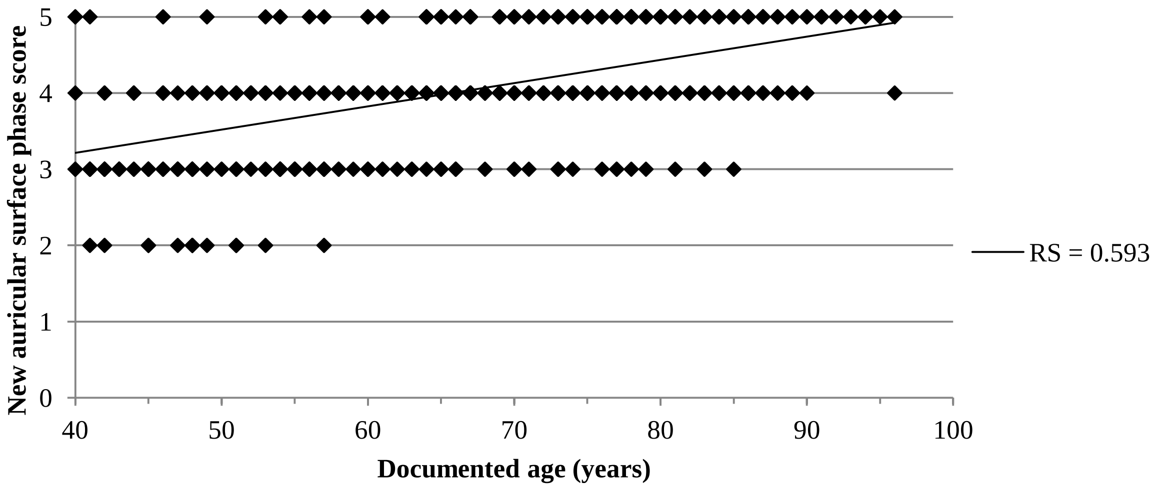


Figure 6.116: *Auricular surface, revised Lovejoy: scatter plot of composite scores against age for individuals in the combined study sample. Spearman's rank correlation coefficient of score against age for is provided.*

The descriptive statistics of age variation within composite scores (Table 6.149) revealed the overall trend of increasing age with increasing score. In addition to the 95% confidence interval, a broader phase with which to estimate age was also provided for each phase score.

Table 6.149: *Auricular surface, revised Lovejoy: descriptive statistics for documented ages-at-death compared to new phase scores in the combined study sample.*

New phase score	N	Mean age (years)	Standard deviation	95% confidence interval (years)	Age estimate (age phase)
1	0	-	-	-	-
2	13	48.1	4.4	45–51	< 55 years
3	105	54.4	11.2	52–57	< 75 years
4	339	67.4	11.0	66–68	45+ years
5	155	76.3	10.7	74–78	60+ years

6.6.1.5.1 Intraobserver Error

A subsample (5 males and 5 females) from each of the four skeletal collections were re-recorded to test for intraobserver error (N = 40). Paired *t*-tests were used to determine any significant differences in the two occasions. No significant variation between the trait scores and composite scores (t = 1.00, df = 39, P = 0.323).

6.6.1.2 Lovejoy et al. (1985b) Auricular Surface Results: Blind Test

A blind test was performed on the left auricular surface of 67 individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The right side was substituted if the left was absent. The sample comprised a total of 82 individuals (mean age, 63.0 years), including 42 males with age-at-death ranging from 40-91 years (mean age, 63.1 years) and 40 females, ranging between 44-89 years (mean age, 63.0 years) (Table 6.150).

Table 6.150: *Auricular surface, blind test of revised Lovejoy: age construction of the CCS sample.*

	Age category (years)					Total
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	6	10	12	9	5	**42**
Female	7	12	8	8	5	**40**
Total	**13**	**22**	**20**	**17**	**10**	**82**

As sexually dimorphic differences in trait expression were not identified while developing the ageing criteria, males and females were analysed together. The Lovejoy et al. (1985b) surface stages, and the newly proposed surface stage 9 were allotted into the five suggested auricular surface phases of degeneration, which were applied to each CCS individual and compared with documented age, as depicted in Figure 6.117.

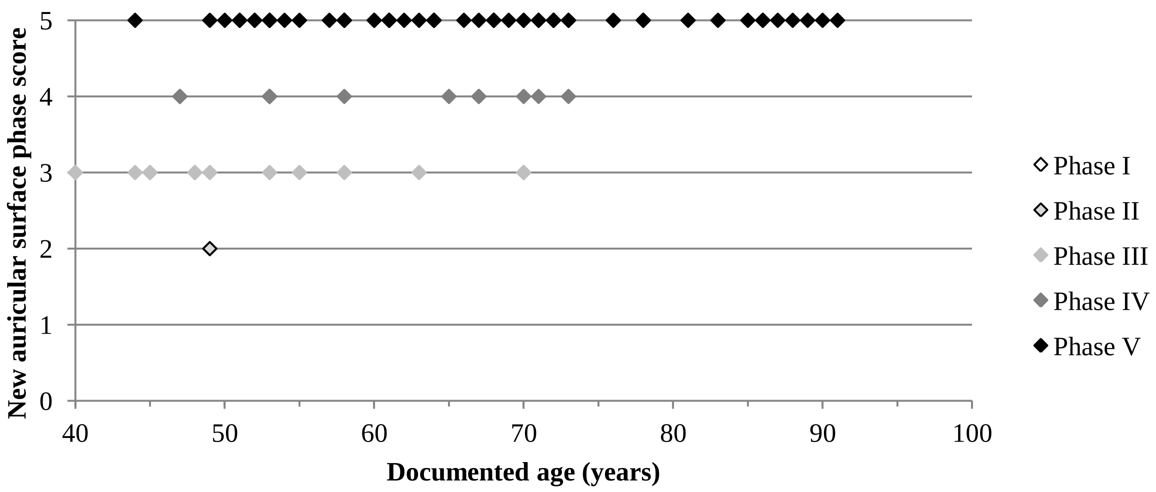


Figure 6.117: *Plot of newly proposed auricular surface phase score against age for all individuals in the CCS sample.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.118). Age estimations were made using a range(s) unique to each age stage.

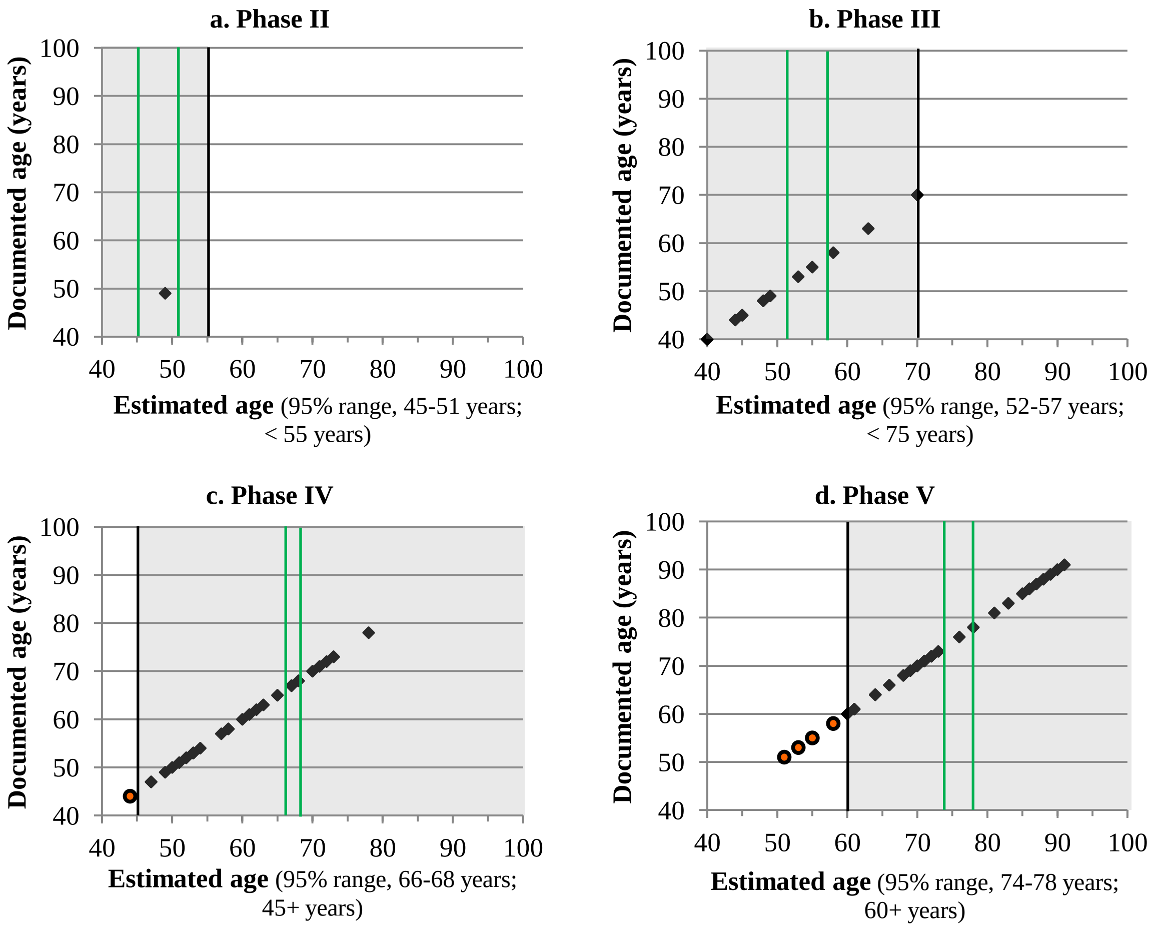


Figure 6.118a-d: *Observed revised auricular surface age phases (estimated age) for CCS individuals, compared with documented ages.*

Table 6.151 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.151: *Age estimations based on the revised Lovejoy appearance of the auricular surface in the blind test sample.*

Phase of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	0	-	-	-	-	-	-	-	-	-	-
II	1	49	45–51	1	100.0	< 55	1	100.0	0	0	no bias
III	14	40–70	52–57	2	14.3	< 75	14	100.0	0	0	no bias
IV	34	44–78	66–68	5	14.7	45+	33	97.1	1	2.9	overaged
V	33	51–91	74–78	2	6.1	60+	28	84.8	5	15.2	overaged
Total	82	-	-	10	**12.2**	-	76	**92.7**	6	**7.3**	**overaged**

Of the 82 individuals, only 12.2% fell within the 95% confidence interval based on this method, and 92.7% fell within the age phase.

6.6.1.2.1 Additional Analyses

To confirm the relationship between age and new auricular surface score, a Spearman's rank correlation was calculated. The result was found to be highly statistically significant ($r_s = 0.625$; $P < 0.001$). The results are plotted in Figure 6.119.

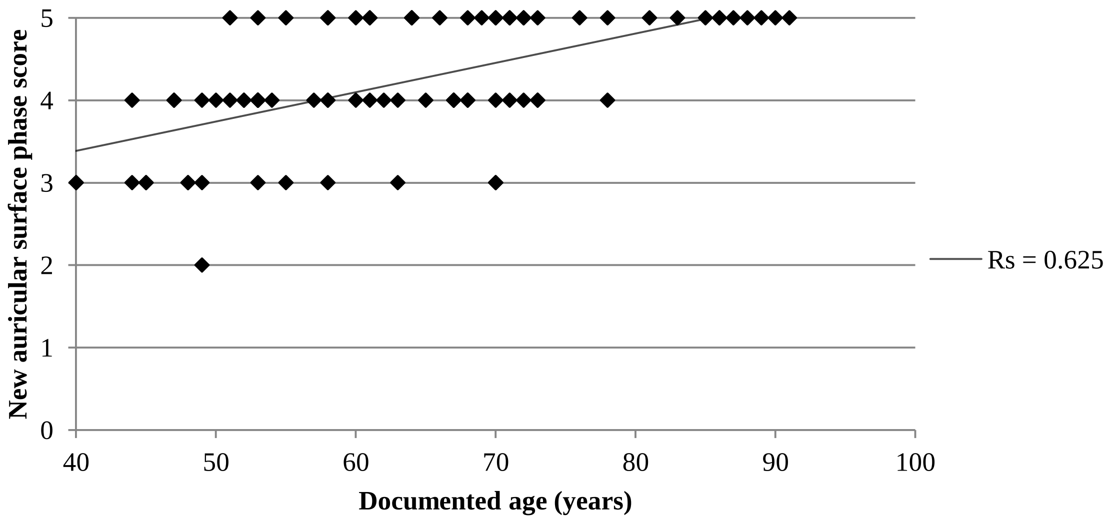


Figure 6.119: *Auricular surface, blind test of revised Lovejoy: scatter plot of composite scores against age for individuals in the CCS sample. Spearman's rank correlation coefficient of score against age for is provided.*

Comparison of the descriptive statistics of age variation within each age stage (Table 6.152) revealed generally younger patterns of mean age, standard deviation and 95% confidence intervals between the developed criteria and the CCS blind test sample.

Table 6.152: *Age estimates from revised auricular surface scores and age phases for the developed criteria and the CCS blind test sample.*

Age phase	Stage	Developed criteria			CCS blind test sample			
		Mean age (years)	Standard deviation	95% confidence interval (years)	N	Mean age (years)	Standard deviation	95% confidence interval (years)
I	1–2	n/a	n/a	n/a	0	n/a	n/a	n/a
II	3–4	48.1	4.4	45–51	1	49.0	-	-
III	5–6	54.4	11.2	52–57	14	52.0	10.0	46–58
IV	7–8	67.4	11.0	66–68	34	59.5	9.1	56–63
V	9	76.3	10.7	74–78	33	71.9	11.7	67–76

6.6.1.2.2 Blind Test Results of Original Lovejoy et al. (1985b) Criteria

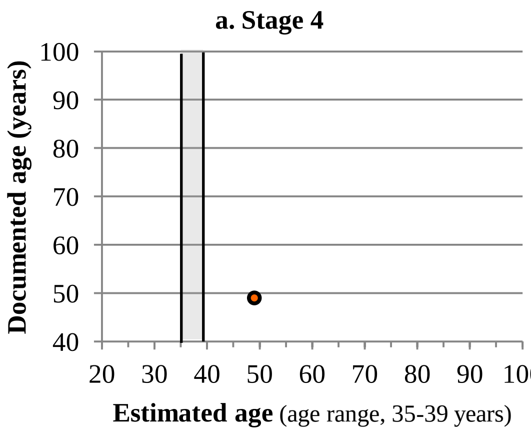
The revised Lovejoy technique was compared against the original method's criteria. The descriptive statistics of the blind tested individuals observed within each Lovejoy phase is presented in Table 6.153. The published age ranges for each age stage Lovejoy et al. (1985b:27) are also provided in Table 6.153 for comparison.

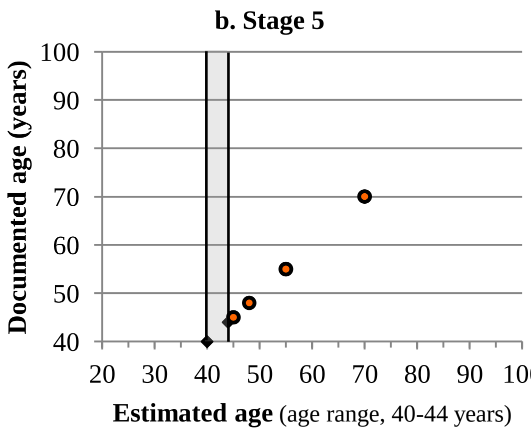
Table 6.153: *Comparison of published Lovejoy et al. (1985b:27) age estimation ranges for the new auricular surface age phase and recorded observations of the CCS blind test sample (N = 82).*

Age stage	Lovejoy et al. (1985b) age range (years)	CCS			
		N	Mean age (years)	Standard deviation	95% confidence interval (years)
1	20–24	0	n/a	n/a	n/a
2	25–29	0	n/a	n/a	n/a
3	30–34	0	n/a	n/a	n/a
4	35–39	1	49.0	-	-
5	40–44	10	50.5	11.1	42–59
6	45–49	4	55.8	6.1	*
7	50–59	34	62.2	11.1	58–66
8	60+	33	69.0	12.3	64–73

*Key: * a sample size greater than 5 is required to obtain a reliable confidence interval.*

To determine whether the characteristic appearance of each Lovejoy et al. (1985b:27) age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (i.e. the age stages and associated ranges published by Lovejoy et al. (1985b)). In Figure 6.120, the minimum and maximum age estimation limits are demarcated by black vertical lines and a grey shaded area. Outliers are highlighted in orange and indicated where the known age for the individual fell out of the age range for that particular stage.





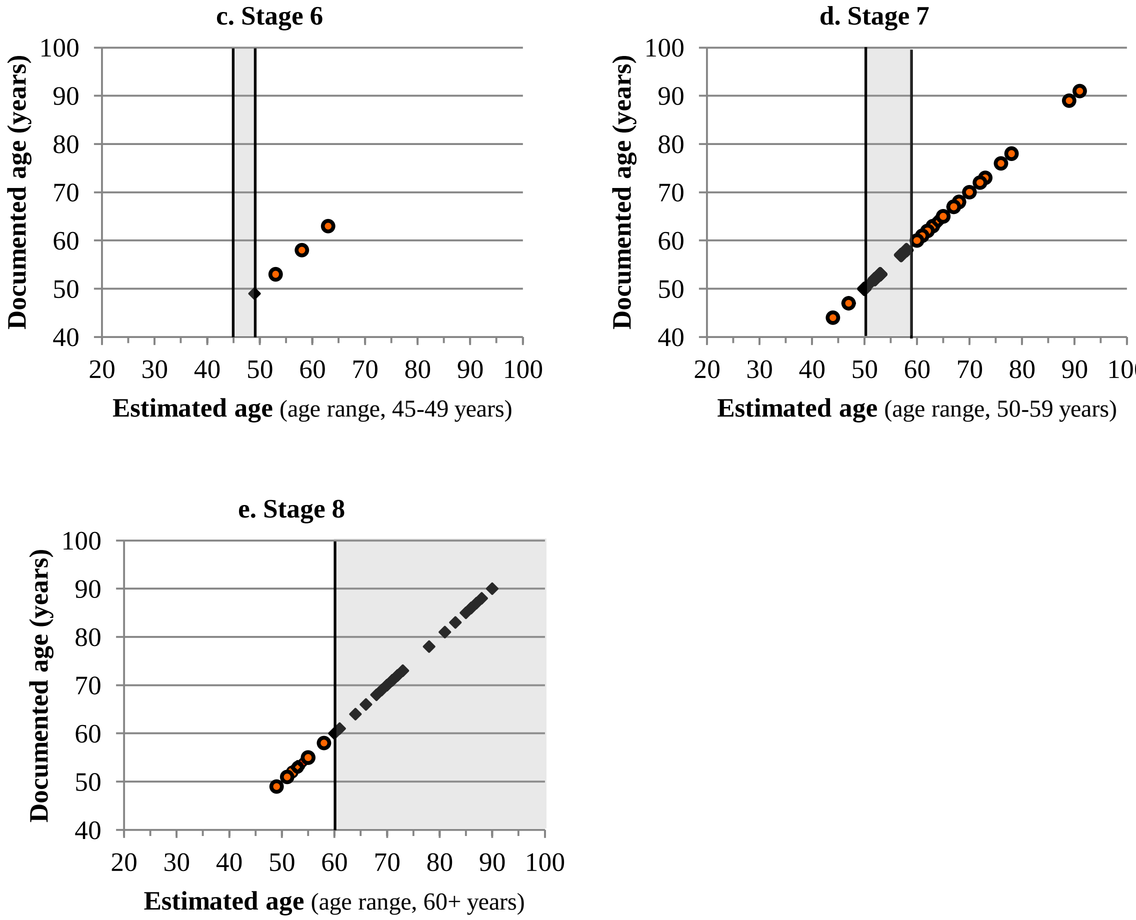


Figure 6.120a-e: *Observed Lovejoy et al. (1985b) auricular surface age stages (estimated age) for the CCS blind test sample, compared with documented ages.*

6.6.1.2.2.1 Inaccuracy and Bias

Table 6.154 depicts the frequency that the documented age fell within the original Lovejoy age range, those that were underaged by the method, and those that were overaged.

Table 6.154: *Accuracy and bias of age estimates using Lovejoy et al.'s (1985b) criteria in the CCS sample (N = 82).*

Lovejoy stage	**N**	**Actual age range of individuals (years)**	**Within Lovejoy range**			**Bias**			
						Underaged		**Overaged**	
			Range (years)	**N**	**%**	**N**	**%**	**N**	**%**
1	0	n/a	20–24	-	-	-	-	-	-
2	0	n/a	25–29	-	-	-	-	-	-
3	0	n/a	30–34	-	-	-	-	-	-
4	1	49	35–39	0	0	1	100.0	0	0
5	10	40–70	40–44	3	30.0	7	70.0	0	0
6	4	49–63	45–59	1	25.0	3	75.0	0	0
7	34	44–91	50–59	11	32.4	20	58.8	3	8.8
8	33	49–90	60+	24	72.7	n/a	n/a	9	27.3
Total	82	-	-	39	**47.6**	31	**37.8**	12	**14.6**

Of the 82 individuals, the known age of 47.6% fell within the Lovejoy age estimation range for the displayed surface appearance.

6.6.2 BUCKBERRY AND CHAMBERLAIN (2002) AURICULAR SURFACE RESULTS

The individual trait scores recorded for each surface feature of the auricular surface, as proposed by Buckberry and Chamberlain (2002). The composite score has possible values ranging between 5 and 19 points (i.e. surface topography and surface texture, scored between 1 and 5; micro- and macroporosity and apex changes, and scored between 1 and 3). The composite score was used to provide an age estimate, as suggested by Buckberry and Chamberlain (2002), and presented as the 95% range.

The accuracy and bias was assessed when the method was applied to each of the study samples. Subsequent analyses re-investigated the degenerative differences between left and right elements, as well as between males and females. The correlation between age and each of the trait expressions was also evaluated. Revisions to the method are suggested. The raw data for each of the study samples is provided in Appendix 4.12, and the statistical results are in Appendix 5.12. The results of the combined sample are presented in this section, and the blind test of the developed criteria (Appendices 6.24 to 6.26). It is acknowledged that the Christ Church Spitalfields collection was used to develop the original Buckberry and Chamberlain (2002) criteria. It was predicted that the blind test results using this assemblage would result in a higher correlation with known age than the four study samples.

6.6.2.1 Buckberry and Chamberlain (2002) Method Results: Combined Sample

Due to the irregularity of trait expressions observed between the reference collections (i.e. many traits were found to be not correlated with documented age), a combination of results from the Buckberry and Chamberlain (2002) method was not feasible. However, the traits of surface texture and the newly proposed raised surface texture both performed very well when compared with documented age. Surface texture was the trait most frequently and highly correlated with age out of the five proposed traits by Buckberry and Chamberlain (2002). As raised surface elevation alters the texture of the auricular surface, a new method of surface texture assessment is proposed, which is ultimately a simplified auricular surface method.

The newly proposed method was performed on the left auricular surfaces of the ilia of 605 individuals from the combined study sample. The sample comprised 331 males with age-at-death ranging from 40-96 years (mean age, 66.1 years) and 274 females, ranging between 40-95 years (mean age, 67.9 years) (Table 6.155).

Table 6.155: *Revised surface texture: age composition of the combined study sample.*

	Age category (years)					Total
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	41	67	79	89	55	**331**
Female	35	42	64	68	65	**274**
Total	**76**	**109**	**143**	**157**	**120**	**605**

6.6.2.1.1 Male Versus Female

The ages were plotted against the revised surface texture scores for males and females in a scatter plot, with a regression line for both sets of data (Figure 6.121). The regression lines indicate that there was little difference between sexes (males, $r_s = 0.578$, $P < 0.001$; females, $r_s = 0.566$, $P < 0.001$).

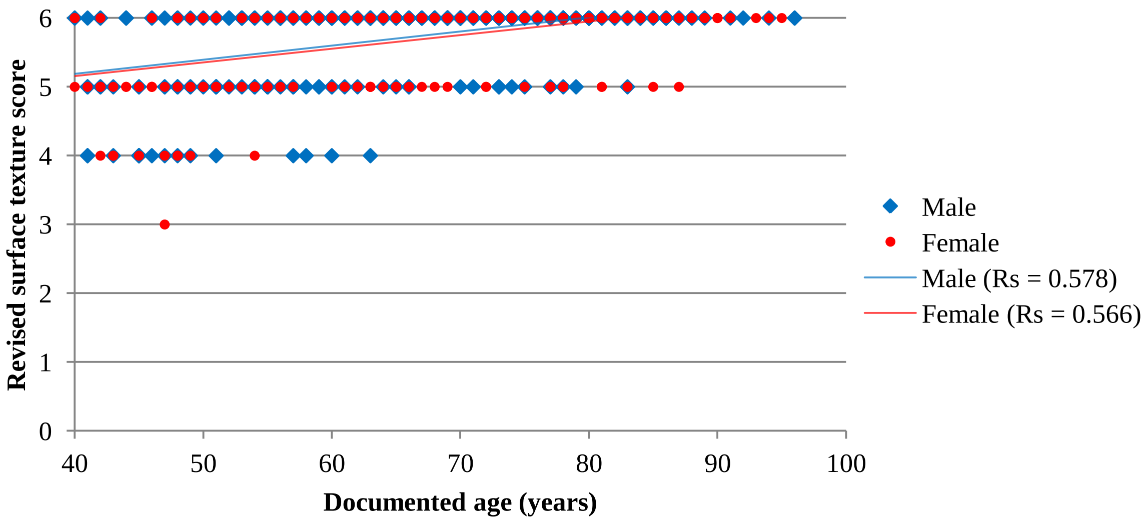


Figure 6.121: *Revised surface texture: scatter plot of revised surface texture scores against known age for the combined study sample. Spearman's rank correlation coefficients of score against age for males and females are provided.*

A standard unpaired (two-sample, two-tailed) *t*-test was also carried out to test for significant differences between males and females for each surface texture trait score. A minimum of two males and two females were required to perform a *t*-test. The highest trait score was found to display statistically significant differences at the 95% confidence level between ages for males and females ($P < 0.05$; see Table 6.156). As a statistically significant difference was found, males and females will be separated for all further analyses. The sample size for the remaining analyses is 331 males and 274 females.

Table 6.156: *Independent two-tailed t-tests between males and females for each revised surface texture score.*

Trait score	*t*	df	*P*
1	none observed		
2	none observed		
3	sample size too small		
4	0.98	23	0.337
5	-0.79	117	0.428
6	-2.12	458	0.034*

*Key: * result is significant at the 95% confidence level (P < 0.05).*

6.6.2.1.2 Surface Texture Score and Age-at-Death

Surface texture expressions were investigated as to its association with age-at-death. A scatter plot of trait score were plotted against age-at-death (Figure 6.122). These figures display a wide variation in the age of trait expression (score) of each of surface texture, females more-so than males.

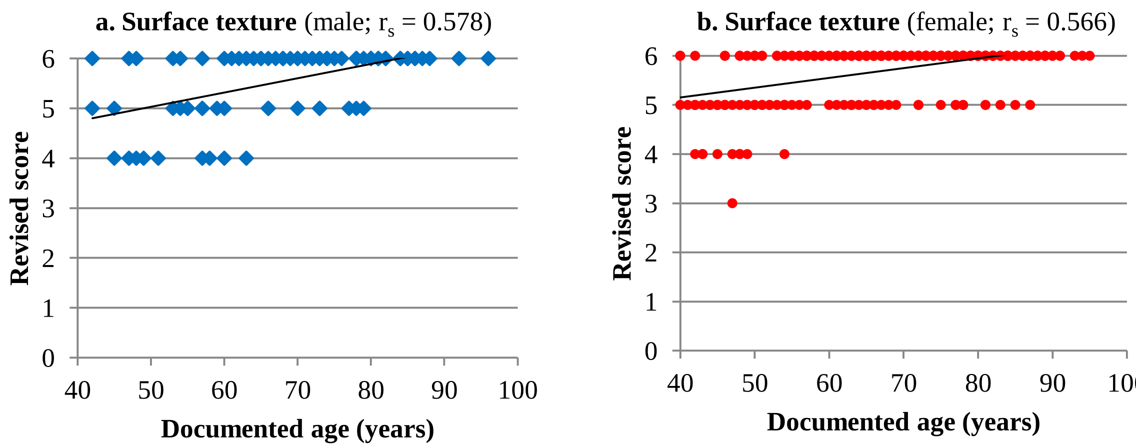


Figure 6.122: *Scatter plots of revised surface texture trait scores against age-at-death in the combined study sample.*

To test whether each feature is correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. The revised surface texture trait expressions were found to be significantly correlated with age-at-death (males, $r_s = 0.578$, $P < 0.001$; females, $r_s = 0.566$, $P < 0.001$).

The descriptive statistics of age variation within composite scores revealed that the overall trend of increasing age with increasing composite score for males and females (Tables 6.157 and 6.158, respectively). In addition to the 95% confidence interval, a broader age phase with which to estimate age was also provided for each revised surface texture score.

Table 6.157: *Descriptive statistics for documented ages-at-death possessing the same revised surface texture trait scores in the combined study sample (males).*

Revised trait score	N	Mean age (years)	Standard deviation	Median age (years)	95% confidence interval (years)	Age estimate (age phase)
1	0	-	-	-	-	-
2	0	-	-	-	-	-
3	0	-	-	-	-	-
4	16	49.0	6.87	46	45–53	< 60 years
5	60	56.7	10.47	55	54–59	45–80 years
6	255	69.4	11.63	70	67–71	60+ years

Table 6.158: *Descriptive statistics for documented ages-at-death possessing the same revised surface texture trait scores in the combined study sample (females).*

Revised trait score	N	Mean age (years)	Standard deviation	Median age (years)	95% confidence interval (years)	Age estimate (age phase)
1	0	-	-	-	-	-
2	0	-	-	-	-	-
3	1	47.0	-	47	-	< 60 years
4	9	46.6	3.78	47	43–50	< 60 years
5	59	58.4	13.06	54	55–62	< 80 years
6	205	71.7	11.72	73	70–73	50+ years

With the exception of scores 3 and 4 in females, all revised scores were distinct from one-another. Unpaired *t*-tests were employed to test for statistically significant differences between the scores (Table 6.159). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.159: *Revised surface texture: results of t-tests between age stages.*

Scores compared	Male			Female		
	t	df	*P*	*t*	df	*P*
4 vs 5	-2.77	74	0.007	-5.59	44	< 0.001
5 vs 6	7.75	313	< 0.001	7.48	262	< 0.001

6.6.2.1.3 Intraobserver Error

A subsample (5 males and 5 females) from each of the four skeletal collections were re-recorded to test for intraobserver error (N = 40). Paired *t*-tests were used to determine any significant differences in the two occasions. No significant variation between the trait scores and composite scores ($t = 1.78$, df = 39, $P = 0.083$).

6.6.2.6 Raised Surface Texture Method Results: Blind Test

A blind test was performed on the left auricular surface of 67 individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The right side was substituted if the left was absent. The sample comprised a total of 82 individuals (mean age, 63.0 years), including 42 males with age-at-death ranging from 40-91 years (mean age, 63.1 years) and 40 females, ranging between 44-89 years (mean age, 63.0 years) (Table 6.160).

Table 6.160: *Revised surface texture, blind test: age construction of the CCS sample.*

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	6	10	12	9	5	**42**
Female	7	12	8	8	5	**40**
Total	**13**	**22**	**20**	**17**	**10**	**82**

As sexually dimorphic differences in trait expression were identified while developing the ageing criteria, males and females were analysed separately. As the derived composite score using the Buckberry and Chamberlain (2002) method was found to be highly variable between all four collections, the blind test was undertaken using the revised surface texture. This method was applied to each CCS individual and compared with documented age. It is noted that as ageing criteria were not able to be derived for surface texture score, due to absence of data in the four study collections, any score below a value of 4 was allocated with a score of 4 for statistical purposes.

6.6.2.2.1 Male

A total of 42 males provided suitably preserved auricular surface for analysis. The known age of each individual was plotted against the revised surface texture score in Figure 6.123.

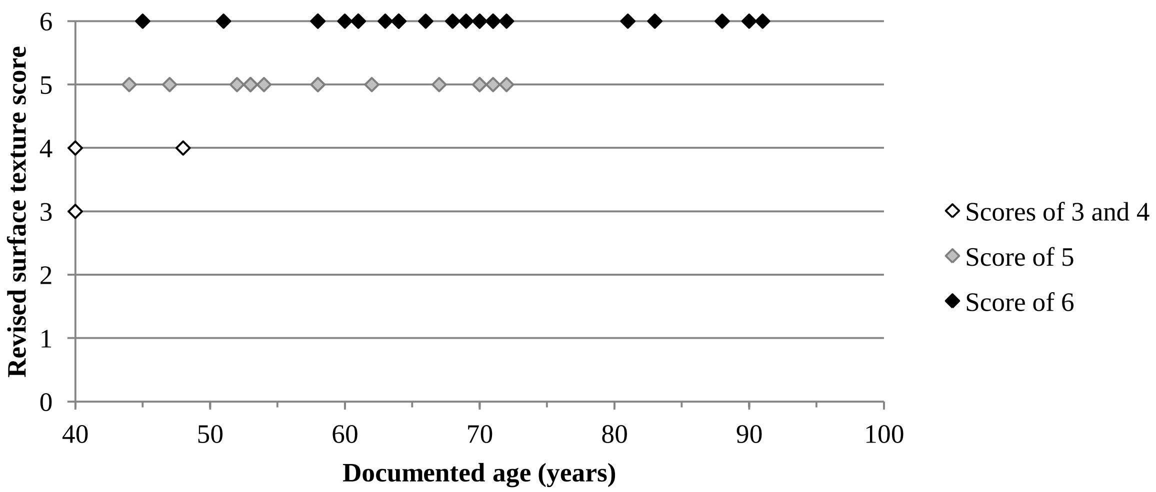


Figure 6.123: *Plot of new auricular surface texture score against known age for males in the CCS blind test sample.*

To determine the whether the characteristic appearance of each surface score enabled chronological age to be accurately estimated for males in this sample, the known age of each individual was plotted against the estimated age (Figure 6.124). Age estimations were made using a range(s) unique to each surface score.

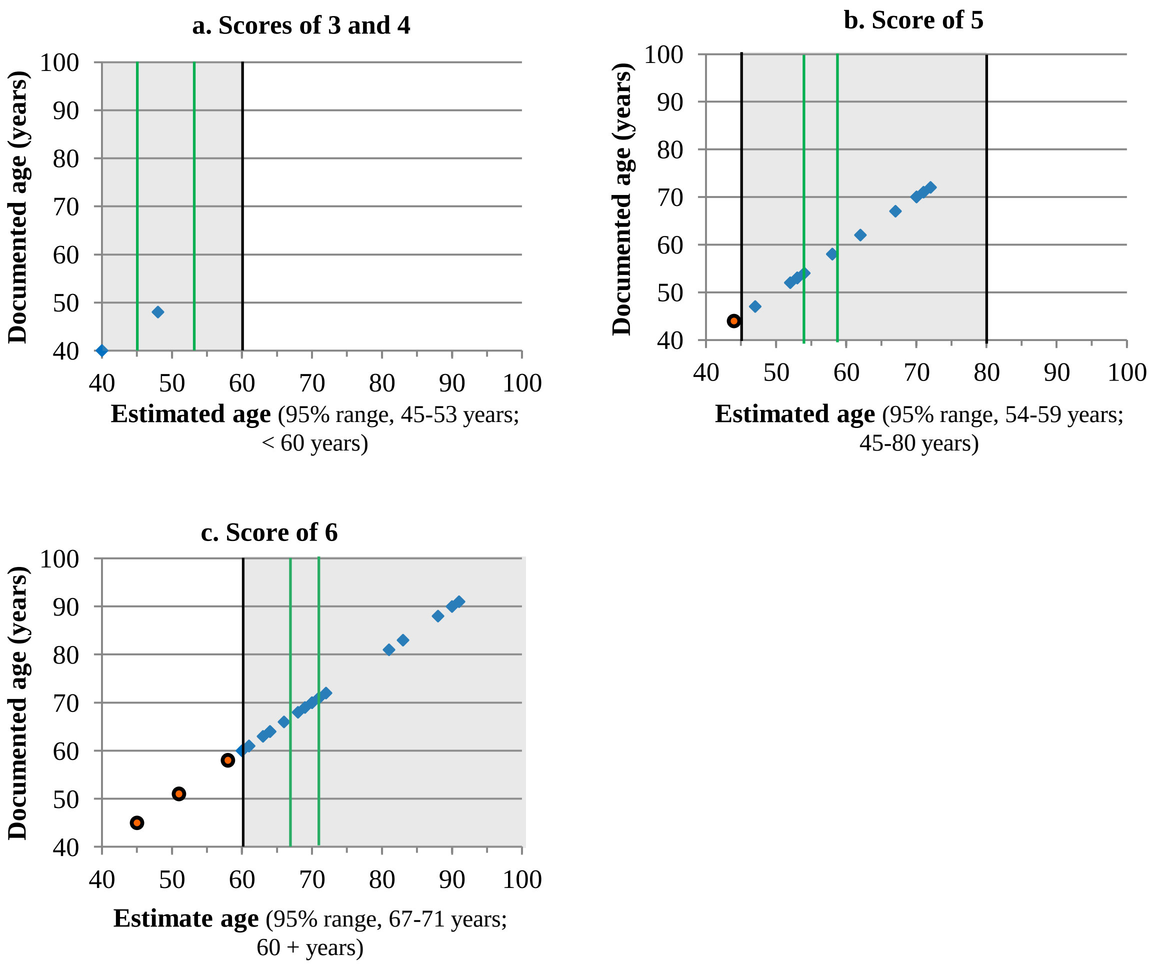


Figure 6.124: *Revised auricular surface texture scores (estimated age) recorded for CCS males, compared with documented ages.*

<u>6.6.2.2.1.1 Inaccuracy and Bias</u>

Table 6.161 depicts the frequency that the documented age fell within the 95% confidence interval for each surface texture stage, and those that fell within the proposed age phase. Those individuals whose known age was not included within either range were assessed as to whether they were underaged or overaged by the method's criteria.

Table 6.161: *Age estimations based on the appearance of the revised surface texture score of the auricular surface in CCS males.*

Score of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
1	0	-	-	-	-	-	-	-	-	-	-
2	0	-	-	-	-	-	-	-	-	-	-
3 + 4**	3	40–48	45–53	1	33.3	< 60	3	100.0	0	0	no bias
5	15	44–72	54–59	3	20.0	45–80	14	93.3	1	6.7	overaged
6	24	45–91	67–71	6	25.0	60+	20	83.3	4	16.7	overaged
Total	42	-	-	10	**23.8**	-	37	**88.1**	5	**11.9**	**overaged**

*Key: ** criteria could not be developed for score of 3, and has been combined with a score of 4.*

Of the 42 males, 23.8% fell within the 95% confidence interval based on this method, and 88.1% fell within the age phase.

6.6.2.2.2 Females

A total of 40 females provided suitably preserved auricular surface for analysis. The known age of each individual was plotted against the revised surface texture score in Figure 6.125.

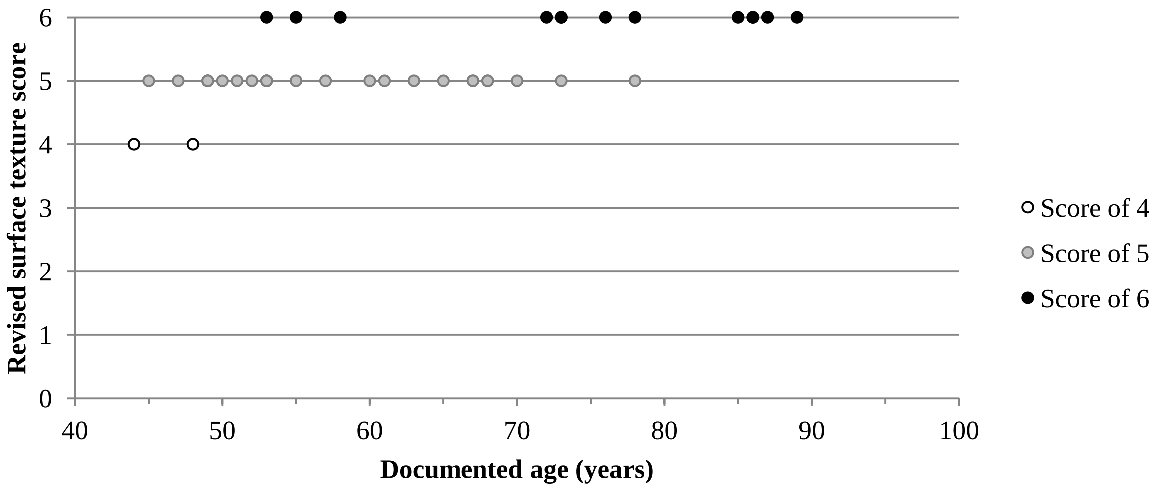


Figure 6.125: *Scatter plot of new auricular surface texture score against known age for females in the CCS blind test sample.*

To determine the whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated for females in this sample, the known age of each individual was plotted against the estimated age (Figure 6.126). Age estimations were made using a range(s) unique to each age stage.

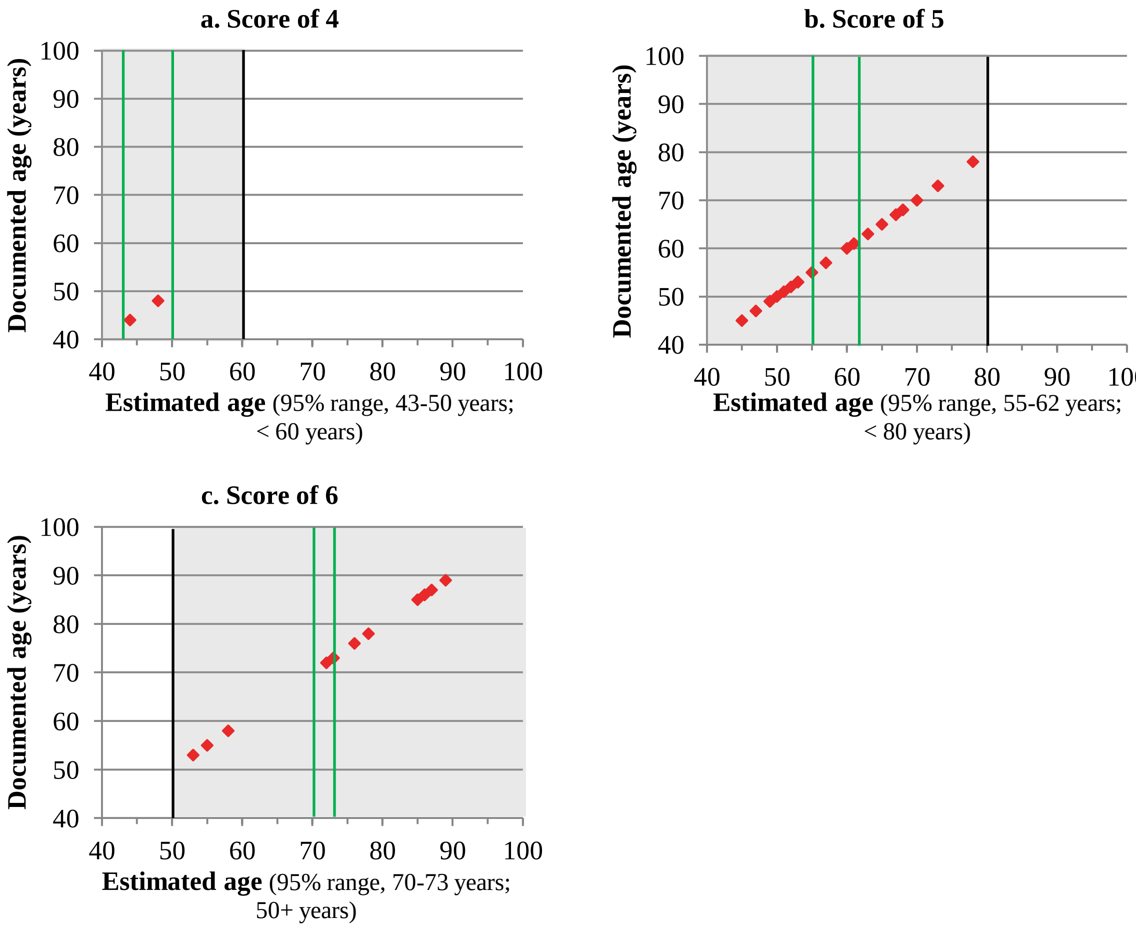


Figure 6.126a-c: *Revised auricular surface age scores (estimated age) recorded for CCS females, compared with documented ages.*

6.6.2.6.2.1 Inaccuracy and Bias

Table 6.162 depicts the frequency that the documented age fell within the 95% confidence interval for each surface texture stage, and those that fell within the proposed age phase. Those individuals whose known age was not included within either range were assessed as to whether they were underaged or overaged by the method's criteria.

Table 6.162: *Age estimations based on the appearance of the revised surface texture score of the auricular surface in CCS females.*

Score of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age phase			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
1	0	-	-	-	-	-	-	-	-	-	-
2	0	-	-	-	-	-	-	-	-	-	-
3	0	-	-	-	-	-	-	-	-	-	-
4	2	44–48	43–50	2	100.0	< 60	2	100.0	0	0	no bias
5	25	45–78	55–67	4	16.0	< 80	25	100.0	0	0	no bias
6	13	53–89	70–73	3	23.1	50+	13	100.0	0	0	no bias
Total	40	-	-	9	**22.5**	-	40	**100.0**	0	**0**	**no bias**

Of the 40 females, only 22.5% fell within the 95% confidence interval based on this method, and 100.0% fell within the age phase.

6.6.2.2.3 Additional Analyses

To test whether each of the features of the original Buckberry and Chamberlain (2002) method and the new feature of raised surface texture were correlated with age-at-death, Spearman's rank correlation coefficients were calculated. Not all individual trait expressions were found to be significantly correlated with known age (Table 6.163). The higher the score (r_s) assigned to a particular trait expression, the more frequently it was associated with older age. This correlation was strongest with the new surface texture females ($r_s = 0.697$, $P < 0.001$) and apex activity in males ($r_s = 0.602$, $P <$ 0.001). The expression of the new surface texture trait was also highly correlated with documented age in males ($r_s = 0.557$, $P < 0.001$).

Table 6.163: *Revised surface texture, blind test: Spearman's rank correlation between age and trait expression of features.*

Feature	**Male**		**Female**	
	r_s	***P***	**r_s**	***P***
Surface topography	0.541	< 0.001	0.431	0.013
Surface texture	0.526	0.051*	0.565	0.023
Microporosity	0.581	0.005	0.591	0.004
Macroporosity	0.451	0.022	0.417	0.050
Apex activity	0.602	< 0.001	0.465	0.019
Composite score	**0.577**	**< 0.001**	**0.551**	**< 0.001**
Raised surface texture	**0.557**	**< 0.001**	**0.697**	**< 0.001**

*Key: * result is not statistically significant at the 95% confidence interval (i.e. P > 0.05).*

The ages were plotted against the revised surface texture scores for males and females in a scatter plot, with a regression line for both sets of data (Figure 6.127). The regression lines indicate that there was little difference between sexes (males, $r_s = 0.557$, $P < 0.001$; females, $r_s = 0.697$, $P < 0.001$).

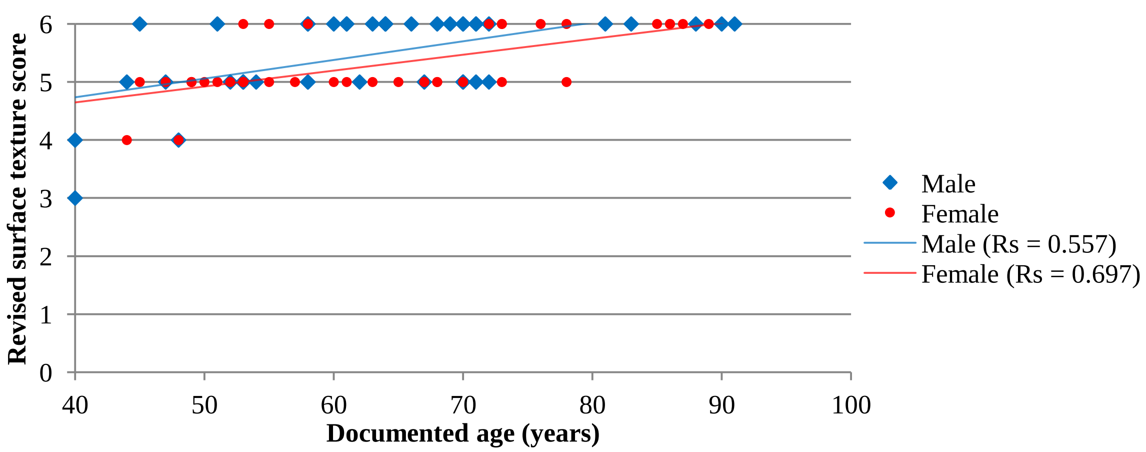


Figure 6.127: *Revised surface texture, blind test: scatter plot of revised surface texture scores against known age. Spearman's rank correlation coefficients of score against age for males and females are provided.*

6.6.2.2.4 Buckberry and Chamberlain (2002) Original Method Blind Test Results

For comparison, the original Buckberry and Chamberlain (2002) auricular surface method was also blind tested. It is acknowledged that correlation and accuracy between age stages and known age should be very high, as the Christ Church Spitalfields known age collection was used in the development of the original technique. Unfortunately, use of the same collection was unavoidable for the blind testing of the developed methods. Sexually dimorphic differences were not observed in the development of the technique, so males and females were analysed together. The derived composite score was recorded for each assessed CCS individual and compared with documented age, as depicted in Figure 6.128. A Spearman's rank correlation was calculated, and found to be statistically significant with age ($r_s = 0.567$, $P < 0.001$). The known age of each individual was plotted against the estimated age in Figure 6.129.

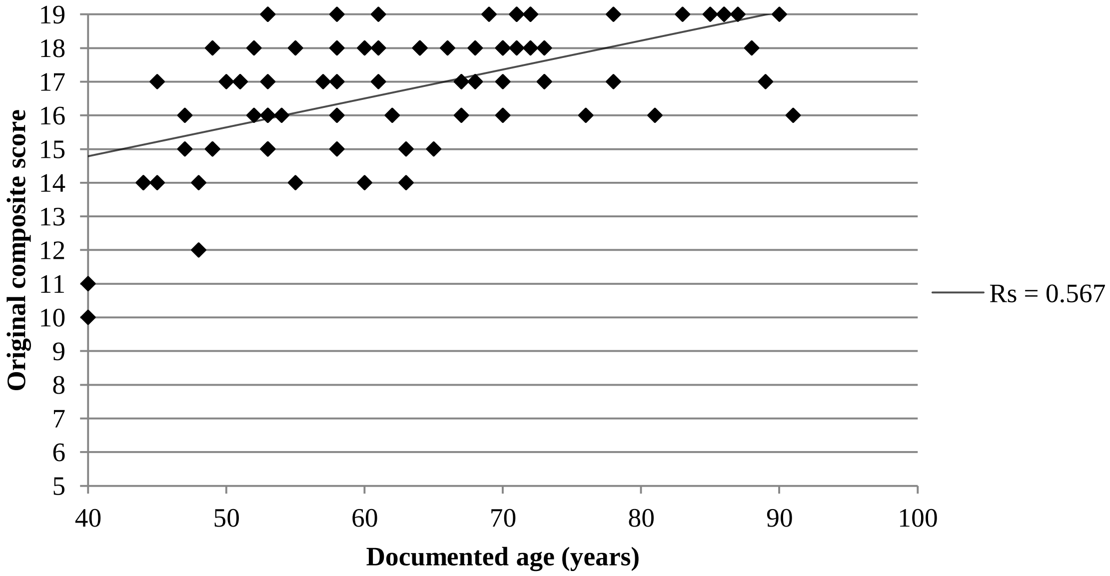
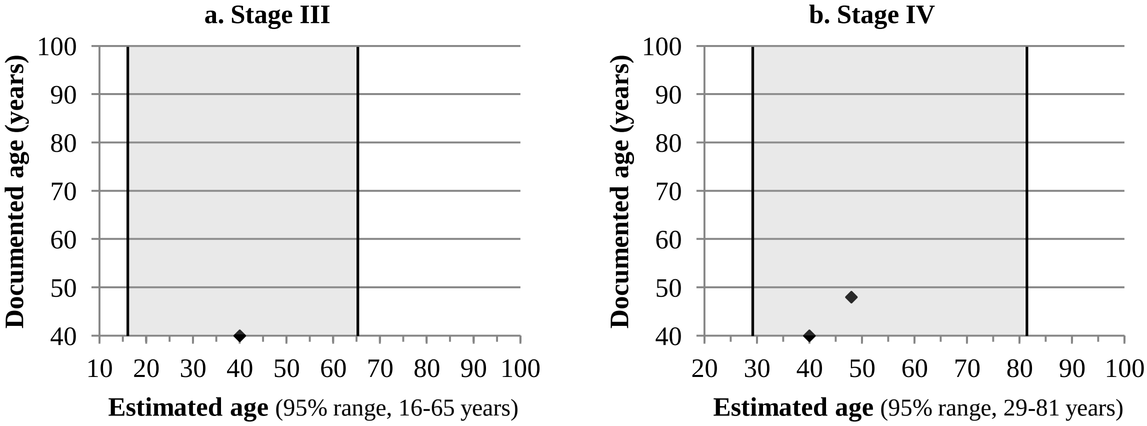


Figure 6.128: *Scatter plot of original Buckberry and Chamberlain (2002) composite scores against known age for the CCS blind test sample. Spearman's rank correlation coefficient of score against age is provided.*



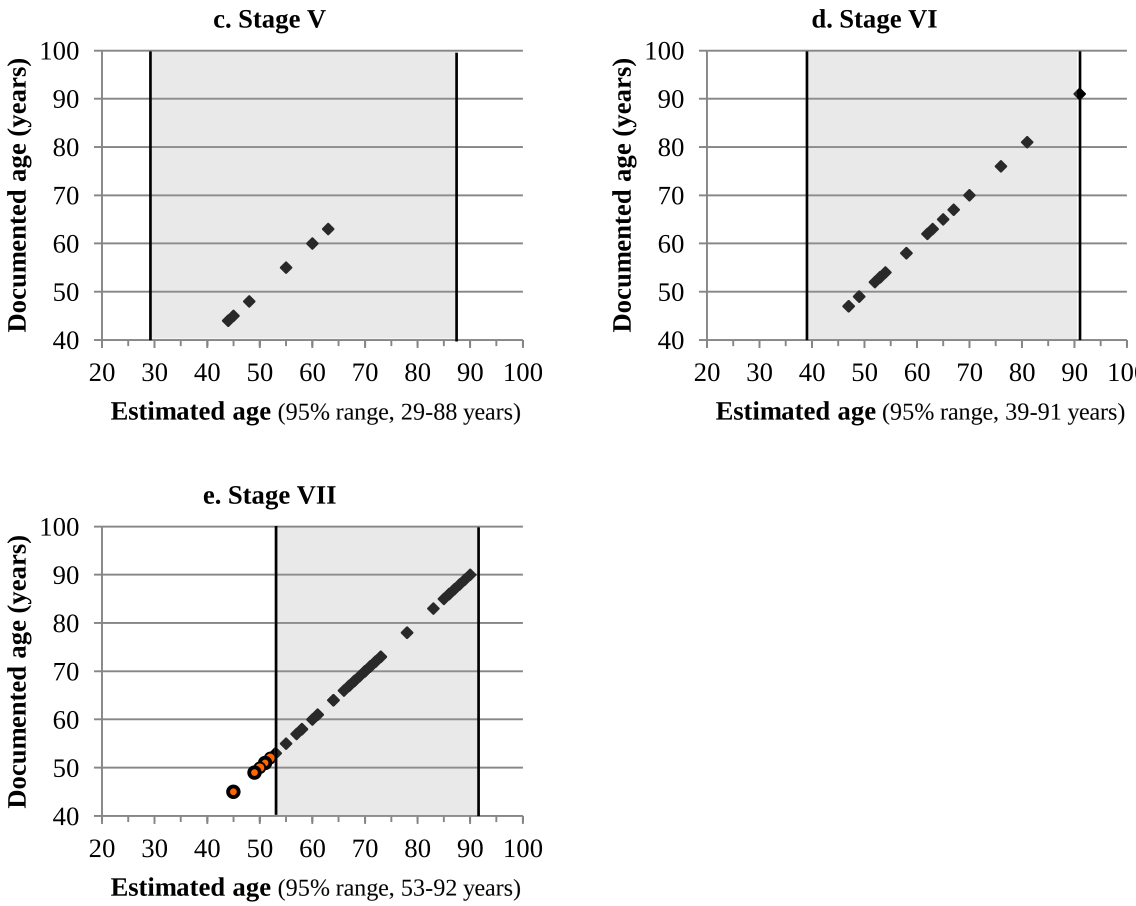


Figure 6.129a-e: *Observed Buckberry and Chamberlain (2002) auricular surface age stages (estimated age) for CCS individuals, compared with documented ages.*

Comparison of the descriptive statistics of age variation within each age stage (Table 6.164) revealed differing patterns of mean age, standard deviation and 95% confidence intervals between the developed criteria and the CCS blind test sample.

Table 6.164: *Age estimates from age stages following Buckberry and Chamberlain (2002) for the CCS blind test sample.*

Age stage	Composite score	Buckberry and Chamberlain (2002)			CCS			
		Mean age (years)	Standard deviation	Range (years)	N	Mean age (years)	Standard deviation	95 % confidence interval (years)
I	5–6	17.3	1.53	16–19	0	-	-	-
II	7–8	29.3	6.71	21–38	0	-	-	-
III	9–10	37.9	13.08	16–65	1	40.0	-	-
IV	11–12	51.4	14.47	29–81	2	44.0	5.66	*
V	13–14	59.9	12.95	29–88	7	51.3	7.99	43–59
VI	15–16	66.7	11.88	39–91	21	59.7	11.78	54–65
VII	17–19	72.3	12.73	53–92	51	67.2	11.63	63–71

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.6.2.2.4.1 Inaccuracy and Bias

Table 6.165 depicts the frequency that the documented age fell within Buckberry and Chamberlain's (2002) 95% range. Those individuals whose known age was not included within this range were assessed as to whether they were underaged or overaged by the method.

Table 6.165: *Age estimations based on the appearance of the auricular surface using Buckberry and Chamberlain (2002) criteria.*

Phase	N	Actual age range of individuals (years)	Estimated age			Inaccuracy		
			Range (years)	N	%	N	%	Bias
I	0	-	16–19	-	-	-	-	-
II	0	-	21–38	-	-	-	-	-
III	1	40	16–65	1	100.0	0	0	no bias
IV	2	40–48	29–81	2	100.0	0	0	no bias
V	7	44–63	29–88	7	100.0	0	0	no bias
VI	21	47–91	39–91	21	100.0	0	0	no bias
VII	51	45–90	53–92	45	88.2	6	11.8	overaged
Total	82	-	-	76	**92.7**	6	**7.3**	**overaged**

Of the 82 assessed individuals, the original Buckberry and Chamberlain (2002) auricular surface criteria correctly aged 92.7%. A bias to overage was suggested as the estimated age of 7.3% of the sample was older than the known age.

6.6.3 SACRO-ILIAC JOINT FUSION

Fusion of the sacro-iliac joint has been suggested as an old age trait, as it tends to occur in individuals over the age of 50 years, primarily in males. Of the 622 individuals that provided innominates for study, a total of 30 (4.8%) displayed either uni- or bilateral ankylosis of the sacro-iliac joint. Of these, 26 were male, and four were female. To assess any trends demonstrated, the number of observations of side of fusion was compared against the known age, separated into ranges by decade (Figure 6.130). The results show that no individual under the age of 60 years displayed ankylosis of the sacro-iliac joint. The raw data is provided in Appendix 4.13.

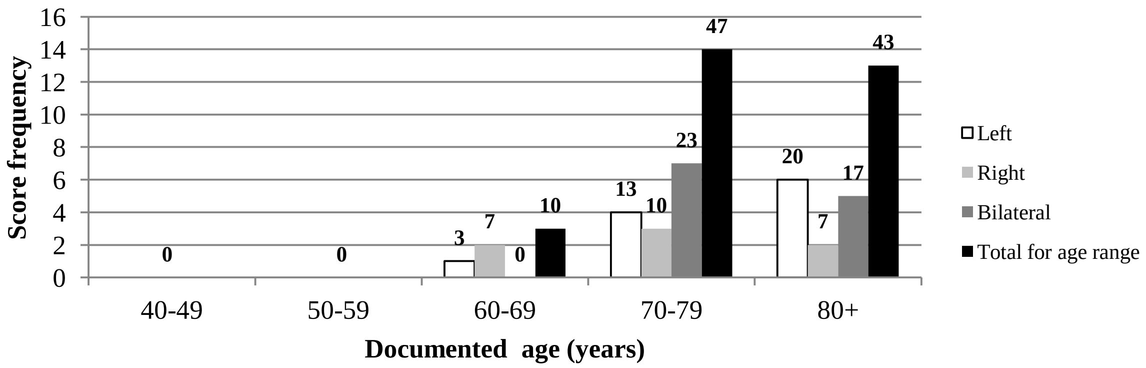


Figure 6.130: *Frequency of observations of side of sacro-iliac ankylosis (N = 30) recorded in the combined study sample. Percentage totals are provided within each age range, and for the total of each age range.*

Males and females were assessed for the location around the auricular surface that the ankylosis occurred (i.e. superior demifaces or inferior demifaces). The results showed that all 26 males demonstrated ankylosis at the superior demiface, while 75.0% (N = 3) of females showed ankylosis along the inferior demiface, and 25.0% (N = 1) displayed ankylosis along both demifaces.

Unfortunately, a true representation of the effects of DISH on sacro-iliac ankylosis could not be performed, as it was not possible to confidently identify DISH in the HTH sample. A total of 15 individuals that displayed ankylosis were from the HTH sample. Of the 15 individuals that demonstrated ankylosis from the PBC, SB and CHC samples, 6 males (40.0%) displayed the osseous vertebral changes indicating DISH, while the remaining 9 (60.0%; male, N = 7; female, N = 2) did not, suggesting it is not an overwhelming causative factor in these individuals. The fact that all individuals over the age of 60 years displayed ankylosis suggests that age may be more of a contributing factor.

6.6.3.1 Sacro-Iliac Joint Ankylosis: Blind Test

The assumption that individuals over 50 years were more prone to sacro-iliac fusion was blind tested using a total of 11 individuals (8 males, 3 females) from the CCS sample that had either uni- (right side, N = 3, 27.3%; left side, N = 3, 27.3%) or bilateral ankylosis (45.4%) of the sacro-iliac joint (Table 6.166). As all individuals the study samples with sacro-iliac fusion were all over the age of 60 years, it was hypothesised that these individuals were of 60 years or older. When the known age of each of these individuals was revealed, four (3 males and 1 female) were between 50 and 90 years of age at the time of death, proving the assumption correct. It is noted that only one of the 11 individuals displayed the characteristic fusion of the thoracic vertebrae indicating DISH.

Table 6.166: *Age estimation based on fusion of the sacro-iliac joint in the blind test sample.*

Skeleton number	Known age (years)	Sex	DISH?	Site of fusion				Estimated age (years)	Bias
				Right side	Left side	Bilateral	Demi-face		
CCS134	89	F	No	Y	-	-	inferior	60+ years	-
CCS152	87	F	No	-	Y	-	both	60+ years	-
CCS363	61	M	No	-	Y	-	superior	60+ years	-
CCS424	56	M	Yes	-	-	Y	superior	60+ years	overaged
CCS430	90	M	No	-	Y	-	superior	60+ years	-
CCS461	74	M	No	-	-	Y	superior	60+ years	-
CCS468	50	M	No	-	-	Y	superior	60+ years	overaged
CCS485	76	M	No	-	-	Y	superior	60+ years	-
CCS518	53	F	No	Y	-	-	both	60+ years	overaged
CCS524	71	M	No	Y	n/a	n/a	superior	60+ years	-
CCS567	52	M	No	-	-	Y	superior	60+ years	overaged

The pattern of fusion, however, was found to be as recorded in the study samples, as all males displayed fusion along the superior demiface compared to females who displayed bony bridges between the auricular surface and sacrum along the inferior demiface (N = 2; 66.7%) or around both demifaces (N = 1, 33.3%).

6.7 RESULTS: PUBIC SYMPHYSIS

Two different ageing methods of the pubic symphysis were assessed, the criteria produced by Brooks and Suchey (1990), and the proposed Phase VII (Berg, 2008). The ability of the published criteria to accurately age individuals aged 40+ years was assessed in the sexes separately in all study samples. The raw data can be found in Appendix 4.14, and statistical analyses of each study sample in Appendix 5.13. The combined sample and blind test results are provided in this section (Appendices 6.27 and 6.28).

Each pubic symphysis was compared with written descriptions (Brooks and Suchey, 1990:232-233), drawings (Buikstra and Ubelaker, 1994:23-24) and casts (Suchey et al., 1988) of the six male and female Suchey-Brooks (1990) phases. To test the applicability of the Suchey-Brooks pubic symphysis ageing method to individuals aged 40+ years, the documented age-at-death was compared with published descriptive statistics by Brooks and Suchey (1990:233), namely the mean age for each phase, the standard deviation (SD) and the 95% range. For consistency, phase score for the left pubic symphysis was used in all analyses when both sides were present, and the side available was used for all other individuals. Males and females will be examined separately due to the age estimation criteria are sexually dimorphic.

6.7.1 PUBIC SYMPHYSIS RESLUTS: COMBINED SAMPLE

When the results of the four skeletal collections were assessed, each demonstrated a very similar pattern of degeneration of the pubic symphysis in males and females (Figures 6.131 and 6.132, respectively), with a bias towards underageing by the current criteria. It was apparent that the upper age estimates of each Suchey-Brooks age phase must be extended to assess the true extent of the degenerative processes of the pubic symphysis. All four collections were combined. For consistency, phase score for the left pubic symphysis was used in all analyses when both sides were present, and the side available was used for all other individuals. Males and females will be examined separately, as the age estimation criteria are sexually dimorphic. The aim of this study was to develop new maximum age limits for each phase.

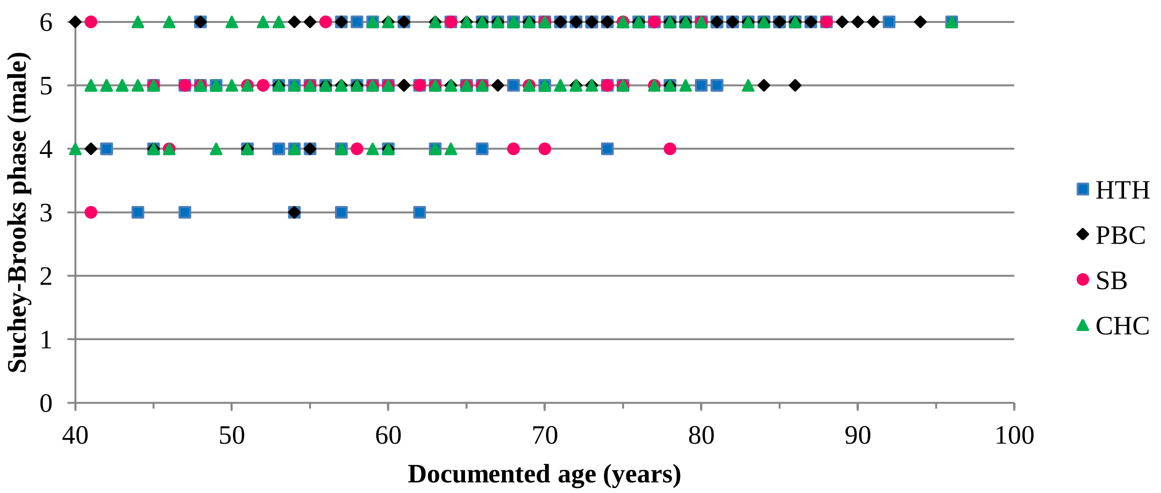


Figure 6.131: *Scatter plot of recorded Suchey-Brooks (1990) phase scores against known age for males in the combined study sample.*

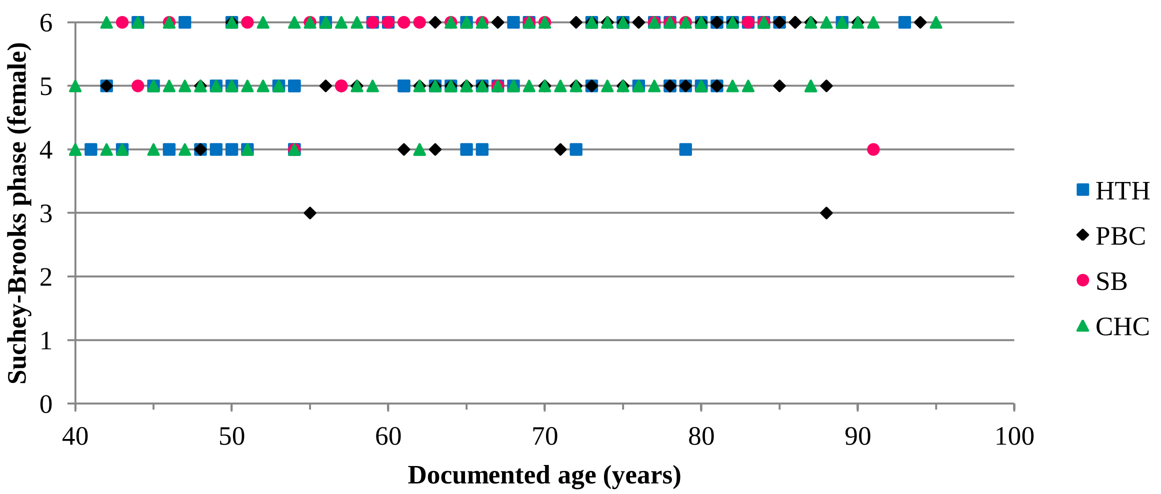


Figure 6.132: *Scatter plot of recorded Suchey-Brooks (1990) pubic symphysis phase scores against known age for females in the combined study sample.*

The total sample sizes used to revise the ageing criteria were 338 left pubic symphyses from male individuals (mean age, 66.7 years) and 251 females (mean age, 67.8 years) (Table 6.167).

Table 6.167: *Suchey-Brooks (1990): age construction of the combined study sample.*

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	40	65	78	95	60	**338**
Female	33	40	56	61	61	**251**
Total	**73**	**105**	**134**	**156**	**121**	**589**

6.7.1.1 Male

At least one pubic symphysis was present for analysis in 338 males. The known age of each individual was plotted against the estimated age (Brooks and Suchey, 1990: 233) (Figure 6.133). Age estimations were made using a range (95% range) unique to each age stage. The 95% confidence interval is denoted by one or two black vertical lines and a grey shaded area. Outliers are highlighted in orange circles and indicated where the known age for the individual fell out of the age range for that particular stage.

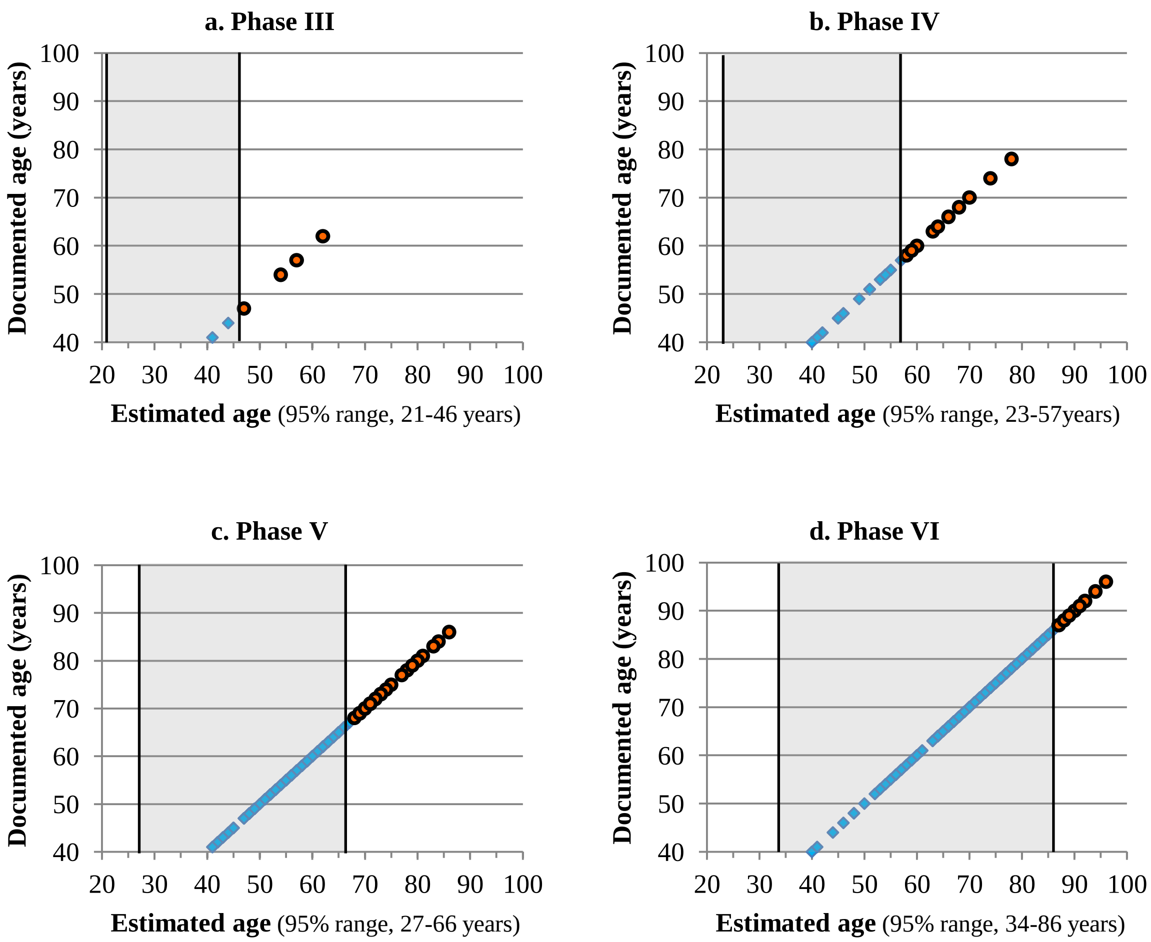


Figure 6.133a-d: *Observed Suchey-Brooks (1990) phases for males, compared with estimated and documented ages.*

Table 6.168 depicts the frequency that the documented age fell within the 95% range suggested by the Suchey-Brooks pubic symphysis age determination method. Bias was determined by the trend of overageing or underageing of individuals whose documented age was not accurately described by any of the ranges.

Table 6.168: *Summary of estimated ages in the combined study sample, based on Suchey-Brooks (1990) 95% ranges developed for male pubic symphysis phases.*

Phase	N	Actual age range of individuals (years)	Estimated age			Bias		
			95% range (years)	N	%	N	%	Trend
I	0	-	-	-	-	-	-	-
II	0	-	-	-	-	-	-	-
III	7	41–62	21–46	2	28.6	5	71.4	underaged
IV	37	40–78	23–57	24	64.9	13	35.1	underaged
V	125	41–86	27–66	86	68.8	39	31.2	underaged
VI	169	40–96	34–86	158	93.5	11	6.5	underaged
Total	338	-	-	270	**79.9**	68	**20.1**	**underaged**

Of the 338 males in the combined study sample, the known age of 79.9% fell within the 95% range of the original technique. A clear bias towards underaging, as 68 (20.1%) had known ages older than the estimated age based on the Suchey-Brooks criteria.

The range of documented ages of the individuals observed within each phase is presented in Table 6.169. The published descriptive statistics for the Suchey-Brooks pubic age determination of male individuals (Brooks and Suchey, 1990:233) were also provided in Table 6.169 for comparison. In addition to the 95% confidence interval, new maximum age limits for each surface phase are also suggested to aid in age estimation.

Table 6.169: *Comparison of published Suchey-Brooks (1990:233) descriptive statistics and recorded observations of male individuals in the combined study sample (N = 338).*

Phase	Suchey-Brooks (1990)			Combined male sample				
	Mean age (years)	Standard deviation	95% Range (years)	N	Mean age (years)	Standard deviation	95% Range (years)	Maximum age limit
I	18.5	2.1	15–23	0	-	-	-	n/a
II	23.4	3.6	19–34	0	-	-	-	n/a
III	28.7	6.5	21–46	7	51.3	7.5	44–58	< 60 years
IV	35.2	9.4	23–57	37	55.0	9.2	51–58	< 75 years
V	45.6	10.4	27–66	125	61.5	10.8	59–63	< 90 years
VI	61.2	12.2	34–86	169	73.7	10.6	72–75	35+ years

6.7.1.2 Female

At least one pubic symphysis was present for analysis in 251 females. Known age of each individual was plotted against the estimated age (Brooks and Suchey, 1990: 233) (Figure 6.134), using a range (95% range) unique to each age stage. The 95% confidence interval is denoted by one or two black vertical lines and a grey shaded area. Outliers are highlighted in orange circles and indicated where the known age for the individual fell out of the age range for that particular stage.

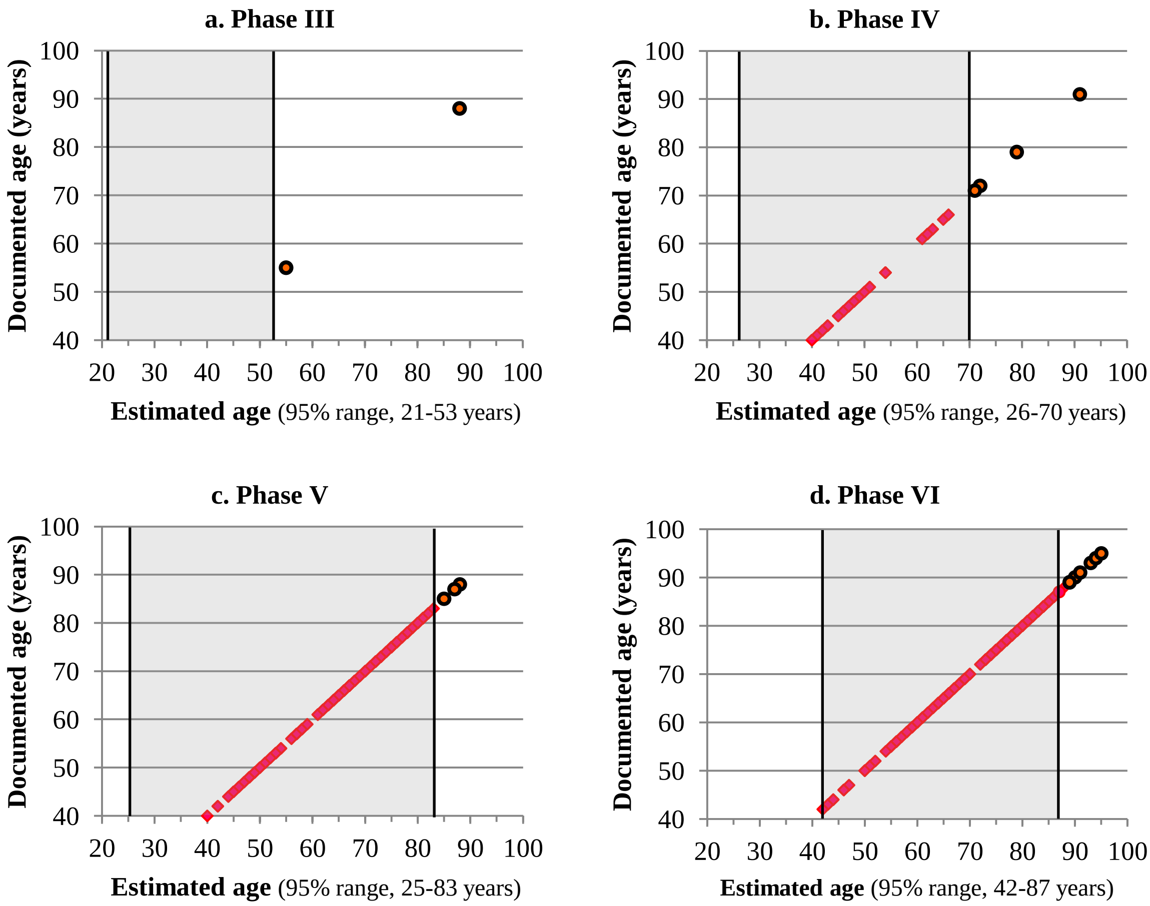


Figure 6.134: *Observed Suchey-Brooks (1990) phases for females, compared with estimated and documented ages in the combined study sample.*

Table 6.170 depicts the frequency that the documented age fell within the 95% range of the surface phase suggested by the Suchey-Brooks pubic symphysis age determination method. Bias was determined by the trend of overageing or underageing of individuals whose documented age was not accurately described by either range.

Table 6.170: *Summary of estimated ages in the combined study sample, based on the Suchey-Brooks (1990) 95% ranges developed for female pubic symphysis phases.*

Phase	N	Actual age range of individuals (years)	Estimated age			Bias		
			95% range (years)	N	%	N	%	Trend
I	0	-	-	-	-	-	-	-
II	0	-	-	-	-	-	-	-
III	2	55–88	21–53	1	50.0	1	50.0	underaged
IV	29	40–91	26–70	25	86.2	4	13.8	underaged
V	96	40–88	25–83	92	95.8	4	4.2	underaged
VI	124	42–95	42–87	113	91.1	11	8.9	underaged
Total	251	-	-	231	**92.0**	20	**8.0**	**underaged**

Of the 251 females in the combined study sample, the known age of 92.0% fell within the 95% range of the original technique. A bias towards underaging was suggested, as 20 (8.0%) had known ages older than the estimated age based on the Suchey-Brooks criteria.

The range of documented ages of the individuals observed within each phase is presented in Table 6.171. The published descriptive statistics for the Suchey-Brooks pubic age determination of female individuals (Brooks and Suchey, 1990:233) are also provided in Table 6.171 for comparison. In addition to the 95% confidence interval, a broader range with which to estimate age was also provided for each age phase.

Table 6.171: *Comparison of published Suchey-Brooks (1990:233) criteria and recorded observations of female individuals in the combined study sample (N = 251).*

Phase	Suchey-Brooks (1990)			Females				
	Mean age (years)	**Standard deviation**	**95% Range (years)**	**N**	**Mean age (years)**	**Standard deviation**	**95% Range (years)**	**Newly proposed age limits**
I	19.4	2.6	15–24	0	-	-	-	-
II	25.0	4.9	19–40	0	-	-	-	-
III	30.7	8.1	21–53	2	71.5	23.3	*	< 60 years
IV	38.2	10.9	26–70	29	54.9	12.5	50–60	< 75 years
V	48.1	14.6	25–83	96	65.5	12.1	63–68	< 90 years
VI	60.0	12.4	42–87	124	72.7	13.0	70–75	40+ years

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.7.1.3 PHASE VII

To evaluate whether the proposed phase VII of pubic symphysis degeneration indicates an individual is over the age of 70 years, the documented ages were plotted against pubic symphysis phase for males and females in a scatter plot (left side), with a regression line for both sets of data (Figure 6.135). The regression lines indicate that there was some difference between sexes (males, $r_s = 0.584$, $P < 0.001$; females, $r_s = 0.416$, $P < 0.001$).

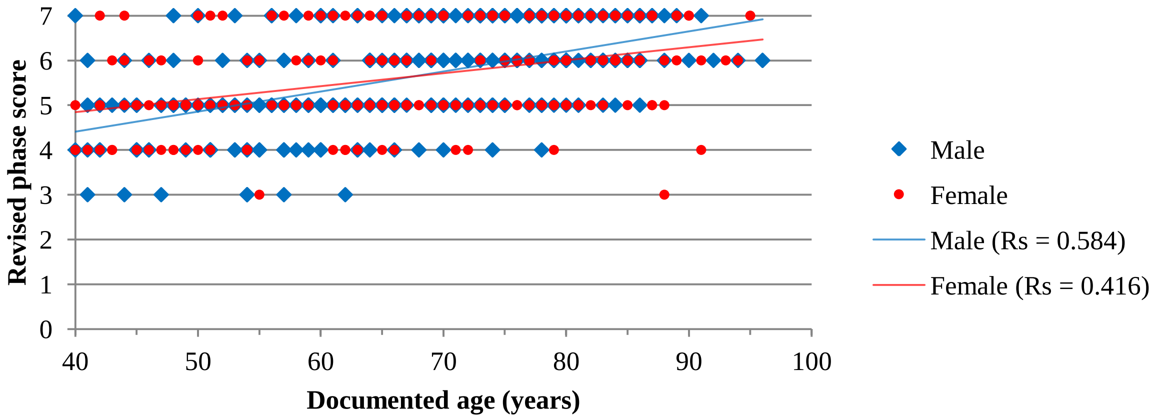


Figure 6.135: *Scatter plot of revised pubic symphysis phase score against known age for combined sample. Spearman's rank correlation coefficients of score against age for males and females are provided.*

The descriptive statistics of age variation within surface phases for males and females (Tables 6.172 and 6.173, respectively) revealed the overall trend of increasing age with increasing phase score. Significant differences were not present between Phases VI and VII, indicating the addition of a seventh phase of pubic symphysis degeneration would not add to the ageing ability of the pubic symphysis degeneration. Significant differences were not found between phases VI and VII for either sex.

Table 6.172: *Descriptive statistics for documented ages-at-death found to possess same pubic symphysis phase of males in the combined study sample (N = 338).*

Phase	N	Mean age (years)	Standard deviation	95% range (years)
I	0	-	-	-
II	0	-	-	-
III	7	51.3	7.5	44–58
IV	37	55.0	9.2	52–58
V	124	61.4	10.8	59–63
VI	85	73.2	11.5	70–76
VII	85	74.2	9.7	72–76

Table 6.173: *Descriptive statistics for documented ages-at-death found to possess same pubic symphysis phase of females in the combined study sample (N = 251).*

Phase	N	Mean age (years)	Standard deviation	95% range (years)
I	0	-	-	-
II	0	-	-	-
III	2	71.5	23.3	*
IV	29	54.9	12.5	50–60
V	96	65.5	12.1	63–68
VI	53	70.9	14.5	66–75
VII	72	73.8	11.7	71–77

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.7.2 PUBIC SYMPHYSIS RESULTS: BLIND TEST

A blind test was performed on the left pubic symphysis of 62 randomly chosen individuals from the Christ Church Spitalfields Documented Skeletal Collection (CCS). The right side was substituted if the left was absent. The sample comprised 30 males with age-at-death ranging from 40-91 years (mean age, 61.7 years) and 32 females, ranging between 44-89 years (mean age, 62.8 years) (Table 6.174).

Table 6.174: *Suchey-Brooks (1990), blind test: age construction of the CCS sample.*

	Age category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	4	8	9	7	2	**30**
Female	6	10	7	4	5	**32**
Total	**10**	**18**	**16**	**11**	**7**	**62**

Each pubic symphysis was compared with written descriptions (Brooks and Suchey, 1990:232-233), drawings (Buikstra and Ubelaker, 1994:23-24) and casts (Suchey et al., 1988) of the six male and female Suchey-Brooks (1990) phases. Age was estimated by comparison of the Brooks and Suchey (1990:233) phases and descriptive statistics (i.e. the mean age, standard deviation (SD), and the 95% range), as well as the newly proposed age limits.

6.7.2.1 Male

At least one pubic symphysis was present for analysis in 30 males. Known age of each individual was plotted against the estimated age (Figure 6.136). Age estimations were made using a range(s) unique to each age stage.

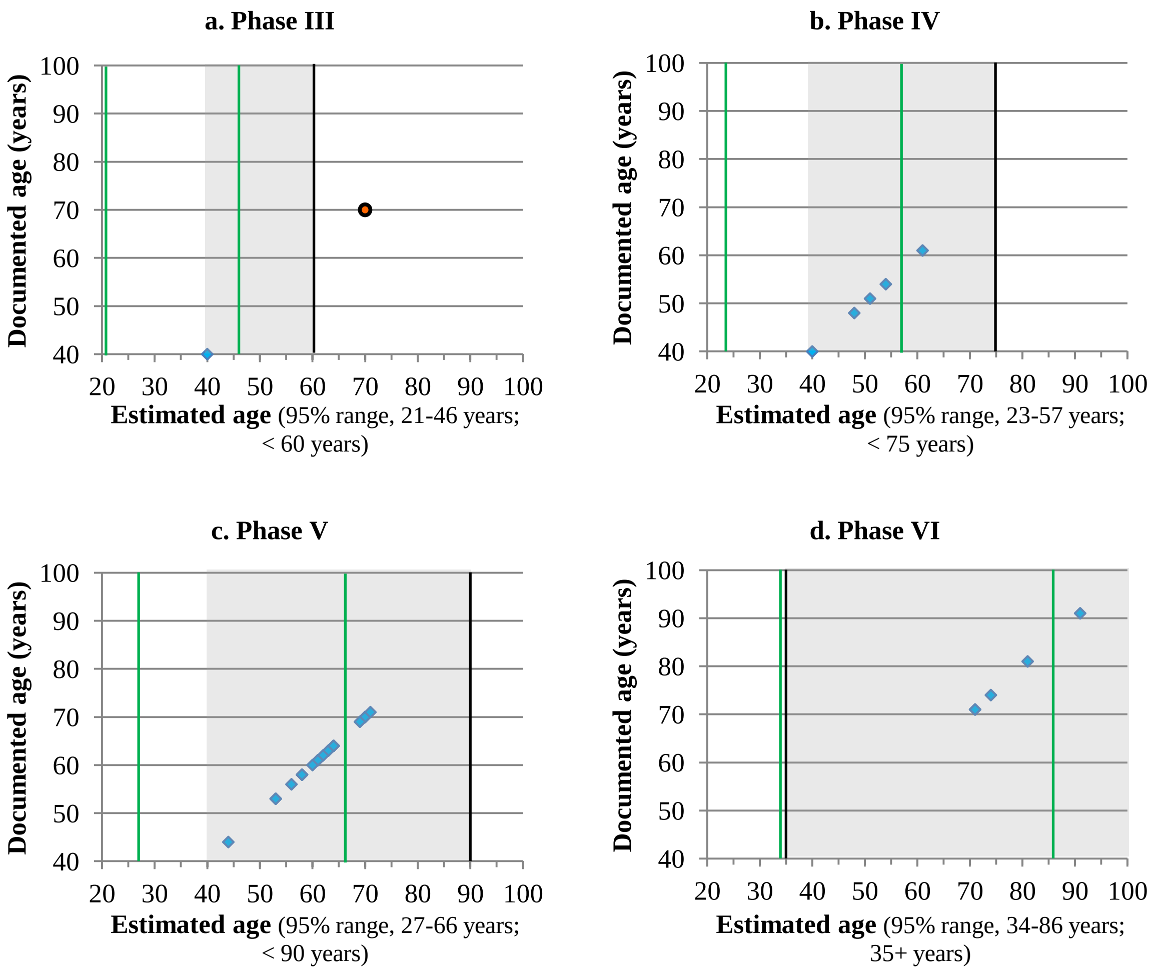


Figure 6.136a-d: *Observed Suchey-Brooks (1990) phases for males, compared with estimated and documented ages in the blind test sample.*

Table 6.175 depicts the frequency that the documented age fell within one standard deviation of the mean age suggested by the Suchey-Brooks pubic symphysis age determination method, as well as the frequency the documented age fell within the 95% range, and the newly suggested age limits. Bias was determined by the trend of overageing or underageing of individuals whose documented age was not accurately described by any of the ranges.

Table 6.175: Suchey-Brooks (1990), blind test: age estimations based on the appearance of the pubic symphysis in males.

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age range			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	0	-	-	-	-	-	-	-	-	-	-
II	0	-	-	-	-	-	-	-	-	-	-
III	2	40–70	21–46	1	50.0	< 60	1	50.0	1	50.0	underaged
IV	5	40–61	23–57	4	80.0	< 75	5	100.0	0	0	no bias
V	18	44–71	27–66	14	77.8	< 90	18	100.0	0	0	no bias
VI	5	71–91	34–86	4	80.0	35+	5	100.0	0	0	no bias
Total	30	-	-	23	**76.7**	-	29	**96.7**	1	**3.3**	**underaged**

Of the 30 male individuals, 76.7% fell within the 95% confidence interval based on this method, and 96.7% fell within the age range.

6.7.2.2 Female

At least one pubic symphysis was present for analysis in 32 females. The known age of each individual was plotted against the estimated age (Figure 6.137), using a range(s) unique to each age stage.

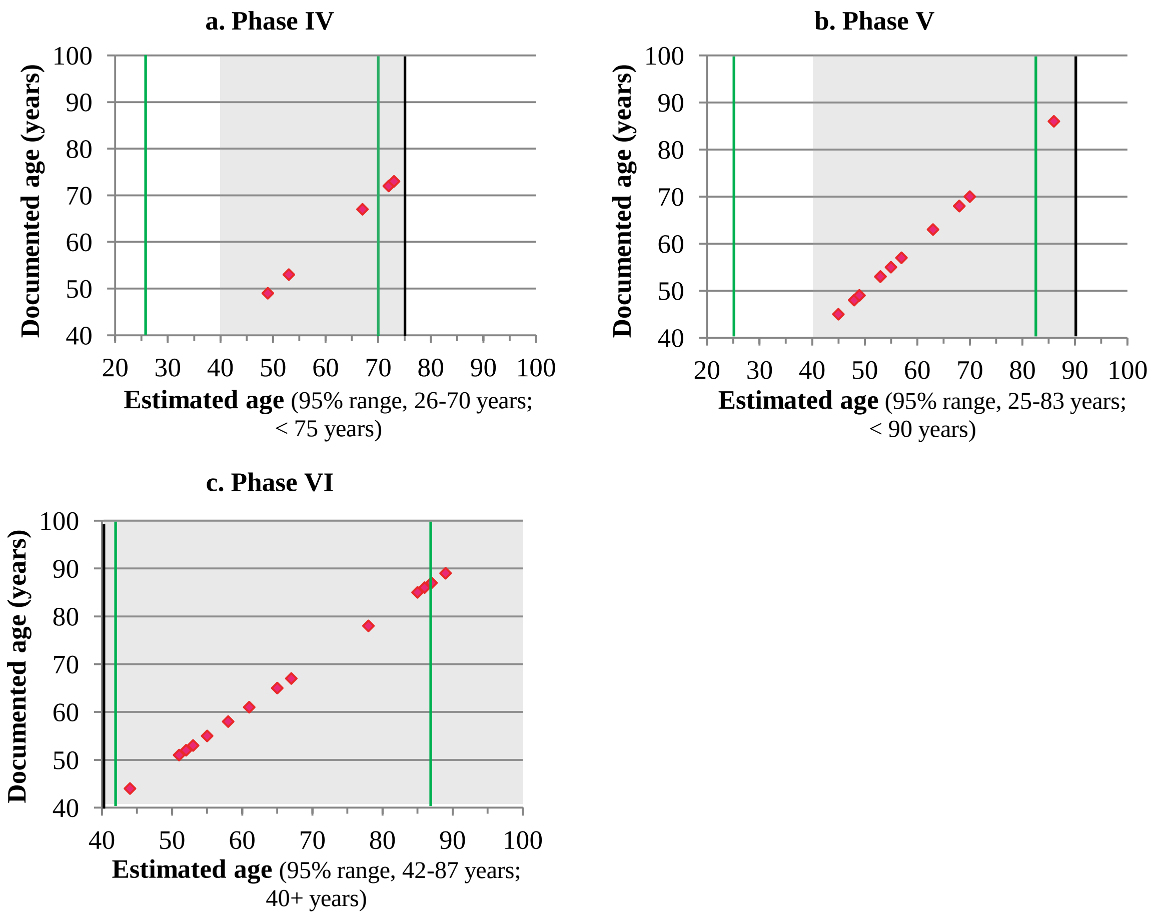


***Figure 6.137a-c**: Observed Suchey-Brooks (1990) phases for females, compared with estimated and documented ages in the CCS sample.*

Table 6.176 depicts the frequency that the documented age fell within one standard deviation of the mean age suggested by the Suchey-Brooks method, as well as the frequency the documented age fell within the 95% range and new age limit. Bias was determined by the trend of overageing or underageing of individuals whose documented age was not accurately described by any of the ranges.

Table 6.176: *Suchey-Brooks (1990), blind test: age estimations based on the appearance of the pubic symphysis in females.*

Stage of appearance	N	Actual age range of individuals (years)	Estimated age						Inaccuracy		
			Within 95% confidence interval			Within age range			Under- or overaged		
			Range (years)	N	%	Range (years)	N	%	N	%	Bias
I	0	-	-	-	-	-	-	-	-	-	-
II	0	-	-	-	-	-	-	-	-	-	-
III	0	-		-	-	< 60	-	-	-	-	-
IV	5	49–73	26–70	3	60.0	< 75	5	100.0	0	0	no bias
V	13	45–86	25–83	12	92.3	< 90	13	100.0	0	0	no bias
VI	14	44–89	42–87	13	92.9	40+	14	100.0	0	0	no bias
Total	32	-	-	28	**87.5**	-	32	**100.0**	0	0	**no bias**

Of the 32 female individuals, 87.5% fell within the 95% confidence interval based on this method, and 100.0% fell within the age range.

6.7.6.3 Additional Observations

To evaluate whether pubic symphysis degeneration, as scored using the Suchey-Brooks criteria, is correlated with age-at-death, the documented ages were plotted against pubic symphysis phase for males and females in a scatter plot, with a regression line for both sets of data (Figure 6.138). The regression lines indicate that there was a large difference between sexes (males, $r_s = 0.700$, $P < 0.001$; females, $r_s = 0.207$, $P = 0.444$), as pubic symphysis degeneration was non-significantly correlated with age in females.

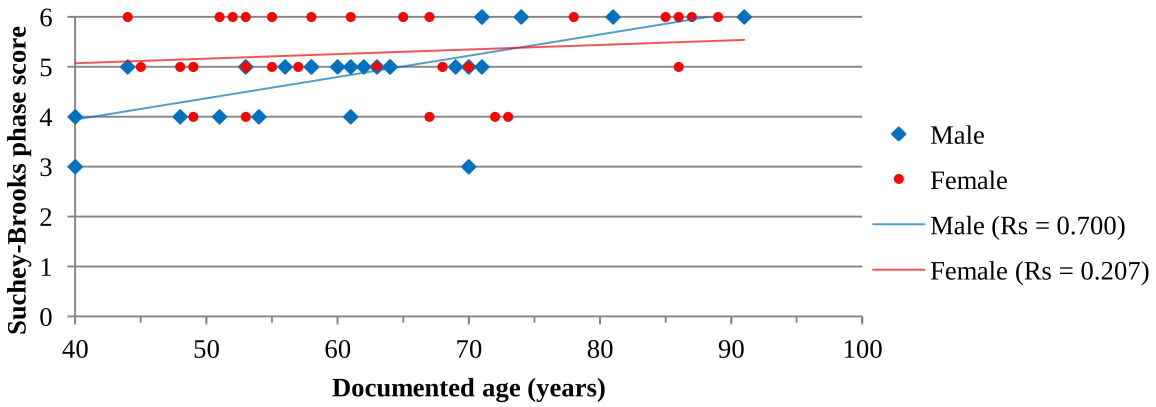


Figure 6.138: *Suchey-Brooks (1990), blind test: scatter plot of pubic symphysis phase score against known age. Spearman's rank correlation coefficients of score against age for males and females are provided.*

The range of documented ages of the individuals observed within each phase is presented in Table 6.177. The published descriptive statistics for the Suchey-Brooks pubic age determination of male individuals (Brooks and Suchey, 1990:233) are also provided in Table 6.177 for comparison.

Table 6.177: *Comparison of published Suchey-Brooks (1990:233) criteria and recorded observations of male individuals in the blind test sample (N = 30).*

Phase	Suchey-Brooks (1990)			Males			
	Mean age (years)	Standard deviation	95% Range (years)	N	Mean age (years)	Standard deviation	95% Range (years)
I	18.5	2.1	15–23	0	-	-	-
II	23.4	3.6	19–34	0	-	-	-
III	28.7	6.5	21–46	2	55.0	21.2	*
IV	35.2	9.4	23–57	5	50.8	7.7	*
V	45.6	10.4	27–66	18	61.0	7.0	57–65
VI	61.2	12.2	34–86	5	77.6	8.5	*

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

The range of documented ages of the individuals observed within each phase is presented in Table 6.178. The published descriptive statistics for the Suchey-Brooks pubic age determination of female individuals (Brooks and Suchey, 1990:233) are also provided in Table 6.178 for comparison.

Table 6.178: *Comparison of published Suchey-Brooks (1990:233) criteria and recorded observations of female individuals in the blind test sample (N = 32).*

Phase	Suchey-Brooks (1990)			Females			
	Mean age (years)	Standard deviation	95% Range (years)	N	Mean age (years)	Standard deviation	95% Range (years)
I	19.4	2.6	15–24	0	-	-	-
II	25.0	4.9	19–40	0	-	-	-
III	30.7	8.1	21–53	0	-	-	-
IV	38.2	10.9	26–70	5	62.8	11.1	*
V	48.1	14.6	25–83	13	58.8	11.7	51–66
VI	60.0	12.4	42–87	14	66.5	15.6	57–75

*Key: * a sample size greater than five is required to obtain a reliable 95% confidence interval.*

6.8 RESULTS: ISCHIAL TUBEROSITY

Although three features of the ischial tuberosity were originally recorded (i.e. surface topography, porosity, osteophyte formation), only surface topography was ultimately explored. Porosity resulting from degeneration was difficult to decipher from non-pathological surface defects displayed by some individuals. Osteophyte formations on the superior and medial aspects of the ischium were prone to damage, and were not able to be accurately recorded in all individuals. As a result, these traits were removed from any further analysis. The raw data for each study sample is provided in Appendix 4.15, and the statistical analyses in Appendix 5.14. The results of the combined sample and the blind test are presented in this section (blind test data in Appendix 6.29).

The surface topography of the ischial tuberosity was graded on a four-point scale (1 = smooth/fine granulation, 2 = coarse granulation/rugged patches, 3 = nodule formation, 4 = severe surface irregularity).

6.8.1 ISCHIAL TUBEROSITY RESULTS: COMBINED SAMPLE

As each individual reference collection indicated no significant differences between males and females, all individuals were combined for these results. The topography scores and known age for each collection were plotted against the others (Figure 6.139) to assess whether similar patterns of degeneration were present between populations. The pattern of trait expression was very similar, as no obvious population-specific groupings of trait expressions were observed.

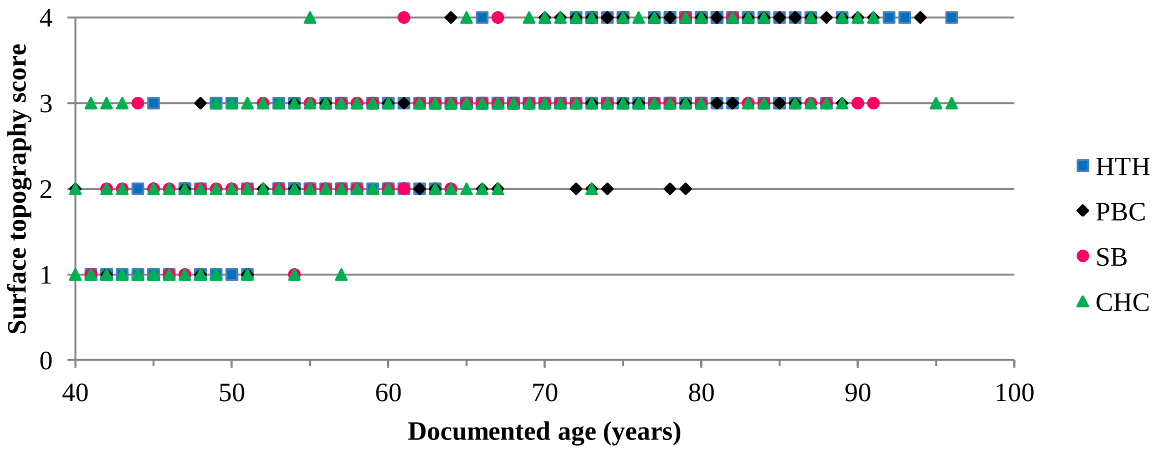


Figure 6.139: *Ischial tuberosity: scatter plot of recorded surface topography score against known age for the combined study sample.*

This study was performed on the superior portion of the left ischial tuberosity of 615 (mean age, 67.1 years). This combined sample comprised 342 males with age-at-death ranging from 40-96 years (mean age, 66.5 years) and 273 females, ranging between 40-95 years (mean age, 67.9 years) (Table 6.179).

Table 6.179: *Ischial tuberosity: age composition of combined study sample.*

	Age Category (years)					Total
	40-49	50-59	60-69	70-79	80+	
Male	41	68	78	93	62	**342**
Female	36	41	63	68	65	**273**
Total	**77**	**109**	**141**	**161**	**127**	**615**

6.8.1.1 Surface Score and Age-at-Death

Trait expressions of a higher individual score were found to cluster within the older age range (see Figure 6.140).

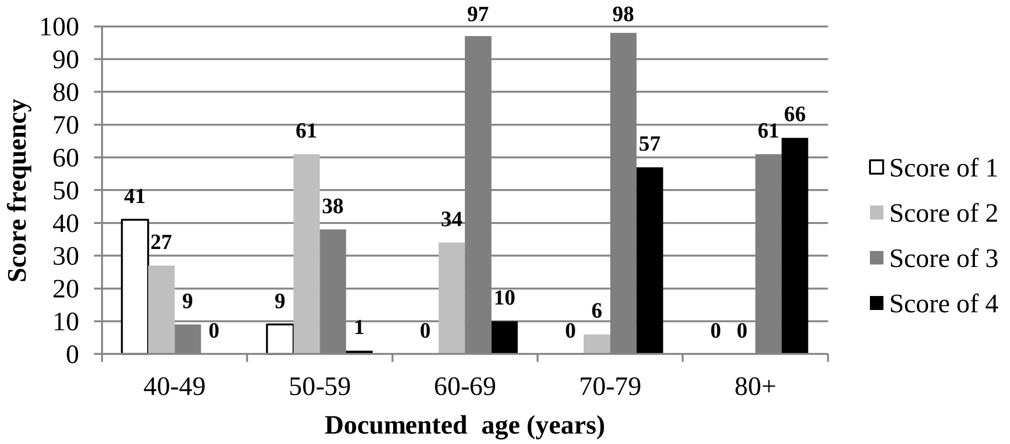


Figure 6.140: *Ischial tuberosity: number of observations of surface scores recorded in the combined study sample.*

Surface topography had observable morphological differences (identified by observed trait score), which altered their expression over a generalized age range. Surface topography expression was investigated for its association with documented age. A scatter plot of trait scores was plotted against age-at-death (Figure 6.141). To test whether osteophyte formation is correlated with age-at-death, a Spearman's rank correlation coefficient was calculated. The result found surface topography to be significantly correlated with age-at-death ($r_s = 0.745$, $P < 0.001$).

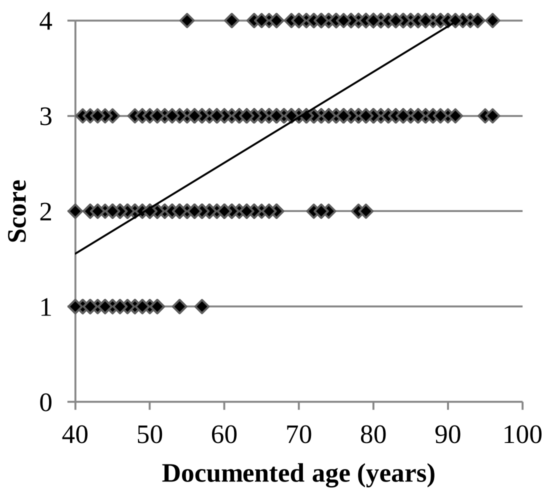


Figure 6.141: *Ischial tuberosity: scatter plot of surface topography score against age-at-death. Spearman's rank correlation coefficient:* $r_s = 0.745$.

The descriptive statistics of age variation within trait scores (Table 6.180) revealed the overall trend of increasing age with increasing surface score. In addition to the 95% confidence interval, a broader age phase with which to estimate age was also provided for each surface topography score.

Table 6.180: *Ischial tuberosity: descriptive statistics for documented ages-at-death found to possess same surface topography score in the combined study sample (males and females).*

Score	N	Mean age (years)	Standard deviation	Median age (years)	Observed range (years)	95% confidence interval (years)	Age estimate (age phase)
1	50	45.8	4.1	45	40–57	44–47	< 60 years
2	128	55.6	7.7	55	40–79	54–57	< 70 years
3	303	70.3	10.3	70	41–96	69–71	50+ years
4	134	78.9	7.4	79	55–96	77–80	70+ years

Unpaired *t*-tests were employed to test for statistically significant differences between the scores (i.e. to determine whether independent stages of degeneration were identifiable) (Table 6.181). All were found to be statistically significant (i.e. $P < 0.05$; statistically distinct stages of degeneration).

Table 6.181: *Ischial tuberosity: results of t-tests between scores.*

Scores compared	*t*	df	*P*
1 vs 2	-10.96	159	< 0.001
2 vs 3	-16.35	315	< 0.001
3 vs 4	-9.92	347	< 0.001

6.8.1.2 Intraobserver Error

A subsample (10 males and 10 females; n = 80) from each of the four skeletal collections were re-recorded to test the reproducibility of observation (i.e. intraobserver error). A paired *t*-test was used to determine any significant differences in the trait scores recorded between the two occasions. No statistically significant difference was found ($t = -0.73$, df = 79, $P = 0.470$).

6.8.1.3 Association Surface Trait Expression and DISH

To assess whether DISH significantly affected the severity of surface topography of the ischial tuberosity, the trait scores of individuals displaying the osseous changes to the thoracic vertebrae were plotted against the scores of individuals that did not demonstrate signs of DISH (Figure 6.142). As before, HTH was not included in this analysis. The results did not show any obvious trends towards surface degeneration in individuals with DISH, suggesting DISH is not a significant factor in the degeneration of the ischial tuberosity.

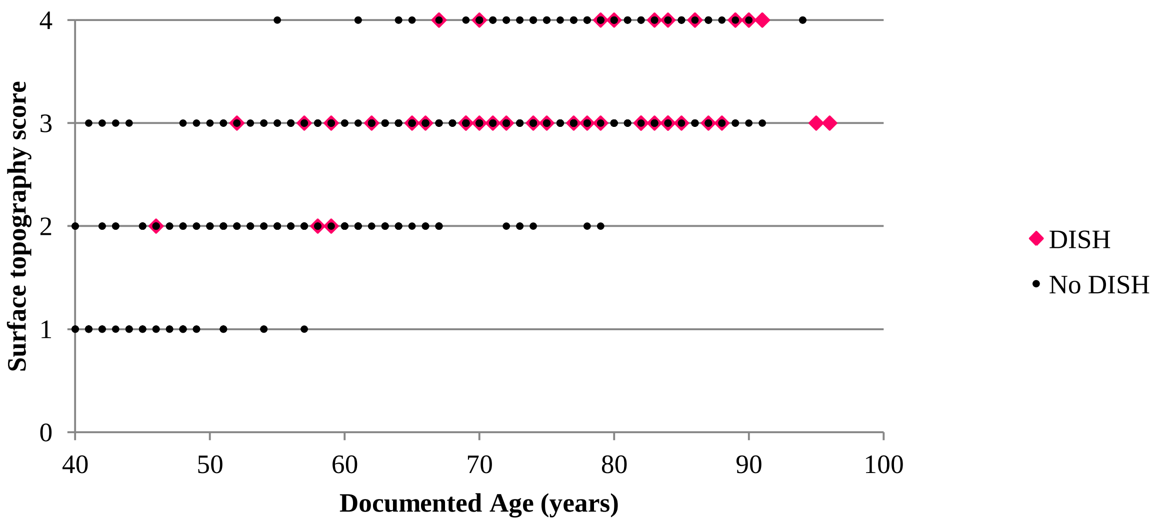


Figure 6.142: *Plot of ischial tuberosity topography score against documented age of individuals with DISH, and those without.*

6.8.2 ISCHIAL TUBEROSITY RESULTS: BLIND TEST

The blind test was performed on the upper portion of the left ischial tuberosity of 83 individuals from the Christ Church Spitalfields documented collection (CCS). The right ischium was substituted if the left was absent or poorly preserved. The sample comprised 44 males with age-at-death ranging from 40-91 years (mean age, 62.1 years) and 39 females, ranging between 44-89 years (mean age, 62.4 years) (Table 6.182).

Table 6.182: *Ischial tuberosity, blind test: age composition of the CCS sample.*

	Age Category (years)					**Total**
	40-49	**50-59**	**60-69**	**70-79**	**80+**	
Male	6	13	11	10	4	**44**
Female	7	12	8	8	4	**39**
Total	**13**	**25**	**19**	**18**	**8**	**83**

As sexually dimorphic ageing criteria were not found to be required, all CCS individuals were assessed together. A plot of surface topography score (age stage) and documented age is presented in Figure 6.143. The developed ageing criteria for each stage was applied to each CCS individual and compared with documented age.

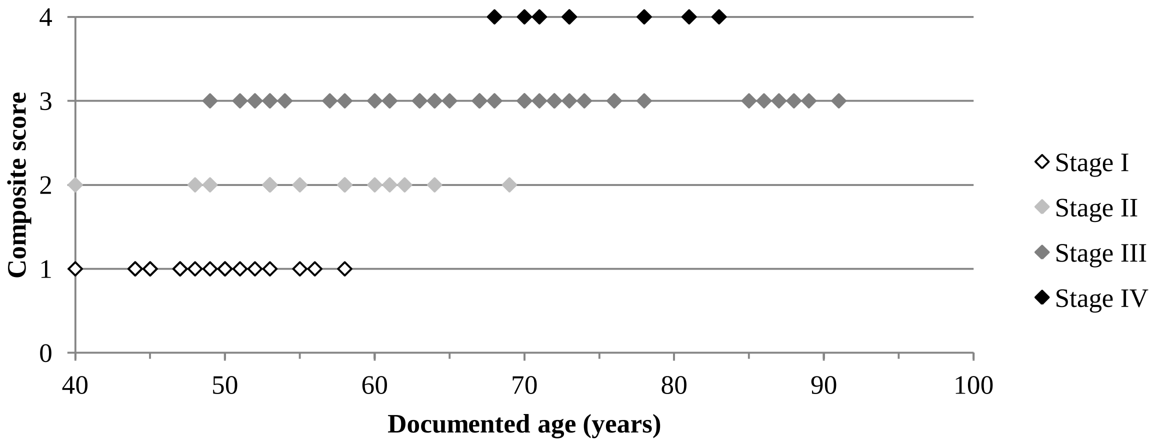


Figure 6.143: *Ischial tuberosity, blind test: scatter plot of composite scores against known age for all individuals in the CCS sample.*

To determine whether the characteristic appearance of each age stage enabled chronological age to be accurately estimated in this sample, the known age of each individual was plotted against the estimated age (Figure 6.144), using a range(s) unique to each age stage.

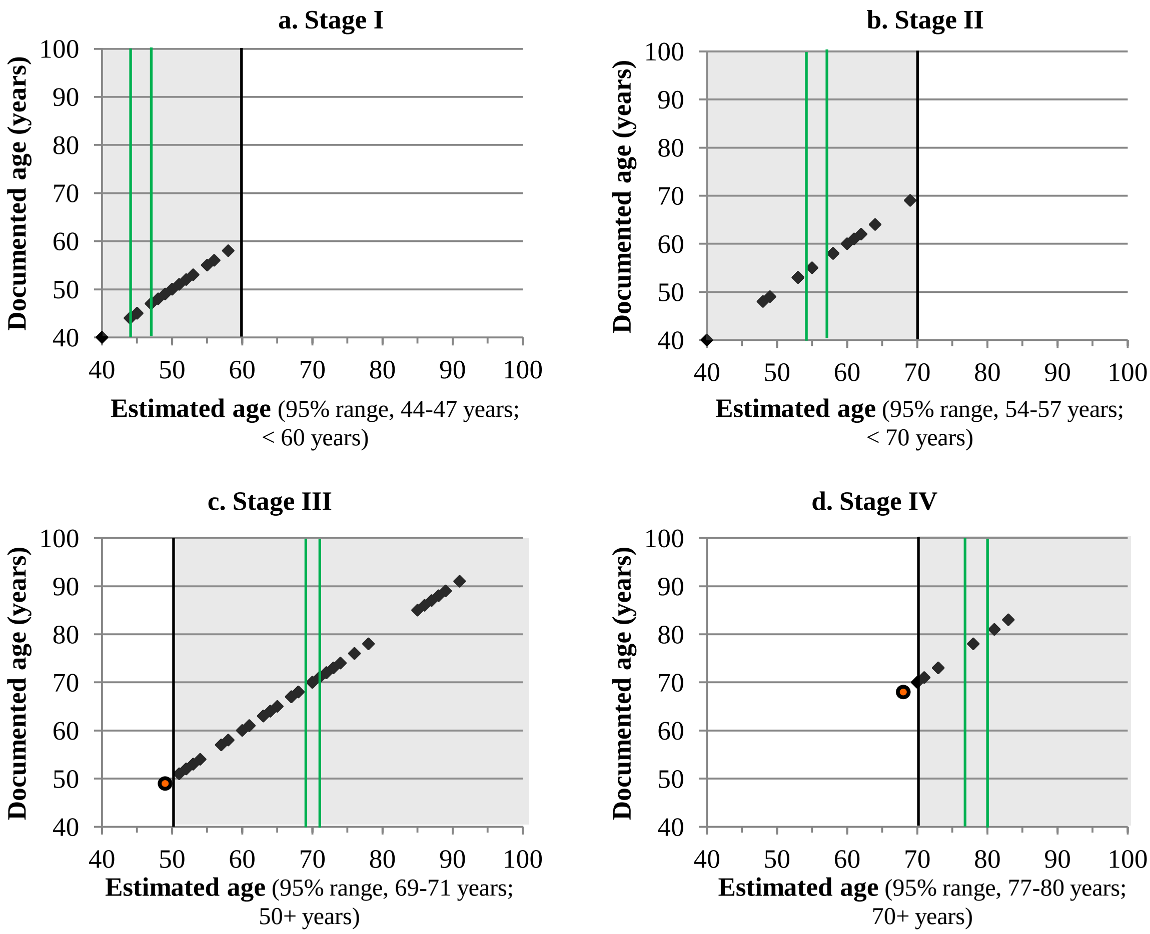


Figure 6.144a-d: *Observed ischial tuberosity surface age stages (estimated age) for CCS individuals, compared with documented ages.*

Table 6.183 summarizes the frequency that the documented age fell within the 95% confidence interval of each age stage, and within the suggested age phase. Those that were not aged within these two ranges were assessed as to whether they were underaged or overaged by the method.

Table 6.183: *Age estimations based on the appearance of the ischial tuberosity in the blind test sample.*

Stage of appearance	**N**	**Actual age range of individuals (years)**	**Estimated age**						**Inaccuracy**		
			Within 95% confidence interval			**Within age phase**			**Under- or overaged**		
			Range (years)	**N**	**%**	**Range (years)**	**N**	**%**	**N**	%	**Bias**
I	17	40–58	44–47	6	35.3	< 60	17	100.0	0	0	no bias
II	17	40–69	54–57	1	5.9	< 70	17	100.0	0	0	no bias
III	41	49–91	69–71	5	12.2	50+	40	97.6	1	2.4	overaged
IV	8	68–83	77–80	1	12.5	70+	7	87.5	1	12.5	overaged
Total	83	-	-	13	**15.7**	-	81	**97.6**	2	**2.4**	**overaged**

Of the 83 individuals, only 15.7% fell within the 95% confidence interval based on this method, and 97.6% fell within the age phase.

6.8.6.1 Additional Analyses

To confirm the relationship between age and surface topography score of the ischial tuberosity, a Spearman's rank correlation was calculated. The result was found to be highly statistically significant ($r_s = 0.753$; $P < 0.001$). The results are plotted in Figure 6.145.

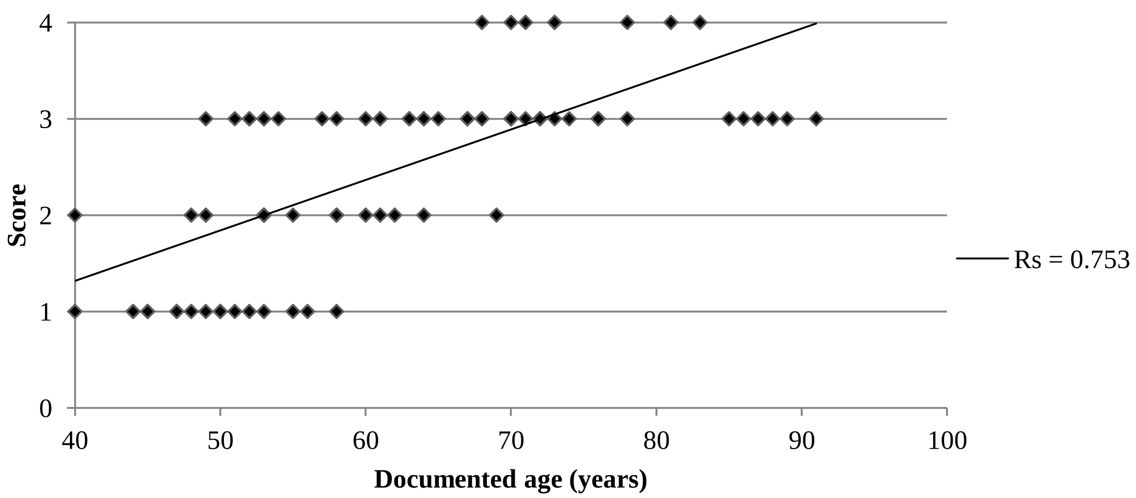


Figure 6.145: *Ischial tuberosity, blind test: scatter plot of surface topography score against known age-at-death for the CCS sample. Spearman's rank correlation coefficient of score against age is provided.*

Comparison of the descriptive statistics of age variation within each score (age stage) (Table 6.184) revealed similar patterns of mean age, standard deviation and 95% confidence intervals between the developed criteria and the CCS blind test sample.

Table 6.184: *Comparison of the descriptive statistics for documented ages-at-death possessing the same ischial tuberosity surface topography score in the combined study sample and blind test sample.*

Score	Developed criteria			CCS blind test sample			
	Mean age (years)	**Standard deviation**	**95% confidence interval (years)**	**N**	**Mean age (years)**	**Standard deviation**	**95% confidence interval (years)**
1	45.8	4.1	44–47	17	49.1	4.8	46–52
2	55.6	7.7	54–57	17	55.7	6.8	52–59
3	70.3	10.3	69–71	41	68.0	11.2	64–72
4	78.9	7.4	77–80	8	74.6	5.4	70–79

CHAPTER SEVEN

NEW AGEING CRITERIA

This chapter presents the new ageing criteria developed based on the results derived in the course of this research. Of the results demonstrated in the previous chapter, arachnoid granulations, degeneration of the sternal articular facet of the manubrium, fusion of the manbrium, sternum and/or xiphoid process, and the pubic symphysis were not found to display characteristics that would allow for confident age estimation, and as a result, are not included in this chapter, although are revisited in Chapter 8. The following sections propose criteria for the cervical vertebrae, clavicle, manubrium, iliac crest, auricular surface, and ischial tuberosity. Written descriptions and photographs are provided for aid in identification of age stages, in addition to descriptive statistics (mean age, standard deviation, 95% confidence interval and age phase) used to produce the age estimates. All described criteria were blind tested on the Christ Church Spitalfields known age collection, and investigations of intraobserver error were found the methods to be repeatable.

On a cautionary note, the criteria developed in the results section are not formal ageing methods, as to apply them to skeletons in their current format, the individual under study would have to be known to be over the age of 40 years. This is due to the use of a truncated reference sample in this study, which has likely skewed the derived age estimates (i.e. mean ages, age ranges, age phases) towards the older end of the age spectrum. Although "Stages I and II" of the described ageing criteria provide adequate assessment of the maximum ages of degeneration, the minimum ages of trait expression will likely be affected by the inclusion of adults aged less than 40 years. If younger individuals (i.e. from the time of epiphyseal fusion of the element under study, to 39 years) were assessed to confirm that they do not display the degenerative stages, and/or at what age degenerative traits do indeed start to appear, then formal ageing techniques could be developed. Although in the remaining discussion the developed criteria are stated as "methods", this is meant in the loosest of terms, as they cannot be currently be applied to all adult individuals at the present time.

7.1 CERVICAL VERTEBRAE: DEGENERATION OF THE ATLAS AND AXIS

As stated in the Results chapter, the degenerative changes to the cervical spines of the SB study sample differed from those recorded in the other three, more modern samples. The differences may result from different activities undertaken between the differing time periods, which placed differing stresses and strains on the necks of the SB individuals. Although the degenerative pattern was different in the SB study sample, and its removal from the final study would have increased the precision of the developed criteria, each cervical spine provides information of the variation in the ageing process. It is possible that degeneration on the cervical vertebrae may only be a modern indicator of age, and future ageing studies should be limited to forensic applications.

7.1.1 DEGENERATION OF THE DENS FACET OF THE ATLAS

By combining all study samples, a true evaluation of trait expression was observed. No difference was present between males and females, and all traits and composite scores were highly statistically correlated with documented age (i.e. composite score, r_s = 0.549, P < 0.001). Similar descriptive statistics for several composite scores produced three distinct stages of dens facet degeneration, each with the ability to provide very broad age estimations.

7.1.1.1 Stage I

Stage I is comprised of composite score 3, where the dens facet on the atlas is generally smooth and rounded in appearance. All traits recorded are lacking expression (i.e. no porosity, osteophytic formation or eburnation). The facet can be flush with the rest of the bone (Figure 7.1a), or slightly elevated off the surface, and cupped in profile (Figure 7.1b). No minimum age limit can be proposed for this stage, as individuals under the age of 40 years were not assessed in the study. It is possible that this smooth appearance is present from the time the first cervical vertebra completes development (at approximately 6 years of age) and can last until the approximate age of 70 years (mean age, 54.4 years; 95% confidence interval, 51–57 years).

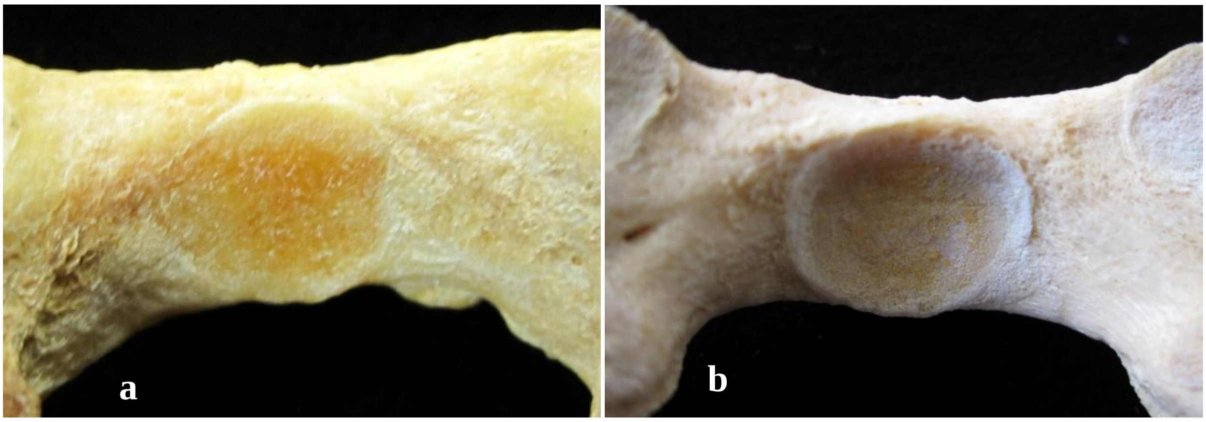


Figure 7.1a-b: *Dens facet of the atlas, Stage I (composite score of 3). (a) dens facet is flush with the surrounding bone, (b) dens facet is slightly raised and cupped in profile.*

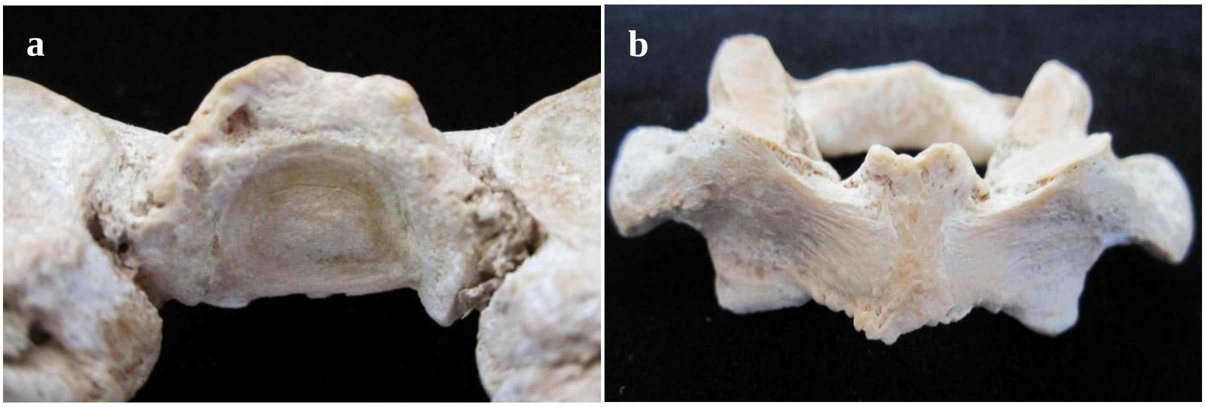
7.1.1.2 Stage II

This stage comprised composite scores 4 and 5. During this stage the surface of the facet is still mostly void of porosity and eburnation (Figure 7.2a). If porosities are present, it is microporosity. Stage II is characterised by the formation of slight to moderate osteophytic lipping around the facet, although the facet is still generally round in shape. The osteophytes are visible from the anterior surface of the vertebra (Figure 7.2b). This stage provides the most non-descript age estimate of all the three stages, with this appearance suggesting an age older than 45 years (mean age, 63.9 years; 95% confidence interval, 62–65 years) based on the 40+ years sample. A maximum cut off was not possible to suggest.

Figure 7.2a-b: *Dens facet of the atlas, Stage II (composite scores of 4 and 5). (a) dens facet is characterised by slight to moderate lipping, (b) osteophytes commonly visible from the anterior aspect of the atlas.*

7.1.1.3 Stage III

This stage is contains composite scores 6, 7 and 8, and signifies peak joint degeneration. All facets display porosity, micro- and/or macroporosity and severe osteophytic lipping. Eburnation may be present (Figure 7.3). Stage III indicates an individual was over the age of 55 years at the time of death (mean age, 75.1 years; 95% confidence interval, 73–76 years).



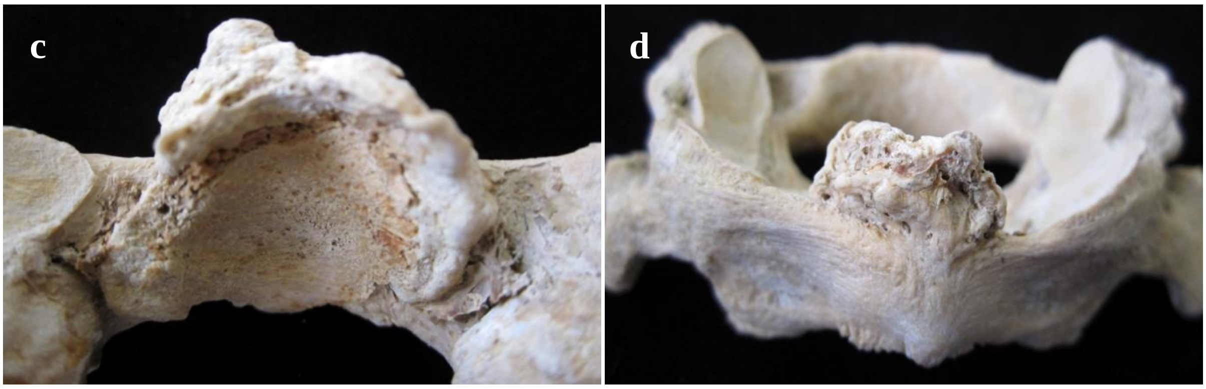


Figure 7.3a-d: *Dens facet of the atlas, Stage III (composite scores 6–8). (a-b) example of composite score 6 (a), and osteophyte formation from the anterior of the atlas (b), (c-d) example of composite score 8 (c), and osteophyte formation from the anterior of the atlas (d).*

7.1.2 DEGENERATION OF THE DENS FACET ON THE AXIS

Descriptive statistics for three distinct stages of dens facet degeneration in males and females separately are produced, each with the ability to place an individual within an age phase. The difference between the sexes occurs with composite score of 4 (i.e. included in stage II for males, and stage I in females).

7.1.2.1 Stage I

Stage I is comprised of composite score 3 in males, and 3 and 4 in females. The facet on the dens process is smooth in texture and does not display any porosity, osteophytic lipping or eburnation in males, and slight osteophytic lipping in females. The facet can be flush with the surrounding bone (Figure7.4a), or slightly raised (Figure7.4b). In males, this stage indicates the individual was under the age of 70 years at the time of death (mean age, 55.1 years; 95% confidence interval, 51–59 years) and under the age of 80 years for females (mean age, 60.8 years; 95% confidence interval, 58–63 years). No minimum age limits are proposed.

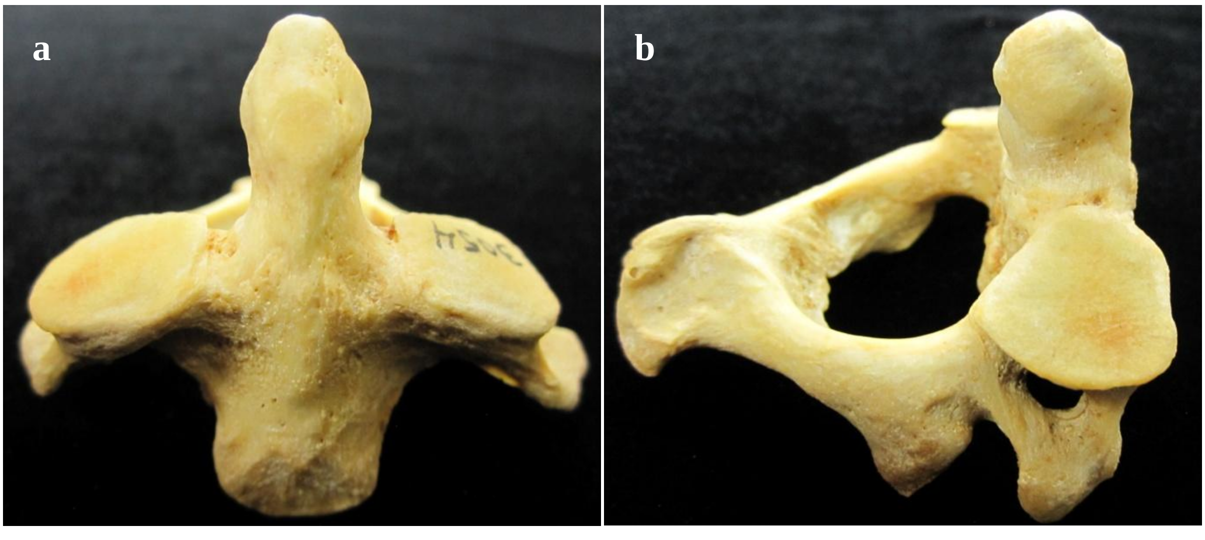


Figure 7.4a-d: *Dens facet of the axis, Stage I (composite score of 3 in males, composite scores of 3 and 4 in females). (a) Composite score of 3, anterior view; (b) lateral view; (c) Composite score of 4, anterior view, (d) lateral view.*

7.1.2.2 Stage II

Male composite scores 4 and 5 are allocated to this age stage, and composite score of 5 for females. This stage is characterised by the presence of both microporosity on the facet, and slight to moderate osteophytic lipping around the edge (Figure 7.5). Eburnation is usually not present. This stage suggests an age under 80 years for males (mean age, 63.6 years; 95% confidence interval, 61–66 years), and between 50 and 80 years for females (mean age, 70.0 years; 95% confidence interval, 66–73 years).

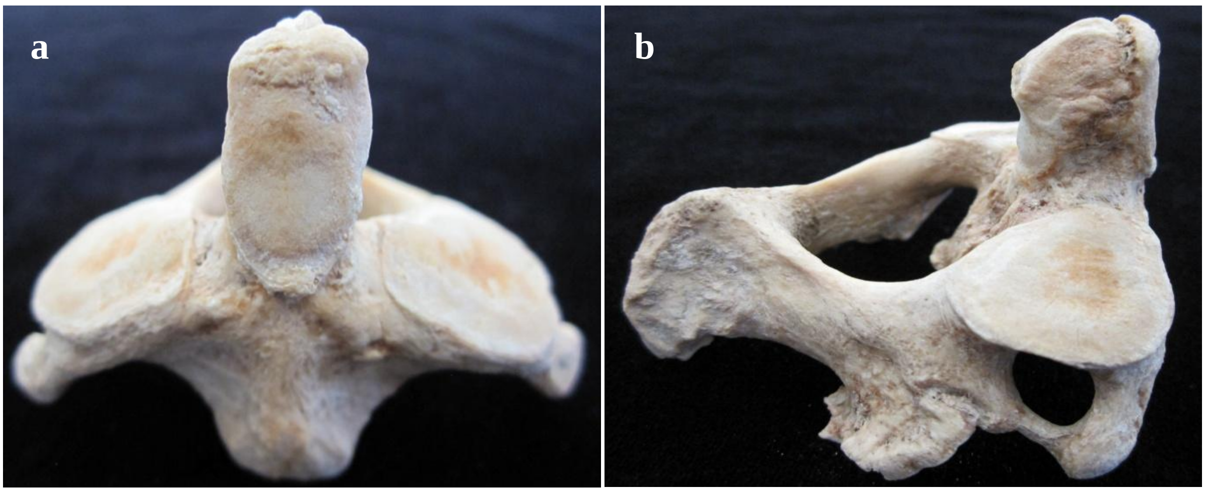


Figure 7.5a-b: *Dens facet of the axis, Stage II (composite scores 4 and 5 in males, composite score of 4 in females). (a) composite score of 5, anterior view, (b) lateral view.*

7.1.2.3 Stage III

The final stage of degeneration is comprised of composite scores 6, 7 and 8 in both males and females. The facet surface displays micro- and/or macroporosity, severe lipping, and may demonstrate patches of eburnation (Figure 7.6). The "age phase" suggested by this stage is over 55 years in males (mean age, 74.5 years; 95% confidence interval, 72–76 years) and over 65 years in females (mean age, 75.1 years; 95% confidence interval, 72–77 years). Based on the 40+ years sample, the presence of eburnation indicates the individual (both sexes) is over the age of 65 years.

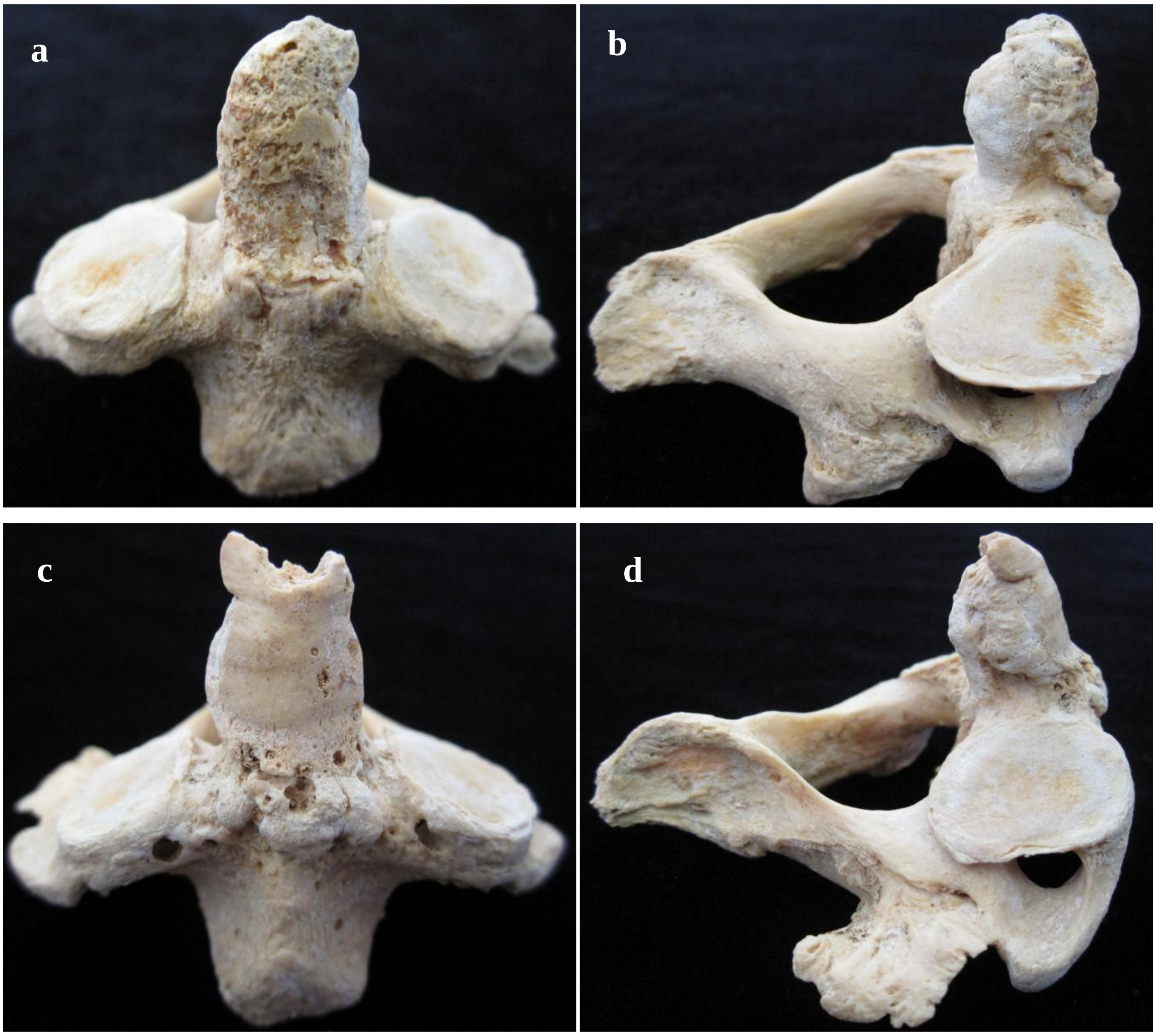


Figure 7.6a-d: *Dens facet of the axis, Stage III (composite scores 6 to 8 in males and females). (a) composite score of 7, anterior view, (b) lateral aspect; (c) composite score of 8, anterior view, (d) lateral view.*

7.1.3 SUMMARY SCORE: COMBINATION OF THE ATLAS AND AXIS COMPOSITE SCORES

Males and females were separated due to the sexually dimorphic trait expression of the dens process. By combining the composite scores for the dens facet of the atlas and the dens process of the axis, the resulting summary score was highly correlated with documented age (i.e. $P < 0.001$). However, in males, the summary score was slightly less correlated with age than the atlas composite score. In contrast, the summary score for females was found to be slightly more correlated with age than the atlas composite score, and much more correlated than the axis composite score.

The summary score was found to form three distinct age stages of the joint. Males' stage I indicates an individual was under the age of 60 years (no lower estimate possible), stage II suggests a minimum age of 45 years, and an individual in stage III is over the age of 60 years. Females' stage I indicates an individual is under 65 years of age, stage II suggests an age between 50 years and 80 years, and stage III indicates an age over 65 years, in this sample.

7.1.4 ACCURACY AND BIAS

The results of the blind tests indicated that the 95% confidence intervals only accurately estimated the age of 16.9% of the CCS sample (males and females combined) using the atlas, and 23.8% of the males and 16.7% of the females were accurately aged using the axis criteria. The generalized age ranges allowed 95.8% of the atlas sample to be accurately aged, while 90.5% of males and 90.0% of females were correctly aged using the axis criteria.

There was no clear direction of bias for the atlas criteria as one individual (1.4%) was underaged by the atlas, and two individuals (2.8%) were overaged. For the female axis criteria, no distinct bias was identified as two individuals (6.7%) were underaged and one (3.3%) was overaged. In comparison, a strong bias towards underaging was observed for the male criteria as four individuals (9.5%) were underaged by this method.

The poor results obtained by the summary scores indicate that the composite scores derived for each articular facet of the dens joint should not be combined to estimate age.

7.2 DEGENERATION OF THE CERVICAL VERTEBRAE: BODIES AND FACETS

7.2.1 DEGENERATION OF THE CERVICAL VERTEBRAL BODIES

Three distinct stages of degeneration were identified in the combined study sample. No difference was found between trait expression in males and females, and all trait expressions were highly correlated with age (i.e. $P < 0.001$). All photographs are of the inferior surface of the seventh cervical vertebral body, unless otherwise stated.

7.2.1.1 Stage I

Stage I is composed of composite scores 4 and 5. The vertebral body is flat and smooth in appearance, with no or slight expression of microporosity and/or osteophytic lipping (Figure 7.7). Surface bone formation and eburnation are absent. No lower age limit is provided, although this stage indicates an individual was under the age of 70 years at the time of death (mean age, 55.6 years; 95% confidence interval, 53–58 years).

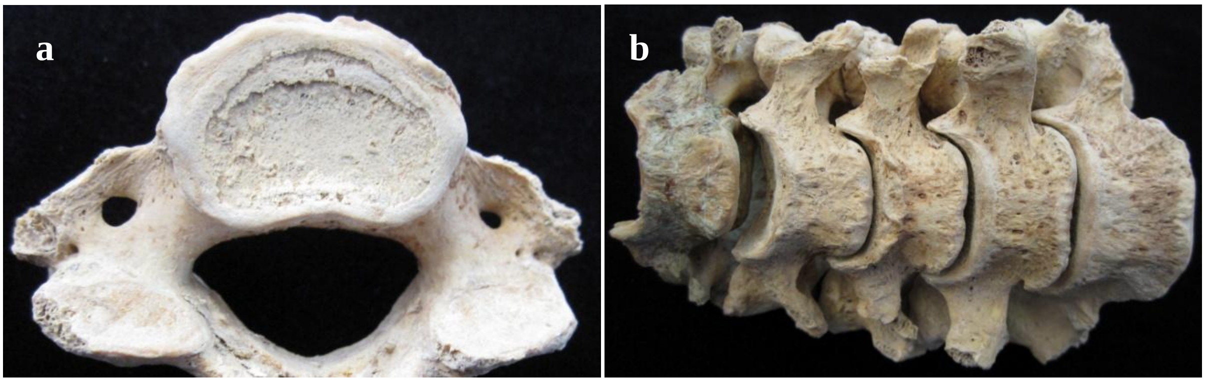


Figure 7.7a-b: *Cervical vertebrae bodies, Stage I (composite scores 4 and 5). Example of composite score of 4, (a) inferior aspect of body, (b) anterior view.*

7.2.1.2 Stage II

Stage II comprises composite scores 6 and 7. During this phase of body degeneration, surface microporosity is frequent, as is slight to moderate osteophytic lipping (Figure 7.8). Surface new bone formation and eburnation can occur, but infrequently. Based on the 40+ years sample, Stage II allows an individual to be assigned to an age phase of over 45 years, and younger than 80 years (mean age, 65.0 years; 95% confidence interval, 63–67 years).

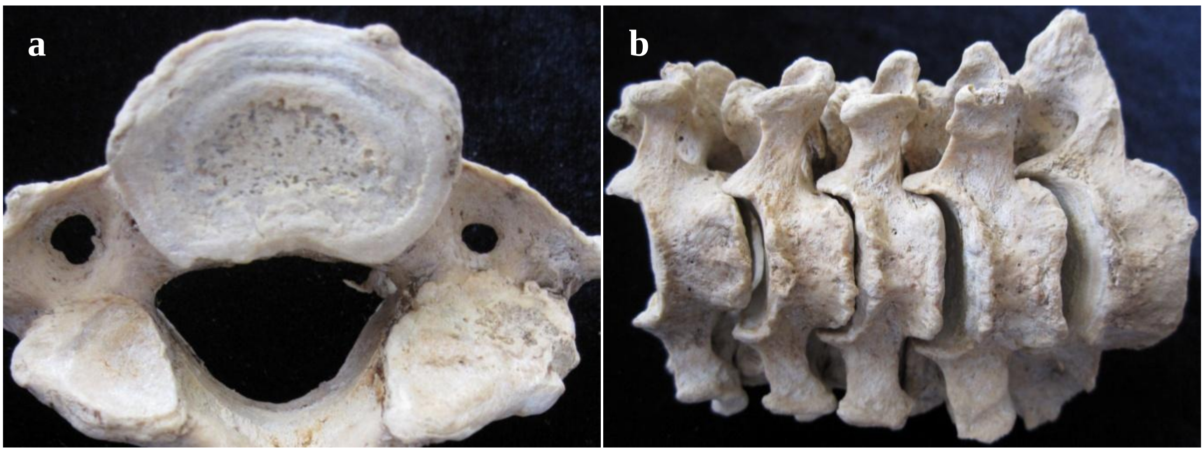


Figure 7.8a-b: *Cervical vertebrae bodies, Stage II (composite scores 6 and 7). Example of composite score of 6, (a) inferior surface of body, (b) anterior view.*

7.2.1.3 Stage III

Stage III indicates peak degeneration of the vertebral bodies (composite scores 8 to 10), and/or fusion of two or more cervical vertebrae (composite scores 13 or 14). In this stage, the surface is highly irregular with frequent macroporosity and new growth (Figure 7.9). Eburnation can occur, and the osteophytic lipping is severe (Figure 7.9c), or ankylosing (Figure 7.9d). This stage indicates an individual is over the age of 65 years (mean age, 75.6 years; 95% confidence interval, 74–77 years).

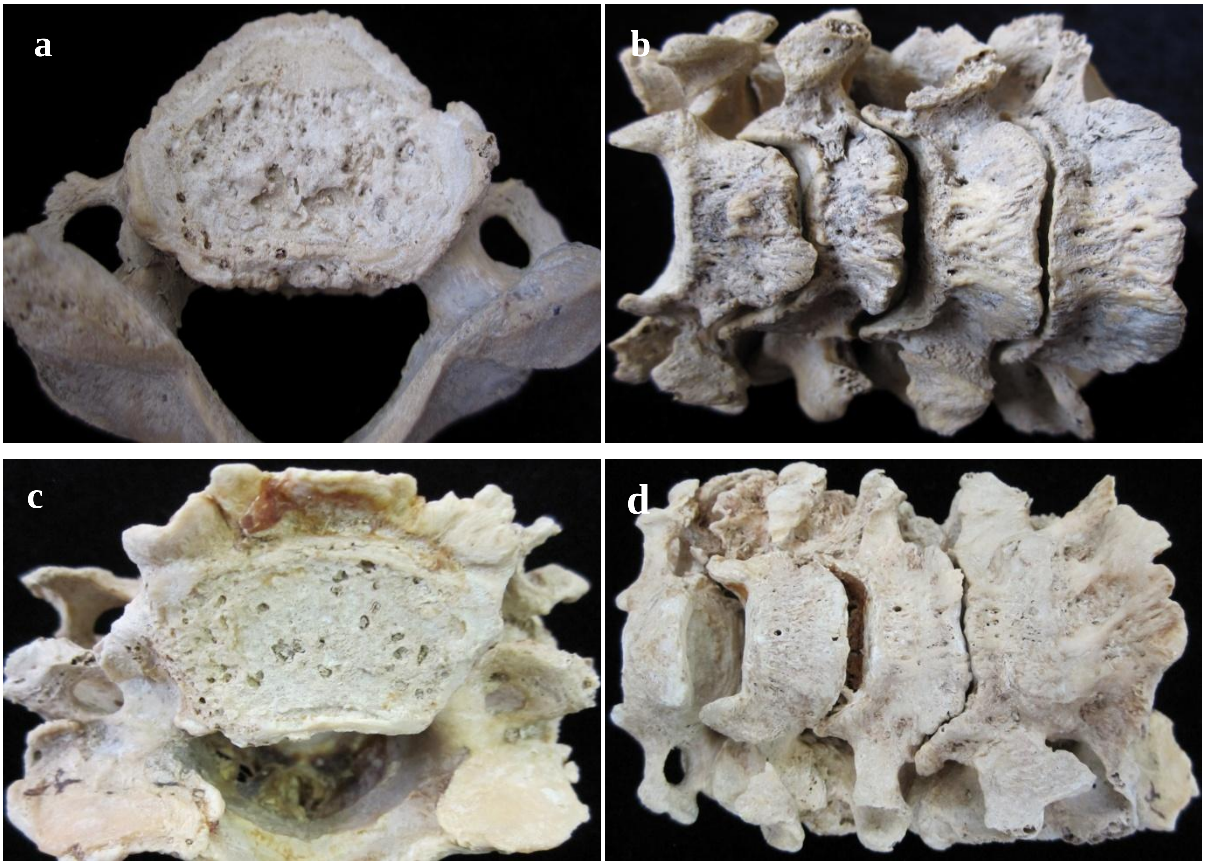


Figure 7.9a-d: *Cervical vertebrae bodies, Stage III (composite scores 8–14). (a+b) Example of composite score of 9, (a) superior view of body, (b) anterior aspect. (c+d) Example of composite score 13 (vertebral ankylosis), (a) inferior view of body, (b) anterior view.*

7.2.2 DEGENERATION OF THE CERVICAL VERTEBRAL FACETS

Degenerative changes in the vertebral facets differed between males and females. Three stages of degeneration were suggested in males, and two for females. Only very broad age estimations were possible, as there is little distinction between degenerative changes and age, especially in females. As a result, only very broad age estimations are possible from the articular facets. All photographs are of the superior surface of the fourth cervical vertebra.

7.2.2.1 Stage I

Composite score 3 for males and 3 and 4 for females. Facets are smooth, no porosity, osteophyte formation or eburnation (Figure 7.10). This stage indicates a male individual is under the age of 70 years (mean age, 56.0 years; 95% range, 53–58 years), under the age of 80 years in females (mean age, 60.8 years; 95% confidence interval, 58–63 years). Minimum age estimates were not produced.

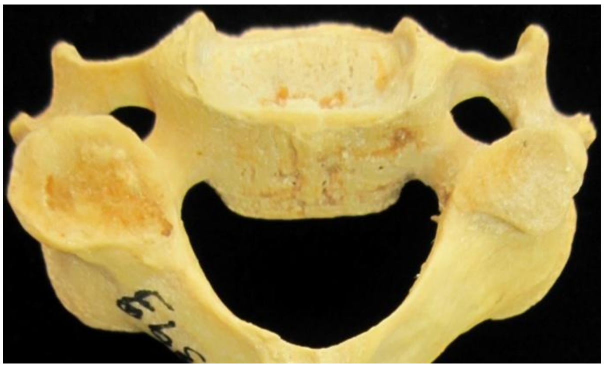


Figure 7.10: *Cervical vertebral facets, Stage I (composite score of 3 in males, and 3 and 4 in females). Example of composite score of 3.*

7.2.2.2 Stage II

Stage II comprises composite scores 4 and 5 in males. While facet degeneration in males progresses into stage III, females reach peak degeneration in stage II (composite scores 5 to 8) (see stage III for trait details). In stage II, the most frequently difference recorded on the facets was osteophytic lipping, although some individuals begin to display microporosity on the surface itself (Figure 7.11). Based on the 40+ years sample, males in this stage indicates the individual is over the age of 50 years, and younger than 80 years (mean age, 67.5 years; 95% confidence interval, 65–70 years). In females, this stage suggests an age over 60 years (mean age, 75.3 years; 95% confidence interval, 73–77 years).

Figure 7.11: *Cervical vertebral facets, Stage II (composite scores of 4-5 in males, and 5-8 in females). Example of composite score of 5.*

7.2.2.3 Stage III

Stage III indicates peak degeneration in males, and is represented by composite scores 6, 7 and 8. In this stage, severe osteophytic lipping around the facets makes the outline irregular (Figure 7.12a). On the surface itself, presence of macroporosity and/or eburnation also add to the irregularity of the facets (Figure 7.12b). Stage III suggests a male individual was over the age of 60 years at the time of death (mean age, 74.0 years; 95% confidence interval, 72–76 years). Again, in females, these observations are present in Stage II.

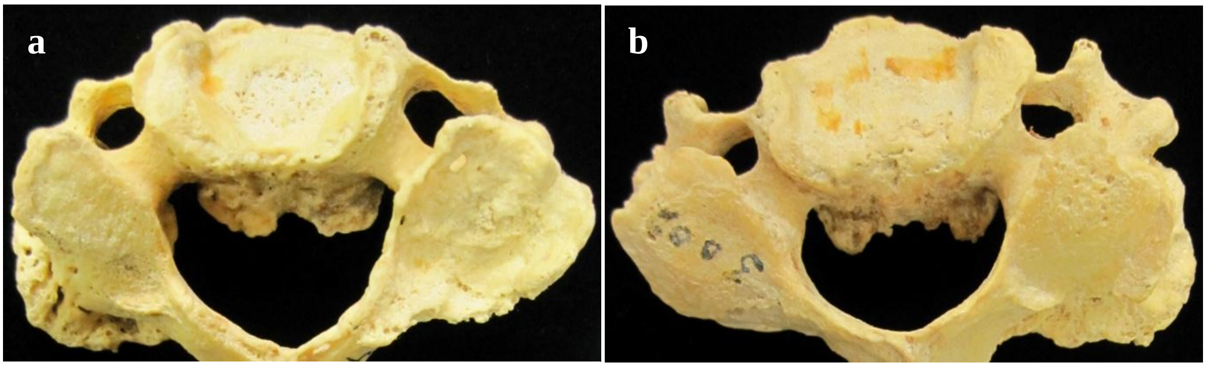


Figure 7.12: *Cervical vertebral facets, Stage III (composite scores 6-8 in males only). Examples of (a) composite score of 6, and (b) composite score of 8 (with eburnation).*

7.2.3 SUMMARY SCORE: COMBINATION OF CERVICAL VERTEBRAL BODY AND FACET COMPOSITE SCORES

By combining the composite scores, a more accurate assessment of the state of degenerative disease in the cervical spine can be reached, as it takes into account the differing degenerative processes (i.e. the bodies degenerate from the lower spine up, and the facets degenerate from the upper vertebrae down). It was necessary to separate the sexes, as facet observations were sexually dimorphic. The results found summary scores could be separated into four distinct age stages, for both males and females. Stage I indicates individuals under the age of 60 years, stage II suggests ages between 45-70 years, stage III indicates a minimum age of 60 years in males and 55 years in females, and stage IV provides evidence the individual was over the age of 70 years at the time of death in males and 65+ years in females.

7.2.4 ACCURACY AND BIAS

The results of the cervical body blind test indicated that only 23.1% of the CCS blind test sample had their ages accurately estimated by using the 95% confidence interval for the method. The proposed age ranges are broad and allowed for 88.5% of the sample to be accurately aged. A clear bias towards overageing was observed for this method, as the estimated age of nine individuals (11.5%) were older than the known age.

By contrast, the results of the facets blind test indicated that the 95% confidence intervals only accurately aged 20.9% of males and 9.1% of females in the CCS sample. The generalized age range allowed for 95.3% of males and 96.7% of females in the blind test sample to be accurately aged. A clear bias for either criteria was not observed, as one male individual (2.3%) was underaged and one male (2.3%) was overaged, while one female was found to be underaged.

The results of the blind test of the body and facet summary score indicated that the 95% confidence intervals could only accurately aged 27.9% of the males and 25.0% of the females in the CCS sample. The generalized ranges allowed for 93.0% of males and 93.8% of females to be accurately aged. A bias towards overageing was observed for both sexes, as the estimated ages of three males (7.0%) and two females (6.2%) were older than the known age using these criteria. The reason for this may be related to the fact that the Christ Church Spitalfields is also an historic skeletal assemblage (similar to St Bride's documented collection).

7.3 THE CLAVICLE

7.3.1 DEGENERATION OF THE LATERAL SURFACE OF THE CLAVICLE

Despite some existing overlap between age ranges, three distinct stages of surface degeneration were found to be statistically significant, and have the ability to aid in adult age estimation. Although the 95% confidence interval for the mean of each individual age stage are very concise (spanning 3 to 5 years), the observed range of ages represented by each stage are much broader, and to allow for the true variability in surface degeneration that was observed between individuals to be demonstrated. As similar patterns were observed in each of the four study samples, the data presented here was derived from the combined results of all collections.

7.3.1.1 Stage I

Stage I is defined by composite scores 2 and 3 in which the appearance of the lateral surface is smooth, the granularity is fine, and no porosity is present (Figure 7.13). Individuals under the age of 40 years were not assessed during this research, although further investigation of younger skeletons may confirm that this slightly roughened surface texture is present from the time the lateral epiphysis fully fuses to the clavicle, which occurs between 18-20 years (Scheuer and Black, 2004). The mean age for stage I was found to be 45.4 years (95% confidence interval, 43–48 years). This study has shown that this stage lasts until the approximate age of 50 years.

Figure 7.13: *Lateral surface of the clavicle, Stage I (composite scores 2 and 3). Example of composite score of 3, smooth with slight granulation, no porosity.*

7.3.1.2 Stage II

Stage II is defined by composite scores 4, 5, 6 and 7. In this stage, the surface of the lateral clavicle changes in texture, displaying coarse granulation (Figure 7.14). It is also during this stage that porosities can begin to form (primarily microporosity, but small areas of macroporosity can also form; < 50% of the surface). The mean age for this stage was found to be 58.7 years (95% confidence interval, 57–60 years). This surface appearance occurs until approximately 65 years of age.

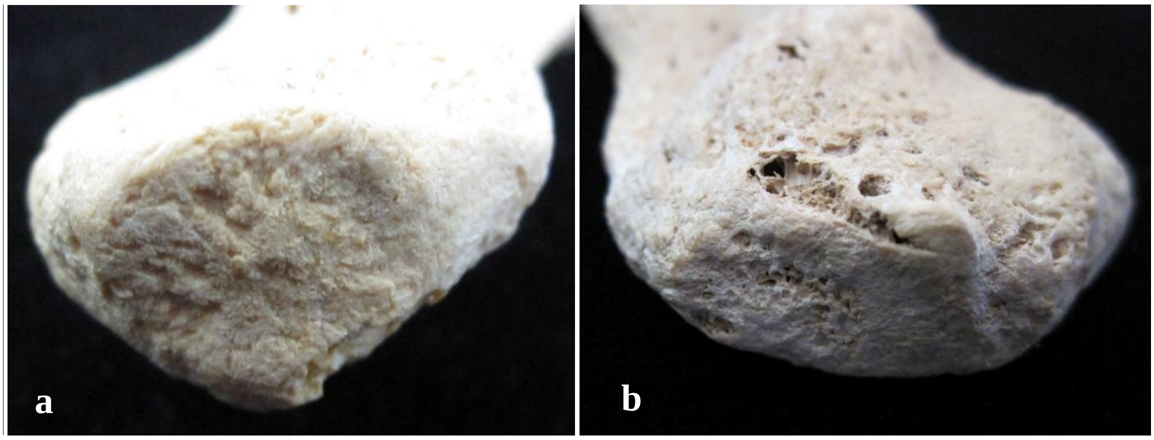


Figure 7.14a-b: *Lateral surface of the clavicle, Stage II (composite scores 4–7). Examples of: (a) composite score 5, coarse granulation, no porosity; (b) composite score 7, coarse granulation, macroporosity.*

7.3.1.3 Stage III

Stage III is defined by composite scores 8, 9, 10, 11 and 12. These higher composite scores record the lateral surface of the clavicle reaching peak degeneration. The surface has lost any granulation, and has become dense and flat. Eburnation may be present. Although the trait expressions were part of the recording criteria, not many individuals show a billowing, undulating or irregular surface topography (Figure 7.15). Macroporosity is also very frequent in this stage (affecting 50%+ of the surface), with many surfaces taking on a honeycomb appearance. The mean age for this stage was found to be 73.4

years (95% confidence interval, 72–75 years). Based on the 40+ years sample, Stage III is a distinct indication that the skeletal individual was over the age of 60 years at the time of death.

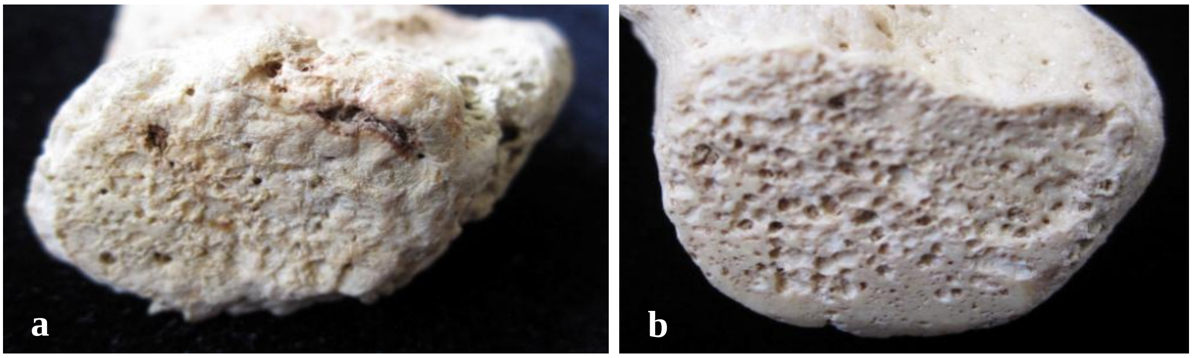


Figure 7.15a-b: *Lateral surface of the clavicle, Stage III. Examples of: (a) composite score 10, dense topography, macroporosity affecting > 50% of surface; (b) composite score of 12, with eburnation and honeycomb appearance.*

7.3.1.4 Accuracy and Bias

The results of the Christ Church Spitalfields blind test indicated that the 95% ranges are too narrow, as it only accurately aged 6.0% of the CCS blind test sample. The generalized range allows for the true variation of trait expression between individuals to be taken into consideration. Although these ranges are much broader, it allows for 85.0% of the sample to be accurately aged. A clear bias for this method was not observed, as four individuals (6.0%) were underaged by this method, and 6 (9.0%) were overaged.

7.3.2 DEGENERATION OF THE STERNAL SURFACE OF THE CLAVICLE

Although some overlap exists between, five distinct stages of surface degeneration were observed (i.e. found to be statistically significantly different from each other), and have the ability to aid in adult age estimation. The 95% confidence interval for the mean of each individual age stage are concise (spanning 3 to 8 years), but the observed range of ages represented by each stage are much broader, and to allow for the true variability in surface degeneration that was observed between individuals to be demonstrated. General surface morphologies are described, and as similar patterns were observed in each of the four study samples, the data presented here was derived from the combined results of all collections.

7.3.2.1 Stage I

This stage is defined by composite scores 3, 4, and 5 for both males and females. The sternal articular surface is generally smooth and flat. The surface texture can be slight or coarse granulation, with a complete absence of nodule formation, porosity and osteophyte formation (Figure 7.16). A minimum age limit is not produced for this stage. It is possible that this smooth, slightly roughened surface texture is present from the time the epiphysis fully fuses to the sternal clavicle (occurs into the early to mid 30s) until the approximate age of 60 years for males (mean age, 48.8 years, 95% confidence interval, 46–51 years) and 55 years for females (mean age, 49.3 years, 95% confidence interval, 46–52 years).

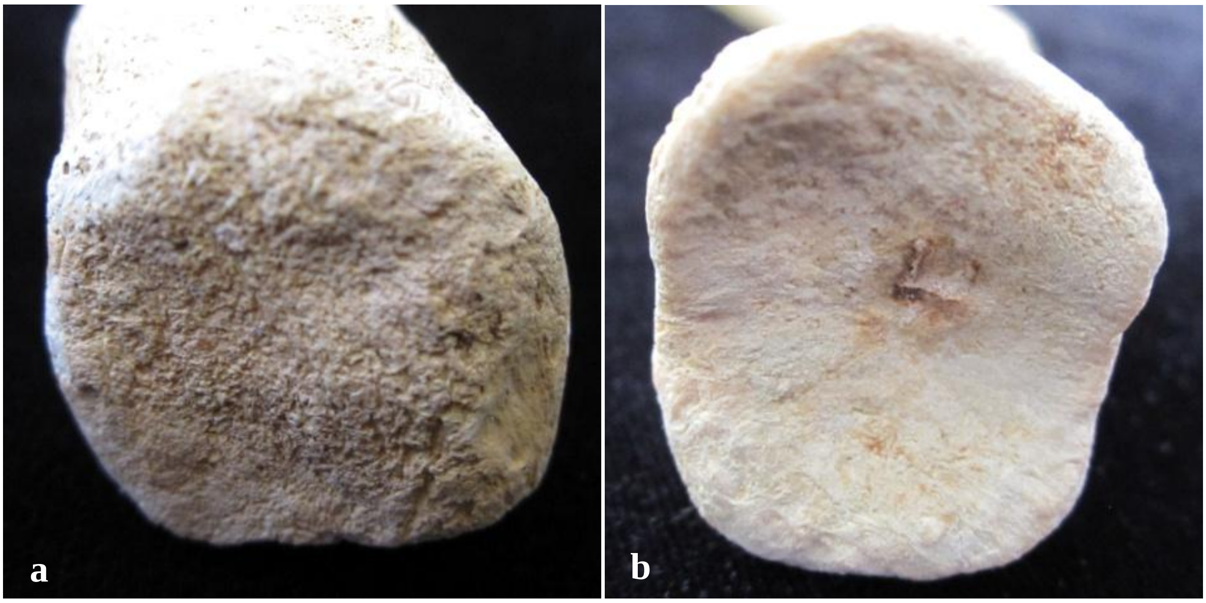


Figure 7.16a-b: *Sternal surface of the clavicle, Stage I (composite scores 3, 4 and 5). Examples of: (a) composite score of 3; (b) composite score of 5.*

7.3.2.2 Stage II

This stage comprised composite scores 6 and 7 in males and 6 to 8 for females. During this stage the surface texture becomes increasingly rugged and coarse in texture, and small nodules begin to form, which slightly alter the generally flat surface (Figure 7.17). Porosities (primarily microporosity) also start to appear, and some individuals demonstrate slight osteophyte formation. It is during this stage that differences between males and females are first notable. Although based on the 40+ years sample, both sexes have a minimal age of 45 years for this stage, this surface can extend to 65 years in males (mean age, 55.2 years, 95% confidence interval, 52–58 years), and 80 years in females (mean age, 64.5 years, 95% confidence interval, 61–67 years). Nodules were only scored as present or absent, it is possible that with further revision of this method, taking into the proportion of the surface displaying nodules may allow for this non-descript stage to be separated into more than one.

Figure 7.17: *Sternal surface of the clavicle, Stage II (composite scores 4, 5 and 6). Example of composite score 7.*

7.3.2.3 Stage III

Stage III is composed of composite scores 8 and 9 for males, and 9 to 10 for females. The sternal surface is characterized by increased irregularity in the surface topography (Figure 7.18). Males demonstrate mixture of coarse granulation and nodule formation, while females display uniform nodule formation. Macroporosities begin to appear on less than 50% of the surface in addition to microporosities, and slight osteophyte formation also becomes more frequent. This stage signifies males are between the ages of 50 and 80 years (mean age, 65.7 years, 95% confidence interval, 63–68 years), and over 60 years for females (mean age, 72.0 years, 95% confidence interval, 69–74 years).

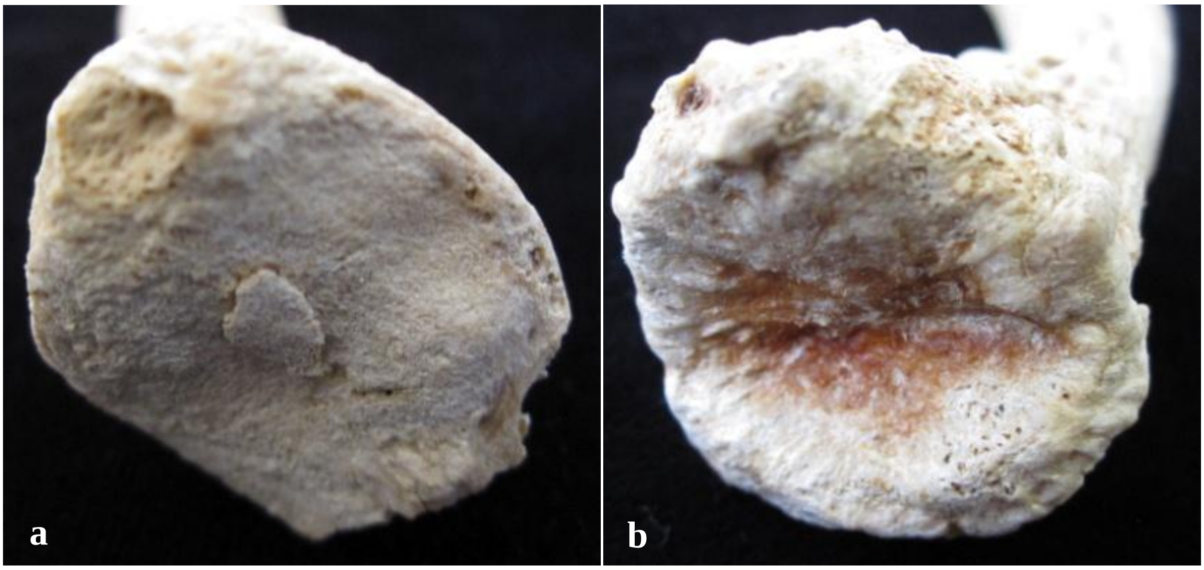


Figure 7.18: *Sternal surface of the clavicle, Stage III (composite scores: male, 8 and 9; females, 9 and 10). Examples of composite scores of 9: (a) nodule formation, macroporosity, no osteophyte formation; (b) billowing topography, microporosity and slight osteophyte formation.*

7.3.2.4 Stage IV

Stage IV comprises male composite scores 10 to 12 and female scores 11 and 12. These higher composite scores indicate the sternal surface of the clavicle is nearing, although has not quite reached, complete surface breakdown. The surface topography is dominated by extensive nodule formation and billowing, producing an irregular surface (no longer a flat surface). Macroporosity is frequent, and affects over 50% of surface (Figure 7.19). Osteophyte formation ranges from slight to moderate in males, and slight in females. Stage IV indicates a male is between 60 and 90 years of age (mean age, 74.9 years, 95% confidence interval, 73–76 years), and over 70 years in females (mean age, 79.3 years, 95% confidence interval, 76–82 years).

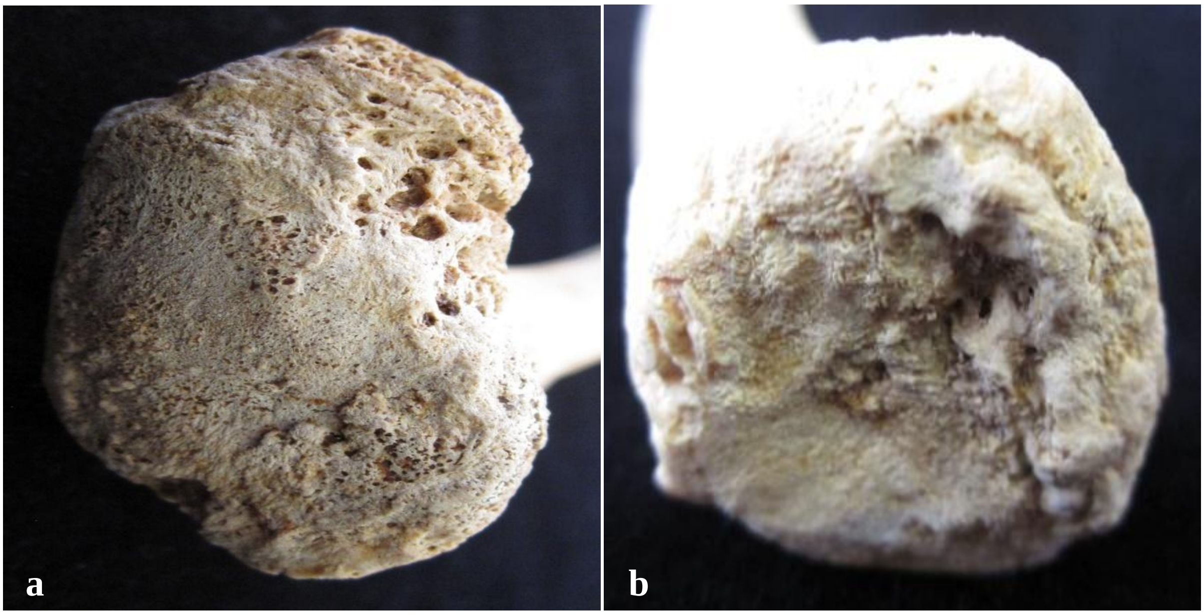


Figure 7.19: *Sternal surface of the clavicle, Stage IV (composite scores: male, 10 and 11; females, 11 and 12. Examples of composite score 11. (a) nodule formation, macroporosity and moderate osteophyte formation. (b) billowing topography, macroporosity, slight osteophyte formation.*

7.3.2.5 Stage V

This final stage (V) describes complete surface breakdown, with no further observable feature(s) that could distinguish it from further stages of degeneration. This is signified by composite scores between 13 and 16 points for both males and females. Surface topography reflects severe billowing and irregularity (Figure 7.20). Macroporosity commonly affects the majority of the joint surface, and osteophytes can be moderate to severe in expression for males, and slight to moderate in females. This final stage suggests an age of 70 years or older for males (mean age, 83.1 years, 95% confidence interval, 79–87 years), and 85+ years for females (mean age, 87.0 years, 95% confidence interval, 85–88 years). Very few individuals will display eburnation of the sternal articular surface.

7.3.2.6 Accuracy and Bias

The results show that although the 95% ranges were slightly broader than in other of the blind tested methods, they are still too narrow as only 31.4% of the males and 34.3% of the females in the CCS blind test sample were accurately aged. The generalized range allows for the true variation of trait expression between individuals to be taken into consideration. Although less precise, these ranges are much broader, it allowed for 94.3% of both the males and females in the sample to be accurately aged. A bias towards underageing was found in both sexes, as two males (5.7%) and two females (5.7%) had known ages that were older than the estimated age allocated by the criteria using this method.

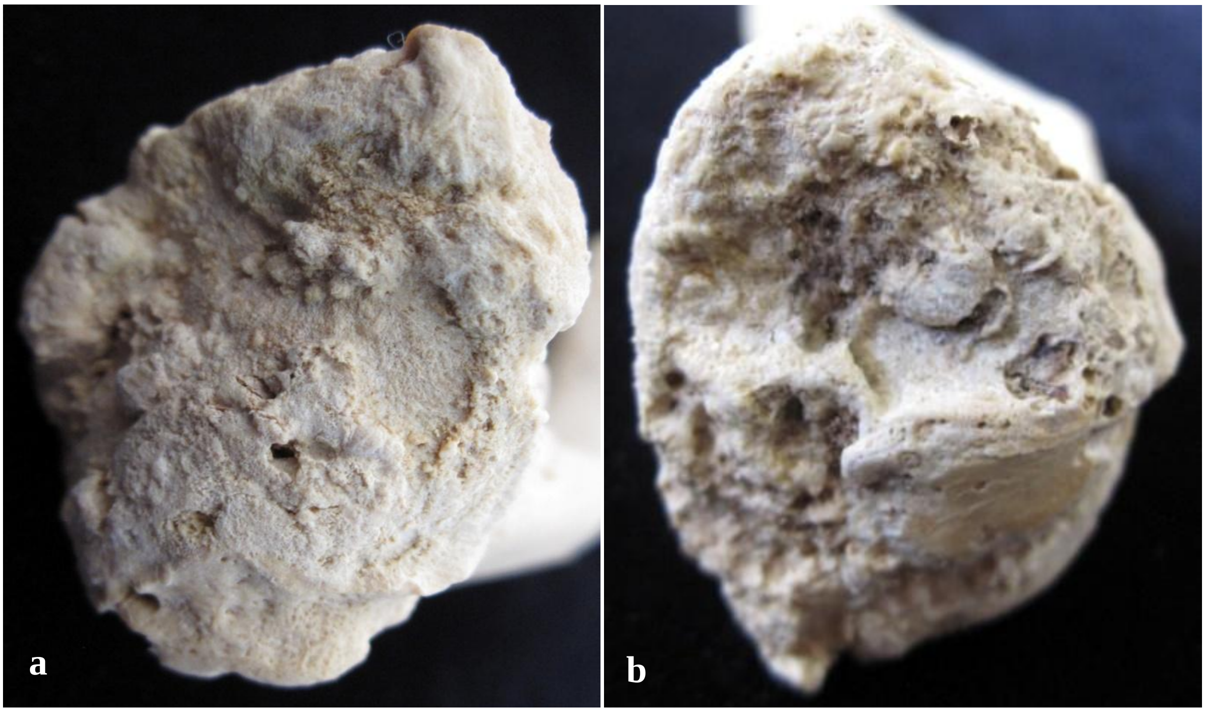


Figure 7.20a-b: *Sternal surface of the clavicle, Stage V (composite scores 13 to 16). Examples of: (a) composite score 13; (b) composite score 15, with eburnation.*

7.3.3 COMBINED LATERAL AND STERNAL SURFACES OF THE CLAVICLE

The combination of composite scores derived from the lateral and sternal articular surfaces of the clavicle into a summary score was found to be highly correlated with age (i.e. $P < 0.001$). This combined correlation was shown to be stronger than examining each end of the clavicle separately. Comparison of composite scores of both ends of the clavicle provides a unique opportunity to act as an accuracy check, as each has the ability to provide independent information on age-at-death.

The criteria were developed through a combination of the study samples. Males and females were analysed separately, as sexually dimorphic criteria were needed for the sternal end of the clavicle. The combination of the composite scores for the lateral and sternal ends, developed a summary score.

Descriptive statistics for the summary scores produced five distinct age stages for males and four for females, and are summarised in Table 7.1.

Table 7.1: *Summary of age estimation based on the combination of the lateral and sternal clavicle composite scores.*

Stage	Male				Female			
	Summary score	**Mean age (years)**	**95% range**	**Age estimate**	**Summary score**	**Mean age (years)**	**95% range**	**Age estimate**
I	7–9	43.4	38–49	< 50 years	7–10	46.2	44–48	< 55 years
II	10–14	52.2	50–54	< 60 years	11–16	60.7	58–63	< 70 years
III	15–19	64.7	63–67	50-75 years	17–20	72.6	70–75	55+ years
IV	20–21	73.3	71–75	60+ years	21–28	80.4	78–83	65+ years
V	22–28	78.9	77–80	70+ years	-	-	-	-

7.3.3.1 Accuracy and Bias

The results of the blind test indicated that 28.6% of males and 18.8% of females in the CCS blind test sample were accurately aged using the 95% confidence interval. In contrast, the broad age estimate provided an accurate assessment of age for 92.9% of males and 96.9% if females. A clear bias for this method was not observed, as one male was overaged by this method, and two females were underaged. Overall, the combined assessment of the clavicle performed better than the lateral clavicle on its own (85% accuracy), and was approximately equal to the accuracy of the sternal end of the clavicle (males and females, 94.3%).

7.4 DEGENERATION OF THE CLAVICULAR NOTCH ON THE MANUBRIUM

Four distinct stages of surface degeneration of the clavicular notches were observed, which comprised the same composite scores for males and females. The most marked difference between the sexes was identified in stage II, as females in the stage were older than males. Both 95% confidence intervals and broad age ranges are provided for each stage, with the general surface characteristics described below. Photographs are of the right clavicular notch. Photos were taken with the dorsal surface of the manubrium facing up, as in this position the curvature of the manubrium allows for the notch to photographed the clearer than when the manubrium is in any other position.

7.4.1 STAGE I

This stage is comprised of composite scores 3, 4, and 5 for both males and females. The clavicular notch is generally smooth and flat. The surface texture can be slight or coarse granulation, with a complete absence of nodule formation, porosity and osteophyte formation (Figure 7.21). No minimum age limit is proposed. It is possible that this smooth, slightly roughened surface texture is present from the time the proximal manubrium completes development during puberty and lasts until the approximate age of 65 years in males and females (male, mean age, 52.0 years, 95% confidence interval, 49–54 years; female, mean age, 52.4 years, 95% confidence interval, 49–55 years).

Figure 7.21: *Clavicular notch, Stage I (composite scores 3, 4 and 5). Example of composite score of 4.*

7.4.2 STAGE II

Stage II comprises composite scores 6 through 9 for both males and females. The clavicular notch is smooth and can be flat or rounded. The surface texture becomes more rugged with an increase in coarse granulation and development of surface nodules. Porosity begins to appear (both micro- and macroporosities can be present), and osteophyte formation around the rim of the notch begin to form, forming a slightly irregular outline to the notch (Figure 7.22). Based on the 40+ years sample, this surface appearance indicates an individuals in this sample are over the age of 50 years, and can last until the approximate age of 70 years in males (mean age, 64.0 years, 95% confidence interval, 61–66 years) and 80 years in females (mean age, 68.7 years, 95% confidence interval, 66–71 years).

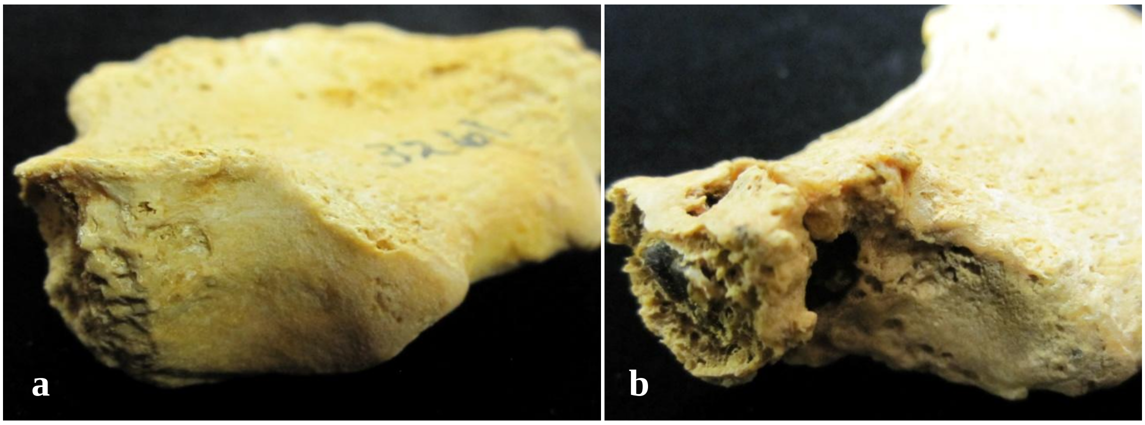


Figure 7.22a-b: *Clavicular notch, Stage II (composite scores 6–9). Examples of: (a) composite score 6, and (b) composite score of 9.*

7.4.3 STAGE III

Stage III is composed of composite scores 10 to 14. This stage is characterised by increased intensity of nodule formation of the surface, which can induce severe surface irregularity and billowing (Figure 7.23). Macroporosity affects the majority of surfaces, and all surfaces display slight to moderate osteophytic lipping. This stage signifies males are over the age of 60 years (mean age, 74.7 years, 95%

confidence interval, 73–76 years), and females are between 65 and 90 years (mean age, 76.0 years, 95% confidence interval, 73–78 years).

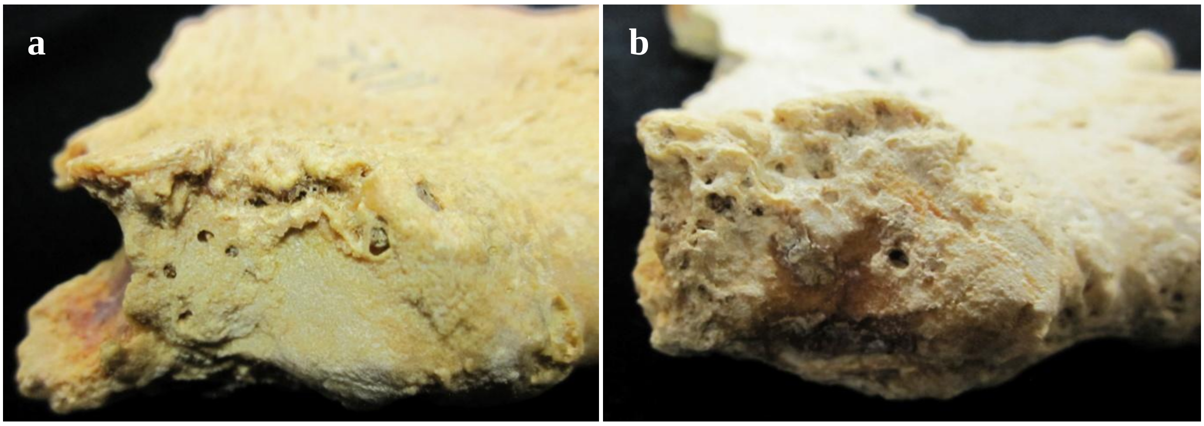


Figure 7.23a-b: *Clavicular notch, Stage III (composite scores of 10–14). Examples of: (a) composite score of 10, and (b) composite score of 13.*

7.4.4 STAGE IV

Composite scores 15 and 16 signify the clavicular notch has reached peak degeneration (Stage IV). Complete surface breakdown reflects a surface topography of severe billowing and irregularity (Figure 7.24). Macroporosity commonly affects the majority of the joint surface causing large surface defects, and osteophytes can be moderate to severe in expression, which expands the outline of the surface. Very few individuals displayed eburnation of this surface. This final stage suggests a minimum age of 75 years for males and females (male, mean age, 88.8 years, 95% confidence interval, 82–95 years; female, mean age, 88.8 years, the 95% confidence interval could not be determined due to the small sample size of females displaying these composite scores in the combined study sample).

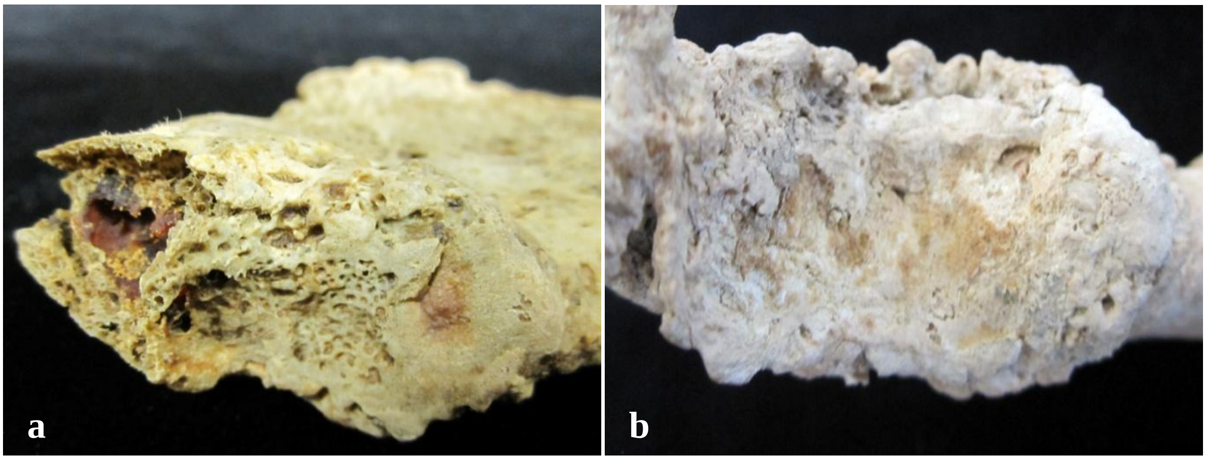


Figure 7.24a-b: *Clavicular notch, Stage IV (composite scores 15 and 16). Examples of: (a) composite score of 15, and (b) composite score of 16.*

7.4.5 ACCURACY AND BIAS

The blind test of the above criteria resulted in 25.0% of the males and 36.4% of the females of the CCS sample to be accurately aged using the 95% confidence intervals. The poor accuracy suggested that the 95% range is too narrow to compensate for the true variation of trait expression between individuals to be assessed. The broader suggested age ranges allowed for 96.4% of males and 86.4% of females to be accurately aged. A clear bias for this method was not observed, as single male individual (3.6%) was overaged by this method, while one female (4.55%) was underaged and one (4.55%) was overaged.

7.5 DEVELOPMENT OF ILIAC CREST OSTEOPHYTES

Three distinct stages of osteophyte formation were found to be statistically significant, and have the ability to aid in adult age estimation. These stages were formed by the combination of osteophyte scores who demonstrated similar descriptive statistics, and as a result, differences were found in the scores combined into age stages between males and females.

7.5.1 STAGE I

Stage I is defined by trait scores 0 and 1 in males and females, indicating osteophyte formation is absent or minimal (Figure 7.25). Although individuals under the age of 40 years were not assessed during this research, further investigation of younger skeletons may confirm that this appearance is present from the time the iliac crest epiphyses fully fuse to the ilium, which occurs between 17 and 23 years (Scheuer and Black, 2004). The mean age for stage I was found to be 59 years (95% confidence interval, 57–61 years) in males, and 60 years (95% confidence interval, 57–63 years) in females. This study has shown that this stage can last until the approximate age of 80 years.

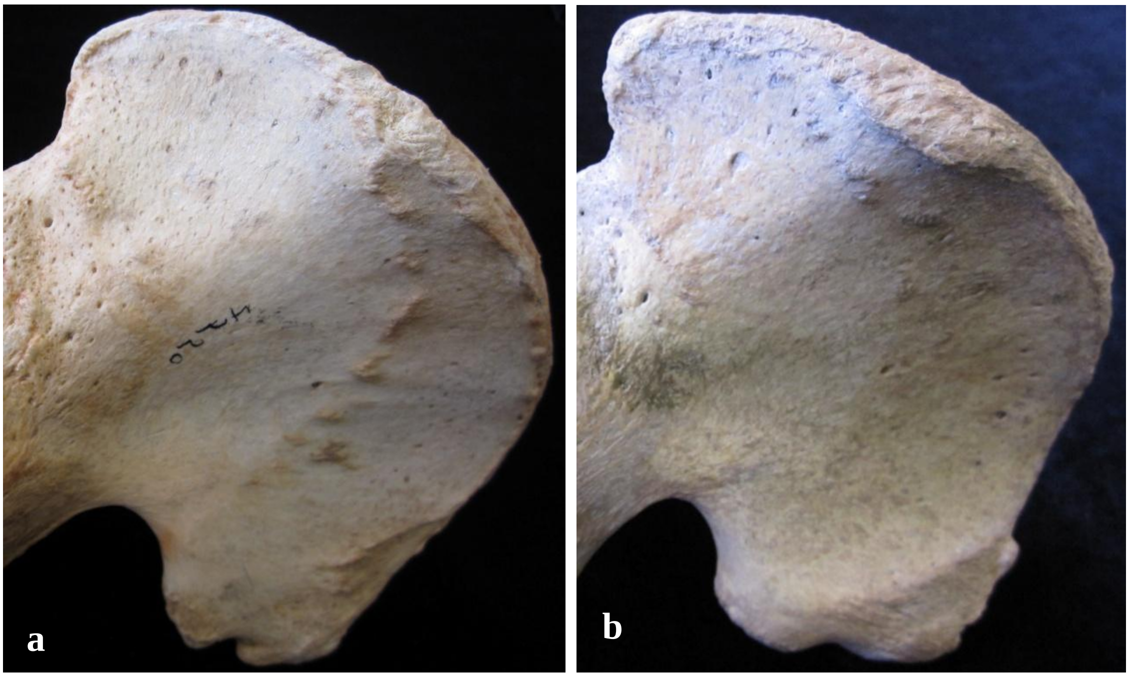


Figure 7.25a-b: *Iliac crest osteophyte development, Stage I (scores of 0 and 1). (a) Score of 0, no osteophyte formation; (b) Score of 1, minimal osteophyte formation, iliac crest has roughened texture.*

7.5.2 STAGE II

This stage is comprised of score of 2 (slight) in males (Figure 7.26a), and scores of 2 and 3 in females (slight to moderate) (Figure 7.26b). The mean age for stage II was found to be 68 years (95% confidence interval, 66–70 years) in males, and 71 years (95% confidence interval, 69–74 years) in females. Based on the 40+ years sample, osteophyte development begins after the age of 50 years in males, and 45 years in females.

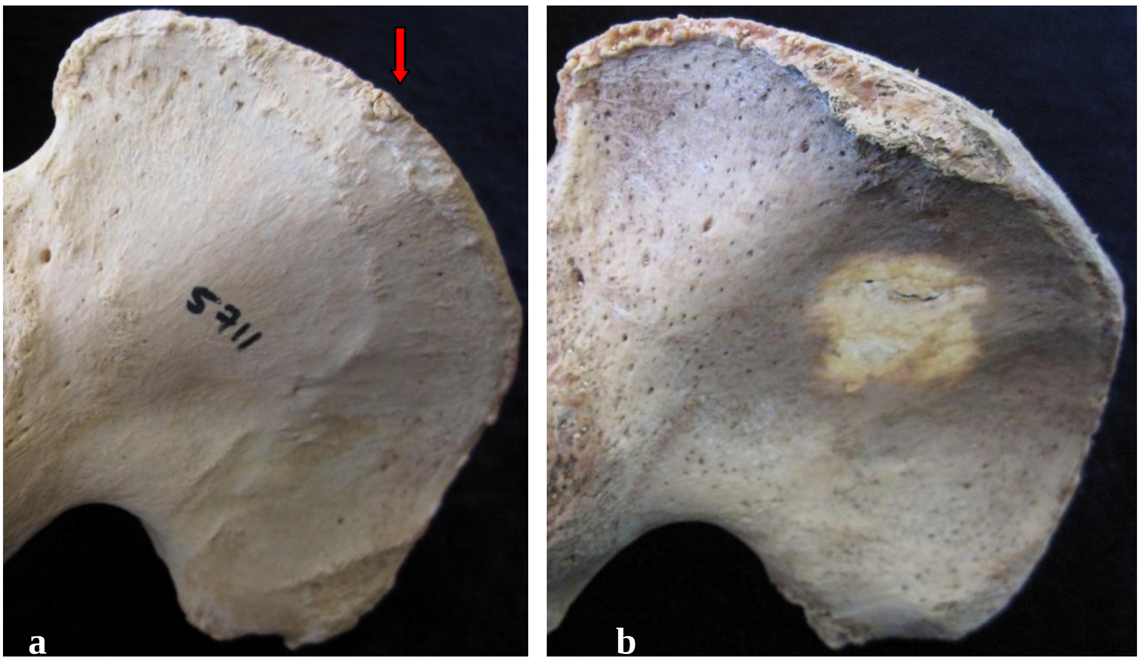


Figure 7.26a-b: *Iliac crest osteophyte development, Stage II. (a) Score of 2, slight osteophyte formation (arrowed); (b) moderate osteophyte formation.*

7.5.3 STAGE III

Stage III comprises scores of 3 and 4 (moderate to severe) in males, and 4 (severe) in females (Figure 7.27). The mean age for stage III was found to be 75 years (95% confidence interval, 72–77 years) in males, and 77 years (95% confidence interval, 73–82 years) in females. This study has shown that severe osteophytes begin to form after the age of 65 years.

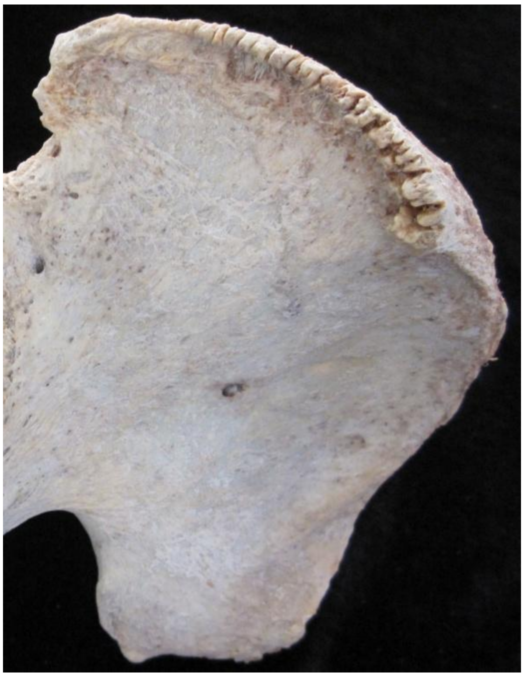


Figure 7.27: *Iliac crest osteophyte development, Stage III, osteophyte score of 4, severe expression.*

7.5.4 ACCURACY AND BIAS

The results of the blind test showed only 18.2% of the males and 10.0% of females in the CCS sample were accurately aged using the 95% ranges, indicating these ranges are too narrow. The open-ended age ranges allowed for 90.9% of males and 100.0% of females in the sample to be accurately aged. A bias was found within this method for males, as four individuals (9.1%) were overaged.

7.6 REVISIONS TO AURICULAR SURFACE OF THE ILIUM METAMORPHOSIS

7.6.1 REVISED AURICULAR SURFACE PHASES OF DEGENERATION

General surface morphologies are described for each new auricular surface phase, with the suggested maximum age cut-off described by each distinct stage of auricular surface degeneration. Lower age estimates can only be suggested following observation of individuals younger than the age of 40 years.

7.6.1.1 Phase I

This phase is comprised of Lovejoy stages 1 and 2, which are characterised by a "youthful" appearance of billowing and very fine granularity, and absence of porosity (Figure 7.28a). Based on the Lovejoy criteria, the suggested age range is 20 to 29 years. No individuals were found to display this phase in any of the study samples.

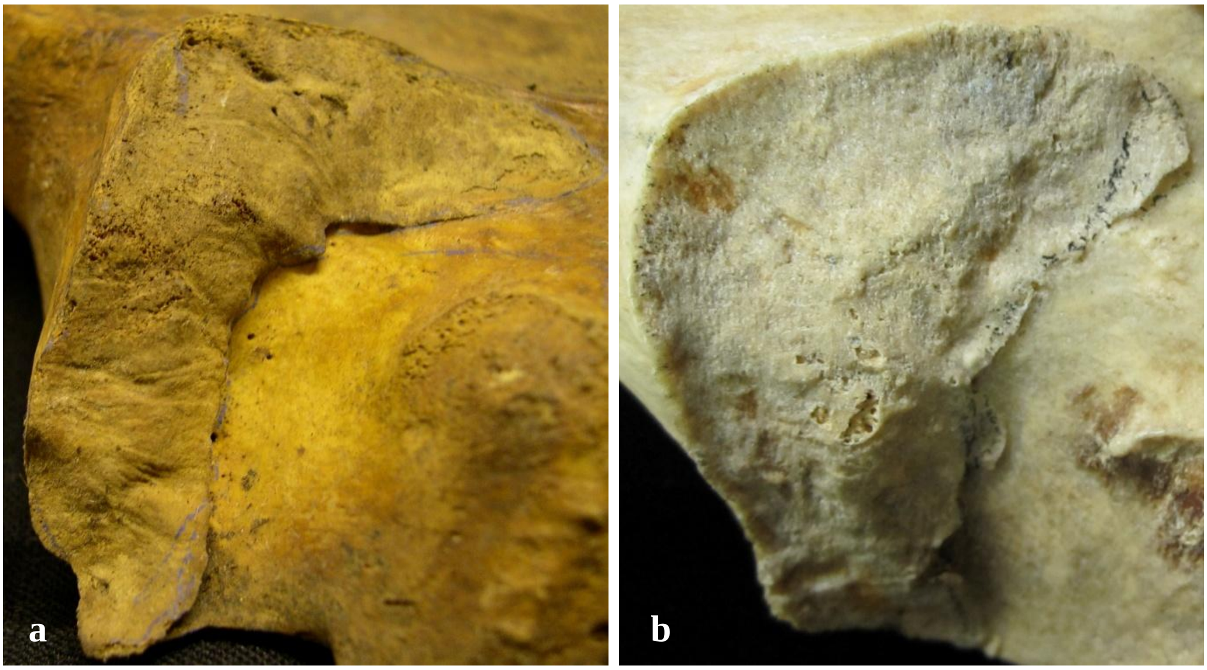


Figure 7.28a-b: *Revised auricular surface, (a) phase I, billowing and very fine granulation.(b) phase II, loss of billowing, some striae, coarse granulation, possible microporosity.*

7.6.1.2 Phase II

Phase II comprises Lovejoy stages 3 and 4, during which there is a loss of billowing, development of striae, presence of coarse granulation, and microporosity can be observed (Figure 7.28b). Based on this sample, this phase was found to have a mean age of 48.1 years (95% confidence interval, 45–51 years), although generally indicated an age of 55 years or younger (a minimum age could not be suggested). This result is significantly older, as these stages would suggest an age between 30 and 39 years following Lovejoy's suggestions. The discrepancy in mean age between the two studies is the result of the differences between the age composition of this study's samples (i.e. heavily skewed towards older individuals) compared to the original Lovejoy et al. (1985b) reference sample (i.e. higher proportion of younger adults).

7.6.1.3 Phase III

This phase comprises Lovejoy stages 5 and 6 during which the auricular surface changes in texture from coarse granulation to a dense surface, macroporosity can be present (Figure 7.29a). The absence of billowing or striae renders the surface relatively flat. This phase was found to describe individuals under the age of 75 years (mean age, 54.4 years; 95% confidence interval, 52–57). A minimum age could not be suggested. The original Lovejoy method indicated individuals of these surface stages would be aged between 40 and 49 years.

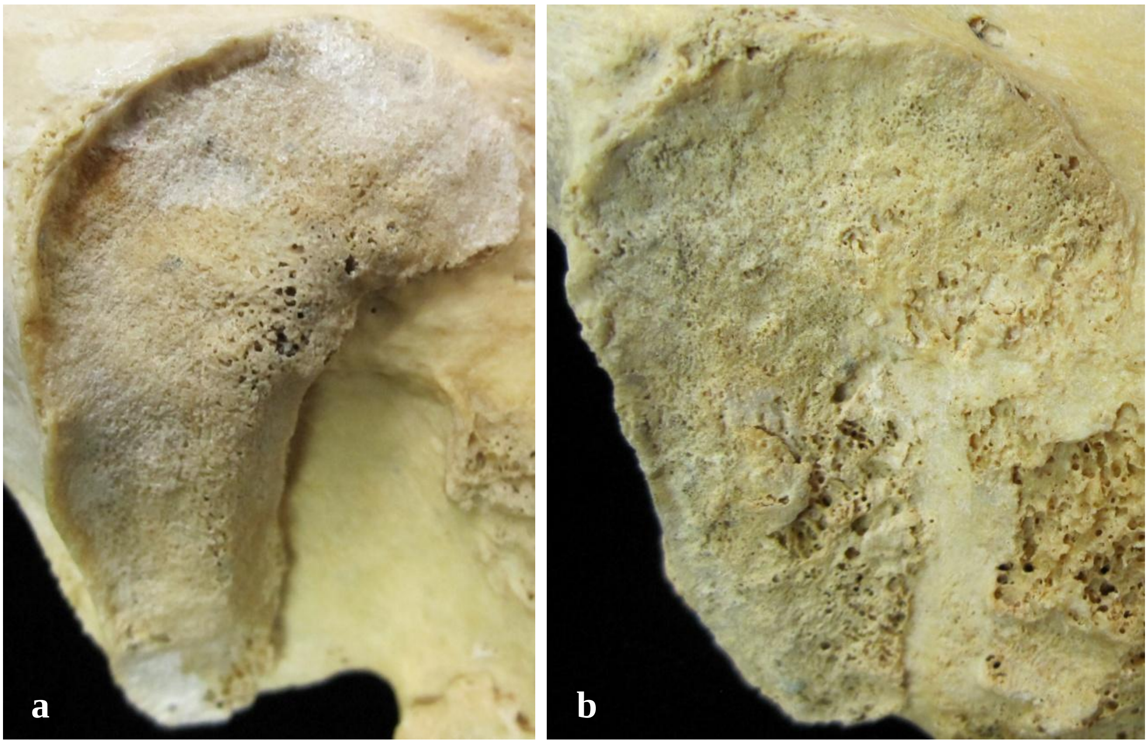


Figure 7.29a-b: *Revised auricular surface, (a) phase III, dens surface, macroporosity possible. (b) phase IV, irregular surface, breakdown, frequent macroporosity, marginal lipping.*

7.6.1.4 Phase IV

Phase IV comprises Lovejoy stages 7 and 8, during which time the dense surface increases in irregularity, although the topography of the auricular surface is still relatively flat. Increasing marginal lipping makes the auricular surface irregular in shape. Macroporosity occurs frequently and covers more of the surface than in previous phases (Figure 7.29b). The combination of these stages suggests an age of 50+ years according to the original study, but found to indicate a minimum age of 45 years in this study (mean age, 67.4 years; 95% confidence interval, 66–68 years).

7.6.1.5 Phase V

Phase V is a completely original stage of auricular surface degeneration. It is characterised by development of surface nodules (raised surface texture) that transform the relatively flat surface found in phase IV into a highly irregular topography (Figure 7.30). Macroporosity is always present, and in combination with marginal lipping add to the overall appearance of surface "breakdown". This phase was not found to be expressed by individuals under the age of 60 years in the study samples (mean age, 76.3 years; 95% confidence interval, 74–78 years).

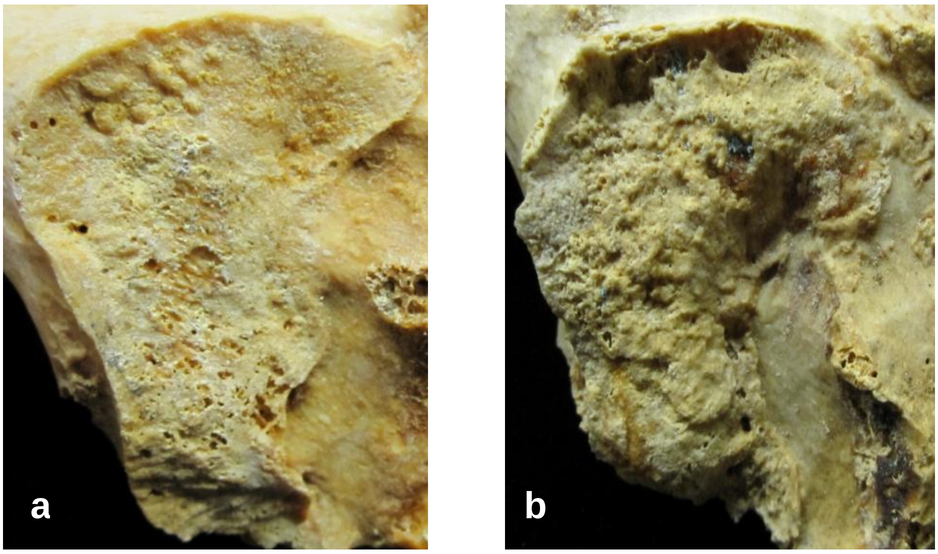


Figure 7.30a-b: *revised auricular surface, phase V. Examples of (a) raised surface texture, and (b) "bubbling" surface appearance.*

7.6.1.6 Accuracy and Bias

In order to evaluate the accuracy, the blind test compared the results of the original Lovejoy and revised methods. As stated previously, the Lovejoy technique was able to accurately predict age in 47.6% of the total blind test sample, with 37.8% of the sample underaged, and 14.6% overaged. Using the revised criteria, the 95% confidence interval was only able to accurately age 12.2%, while the suggested age ranges provided 92.7% of the blind test sample with an accurate assessment of age. A bias towards overageing was found, as 7.3% of the sample had a known age that was younger than the estimated age. Of those that were incorrectly aged, the discrepancy between the known and estimated ages ranged between 1 and 9 years.

7.6.2 SURFACE TEXTURE AS AN INDICATOR OF AURICULAR SURFACE DEGENERATION

Three distinct stages of degeneration for males and females were identified by auricular surface texture score. In addition to 95% confidence intervals, broader ranges were suggested, with which age is to be estimated. The general surface morphologies are described for each surface stage, with the suggested maximum and/or minimum age cut-offs described by each distinct stage of auricular surface degeneration. Lower age estimates can only be suggested following observation of individuals younger than the age of 40 years. Males were found to display more distinct patterns of degeneration, as a great deal of variability was observed in the ageing female auricular surface.

7.6.2.1 Surface Texture Score of 1

No individuals were found to display this trait expression. As described by Buckberry and Chamberlain (2002:233), it is defined as "90% or more of the surface is finely granular" (Figure 7.31a).

Figure 7.31a-b: *Revised auricular surface texture, (a) Surface texture score of 1, the surface is primarily finely granular. (b) Surface texture score of 2, coarse granulation is present in small areas, no dense bone present.*

7.6.2.2 Surface Texture Score of 2

Again, no individuals were found to display this trait expression in the study samples. As described by Buckberry and Chamberlain (2002:233), this score is defined as "50–89% of the auricular surface is finely granular, replacement of finely granular bone by coarsely granular bone in some areas; no dense bone is present" (Figure 7.31b).

7.6.2.3 Surface Texture Score of 3

Buckberry and Chamberlain (2002:233) define this score as "50% or more of surface is coarsely granular, but no dense bone is present" (Figure 7.32a). Only one female (known age, 47 years) individual in the combined sample displayed this trait expression. Barring further research, due to the similarity of the age of this individual with the mean age of surface score of 4, this score was combined with score of 4, and suggested a maximum age of 60 years for males and females displaying these surface expressions.

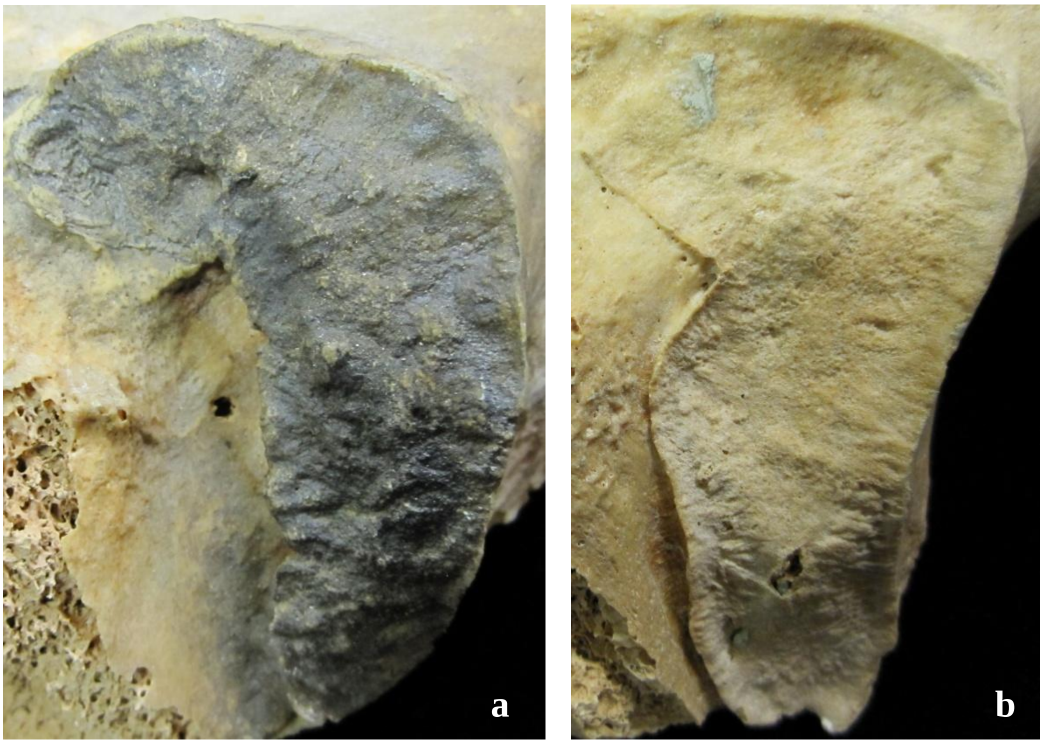


Figure 7.32a-b: *Revised auricular surface texture, (a) Surface texture score of 3, coarsely granular, no dense bone. (b) Surface texture score of 4, dense bone is present, but less than 50% of surface.*

7.6.2.4 Surface Texture Score of 4

An auricular surface texture score of 4 is defined as “dense bone is present, but occupies less than 50% of the surface; this may be just one small nodule of dense bone in very early stages” (Figure 7.32b). Males and females displaying this characteristic appearance were found to be under the age of 60 years (male, mean age, 49.0; 95% confidence interval, 45–53 years; female, mean age, 46.6 years; 95% confidence interval, 43–50 years). A minimum age could not be suggested for either sex.

7.6.2.5 Surface Texture Score of 5

The surface texture score is defined as “50% or more of surface is occupied by dense bone” (Buckberry and Chamberlain, 2002:233) (Figure 7.33a). Males in this study were found to be aged between 45 and 80 years at the time of death (mean age, 56.7 years; 95% confidence interval, 54–59 years), and females were under the age of 80 years, with no suggesting of a minimum age estimate (mean age, 58.4 years; 95% confidence interval, 55–62 years).

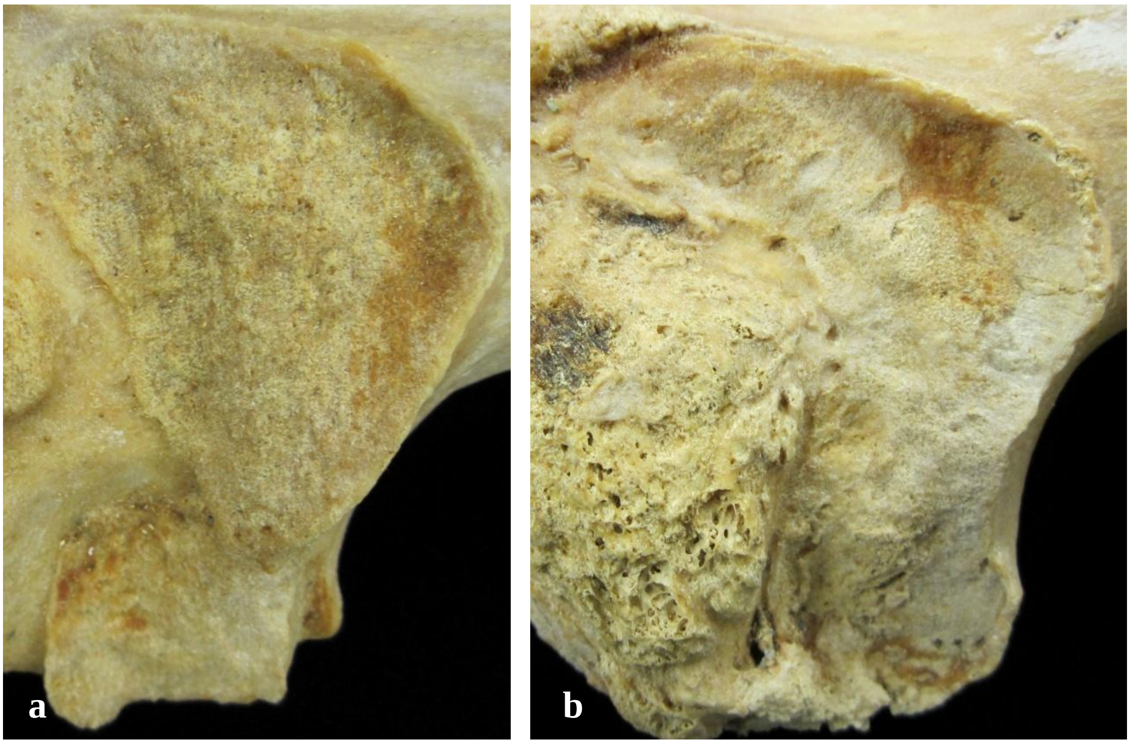


Figure 7.33a-b: *Revised auricular surface texture, (a) Surface texture score of 5, flat and dense; (b) Surface texture score of 6, surface develops a raised texture, making the surface irregular.*

7.6.2.6 Surface Texture Score of 6

Surface texture score of 6 is characterised by new bone growth, which alter the topography to a rugged and irregular surface (Figure 7.33b). This score was found in males over the age of 60 years (mean age, 69.4 years; 95% confidence interval, 67–71 years), and females aged 50 years and above (mean age, 71.7 years, 95% confidence interval, 70–73 years).

7.6.2.7 Accuracy and Bias

The results of the blind test of the 95% confidence interval for each new surface texture score were found to accurately age 23.8% of the males and 22.5% of the females in the CCS sample. The suggested age ranges provided accurate estimates for 88.1% of males and 100.0% of females. A clear bias for males was identified, as five males (11.9%) were overaged by this revised surface texture score.

7.7 DEGENERATION OF THE UPPER ISCHIAL TUBEROSITY

The stages of degeneration are based on the combined study sample, as similar patterns were observed in all four skeletal collections. Each individual score represents a distinct stage of ischial tuberosity degeneration.

7.7.1 SCORE OF 1

A score of 1 indicates the upper ischial tuberosity is flat and smooth in texture (fine granulation), with a complete absence of nodule formation (Figure 7.34a). This stage was found to have a mean age of 45 years (95% confidence interval, 44–47 years), but in realistic terms suggests that the individual is less than 60 years old. A minimum age limit is not proposed, but it is possible that this smooth surface texture is present from the time the epiphysis fully fuses to the ischium (occurs between the ages of 16 and 18 years).

7.7.2 SCORE OF 2

A score of 2 indicates the ischium is flat, generally smooth, and displays coarse granulation which makes the texture rough to the touch (Figure 7.34b). Again, there is an absence of nodule formation. The mean age of 55 years was found for this surface score (95% confidence interval, 54–57 years), but generally indicates a person is younger than 70 years old. Again, a minimum age could not be suggested.

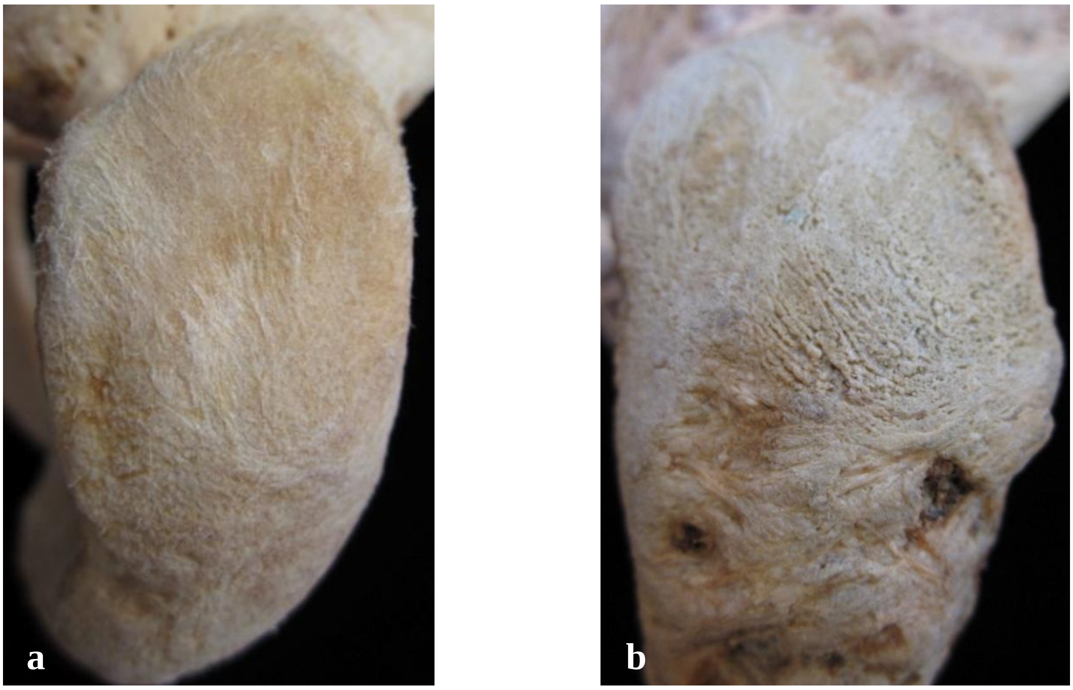


Figure 7.34a-b: *Ischial tuberosity surface topography, (a) Score of 1, (b) Score of 2.*

7.7.3 SCORE OF 3

A score of 3 indicates the ischial tuberosity is beginning the process of degeneration. The surface still displays coarse granulation, but develops area(s) of raised patches cause of the presence of one or more nodules (Figure 7.35a). This stage of nodule formation was found to have a mean age of 70 years

(95% confidence interval, 69–71 years). In general terms, a trait score of 3 reflects a minimum age of 50 years. A maximum age could not be suggested.

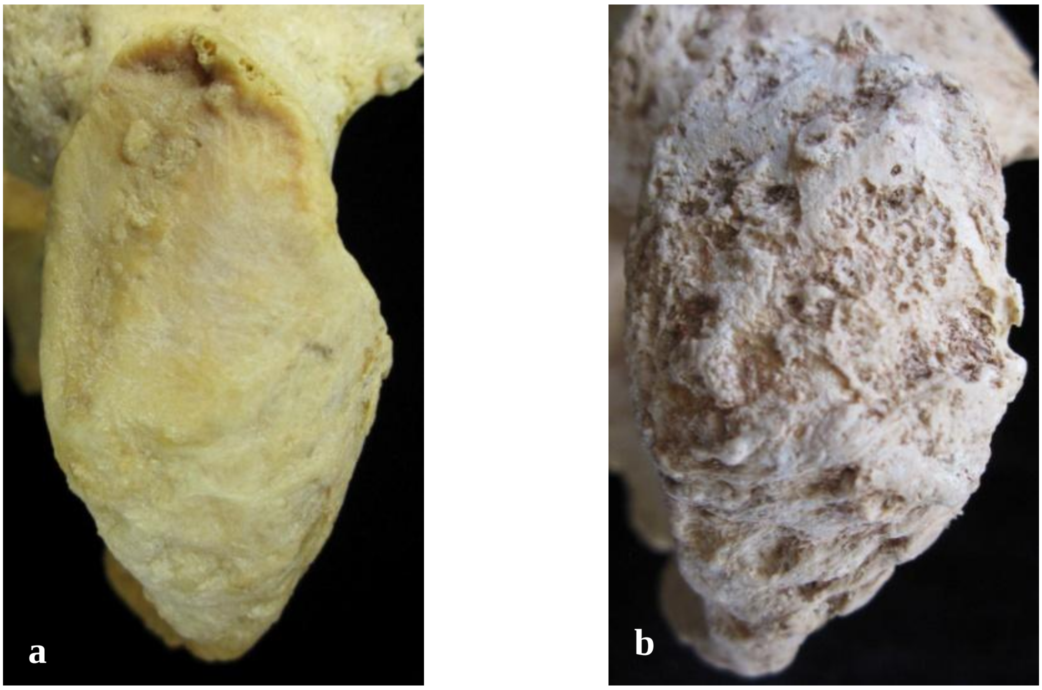


Figure 7.35a-b: *Ischial tuberosity surface topography, (a) Score of 3, nodules form; (b) Score of 4, complete surface breakdown.*

7.7.4 SCORE OF 4

A score of 4 indicates the ischial tuberosity has reached peak degeneration. Portions of the upper ischial tuberosity are no long flat, but rather undulating or billowing resulting from areas of irregular bone formation and remodelling (Figure 7.35b). This degeneration can extend across the entire surface of the tuberosity, although small patches of irregular bone development are the necessary surface characteristic to be included in this score. The mean age for this stage was 78 years (95% confidence interval, 77–80 years), and generally indicates an individual is over the age of 70 years.

7.7.5 ACCURACY AND BIAS

The results of the blind test again indicated only 15.7% of the test sample were accurately aged within the 95% confidence interval. The broader age range allows for the true variation of trait expression between individuals to be taken into consideration, and allowed for 97.6% of the sample's ages to be accurately estimated. A bias to overage individuals was suggested, as the known age of two individuals (2.4%) were lower than the estimated ages suggested by this criteria.

CHAPTER EIGHT
DISCUSSION OF METHODS

"The anthropologist can save himself a lot of time by not trying to make more precise estimates of age than are warranted by the nature of the material" (Washburn, 1958:198-199)

8.1 INTRODUCTION

The aim of this thesis was to identify and develop new methods to accurately identify the "elderly" in archaeological populations. This was accomplished by refining existing methods, and identifying new regions of the skeleton that showed potential for progressive degeneration over the age of 40 years. It was hoped that ageing criteria could be developed that could accurately assess age within 10 year age ranges, however, the results of this study found concise 10-year age ranges were unrealistic. This chapter discusses the study in context of the previously identified difficulties in adult skeletal ageing. The benefits and limitations of the research are acknowledged, with each tested technique and developed method discussed in detail. Recommendations are made for the future of adult ageing in biological anthropology, as well as avenues of further research.

At all stages of this study, from conception through to criteria development, the problems and limitations concerning current osteological ageing methods were acknowledged and rectified where possible. The skeletal elements under study were chosen based on their potential to reliably estimate age, as proposed by Spirduso (1995):

1. <u>the skeletal age indicator under scrutiny must have a strong correlation with age (i.e. continuously remodelling throughout the entire lifespan)</u>.

   Statistically significant relationships between individual surface traits, composite scores and known age were confirmed using Spearman's rank correlation coefficients.

2. <u>the age indicator should not be altered by pathological events</u>.

   It is unavoidable that the majority of degenerative observations in joints are closely linked to the development of osteoarthritis. However, no direct correlations were observed between the severity of surface age stages and the presence of DISH, where investigated.

3. <u>techniques must have a wide application (a generalization across the species), with reliable and identifiable changes that occur within relatively short time intervals when compared to the total lifespan.</u>

   The universal application of the developed criteria was shown by demonstrating that the general pattern of degeneration was the same in all four study samples, irrespective of geographical location; however it should be emphasised that the general applicability is still compromised, until the degenerative trends have been demonstrated as robust in non-truncated reference samples. This issue will be discussed in greater detail in the following section. Also, although every attempt was made to identify degenerative traits that occurred within short concise periods within the life span, the inter-personal variation associated with adult ageing requires age ranges sufficiently broad enough to accurately describe the degeneration process in every individual.

Once these criteria were satisfied, the estimated ages were blind tested for their reliability and their validity.

8.2 LIMITATIONS

It cannot be denied that progressive stages of degeneration of a selection of skeletal elements have been identified in the course of this research, however, the truncated nature of the reference samples used is one of the greatest limitations of this study. Although chosen to maximize the final sample size, and to ensure assessment as many older individuals as possible, by omitting individuals who died in younger adulthood prohibited the formation of ageing methods that could be equally applied to any unknown adult skeleton. Although the identified patterns have suggested degenerative processes do not begin until after the approximate age of 45 years or 50 years (depending on skeletal region under study), by not assessing individuals aged between 20 years and 39 years, it can not be confirmed that the degenerative traits are indeed absent in all individual, and/or at what age the region begins to display surface breakdown. This suggested minimum age of 45 years for the start of skeletal breakdown is very close to the cut off of the age distribution of the study sample (i.e. 40 years).

Related to this fact is that the truncated age composition of the sample likely has skewed the resultant descriptive statistics and ultimately the age estimations that relate to each age stage towards older ages than would have been derived from a reference sample containing a more equal distribution of ages-at-death that spanned the entirety of “adulthood”. As is, the application of the developed criteria is limited to those skeletal individuals for whom the age-at-death is truly 40 years or older. This information can never be confirmed, barring documentary evidence, in an archaeological context.

Conceptually, this study attempts to relate the non-linear process of biological ageing with the linear process of advancing chronological age. As highlighted in Chapter Three, the variation with which physical ageing occurs is often underestimated by biological anthropologists. To compensate, in the absence of notable differences, the four study samples were combined to form the ageing criteria to ensure a wide range of expressions were examined. To reflect this normal variation in trait expressions, broad ranges (i.e. 45+, 55+, 65+ years), or “age phases”, were suggested as age estimations, instead of the much more concise age ranges provided by the 95% confidence intervals.

In biological anthropology today, there are reports of ageing techniques not being accurately correlated with age (i.e. closure of the sagittal suture, Hershkovitz et al., 1997). The use of Spearman's rank correlation coefficients ensured that each trait and composite score were statistically significantly associated with known age of the study samples. Future re-evaluations of this study will be able to test whether the proposed traits and criteria are accurately correlated with age in other skeletal populations. The use of the same statistical test (i.e. Spearman's rank correlation coefficient) in the development of every new ageing criteria allowed the methods to be compared against one another to provide a ranked order of criteria most highly correlated with old age (i.e. methods of highest to lowest r_s values). Discussion of this issue will be presented following the sections outlining the developed degenerative stages of each individual skeletal region, in Section 8.3.9.

One conceptual limitation could not be quantified or overcome; the fact that some individuals might be more liable to producing bone (i.e. bone formers) than others. This issue was not fully investigated during the course of this research, and will need to be examined further in future studies. It is potentially possible that bone formers were the individuals found to display the most severe expressions of iliac crest osteophyte formation, which resulted in very broad age ranges indicating general stages of advanced age, although similar patterns of osteophyte formation were not found on the upper ischial tuberosity. Another factor that is in need of further investigation is the general observation that small bodied females (i.e. very gracile skeletal elements, short stature) did not display the same extremes of trait expression than those females of "normal" body size, and males. This pattern was most notable on the sternal end of the clavicle and development of iliac crest osteophytes (see sections 6.3.2.1.4 and 6.5.1.2, respectively). These females commonly displayed minimal expressions of traits under observation. Although they did not conform to the degenerative patterns observed for the majority of the study sample, such individuals were not removed from the results. These skeletal elements also provide information on the amount of normal variation present in the ageing process of all individuals, not only those of average stature or body size.

The final limiting factor to the application of the methods described in this study is the criteria have not yet been subjected to assessment of interobserver error, as the data collection phase of this research was largely conducted outside of the UK. Analysis of the intraobserver error did not find statistical differences between two separate surface examinations, however, it is yet to be proven that the criteria are able to be understood, applied, interpreted and reproduced by other researchers. Investigations of interobserver error for all developed criteria will take place as soon as possible.

8.2.1 PRESERVATION

Several issues with regards to preservation were identified, and warrant further investigation: in archaeological contexts, will the skeletal elements for which new criteria were developed be suitably preserved to allow examination? It is widely known that the auricular surface is commonly better preserved in the burial environment than the pubic symphysis (Lovejoy et al. 1985b). There is a strong possibility that some of the elements included in this study may too suffer the fate of the pubic symphysis. The manubrium and sternal end of the clavicle are largely composed of trabecular bone, and sit high in the grave of a decomposing body, which may be more susceptible to damage in the burial environment. In comparison, the ischium is robust and often recovered intact. Unfortunately, the preservation of skeletons is not something that can be controlled.

A second possible issue with preservation of skeletal remains is it will play a key role in the criteria involving the surface traits of porosity and osteophyte formation. True porosity may be obscured by postmortem damage, and osteophyte formation is prone to breakages in poorer preserved remains. Although porosity and osteophyte formation have been found to be statistically correlated with age in many of the developed criteria, future revisions of these methods may focus more heavily on the surface topography to avoid misinterpretation of the degenerative stage by preservation issues.

It is recommended that these methods be applied to adults of a large archaeological population (not necessarily known age), to determine if these features are indeed present, and whether assessments of porosity and osteophyte formation are viable candidates for observation in archaeological specimens, or whether the criteria needs to be solely focused on surface topography, which can be determined from small portions of the required surface**.**

The last issue regarding preservation involves the suggestion that the skeletons of "elderly" individuals may be less well preserved than those of younger adults (Walker, 1995). Without the ability to accurately identify the oldest members of a skeletal population, it cannot be known if the remains are not suitably preserved. Instead of the lack of very old people being the result of preservation issues, it could be that it is due to the fact that these individuals simply make up a much smaller proportion of the population under study.

8.2.2 REFERENCE COLLECTIONS

Cautionary procedures were heeded in attempt to avoid the pitfalls currently associated with adult ageing methodology. Reference collections of known age were used to develop the criteria. Inescapable inherent biases are present within the reference collections themselves. Researchers must trust that the "documented" or "known" ages are in fact true, and absent of human error (e.g. transcription mistakes). This problem was highlighted in the Hamann-Todd Human Osteological Collection, the individuals of which have "known" ages of questionable accuracy. In Chapter Four of this thesis, a high frequency of individuals with "known" age ending in the digits "0" and "5" was found, possibly suggesting age rounding. This could be the result of estimation of age based on physical attributes of the cadavers rather than written documentation (e.g. birth certificates).

Given the notorious unreliability of the "known ages" of the Hamann-Todd Human Osteological Collection, it is acknowledged that the inclusion of this sample was not ideal, but unavoidable. Hamann-Todd was visited as the other very large, well established, American documented skeletal collection, the Terry Collection (Washington, D.C., USA), was closed to researchers for the length of the study. All lengths were taken to only include those individuals for whom "known age" was deemed reliable (see Section 4.2.3).

Reference collections were chosen based on a large sample size, as well as contrasting geographical locations, time periods and the socio-economic status of the individuals. As time constraints were a significant factor (i.e. the limited time of granted access at each reference collections), it was necessary to control variables in order to obtain the largest sample sizes possible. To maximize the number of "older" individuals assessed, only those over the age of 40 years were included. White individuals were only studied in this project to inhibit further truncation of the sample sizes beyond that of the necessary male-female separation. While the assessment of only the later portion of "adulthood" has prohibited the development of new universally applicable ageing techniques (barring additional assessments of "younger adults" between the time of epiphyseal fusion and 39 years of age), the samples examined for this thesis have allowed for variability in the degenerative process to be observed, within defined age ranges, which is essential in adult osteological age estimation. Although formal adult age estimation methodologies cannot currently be developed, new locations of progressive degeneration of the skeleton have been identified, and have been statistically shown to demonstrate distinct stages of degeneration which correlate within sufficiently broad ranges of chronological age.

While it would have been ideal to assess equal numbers of males and females within each age range (i.e. 40–49 years, 50–59 years), this was not always possible, the result of a second inherent bias in sample size was found in the demographic structure of the reference collection. Differences in the frequencies of age and sex was observed between documented collections derived from cemetery remains (i.e. Coimbra and St Bride's), donated remains (i.e. Pretoria), and unclaimed bodies (i.e. Hamann-Todd). Skeletal collections using remains derived from cemetery contexts provide a "normal" mortuary pattern of the community (i.e. Coimbra). For example, the general trend of males in CHC collection was to die younger than the females (i.e. more males in 40–60 year age ranges than 80+ years, females had many individuals survive into their 80s and beyond). St Bride's is an exception to this, as they were a subsection of the entire population, as they were interred in the St Bride's crypt as they had the ability to pay the necessary fee, a price that not all Londoners could pay at the time.

Reference collections derived from donated or unclaimed bodies produce an “unnatural” cross-section of the population, as these individuals are a biased subsection of an entire population. The PBC sample contained very few white males between the ages of 40 and 49 years, and even fewer females between 40 and 59 years. However, due to the vast size of the Hamann-Todd collection, no observable trend in ages was able to be observed.

8.2.2.1 Socio-Economic Status

The socio-economic status also differed between the reference collections, which is inextricably linked to other issues such as health and nutritional status. In addition to the ability of these factors to affect the rate of ageing, they also contributed to the demography of the individuals available for inclusion in this study. Comparison of the males in the PBC study sample and the males in the CHC demonstrates how different status can affect final age-at-death (Figure 8.1). The PBC and SB individuals were of a higher social status, while CHC and HTH were of a “lower class”. In general, the PBC sample contained the remains of affluent white individuals who had access to medical care and sufficient nutrition and likely performed much less physically labour-intensive activities, and as a result, the PBC sample was comprised of few males under the age of 50 years (N = 5), but many who died at an older age (i.e. in their 80s; N = 26).

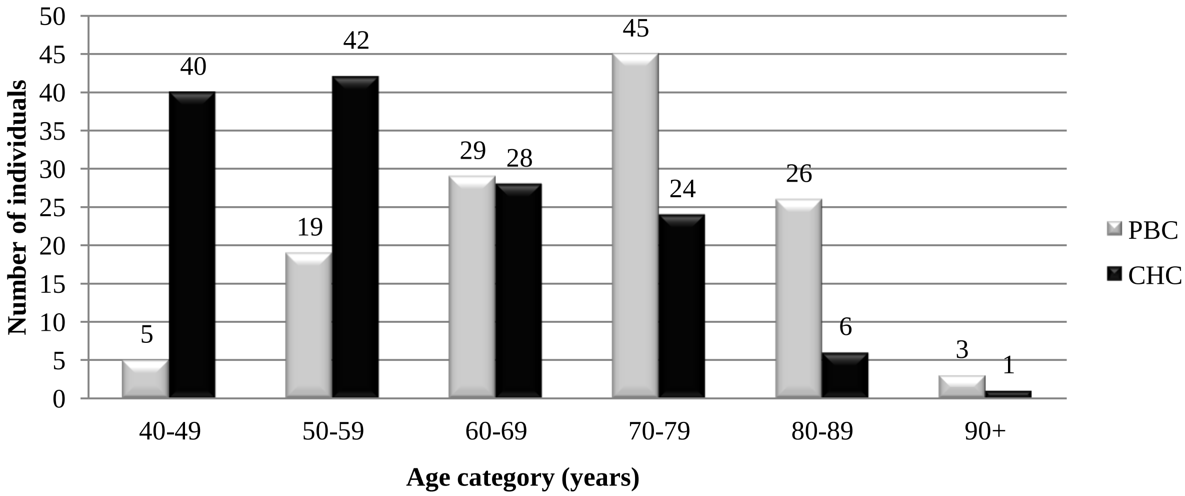


Figure 8.1: *Total number of males present in the PBC (N = 127) and CHC (N = 141) collections.*

In contrast, the CHC study sample was comprised of a lower, working class. The majority of the documented occupations depicted lives full of strenuous physical activity in jobs such as soldiers, farmers, carpenters and shop-keepers. There was an abundance of men who died in their 40s, with a total of 40 males available for study in the CHC collection (only 20 were examined). In contrast, only six were aged in their 80s.

This example illustrates how sex, status, health, nutrition and occupation have the ability to affect all aspects of ageing, not only the rate at which the human body accumulates and expresses age, but also the timing of death. It is likely that archaeological societies would demonstrate a profile more closely resembling that of the CHC, in the absence of excessive wealth and undertaking strenuous occupations, limited access to healthcare to cure disease, or the funds to supplement nutrition. Although there is a peak in mortality in the 40s and 50s, some individuals could survive into their 60s, 70s or even 80s, although in smaller proportions.

8.2.3 OUTLIERS

In the absence of obvious trauma or pathology, all outliers (with the exception of one HTH male sternal clavicle, discussed in section 8.3.3.2.2) were kept in to display as much variation as possible of the ageing process that existed within the study samples. Although removal of those individuals who did not fit the observed degenerative patters would have significantly increased the precision of the resultant age estimation (i.e. narrower age range), the inescapable fact is that with increasing age comes increasing variability of trait expression. The full range of trait expressions must be incorporated if we strive to understand the ageing process. It is only through this can it be determined if skeletal remains have the ability to predictably record age over 50 years. The results of this study demonstrated, despite the large amount of inter-individual variation, several skeletal sites display distinct stages of progressive degeneration, suggesting that is possible to age skeletons of advanced age.

All measures were taken to ensure the developed criteria will be able to be used by other researchers. Written descriptions of different degrees of trait expression were provided in addition to photographs illustrating the general appearance of each state. While the combination of these two pieces of information may be sufficient to understand porosity, they are insufficient to understand the true three-dimensional nature of the traits of surface topography and osteophyte formation. For example, the transformation that the sternal end of the clavicle undergoes from a smooth flat surface to complete surface breakdown is marked, and not accurately described by the provided photographs. Osteophyte formation will ultimately rely on the researcher’s judgement and experience. The production of casts of each of the developed criteria would substantially increase the applicability of the methods, and help to decrease the amount of inter- and intra-observer errors.

8.2.4 COMBINED SAMPLES

Some osteological ageing methods are population specific (e.g. tooth wear), and are inappropriate to apply to different populations. To avoid this, in the absence of clear differences in the degenerative progression, the methods were developed through the combination of all the study samples, each with a unique genetic dispositions, geographical locations, occupations socio-economic, health and nutritional statuses. These are all factors that contribute to the rate ageing. This ensured the age estimations could be applied to any individual from any location and background, to account for the intrinsic and extrinsic factors that cannot be identified or controlled for in unknown skeletal remains. Although suggestions may be made through analysis of grave goods, we cannot confidently know the genetic disposition, or true socio-economic status or occupation of individuals from past societies.

8.2.5 STATISTICAL BIAS

This study was undertaken in full awareness of the identified inherent statistical biases of adult skeletal age estimation. As was highlighted by the Rostock Manifesto (Hoppa and Vaupel, 2002), reliable age estimations can only be made within archaeological populations must meet four key concepts (i.e. better osteological methods, better reference samples, use Bayes' theorem, and assess distributions of lifespans in target populations). While this study sought to investigate the first major element (i.e. produce better osteological methods to identify older individuals), it was inescapably tied to two of the other aspects of the manifesto, which were not feasible to investigate or rectify within the time frame of the given project.

1) <u>the need for better reference samples</u>: well established documented age skeletal samples were used to identify the degenerative trends presented in this thesis. Although each individual included in this study were stated to have known age, these claims could not be validated by the author. As has been acknowledged, the accuracy of the "known ages" within the Hamann-Todd collection has been questioned. Similarly, unsubstantiated rumours of mixing of elements between skeletons are also common for documented skeletal assemblages (e.g. St Bride's and Pretoria).

2) <u>the need for Bayes' theorem</u>: the age structure of the reference sample is of the utmost importance when developing new ageing methods, as there is no escaping the fact that the age estimations reflect the originating sample's age structure. This has a direct effect on the mean ages derived for each ageing method developed in this thesis. As Table 8.1 illustrates, the differences in mean ages range from 61.6 years for males in the CHC sample to 70.8 years in the PBC. On average, the female mean ages were slightly older (65.5 years in CHC to 73.1 years in PBC). It is suggested that further research of the developed methods apply Bayesian statistics to remove the bias imposed by age structure of the reference collections. Unfortunately, this was not possible within the time frame of the current project.

Table 8.1: *Mean ages of study samples.*

Study sample	Males (years)	Females (years)
HTH	68.4	69.1
PBC	70.8	73.1
SB	62.3	65.6
CHC	61.6	65.5

All individual traits used to develop the ageing criteria were proven to be statistically significantly correlated with age, combined into composite scores (where applicable), and finally grouped into identifiable stages of surface degeneration (composite scores grouped together that describe the same surface appearance). Differences between derived surface degenerative stage (i.e. composite scores describing the sample surface appearance) and mean ages and 95% confidence intervals, however, general range of ages (i.e. age phases) were more consistent between populations. More emphasis should be placed on the similarity in composite score expression between populations and broad age range, rather than the population-specific correlated mean age-at-death.

It is important to highlight the observable differences between the 95% confidence intervals (which commonly spanned 3 to 8 years), and the proposed age phases (which spanned 20 to 30 years, or were open-ended). As demonstrated in the blind tests, the 95% confidence intervals were found to be too concise to provide an accurate assessment of age-at-death. The reason for the narrow 95% ranges could be the result of the large sample sizes used to develop the ageing criteria, or the use of truncated ages in the study samples (i.e. 40+ years). Although less precise, the broader age phases provided a greater accuracy.

Comparison of each degenerative age stage of the combined populations gives a realistic assessment of the amount of variability of the ageing process between individuals of the same age in multiple populations of differing socio-economic statuses, activity levels and geographical regions. These are three important factors that will be unknown in all excavated archaeological remains. The distinct surface stages were present and observed in all populations, the ageing method should be applicable to all populations.

Specific caution was adhered to when revising the established methods (i.e. pubic symphysis and auricular surface), namely avoidance of perpetuating the trend of underageing individuals using the established criteria. The current criteria were critically assessed to determine whether maximum age limits for these methods should indeed be lower than stated.

8.3 INDIVIDUAL METHODS

8.3.1 ARACHNOID GRANULATIONS

8.3.1.1 Accuracy and Bias

Initial assessments of the results using Barber’s (1997) regression equation suggested that the method does have the ability to accurately estimate age to some extent. The males and females of the HTH, PBC and SB collections were evaluated using Barber’s regression equation. When applied to the study samples, the accuracy of the method increased with broader age ranges. As Table 8.2 summarises, overall the estimated age of approximately 33% to 44% of individuals were found to be within 10 years of the known age, and 60% to 78% were aged within 20 years.

Table 8.2: *Summary of accuracy of age estimations using Barber's (1997) regression equation.*

Accuracy	HTH	PBC	SB
± 5 years	36 (22.8%)	23 (15.4%)	1 (11.1%)
± 10 years	57 (36.1%)	49 (32.9%)	4 (44.4%)
total aged within ± 20 years	107 (67.7%)	89 (59.7%)	7 (77.7%)

A marked bias was present for individuals with known age between 40-59 years, who were overaged by 25 to 38 years (Table 8.3). The older age ranges faired slightly better, although still overaged, the amount of inaccuracy of individuals aged 60+ years ranged from two years to 25 years. The exceptions to this were the HTH and the SB individuals aged 80+ years, who were only underaged by approximately eight years.

Table 8.3: *Summary of inaccuracy and bias using Barber's (1997) regression equation.*

Age range (years)	HTH		PBC		SB	
	Inaccuracy	Bias	Inaccuracy	Bias	Inaccuracy	Bias
40–49	27.1	26.6	28.3	28.3	27.2	27.2
50–59	27.5	27.5	38.3	38.3	24.6	15.5
60–69	13.7	9.7	27.6	25.8	7.9	7.9
70–79	13.4	2.2	21.9	17.9	-	-
80+	12.6	-7.5	15.5	2.6	8.0	-8.0
40+	17.7	9.5	23.2	17.7	19.6	13.8

There was no positive relationship between the number of pits and depressions and increasing age. The SB sample was the only collection to demonstrate a vaguely increasing slope, while in the other two collections, as the regression line's slope is decreasing (HTH), indicating this correlation is negative, or flat (neither increasing or decreasing, PBC). A truncated sample, lacking younger individuals will have an effect on the slope of the regression line, however, Barber (1997) reported that the number of pits and depressions increased primarily after the age of 50 years. The findings of this study do not agree with those of Barber's original research (Barber et al., 1995; Barber, 1997). However, the neutral correlation between total arachnoid granulation count and known age support the studies of Basmajian (1952) and Duray and Martel (2006) who found that the frequency of arachnoid granulations was not significantly correlated with age.

8.3.1.2 Problems and Limitations

Barber (1997) claimed the main benefit of the quantification of arachnoid granulation technique was the ease of application (i.e. counting pits and depressions), however, this was not the finding of this study. A contributing factor to the discrepancies between the findings of this study and that of Barber

(1997) may be related to the interobserver error associated with the application of the arachnoid granulation identifying criteria. In theory, the criteria are very clear – simply count the number of pits, cluster of pits, and depression. However, in practice, the method is far from straight forward as the physical appearance of the arachnoid granulations is highly variable. No two pits or depressions have the same size, shape or internal morphology. They do not always occur in isolation. As Barber (1997:175) proposed, each definable cluster of villi, regardless of size or shape, should be counted as one single arachnoid granulation. The problem lies in that individual definable clusters of villi are difficult to decipher when found in close quarters with others. Although they look like they may be independent structures, it may be possible that they originated from the same villi. How does one decide? This method was very difficult and frustrating to apply, as it relies entirely on the judgement of the researcher, who may or may not have the functional knowledge of the processes resulting arachnoid granulation formation that would aid in the confident determination of total number of pits and depressions present.

Barber (1997) stated that there is no maximum cut off for age estimations using the regression equation, however, in the presence of many arachnoid granulations, this can produce unreasonable age estimations. For example, in this study, an individual with a known age of 63 years was overaged by 97 years, after the estimated age of 159 years was calculated.

The state of cranial preservation was a substantial limiting to the application of this method. Observation of the endocranial surface of the parietal bones could not be carried out in crania that were too intact or too fragmentary. This greatly reduced the study sample sizes. For example, in the CHC sample, where all crania were in excellent condition, arachnoid granulations could not be recorded in any individual.

8.3.1.3 Further Research

This study suggested the relationship between arachnoid granulation counts and age-at-death was not one through which age could be reliably estimated. Future research should be aimed at investigating relationships between an individual's health and arachnoid granulation development. It is also suggested that if future researchers are to find this method more accurate than this study did, a maximum age limit must be imposed to relate a maximum number of granulations to a maximum age estimation (e.g. a total score of 16+ pits and depressions correlates to 80+ years).

8.3.2 CERVICAL VERTEBRAE

As highlighted in the results chapter, three of the four study samples demonstrated similar patters of degeneration of the cervical spine. The exception to this was the St Bride's assemblage. Although the exact cause of this is not known, the most notable differences between the SB collection and the other three are the poorer state of preservation, the smaller study sample size, they are of a higher socio-economic status, and are from an earlier time period in history.

Without further research, the reason for the SB collection being so markedly different from the other study samples will remain unknown. As the rate of degeneration of skeletal elements is strongly influenced by the amount of wear and tear placed on the body over time, it is possible that the noted difference is related to the fact that the SB assemblage is historic in date and/or of higher status. The observed discrepancy may result from different activities undertaken between individuals in the differing time periods, which placed differing movements, stresses and strains on the necks of the SB individuals. For example, the reliance on horses for transportation in time periods before the widespread use of automobiles may place different forces on the neck.

Although the degenerative pattern was different in the SB study sample, each cervical spine provides information of the variation in the ageing process within humans, and as a result, they were not removed from the combined samples.

8.3.2.1 Atlanto-Dens Articulation

The statistical analyses found varied results between the two articular surfaces of the joint. Despite differences found between the SB sample and the rest of the study samples, general patterns of degeneration were discernable.

8.3.2.1.1 Dens Facet on the Atlas

Significant differences were not observed for the severity of degeneration between males and females for all reference collections, with the exception of the SB sample. Although the unpaired *t*-tests did not identify any statistically significant differences between the composite score and known age of males and females in three of the four assemblages, only composite scores for males were found to have a statistically significant relationship with age-at-death in the SB assemblage. All three surface features (topography, porosity and osteophyte formation) and composite scores were shown to be correlated with documented age-at-death in the HTH, PBC and CHC samples (i.e. $P < 0.05$). Again, SB was the exception to this, as only increasing porosity was statistically significant with age. The presence of eburnation was consistently found to be the most frequently associated with older age (i.e. r_s value was highest) in the HTH and PBC samples, while porosity most significant in the SB and CHC samples. It is interesting to note that despite Spearman's rank correlation coefficients of osteophyte formation and eburnation indicating no correlation was present with known age in the SB sample (i.e. $P > 0.05$), the composite score was still found to have a statistically significant relationship with known age.

When the results from the four skeletal collections were plotted against one-another (males and females combined), no differences were identified. The composite score of the dens facet on the atlas was more highly correlated with known age than any of the individual traits. The combination of composite scores with similar descriptive statistics resulted in the production of three distinct age stages.

8.3.2.1.2 Dens Facet on the Axis

In contrast to the atlas, the dens facet on the axis found a much more variable pattern of degeneration with regards to trait expression and the sexes. Unpaired *t*-tests did not identify any statistically significant differences between the composite score and known age of males and females in the HTH and CHC samples, however, differences were found in PBC. Again the SB sample was the most markedly different, as composite scores of males were not statistically correlated with age-at-death. All three surface features (topography, porosity and osteophyte formation) were shown to be correlated with documented age-at-death in the HTH, CHC and PBC (males). Osteophyte formation was not significantly related to age in the PBC females, and none of the surface features were correlated with age in the SB females. The presence of eburnation was consistently found to be the most frequently associated with older age (i.e. r_s value was highest), with the exception of the SB females. Again it is interesting to note that despite Spearman's rank correlation coefficients of the three surface traits demonstrating no correlation with known age in the SB females (i.e. $P > 0.05$), the composite score was still found to have a statistically significant relationship with known age.

Due to half of the study samples displaying differences between males and females, they were separated when the results from the four skeletal collections were plotted against each other. No marked differences were identified in either sex. Like the dens facet on the atlas, the combination of composite scores with similar descriptive statistics resulted in the production of three distinct age stages.

Although all trait expressions and composite score were statistically correlated with age, it is interesting to note that although all traits for the dens facet of the atlas were found to be significantly correlated with known age, the presence of eburnation (male, $r_s = 0.548$, $P < 0.001$; female, $r_s = 0.544$, $P < 0.001$) was more highly correlated with age than the composite score for males and females (male, $r_s = 0.530$, $P < 0.001$; female, $r_s = 0.473$, $P = 0.001$). Within the 40+ year sample, this suggests, irrespective of composite score, if eburnation is present on the dens facet of the axis, individuals are aged 65+ years. If eburnation is not present, composite score and age stages will estimate age. It is essential that these observations are subjected to further research on a non-truncated sample, as the estimated ages may have been influenced by the age composition of the reference sample, and may differ when applied to other, non-truncated, skeletal assemblages.

8.3.2.1.1 Limitation of Technique

The atlanto-dens articulation is a true synovial joint, which, based on its location in the spine, is affected by differing stresses and forces than the articular facets between vertebrae. This location was chosen for this study, as the dens process and first cervical vertebra are usually well preserved in archaeological skeletons. Although found to have a statistically significant relationship with age, the degeneration of the dens joint of the atlas and axis provides only a general indication of young or old age. As indicated by the proposed age ranges, this degeneration occurs at a slow rate that is variable between individuals. Degenerative changes can be absent until the age of 70 years in some individuals, while in others they begin by the age of 45 years, and severe expression at 55 years. Only very broad, open-ended age estimations are able to discern younger individuals from the very old.

The cause of this is unknown, but the high variability could be due to the fact that the dens joint is synovial in nature. It allows a great deal of movement required to allow the neck to turn and tilt the skull. In contrast, the joints between the cervical bodies are fibrous in nature, allowing much more limited movement.

The main limiting factor to age estimation using the cervical spine is that it is potentially only applicable to modern populations. The differences observed the SB study sample likely relate to differing activities undertaken in this older population. They are doing something different with their necks than in the 19th and 20th century populations. As similar patterns were recorded for the modern populations, degeneration of the cervical vertebrae it is suggested that the most reliable results will only be obtained by examination of 19th to 20th century populations.

8.3.2.2 C3-C7 Body and Facet Degeneration

The degenerative patterns observed between the bodies and facets were very different. Three of the four collections demonstrated similar patterns of degeneration of the cervical vertebral bodies (i.e. no difference in trait expression between the sexes, and all traits significantly correlated with age), with the exception of the SB sample.

In contrast, the statistical results were highly variable for the cervical vertebral facets. Two collections found no difference between males and females (HTH and CHC), one sample found sexually dimorphic differences (PBC), and one found the degeneration of the facets in females to be not significantly correlated with age (SB). Trait expression was also variable between samples and sexes, although osteophyte formation was the most consistently highly correlated trait with age, eburnation was not statistically correlated with age in the PBC females and SB males. Males in the SB sample also displayed a non-significant relationship with porosity.

As was discovered in the dens joint, the SB sample displayed the most different pattern of degeneration of the four study samples. It is possible that this is more of a reflection of the sample size than the traits themselves (N = 70). In the SB collection, statistical analyses identified sexually dimorphic trait expressions existed, and that eburnation was not correlated with age (i.e. $P > 0.05$) for the bodies. For the facets, only males were found to be correlated with age, even though porosity and eburnation did not display a statistically significant relationship with age.

Three general patterns were observed in all four collections:

1. the most severe degeneration occurred in the vertebral bodies of the lower cervical vertebrae (i.e. C6-C7) in contrast to the upper (i.e. C3-C5).
2. the most severe degeneration occurred in the facets of the upper cervical vertebrae (i.e. C3-C4).
3. ankylosis of vertebrae tended to occur after the age of 60 years in all study samples.

As the composite scores for this method were taken from the most severe expression of traits in all of the available cervical vertebrae present in each individual, it is possible that if the lower bodies are absent, an individual will appear to be younger than would be found if the lower bodies were present, and vice versa with regards to the facets.

Despite the highlighted differences between individual study samples, when combined, no marked differences were identified. Separate criteria were developed for assessment of facet degeneration in males and females, and the sexes combined for body degeneration.

8.3.2.2.1 Limitations to the Body and Facet Techniques

The variation in trait expression is detrimental to the application of this technique. As the bodies of the lower cervical vertebrae show more severe changes than the upper, and facets of the upper vertebral vertebrae demonstrate the most severe degenerative expressions, if the entire cervical spine is not present, an accurate assessment of the ageing process may not be possible. Similar to the atlanto-dens articulation results, the difference in degeneration recorded in the SB assemblage may suggest that its applicability should be restricted to modern populations.

8.3.2.2.2 Previous Ageing Studies of the Cervical Spine

While this study was modified from the methods developed by Sager (1969), it is difficult to compare the results of the studies. Sager (1969) assessed each cervical vertebra separately, and provided trends based on a vertebra by vertebra basis. Sager (1969) did not produce a formal ageing technique despite his aim to assess the appearance and changes of arthritis in the cervical spine throughout the life span. This study assessed the general trends demonstrated by the third to the seventh vertebrae, comparing the most severe expression of the cervical spine against documented age to identify any pattern of degeneration present.

The majority of previous ageing studies using the cervical spine focused on the degree of vertebral body osteophytic lipping, which also makes comparisons with the findings of this study difficult. The only findings that can be compared to previous studies relate to the location in the cervical spine of the highest degree of severity. This study found the lower vertebrae (i.e. C6-C7) and the upper facets (i.e. C3-C4) demonstrated the most severe forms of degeneration. These findings were also documented by Sager (1969), Stewart (1958), Snodgrass (2004), Van der Merwe et al. (2006), and Watanabe and Terazawa (2006).

8.3.2.2.3 Further Research

Although the changes are correlated with advancing age, other factors must contribute to the rate of degeneration. As the neck is a very mobile region of the human skeleton, the relationship between activity and the degeneration may provide more information regarding the rate of degeneration. Undertaking a review of archaeological assemblages of differing socio-economic status is suggested to determine if degeneration depends on activity.

A re-evaluation of the degeneration of the cervical spine with focus on modern populations is suggested, as the findings of this study indicate they have the potential to create an accurate means of identifying the very old in forensic contexts.

Further investigations in the maturation of the dens facet on the atlas may aid in age estimation throughout the life span. Does the demarcation of it from the surrounding bone change from childhood? Does age determine whether the facet is flush with the surrounding bone, or slightly raised and cupped in profile, or is it in response to interpersonal variation?

8.3.3 Summary

This study has demonstrated that the degeneration of the cervical vertebrae is a variable process, as highlighted by differences between trait expression and the sexes in each of the study samples. In general, assessment of the cervical vertebrae has the ability to distinguish individuals over the age of 60 years at the time of death. Concise estimates are not possible, and estimates of age are stated in broad terms. A general trend was identified for ankylosis of cervical vertebral bodies to occur after the age of 60 years.

8.3.3 CLAVICLE

The lateral and sternal surfaces of the clavicle were assessed using the same trait criteria. No identifiable differences were found between the severity of degeneration (composite score) of the left and right clavicles, with the exception of the sternal end in the CHC sample. Perhaps this is related to handedness, or the occupational stresses of the population, as these individuals were of a lower class and known to have participated in heavy manual labour, as demonstrated by their documented occupations (e.g. farmer, soldier, builders). For consistency, the ageing criteria for both ends of the clavicle were developed for the right side of the body, due to this element being most frequently present in the collections, compared to the left side (right clavicles, N = 556; left clavicles, N = 546).

For the lateral surface, unpaired *t*-tests did not identify any statistically significant differences between the composite score and known age of males and females. The sexes were not separated for the remaining analyses. Only two of the three surface features (topography and porosity) were shown to be correlated with documented age-at-death. Osteophyte formation was not found to be significantly associated with increasing age except in the CHC study sample. Again, the reason for this is unknown, but perhaps is the result of occupation (i.e. labour-intensive jobs such as farming) or genetic factors. As a result, only surface topography and porosity were explored for their age estimation possibilities in the lateral clavicle. By combining composite scores that demonstrated similar mean age, standard deviation, observed range of ages, three age stages of surface degeneration were identified. When the results from the four skeletal collections were plotted against one-another, no differences were identified, which suggests that the same criteria can be applied to the lateral articular surface of any non-pathological clavicle.

In contrast, unpaired *t*-tests undertaken of the data obtained from the sternal surface found significant differences between the sexes for the composite score and age in the HTH and PBC study samples. As a result, the sexes were analysed separately, and sexually dimorphic criteria were developed. The reason for this is unknown, although possibly related the differing load-bearing capabilities and activities between males and females. The sternoclavicular joint is non-weightbearing, however, it is involved in the movements of the arms and the ribs, and acts a pivot to stabilize the shoulder joint. As males are generally stronger than their female counterparts, perhaps differing stresses and strains are placed on the male joint causing the observable differences. The two most notable differences between males and females were that osteophyte formation in females rarely developed beyond a “slight” expression, while these more severe forms of this trait were found in males. In addition, males were found to frequently use the higher ranges of composite scores (i.e. 13+), while females had only a few recorded observations (i.e. 17 males compared to 4 females in the combined results). In general, males demonstrate degeneration at a faster rate and earlier age than females.

All three of the surface features (topography, porosity, and osteophyte formation) were shown to be correlated with documented age-at-death for the sternal end of the clavicle. Although the Spearman's rank correlation coefficients for each surface trait were found to vary between populations, all were statistically correlated with age (i.e. $P < 0.05$). The severity of surface topography was consistently found to be the most frequently associated with older age (i.e. r_s value was highest), and was also commonly higher in value than the Spearman's rank correlation coefficient for the relationship between composite score and documented age. Although all traits are inter-related in the degenerative process, future revisions of these criteria should investigate the potential of placing increased weight on surface topography.

By combining composite scores that demonstrated similar descriptive statistics, five stages of surface degeneration were identified for both males and females in all study samples. When the results from the four skeletal collections were plotted against one-another for males and females, no differences were identified. This suggests that the degeneration of the right sternal end of the clavicle follows a similar pattern in all males, and all females. It suggests that ageing criteria developed for males during this research may be equally applied to males of any population, and the female developed criteria may be applied to any female individual.

8.3.3.1 Lateral Surface of the Clavicle: Comparison of Results with Previous Studies

Miles (1999) described the age-related change in 152 acromio-clavicular joints. Although his observations were primarily microscopic in nature (using a hand lens and a dissecting microscope), some observations were macroscopic. The results Miles (1999) obtained using a five-grade scale primarily relating the presence and appearance of "pits", "erosion" and osteophyte formation.

The results of this study and Miles (1999) have one notable difference. Both studies found that changes occurred at approximately the same age in both males and females, and the quality (micro- and macroporosity) and quantity of porosity increases with advancing age. Miles (1999) found osteophyte formation around the articular surface to be significantly correlated with documented age, this was not evident in the current study.

The results of Miles (1999:91-94) study found several similarities with this study:

- <u>at 36–45 years</u>: facets were rough to the touch and half of the individuals had pits (Miles, 1999).
    - This observation relates to Stages I and II in the current study; presence of slight and/or coarse granulation. Stage II; displays micro- and macroporosity.
- <u>at 46–55 years</u>: all facets showed pits or erosion (Miles, 1999).

    - Stage II; micro- and macroporosity.
- at 56–65 years: destruction of the basic joint morphology by erosion (Miles, 1999).
    - Stages II and III; macroporosity.
- at 66+ years: nearly all joints were distorted by gross morphological change and erosion. Many surfaces were sclerosed (Miles, 1999).
    - Stage III; marked by severe degeneration and possibly eburnation.

8.3.3.2 Sternal End of the Clavicle

Two additional issues were highlighted through the examination of the sternal surface of the clavicle. The first was the assessment of degenerative processes of the manubrium facet, and secondly, an outlier was removed from the HTH study sample prior to development of ageing criteria using the combined study sample.

8.3.3.2.1 Contribution of the Manubrium Facet of the Sternal Clavicle

The manubrium facet is a small joint surface located on the inferior surface of the sternal end of the clavicle for which the surface topography, porosity and osteophyte formation were recorded. As was found in the lateral and sternal surfaces, no differences were found between trait expression of left and right elements, although it was suggested that sexually dimorphic criteria was required as the PBC females found no correlation with age. Results from all four skeletal collections strongly suggested that an ageing method using the manubrium facet of the sternal clavicle was not feasible; results of Spearman’s rank correlation tests varied between populations, and porosity in the HTH male sample and osteophyte formation in the SB females were not found to be correlated with age. The Spearman’s rank correlation coefficient for the composite score was rarely the most highly correlated with age when compared to individual traits.

The high degree of variation between the study samples demonstrates the highly variable nature of the degenerative process between individuals and populations. The general morphology of the facet itself was also variable, as they differed in size between individuals ranging from non-existent to large raised patches of bone. Finally, preservation of this fragile part of the sternal end of the clavicle limits its applicability. Damage was frequently noted around the rim of this facet, inhibiting true expression of osteophyte formation. Due to all of these reasons, the manubrium facet of the sternal end of the clavicle was not used in combination with the metamorphosis of the sternal surface of the clavicle.

8.3.3.2.2 Outliers

One male individual was found to distinctly differ from the general pattern of degeneration observed in this study. This individual (HTH 1488), was a white male with a “known” age of 61 years. In the original analysis, the trait scores and composite score for the right clavicle were used. Upon re-evaluation, a well-healed fracture affecting the sternal surface was identified. The gross degeneration of the right clavicle (Figure 8.2a) was in marked contrast to that of the left element (Figure 8.2b). This individual was the only outlier removed from the analysis.

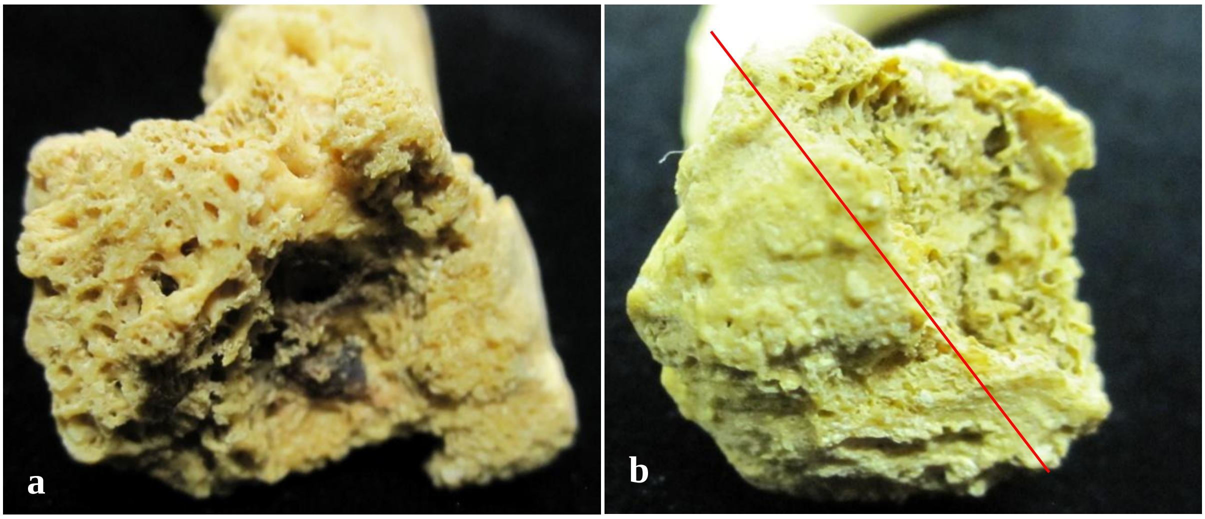


Figure 8.2a-b: *The sternal surfaces of the clavicle recorded for HTH skeleton number 1488 (outlier). (a) right side, composite score of 16; (b) left side, composite score of 10 (damage to the right side of the photo indicated by red line).*

8.3.3.3 Previous Studies

The sternal articular disc begins to increase in thickness in the fourth decade, and continues to increase with advancing age. This is believed to occur in response to connective tissue proliferation within the fibrocartilaginous structure (DePalma, 1957), with the right disc thicker than the left. It has been proposed that this thickening delayed sternoclavicular joint degeneration until the eighth decade, at which time maximum degeneration was reached (DePalma, 1957). This correlates very well with the findings of this study, with peak degeneration recorded in male individuals over the age of 70 years (Stage V), and 85 years in females (Stage V, although a very small sample size; Stage IV, 70+ years).

The medial epiphysis of the clavicle is one of the latest fusing aspects of the human skeleton, which becomes fully fused in all individuals in the early to mid 30s. The distinctive fusion process of the medial epiphysis has been extensively studied in numerous populations. The combination of the developmental information and the degenerative processes outlined in the current study allow for an ageing technique that traces sequential changes from development in childhood into old age (using developmental data from Scheuer and Black, 2004) as follows:

- < 18 years: no epiphysis fusion.
- 16–21 years: an epiphyseal flake fuses.
- 24–29 years: the epiphysis covers most of the articular surface.

- 30–34 years: the medial clavicle completes epiphyseal fusion (it may be possible to combined with Stage I as defined by this study, if further research finds that the post-fusion surface is finely granular, with no microporosity or osteophytes).
- 45+ years (male and female): coarse texture with nodules, microporosity, possible slight osteophytes.
- 50+ years (male), 60+ years (female): coarse texture with nodules in males, uniform nodules in females. Macroporosity, slight osteophytes.
- 60+ (male), 70+ (female): irregular and billowing surface, macroporosity, slight to moderate osteophytes in males. Females demonstrate slight osteophytes.
- 70+ (male), 85+ years (female): complete surface breakdown. Severe billowing and/or eburnation, extensive macroporosity and moderate severe osteophyte formation in males. Slight to moderate osteophytes in females.

8.3.3.4 Combined Lateral and Sternal Surfaces of the Clavicle

The combination of composite scores derived from both ends of the clavicle into a summary score was found to have a stronger correlation with age-at-death than either surface separately. As the lateral and sternal articular surfaces each provide independent information on age, the comparison of the degree of degeneration has the ability to act as an accuracy check.

8.3.3.5 Limitations to Study

The shapes of the clavicular ends are not uniform. The lateral surface can be pinched, with a complete absence of articular surface (Figure 8.3a). It was found to not be possible to confidently assess the trait expressions in individuals displaying this unusual morphology. The sternal end of the clavicle can display a multitude of differing general shapes: circular, ovoid, or triangular. The surface itself was found range from convex, to flat and concave. Few individuals demonstrated a conical surface, caused by a deep central depression, usually associated with a large surface defect (Figure 8.3b). These morphologies were not always bilateral, and differed in the extent of depth of the sunken central surface. In cases where this depression with surface defect was very pronounced, it masked the degenerative trait expressions, limiting the application of the proposed ageing criteria.

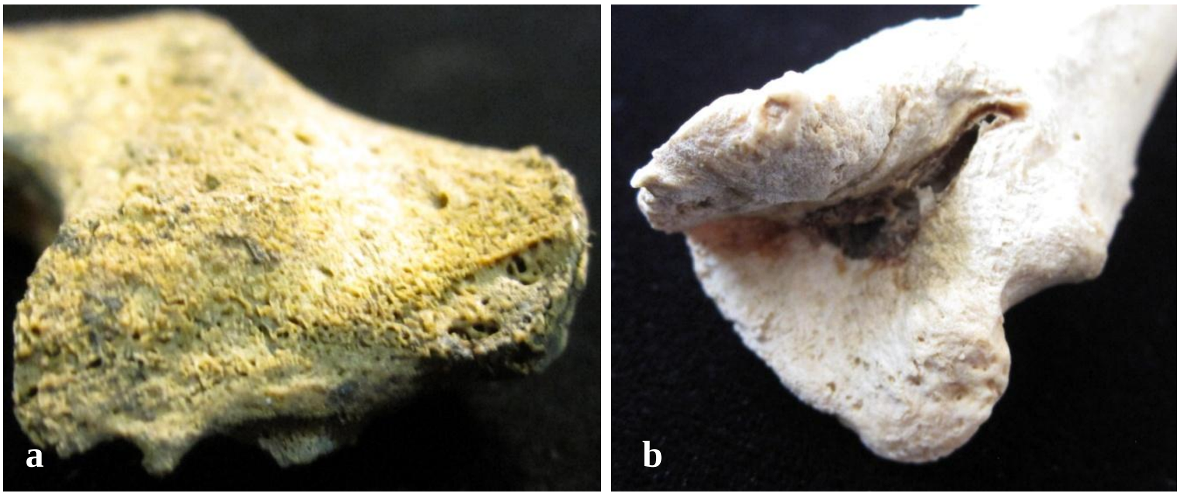


Figure 8.3a-b: *Irregular morphologies of the clavicular ends, (a) lateral end of the clavicle: pinched appearance, absence of articular facet. (b) sternal end of the clavicle: conical surface appearance, with central defect.*

8.3.3.6 Further Research

Several avenues for further research are highlighted:

- traits need to be investigated to identify when they first appear. This will lead to a revision of age stages, as younger individuals may produce one or more additional age stages between the time of epiphyseal fusion and the age of 40 years (where this study began). Undertaking this examination will allow for lower range limits of stages I and II to be developed, as at the moment, there is no lower age limit (i.e. < 50 years and < 65 years, respectively).
- revisions of this method by employing weighting of traits based on their Spearman's rank correlation results may increase the accuracy of the resultant age estimation. Currently composite score 7 and age stage III (sternal end) both denote exceptionally broad non-descript ranges of age, which may be rectified with further statistical alterations.
- development of sexually dimorphic ageing criteria for the lateral surface of the clavicle may increase the accuracy of the method, even though statistically significant differences were not found between trait expression between males and females.
- the relationship between activity and degeneration need to be investigated, as differences were only found between the left and right sternal ends of the clavicle within the CHC study sample, who were known to have undertaken regular heavy laborious tasks.
- these methods may also prove to be useful in forensic settings, although the focus of this thesis is on archaeological populations.

8.3.3.7 Summary

The results have shown that the degeneration of the lateral surface of the clavicle start to appear earlier in life and progress much more quickly than equivalent observations in the sternal clavicle, which ultimately results in the maximum surface destruction occurring at a younger age. This could be the result of the higher mobility and stress loading of the lateral end, as it is an integral part of the movement of the shoulder. This study has shown that peak degeneration of the lateral surface of the clavicle occurs in individuals over the age of 60 years (Stage III). At approximately the same age, the sternal clavicle is beginning to show distinct morphological degenerative changes (Stage III, male, 50–80 years; female, 60+ years). The accumulation of degenerative traits occur more gradually, and maximum surface destruction does not occur until several decades later (Stage V, male, 70+ years; female, 85+ years). Both developed criteria were found to be accurate and reproducible, although the sternal clavicle was more accurate than the lateral surface. Combination of the surfaces resulted in an accuracy equivalent to that of the sternal clavicle.

8.3.4 MANUBRIUM, STERNUM AND XIPHOID PROCESS

Three aspects of the manubrium, sternum and xiphoid process were examined: fusion of all three skeletal elements, and degeneration of the sternum articular surface of the manubrium and clavicular notches of the proximal manubrium. The ability to aid in age estimation greatly varied between sites, as discussed below.

8.3.4.1 Clavicular Notches on Proximal Manubrium

Although statistical results varied slightly between study samples, general patterns were discernable. Significant differences were observed for the severity of degeneration between the left and right sides of the manubrium for all reference collections, with the exception of the HTH sample. The differences between the left and right elements suggest that it is likely related to handedness, or the occupational stresses of the populations. For consistency, the ageing methods were developed for the right side of the body to allow for comparisons to be made with the sternal surface of the clavicle, which was made using the right side.

Although the unpaired *t*-tests did not identify any statistically significant differences between the composite score and known age of males and females, a marked trend for females to have lower composite scores than males was identified. As a result, the sexes were analysed separately, and sexually dimorphic criteria were developed.

All three surface features (topography, porosity and osteophyte formation) were shown to be correlated with documented age-at-death. Although the Spearman’s rank correlation coefficients for each surface trait were found to vary between populations, all were statistically correlated with age (i.e. $P < 0.05$). The severity of surface topography was consistently found to be the most frequently associated with older age (i.e. r_s value was highest), with the exception of males in the PBC sample for whom porosity provided the highest r_s value.

When the results from the four skeletal collections were plotted against one-another for males and females, no differences were identified. This suggests that the degeneration of the right clavicular notch follows a similar pattern in all males, and all females. It suggests that ageing criteria developed for males during this research may be equally applied to males of any population, and the female developed criteria may be applied to any female individual. Although all trait expressions and composite score were statistically correlated with age, surface topography was found to be a higher value than the Spearman's rank correlation coefficient for the relationship between composite score and documented age. Future revisions of this method should investigate the placing of increased weight on topography.

Descriptive statistics of age variation within composite scores revealed similar patterns to the distributions of ages of expression. The generally positive association of composite scores with age found supports the observation that composite scores facilitate age estimation from quantified individual features, however, the mean ages did not always increase in age with increasing composite score. Nevertheless, composite scores with similar descriptive statistics were combined into surface age stages.

Although some overlap exists between, four distinct stages of surface degeneration were observed and were found to be statistically significantly different from each other), and have the ability to aid in adult age estimation. The 95% confidence interval of age stage were concise (ages spanning 3 to 13 years), but the observed range of ages represented by each stage are much more broad, and to allow for the true variability in surface degeneration that was observed between individuals to be demonstrated, allowing a more accurate assessment of age.

8.3.4.1.1 Limitations of the Method

Preservation of the manubrium in the burial environment may be the most significant limiting factor to the application of these criteria. The manubrium is primarily composed of trabecular bone, which is not always well preserved in archaeological contexts.

Also, interobserver error will be a limiting factor, as a full understanding of how to score the traits outlined in this study will require practice and observation of many manubria. Although written descriptions of each trait and the differing grades of expression are provided, and photographs to illustrate how the traits can look, the true three-dimensional nature of degeneration cannot be fully described. The production of produce casts may ease trait identification and decrease interobserver error.

8.3.4.1.2 Further Research

It is important that the differences in trait expression between the left and right sides of the manubrium are investigated. There is evidence that the proximal manubrium may be strongly influenced by the repetitive movements of the upper limbs. These findings may contribute to our ability to identify handedness in skeletal remains, which remains elusive.

Refinement of scoring criteria is also an avenue of future research. As noted, surface topography performed slightly better in statistical tests than the composite score. Any revision of this study should focus on topography, perhaps adding weight to this trait may increase the accuracy of the method. Other aspects of the methodology that can be investigated is determining whether the distribution of nodule formation on the surface (e.g. ± 50% of the surface affected), may allow better description of the surface rather than the current criteria, which simply takes into account the presence/absence of nodules.

8.3.4.2 Fusion of the Manubriosternal Joint

The results of this study found that the manubrium fuses to the sternum in less than 25% of individuals over the age of 40 years. A sexually dimorphic bias was not found, as approximately equivalent numbers of males and females displayed fusion. The xiphoid process was found to ossify and fuse to the sternal body in approximately 50% of individuals. A bias was found towards males, for whom fusion was more common. Each of the study samples found a non-significant relationship between the state of fusion of the manubrium or the xiphoid process and known age.

It was also found that less than 15% of individuals had full fusion of the manubrium, sternum and xiphoid process. Again, a bias was found for full fusion in males. DISH did not appear to be a contributing factor (a consistently low percentage of individuals with DISH display fusion of all three elements).

8.3.4.2.1 Previous Studies

The findings of this study support those of Molleson and Cox (1993) who found the fusion of the manubrium and sternum did not relate to age or sex. However, they noted that the ossification of the xiphoid process increased with age, which was not identified in this study. They found in the Christ Church Spitalfields sample that: 8% displayed fusion in the 25-34 year group, 43% in the 35-44 year group, and 50% in the 45-54 year group.

8.3.4.3 Degeneration of the Manubrium Articular Surface

Due to the similarities in joint type and function (i.e. fibrocartilaginous and non-weightbearing) as the pubic symphysis, it was hypothesised the degeneration of the manubriosternal articular surfaces of unfused joints would aid in age estimation, however, statistical results varied significantly between study samples. Sexually dimorphic ageing criteria were required as composite score was not significantly correlated with female known age in three of the four study samples. The exception to this was in CHC, for which both males and female composite scores were correlated with age. The reason for this is unknown. Individual trait expressions all displayed a wide variation in the age of trait expression (score) of each of the features, and were rarely found to be correlated with documented age. In the PBC and SB collections, the only statistically significant trait was porosity. Although the two of the three traits were found to not relate to age in PBC and SB, the composite score was found to be statistically significantly correlated with age. All traits and composite scores were correlated with age in the HTH and CHC.

Due to the highly variable nature of the results obtained by statistical analysis for the degeneration of the sternum articular facet on the distal manubrium, it is not feasible to produce an accurate ageing technique that would apply to all skeletal individuals (or even males or females separately). A technique cannot be built on a method that combines the scores of traits that are not linked to advancing age.

8.3.4.3.1 Further Research

It would be interesting to investigate this joint for age-related changes in young individuals (non-adults) to see if any changes in the surface morphology occur from the time of development through to adulthood. Discernable degenerative changes were not found after the age of 40 years, perhaps the traits that contribute to degeneration reach maximum expression earlier in life.

8.3.4.4 Summary

This study found that only the clavicular notch of the manubrium was able to contribute to the understanding of ageing older adults. The right clavicular notch was found to be more accurate for males than females, as the blind test of the criteria allowed for 96.4% of males to be correctly aged with the suggested broad ranges, in contrast to only 86.4% of females. Fusion of the manubriosternal and xiphisternal joints was not correlated with advancing age, nor was the degeneration of the sternal articular surface of the manubrium.

8.3.5 ILIAC CREST

Statistical results varied between study samples. No difference was observed for the severity of osteophyte formation between the left and right iliac crests or between males and females for all reference collections, with the exception of the HTH sample. Statistically significant differences were indicated between the sexes at osteophyte score of 3. The reason for this is unknown. For consistency, the ageing methods were developed for the left side of the body, as this is the standard for osteological methods.

Due to this sexually dimorphic appearance in the HTH, the sexes were separated for analysis when the four study samples were combined to assess true trait variability. When the combined results were plotted against one-another (males and females separately), no marked differences were identified within each sex. This suggests that osteophyte formation along the iliac crest follows a generally similar pattern in all males, and all females, indicating that the ageing criteria developed for males during this research may be equally applied to males of any population, and the female developed criteria may be applied to any female individual.

Trait expression was observed to be most severe at the iliac tubercle. Osteophyte formation was shown to be statistically significantly correlated with documented age-at-death (combined sample: male, r_s = 0.513; female, r_s = 0.464), although this trait expression was found to be variable, as demonstrated by each individual trait score extending across a wide range of ages. It is noted that although the results of the Spearman's rank correlations indicated a statistically significant relationship between osteophyte score and known age, the correlation coefficients were among the lowest values obtained during the course of this research, suggesting this trait may act as a general indication of advanced age, and not provide age estimates within ranges.

The descriptive statistics of age variation within trait scores revealed a generally positive association of osteophyte formation scores. Three distinct stages of osteophyte formation were observed in both males and females (i.e. found to be statistically significantly different from each other), and have the ability to aid in adult age estimation. The 95% confidence intervals for the age stages appear to be very concise (i.e. range of 4 to 5 years in males, 5 to 9 years in females). Age phases were also suggested and are very broad (and open-ended). This is a strong indication that the iliac crest will be primarily utilized to identify the young from the old, not to provide a specific age estimation range.

8.3.5.1 Limitations of this Study

Despite finding the criteria reproducible in this study (low intraobserver error), a limitation to the use of this study will be the ability for other researchers to apply the criteria. As allocation into one group or another does not depend on a quantitative value, the identification of the state of osteophyte development relies entirely on the experience and judgement of the investigator. During the course of this research it was often found to be difficult to distinguish between the stages for individuals that displayed characteristics graded between the set categories. For example, should a slight-moderate appearance be allocated to the slight category or the moderate one? Perhaps associating the development of osteophytes along the iliac crest should be analysed metrically, with the osteophyte formation differentiated between categories based on a physical measurement.

Secondly, iliac crest osteophyte formation cannot be applied as a formal ageing method, as it can only really provide information differentiating the very old from the rest of the adult population, as it cannot provide age estimations beyond open ended ranges.

Lastly, as was found with the developed criteria for the sternal end of the clavicle in this study, small bodied females did not display the same range of osteophyte development expressions as observed in males and "normal" sized females. Observations were most commonly minimal or slight for these individuals.

8.3.5.2 Further Research

A clear pattern of more severe osteophyte development was not observed for individuals with the vertebral changes associated with DISH compared to those without the disease, however, their relationship must be subjected to further research. Investigations also need to be undertaken to determine what causes osteophytes to form on the iliac crest, as not everyone develops them in later years (i.e. none and minimal osteophytes are found in individuals aged 90+ years). Is this an indicator of the differences between bone formers and individuals who do not form bone more readily? Similarly, the relationship between physical activity and iliac crest osteophytes should be studied.

Also noted during the analysis of the ilia, was the frequent observation of thinning of the iliac blade as demonstrated in Figure 7.26b. This appearance could be subjected to further study to determine whether it occurs in response to age, other another cause, or is it simply human variation.

8.3.6 AURICULAR SURFACE OF THE ILIUM

The auricular surface is one of the most frequently applied adult age estimation method used in biological anthropology today (Falys and Lewis, 2011). The original Lovejoy et al. (1985b) method and the recently proposed Buckberry and Chamberlain (2002) revised auricular surface methods are both being used. As a result, it is of the utmost importance that these heavily relied upon techniques are able to provide accurate results. Both of the aforementioned methods were evaluated for their abilities to accurately estimate the age of individuals over 40 years from the study samples. With findings of previous research into the auricular surface in mind, revisions of the criteria and method were made where possible.

8.3.6.1 Lovejoy et al. (1985b) Auricular Surface

When applied to each of the four study samples, the accuracy of the Lovejoy et al. (1985b) method was found to range between 43.9% (HTH) and 69.5% (PBC). This was due to the majority of each of the samples displaying Lovejoy Stage 8, which indicates an age of 60+ years. All other stages performed poorly. An overwhelming bias was identified towards underageing, with between 23.8% (PBC) to 51.6% (HTH) underaged. Between 4.5% (HTH) and 14.7% (SB) were overaged. These findings suggest the age ranges, with the exception of stage 8 (60+ years), are too small to allow for the true amount of variation to be taken into account within each stage. Similar to the accuracies found in the study samples, 47.6% of the individuals in the blind test sample were accurately aged, a bias towards underageing, as 37.8% of the sample had known ages to be older than determined by the auricular surface criteria, and 14.6% were overaged.

Further investigations of the auricular surface found no significant differences between the surface stage recorded for the left and right elements were present in any of the study samples, with the exception of the HTH collection. No differences were found between males and females for the same surface stages in all study samples, with the exception of the CHC sample. It was found that males and females differed in the age of expression of a surface score of 8. The reason for this is unknown, although it could potentially be due to the heavy labour jobs recorded in the occupations. A Spearman's rank correlation coefficient was calculated to determine the relationship between the original criteria and known age in the combined study sample. The result found a statistically significant correlation between the two factors ($r_s = 0.553$; $P < 0.001$).

8.3.6.1.1 Previous Studies

Many studies have tested the ability of the Lovejoy et al. (1985b) original auricular surface technique to accurately estimate the age of unknown skeletal individuals. Two major themes are consistently indicated:

1) the criteria are difficult to apply due to the obscurity of the terminology, written descriptions, and ability to identify the traits, and also it has been found to be difficult to interpret the result if the surface does not clearly fit within one of the Lovejoy stages. Although black and white photographs were present in the original publication (Lovejoy et al., 1985b:24-25), and colour photographs were subsequently produced (Bedford et al., 1989), the ability to differentiate between the many interacting aspects of the auricular surface did not ease the application.

2) age estimations made using the Lovejoy criteria are allocated into 5 to 10 year age ranges. Subsequent re-evaluations of the method have proven that these narrow age ranges are too optimistic. A five year interval does not provide an adequate range of ages to account for

variation in the ageing process. As a result, younger individuals are generally found to be overaged using the Lovejoy method, and older adults are underaged.

8.3.6.1.2 Revising the Lovejoy Criteria

Osborne et al. (2004) re-evaluated the Lovejoy criteria, in particular the narrow age ranges. They found that 33% of their study sample was correctly aged within the suggested 5-year intervals. By comparing the descriptive statistics derived by individuals within each surface phase, they found that the stages did not always significantly differ from one another, and as a result, Osborne et al. (2004) proposed a six phase scoring system achieved by collapsing phases 1 and 2 together, and 5 and 6. The 95% confidence intervals were used for age estimation, and concluded that "although the method is somewhat inaccurate, this is more of a reflection on adult age estimation in general rather than a problem specific to the auricular surface" (Osborne et al., 2004:6).

With the well-cited shortcomings of the auricular surface method in mind, revisions of the Lovejoy method aimed to broaden the age ranges. To accomplish this, the original technique's eight stages were collapsed into four phases based on the main features of the surface itself: surface topography (i.e. billowing, striae, flat), texture (i.e. granulation and density) and porosity (as described in Table 5.8). A fifth phase was introduced based on the identification of rounded nodules of new bone on the surface itself, giving a bubbling appearance. Aspects previously described by Lovejoy et al. (1985b), including the appearance of the retroauricular area and apical changes were not included in the revision.

This new trait was identified following observation of many auricular surfaces. Lovejoy's stages 6 and 7 are described as being dense surfaces, stage 8 is characterised by breakdown with marginal lipping. The word "breakdown" gives the impression that the surface is eroded and extensive formation of osteophytes surrounding the auricular surface. A pattern was observed that in some individuals, during "breakdown", the dense surface was transformed by small or large areas of new bone formation on the surface itself. These growths could take the forms of sheets or rounded nodules of bone ("bubbling" of the surface). Presence of this bone formation on the surface itself was recorded as phase V.

Proposed age estimations for the revise method were not made by simply combining the age ranges supplied by Lovejoy et al. (1985b), as the investigations of the original method identified the narrow nature of the 5 to 10 year ranges were deficient in identifying known age. In order to allow for sufficient variation in auricular surface degeneration to be accounted for, age estimations for the revised method were provided by the combination of all four study samples. The 95% confidence interval for each age phase was calculated, and broader, open-ended age ranges were proposed. This follows the findings of Falys et al. (2006), in which it was hypothesised that the auricular surface does not provide concise age estimation, but rather broad phases (e.g. young, middle and old adults).

The new phases were investigated in each of the study samples. To justify the combining of Lovejoy stages with the same surface characteristics and introduction of the new surface stage 9 (phase V), unpaired *t*-tests were employed to test for differences between the new phases, all of which were found to be statistically significant, with the exception of phases IV and V in the HTH sample (t = -1.98, df = 94, P = 0.051). The reason for this could be due to the fact that the pattern regarding development of surface nodules was identified half way through the data collection phase at the HTH collection. Trait identification of half of the HTH sample was made based on photographs taken of the auricular surfaces at the time of analysis. It is possible that the photographs did not illustrate clearly development of surface nodules characterising stage V.

Slight differences were also found when the results of the revised criteria of all four study samples were plotted together. The HTH sample was found to display different patterns of phases II and III than compared to the other collections (see Table 6.287). Despite that, each surface phase was found to display a differing maximum cut-off age. To determine the relationship between the new scoring scheme and known age, a Spearman's rank correlation was performed. As the higher the score (r_s) assigned to a particular surface feature, the more frequently it was associated with older age, the result of this test was used to determine if the new method performed any better than the original criteria. Although both methods were found to be highly statistically significant (i.e. $P < 0.001$), the revised system did provide an increased Spearman's rank correlation coefficient (original Lovejoy, r_s= 0.553, $P < 0.001$; revised, r_s= 0.593, $P < 0.001$).

8.3.6.2 Buckberry and Chamberlain (2002) Auricular Surface

When the original Buckberry and Chamberlain (2002) revised auricular surface ageing method was applied to each of the four study samples, the results were highly accurate, with all accuracies ranging between 90.0% (CHC) and 95.7% (PBC). A slight bias towards overageing was suggested, as between 2.9% (PBC) and 8.8% (CHC) of the populations were overaged by the auricular surface criteria. Similarly, when blind tested on the CCS sample, of the 82 assessed individuals, the original Buckberry and Chamberlain (2002) auricular surface criteria correctly aged 92.7%. Again, a bias to overage was indicated as the estimated age of 7.3% of the sample was older than the known age.

8.3.6.2.1 Previous Studies

These highly accurate results were expected, due to the wideness of the 95% ranges supplied by the published criteria for use to derive estimates of age, as suggested by previous studies.

8.3.6.2.2 Additional Observations

For completeness, trait expression, composite score and auricular surface stages were investigated, to allow comparison with the original Buckberry and Chamberlain (2002) study. Statistical analysis of surface trait expression between the left and the right sides of the body resulted in a non-significant difference in all study samples, indicating that the criteria can be applied to either auricular surface. However, for the first time in any study, significant differences were found between males and females in all samples. Two of the collections found female composite scores to not be correlated with age (i.e. PBC and SB; Spearman's rank correlations, $P > 0.05$). The results of the unpaired *t*-tests that tested for differences between males and females for age of expression of each composite score in the other two samples (HTH and CHC) indicated that statistically significant differences were indeed present. The HTH sample showed a difference between the sexes at composite score 14, and the CHC demonstrated the difference at the highest scores, composite scores 18 and 19. Despite the non-correlation between composite score and age-at-death, statistical analyses were carried out for the PBC and SB females in order to evaluate the relationship between the individual surface features with age (i.e. Spearman's rank correlation) to see if any of the five traits were related to age.

Each surface feature was found to have observable morphological differences (identified by observed trait score), which altered their expression over an age range represented by each composite score. The higher trait scores tended to be found in the higher composite scores. A wide variation in the age of trait expression (score) of each of the features was also commonly found.

A Spearman's rank correlation coefficient was calculated for each feature in males and females in each collection to test if it was correlated with age-at-death. Rarely were all individual trait expressions found to be significantly correlated with age-at-death. The only trait that was consistently found to display a significant relationship, and therefore most frequently was associated with older age, was surface texture. This trait was also commonly found to provide a higher r_s value than the composite score. It was interesting to note, that despite one or more of the individuals traits not being correlated with known age, the combined score (composite score) was significant, meaning that age estimations made based on composite scores are not being made using traits that have the ability to progressively alter with advancing age, rendering estimations inaccurate. The age estimations appear to be accurate due to their broadness, and not necessarily due to the appearance of the auricular surface itself.

The fact that the Buckberry and Chamberlain (2002) method was able to estimate the age of the individuals in all four study samples with a minimum accuracy of 90.0% must relate to the broad range of ages represented by each age stage, as the age estimates are based on features that are not always correlated with age, and differ between males and females.

8.3.6.2.3 Revising the Revised Auricular Surface Criteria

The assessment of Buckberry and Chamberlain (2002) trait expression in older individuals, as described in this study indicated the presence of differences in surface topography, microporosity, macroporosity and apex changes are not always correlated to age-at-death. Previous studies have found these to be consistently related to age in younger individuals (Falys et al., 2006), however, they become more variable with advancing age. The aim of re-examining the revised criteria was to provide assessments of the sexually dimorphic nature of auricular surface ageing based on the only trait that was found to be consistently associated with age, surface texture. The scoring system followed that published by Buckberry and Chamberlain (2002:233), with the addition of surface bone growth (raised surface texture), which was found in the previous section to occur in advanced degeneration of the auricular surface, changing its texture from dense bone. The revised scoring system provided values between 1 and 6 points.

Expression of surface texture was found to differ between males and females in the later stages of degeneration, at a score of 6. Revised surface texture was found to be significantly correlated with age for males and females (males, $r_s = 0.578$, $P < 0.001$; females, $r_s = 0.566$, $P < 0.001$), which was more correlated than that derived through the use of the original Buckberry and Chamberlain (2002) composite scores ($r_s = 0.388$, $P < 0.001$). The descriptive statistics of age variation within composite scores revealed that the overall trend of increasing age with increasing composite score for males and females. With the exception of scores 3 and 4 in females, all revised scores were statistically different from one-another, indicating each represents a distinct stage of auricular surface degeneration. The similarity of ages produced by female scores of 3 and 4 is likely due to the very small sample size of individuals recorded displaying these appearances of surface texture. Younger individuals (i.e. under 40 years) must be examined to determine whether these two scores provide statistically distinct stages.

8.3.6.3 Ankylosis of the Sacro-Iliac Joint

Analysis of the study samples found that 4.8% of individuals displayed either uni- or bilateral ankylosis of the sacro-iliac joint. A clear bias was not observed between side of fusion. No individuals aged under 60 years of age had fusion of this joint, and the frequency increased significantly after the age of 70 years. Differences were found between males than females, as not only were males more frequently affected, the sexes displayed differing patterns of fusion (i.e. male sacroiliac joints were fused along the superior edge of the superior demiface only, females displayed fusion along the inferior demiface, or around the entire joint). DISH did not appear to be a contributing factor, only 40.0% of the individuals that displayed sacro-iliac fusion had the osseous changes to the thoracic vertebrae.

The assumption that individuals over 50 years were more prone to sacro-iliac fusion was proved true in the Spitalfields sample, as those individuals displaying bony bridges between the sacrum and auricular surface were between the ages of 50 and 90 years. This finding suggests that factors other than age and DISH contribute to the fusion of the sacro-iliac joint, which results in interpopulation differences in the development of sacro-iliac fusion. It is interesting to note that sacro-iliac fusion began occurring at an earlier age in the historic Spitalfields sample (i.e. 50+ years) than in the more modern study samples (i.e. 60+ years). As was found with the cervical vertebrae studies, perhaps this results from differing activities undertaken in older populations than in modern times. As a forensic indicator, a minimum age of 60 years should be suggested.

8.3.6.4 Limitations to the Study of the Auricular Surface

Although alterations to the established methods have been proposed for this region of the skeleton, the revisions did not extend to the degenerative characteristics of the auricular surface. Although photographs of examples of trait expression have been supplied in this study, the changes to the auricular surface are subtle (especially identifying state of granularity) and variable between individuals of equivalent ages. Trait identification relies entirely on judgement and experience. Based on personal experience, identification of surface texture (i.e. fine and coarse granulation and dense surface) are the most challenging aspects of the auricular surface metamorphosis, and unfortunately, it is these aspects that this study has found to be the most correlated with age-at-death. Intra- and inter-observer errors will always be high in this method.

The preservation of the auricular surface in archaeological contexts is a key limiting factor, as postmortem damage can appear as porosities, and identification of granulation can be difficult.

8.3.6.5 Further Research

Beyond applying the revised criteria on other known age skeletal collections in order to determine minimum age limits for each proposed score, suggestions for further research involving the auricular surface itself could not be proposed. Time and time again the Lovejoy et al. (1985b) criteria have been re-evaluated on documented populations of differing geographical locations and time periods. The results are always the same, with trends identified towards underageing older individuals, and overageing younger ones, high inter-observer error between researchers, and criticisms of how the method is applied and how to interpret the results (Murray and Murray, 1991; Saunders et al., 1992; Bedford et al., 1993; Schmitt, 2004). Similarly, the Buckberry and Chamberlain (2002) is praised for its ease of application, and criticised for its inability to estimate age with precision (Mulhern and Jones, 2005; Falys et al., 2006; Wittwer-Backofen et al., 2008). It is suggested that the focus of future auricular surface ageing is to conclude that the surface does not display regular and predictive stages of degeneration that can provide narrow estimates of age, but rather, phases of progressive degeneration that can identify the young individuals from the old.

Research must be undertaken to explain the need for sexually dimorphic criteria in the Buckberry and Chamberlain (2002) criteria, as differences were found in this study, as well as Hens and Belcastro (2012).

Further research with regard to the ankylosis of the sacro-iliac joint is suggested to investigate the observed patterns of sexually dimorphic fusion noted in this study. The physical mechanism that results in sacro-iliac fusion must differ between males and females, which results in male ankylosis occurring along the superior demiface, and females at the inferior demiface or both demifaces.

8.3.6.6 Summary

The findings of this study found that the original methods developed to assess the passage of age based on the metamorphosis of the auricular surface, despite all shortcomings of underageing older individuals, set a maximum age limit that was accurate (i.e. 60 years). However, the revision of surface characteristics in this study found differing traits that allowed this maximum age limit to be confidently reached, without underageing. The auricular surface is one of the most applied ageing methods, despite the well documented pitfalls. If researchers are going to use it, we must ensure that age estimates are accurate. These findings suggest that the conclusions obtained by Falys et al. (2006) may truly reflect the ability of the auricular surface to provide age. It can distinguish between the young, middle, and old, but not precise age range estimates, as proposed by Lovejoy et al. (1985b).

8.3.7 PUBIC SYMPHSIS

The pubic symphysis is one of the most frequently applied adult age estimation method used in biological and forensic anthropology, and is also one of the most widely tested. The original Brooks and Suchey (1990) method, and the recently proposed Berg (2008) revised surface phase technique, which introduced a new Phase VII for females, were both investigated in this study. Investigations were undertaken to test the ability of pubic symphysis to identify advanced age. Unfortunately, no revisions of surface criteria could be proposed, although increased maximum age limits for each Suchey-Brooks stage were suggested.

8.3.7.1 Suchey-Brooks (1990) Criteria

Males and females were assessed using the sexually dimorphic criteria published by Brooks and Suchey (1990). The accuracies of age estimation derived using the individuals in the study samples found that females were more frequently predicted correctly than males. The male accuracy ranged between 71.9% (SB) and 84.6% (PBC), while females were found to be between 89.0% (CHC) and 95.8% (SB). A strong bias towards underageing was apparent, as every estimated age that fell outside of the 95% confidence interval indicated the known age was being underestimated by the Suchey-Brooks (1990) criteria, this discrepancy was found to be between 15.4% and 22.5% of the male in the study samples and 4.2% to 11.0% of the females. The overall accuracy of the combined study sample found 79.9% of males were accurately aged, and 92.0% of females. Although some of the identified underageing discrepancy within this the application of this method originates in the age biases caused by the differences between age composition of the original Suchey-Brooks (1990) forensic reference sample (i.e. biased towards younger adults) and the truncated target samples used in this research (i.e. biased towards older adults), overall, these findings did still suggest that the maximum age limit of each Suchey-Brooks phase was not old enough to account for pubic symphysis variation.

8.3.7.1.1 Additional Analyses

Although statistical results varied between study samples, the general patterns of pubic symphysis degeneration were similar in all collections. No difference was observed for the severity of degeneration between the left and right pubic symphyses for all reference collections, with the exception of the PBC sample. The cause for this is unknown, however, the main difference between the PBC and the rest of the collections was the frequent evidence of access to medical and surgical intervention. Several of the assessed males and females had hip or knee replacements. It is hypothesised that advanced degeneration of the hip joint and the subsequent replacement may have the ability to alter the load-bearing mechanics of the innominates, which in turn alters how the halves of the pubic symphyses associate with each other. It is noted that no published research was found to validate this assumption. For consistency, the Suchey-Brooks criteria were applied to the left pubic symphysis, as per the standard for osteological methods, or the right side if the left was absent or damaged.

The relationship between the pubic symphysis phase scores and known age was assessed using Spearman's rank correlation coefficients, which found a highly significant correlation for both sexes (males, $r_s = 0.584$, $P < 0.001$; females, $r_s = 0.416$, $P < 0.001$). The descriptive statistics for each age phase did not resemble those of the original technique, as the age range of assessed individuals in this study was truncated (40+ years), meaning the lower age limits of each surface phase could not be investigated, as they range from the 20s and 30s. However, the accuracy of the maximum age limits (i.e. older estimate of the 95% range) provided by Brooks and Suchey (1990), as previously stated, did not sufficiently describe all individuals within an age stage. To fully acknowledge the variability in the ageing process, the upper age limit must be extended. New upper age limits for each phase are suggested, based on the combined study sample. Lower limits could not be given, as individuals under the age of 40 years need to be included in the study. The proposed maximum age limits are:

- Phase III indicates an age under 60 years for both males and females.
- Phase IV suggests an age-at-death of younger than 75 years, in both sexes.
- Individuals under the age of 90 years display Phase V.
- Phase VI indicates an age over approximately 35 years in males (based on the observations of Suchey-Brooks, as this study does not have data under 40 years), and over 40 years for females.

8.3.7.1.2 Accuracy and Bias

A blind test was undertaken to determine whether the proposed increased maximum age limits for each phase could increase the accuracy. The blind test results show that the Suchey-Brooks (1990) 95% ranges accurately aged 76.7% of the male CCS blind test sample, and 87.5% of the females. The generalized range allows for the true variation of trait expression between individuals to be taken into consideration. Although these new minimum or maximum ranges are much broader, it allowed for 96.7% of the males in the sample to be accurately aged, and 100.0% of the females. As was found with the original technique, a suggested bias towards underageing was observed, as one male individual (3.3%) was older than the criteria deemed them using this method.

8.3.7.1.3 Previous Studies

The findings of this study both agreed and disagreed with previously identified shortcomings in pubic symphysis ageing (section 3.5.4.1). Contrary to the criticism of the use of broad age ranges by Cox (2000), these wide ranges are necessary to account for the variability in the ageing process of adult individuals. As demonstrated by this study, the age ranges associated with each age phase must increase their maximum limits, as they currently result in the underageing of older individuals. Klepinger (1992) indicated that differences in accuracy were found between the sexes, with males able to be more accurately aged than females using the Suchey-Brooks (1990) casts. In contrast to this finding, the current study found estimated ages of females to be more accurate than males. And finally, population specificity was not noted in this study, however, asymmetry between left and right pubic symphyses was found in the PBC study sample. In the absence of pathology, the cause of differences between left and right pubic symphyses is unknown, but worthy of further research. Such variation can have large repercussions for adult age estimation.

8.3.7.2 Pubic Symphysis Phase VII (Berg, 2008)

Investigations were carried out into the applicability of the revised pubic symphysis Phases V to VII as suggested by Berg (2008). The full method was not employed, as the criteria followed was morphological, not based on "weights" of the elements to determine the osteopenia/osteoporosity of the bone, as instructed by Berg (2008). Preservation of bone would greatly change the weight of bone in archaeological contexts. Also deviating from Berg's (2008) method, the surface morphological criteria was also applied to both sexes, not just females, as instructed in the published research. Berg's ideas were simply used as a guideline to examine other possible avenues of pubic symphyseal degeneration, beyond those proposed by Brooks and Suchey (1990).

As a test, allocation into phases VI and VII relied on the quality of surface bone (i.e. compact bone), the amount of surface porosity, and the lipping around the rim. By not taking into account the weight of the bone, Phase V remained the same as the Suchey-Brooks method. Berg (2008) suggests that individuals in this stage are aged in the early 50s. The Suchey-Brooks Phase VI was separated into new phases VI and VII, which were separated primarily by the amount surface (macro)porosity and general erosion of the symphyseal face, as the degree of lipping around the rim was deemed by Berg (2008:577) to be highly variable, as it may be mild, moderate or severe. The revised phase VI is said to occur in females in their mid 50s to mid 60s, and new Phase VII only occurs after the mid 70s.

The results of this study found that the seven phase pubic symphysis method was significantly correlated with known age (i.e. Spearman's rank correlation) for both sexes in all study samples, with the exception of the SB collection. The reason for this could be related to the state of preservation of the pubic symphyses, which was not always ideal, and could have mis-identified postmortem erosion with macroporosity. The descriptive statistics revealed the overall trend of increasing age with increasing phase score, however, distinct differences between phases VI and VII were not present (i.e. results of *t*-tests resulted in *P* values larger than 0.05). This indicates that although phase VII provides criteria to identify an increased (more severe) form of pubic symphysis degeneration, it does not improve the age estimation of the method as it is not statistically different from phase VI.

These results differ from both that of Berg (2008) and Hartnett (2010), who both found the introduction of phase VII to be able to provide an accurate age of 70+ years in female individuals.

8.3.7.3 Limitations to the Study

Preservation of the pubic symphysis in archaeological context will always be the main limiting factor to the application of this technique.

8.3.7.4 Further Research

The pubic symphysis has been evaluated and re-evaluated consistently since first being proposed. The current criteria have reached their maximum age limits, which appear to be 40 years old. No further work can be suggested.

8.3.7.5 Summary

These findings suggest that the pubic symphysis is not a reliable way to identify elderly individuals in past populations. Although extension of the maximum age limits has been proposed as a way to ease the inherent underageing of pubic symphysis, evidence was not found in this study to refute the suggestion that the pubic symphysis can accurately assess age over 40 years. Once the ventral rampart has fused and age estimation relies entirely on the degenerative characteristic of the pubic symphyseal face itself, the process is too variable between individuals to provide an accurate assessment of age.

8.3.8 ISCHIAL TUBEROSITY

Statistical results did not vary greatly between study samples. No differences were observed for the severity of osteophyte formation between the left and right ischial tuberosities or expression between males and females for all reference collections. All individual surface topography scores were found to be significantly different from one-another, with the exception of scores 3 and 4 in the SB sample. This may reflect the small number of the older age groups in the study sample.

For consistency, the ageing methods were developed for the left side of the body, as is the standard for osteological methods. Due to the lack of need for sexually dimorphic criteria, all individuals were assessed together when the combined results for all samples were plotted together. No marked differences were identified between the samples, suggesting that the surface topography of the upper ischial tuberosity follows a generally similar pattern in all individuals, indicating that the ageing criteria developed during this research may be applied to any male or female in any population.

Surface topography was shown to be highly significantly correlated with documented age-at-death (combined sample: $r_s = 0.745$), which was one of the highest Spearman's rank correlation coefficients derived for any criteria developed during the course of this research. As the higher the score (r_s) assigned to a feature, the more frequently it was associated with older age, it is suggested that this surface topography of the ischial tuberosity is a good indicator of advanced age.

The descriptive statistics of age variation within trait scores revealed a positive association of age with increasing surface topography scores. Each surface topography score was found to be statistically different from the others, forming four distinct stages ischial degeneration. The 95% confidence intervals for each age stage are very concise and unrealistic (i.e. range of 2 to 3 years). Age ranges were also suggested, which were broader, but allowed for a true representation of trait expression with age.

8.3.8.1 Relationship Between Surface Topography and DISH

When the ischial surface topography for individuals with DISH were plotted against those individuals without DISH, no clear pattern was observed. The trait severities of the individuals with DISH were all within the “normal” range of the observations demonstrated by the individuals without DISH.

8.3.8.2 Limitations of Method

Two other degenerative traits were also assessed (i.e. porosity and osteophyte formation). Surface defects were common on the ischial tuberosity, and not always easily distinguished from degenerative porosity formation (Figure 8.4a). As a result porosity was not included in the final study, however, these defects can also cause associated areas of nodule formation. Without experience examining the criteria for this method, these appearances may be wrongly classed as a score of 3. Osteophyte formation was also recorded for the superior and medial portions of the tuberosity. Although both locations did show altering patterns of osteophyte formation, the both aspects were prone to frequent damage, and the medial portion was often affected in individuals with DISH (i.e. large osteophytes/ossified ligaments were present; Figure 8.4b).

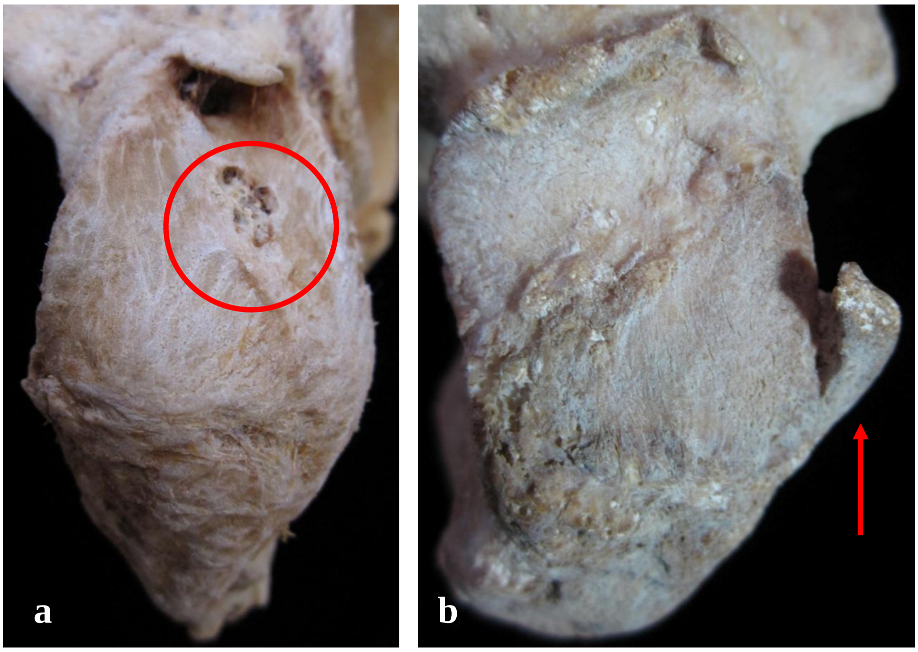


Figure 8.4a-b: *Irregular observations of the ischial tuberosity, (a) surface defects; (b) ossification at ligament attachment, associated with DISH*

8.3.8.3 Further Research

There is a need for refinement of score of 3, as it does not provide a concise age estimate. Currently the stage is defined by the presence/absence of nodule formation. It is suggested to revise the criteria by assessing the distribution of nodules based on a grading-scheme such as slight, moderate, severe or based on the percentage of the surface affected (e.g. < 50% and > 50% of the surface affected). This may allow for this exceptionally broad stage to be broken into two or more separate categories, which may aid in a less ambiguous age estimate.

8.3.9 RELATIONSHIP BETWEEN SKELETAL DEGENERATION AND CHRONOLOGICAL AGE

It is acknowledged that not all observable skeletal degeneration is the direct result of the ageing process, as skeletal age does not equal chronological age. Although they may appear to be linked, such skeletal changes could be the result of specific processes that are, themselves, related to advancing age. For example, biomechanical, hormonal and cellular changes can predispose the skeleton to degeneration, as bone mineral density declines in old age, as the result of decreased physical activity and change in diet. As the quality of bone decreases, skeletal alterations may accumulate with older age, but are not directly caused by age itself. As individuals experience the ageing process differently, trait expression variation was both expected, and noted in this study.

Each of the proposed methods discussed in this chapter have correlated stages of skeletal degeneration with chronological age. All methods developed during the course of this research were created following a similar process (i.e. quantifying qualitative trait scores, combining trait scores to form a composite score), which allowed for comparison of results. Basing the scoring system on ordinal categorical data, and using Spearman's rank correlation tests, individual traits and combined composite scores were able to be investigated for their relationship with advanced age (i.e. the higher the r_s score, the more frequently the feature was related to old age). By using the same statistical methods, the end results could be compared to determine which methods were more accurate for males and females. A summary of findings is provided in Table 8.4. It is proposed that these Spearman's rank correlation coefficients have the ability to determine those methods that are most likely the direct result of the ageing process (or with minimal external factor interference), and those influenced by factors in addition to age. It is important to stress again that the resulting Spearman's rank correlation coefficients were based on a truncated sample. As the full relationship between age and the trait expression is currently unknown (i.e. degenerative changes have not yet been investigated across the entire spectrum of adult ages), these values are likely to be subject to change (i.e. decrease in value). However, the severity of this change is unknown, as it is also noted that many of the observed degenerative traits do not begin to appear until age is advanced past 50 years (e.g. sternal end of the clavicle, clavicular notch of the manubrium, ischial tuberosity).

Based on the 40+ years sample, with the exception of the metamorphosis, or lack there of, at the manubriosternal articular facets in unfused joints, all developed ageing criteria were found to be statistically significant (i.e. $P < 0.05$). It was found that those correlation coefficients with an r_s value of 0.600 and greater (i.e. combined C3-C7, sternal surface of the clavicle, combined lateral and sternal clavicle, clavicular notch of the manubrium, and ischial tuberosity) displayed distinct patterns of degeneration with increasing age, when plotted against each other. These skeletal locations were able to provide greater precision than those with r_s scores smaller in value than 0.600, as it was possible to suggest ageing criteria within four or five distinct age ranges instead of open-ended ranges. These regions generally are not weight-bearing and with the exception of the cervical vertebrae, are not true (the articulation between two skeletal elements) or freely-moving joints. The sternal end of the clavicle does not physically meet with the clavicular notch of the manubrium, rather they are anchoring sites for ligaments, similarly to the function of the ischial tuberosity.

Table 8.4: *Summary of Spearman's rank correlation coefficients for all assessed ageing criteria for males and females. Methods and scores (r_s) valued above 0.600 are highlighted in bold.*

Method	**Male**	**Female**
	r_s	**r_s**
Dens facet on atlas	0.549	0.549
Dens process on axis	0.530	0.473
Combined atlas and axis	0.581	0.525
C3-C7 bodies	0.535	0.535
C3-C7 facets	0.568	0.548
Combined C3-C7	**0.652**	**0.609**
Lateral surface of the clavicle	0.583	0.583
Sternal surface of the clavicle	**0.755**	**0.644**
Combined clavicle (sternal and lateral surfaces)	**0.765**	**0.726**
Sternal clavicle manubrium facet	0.539	0.411
Clavicular notch (manubrium)	**0.652**	**0.624**
Iliac crest	0.513	0.464
Revised Lovejoy auricular surface	0.593	0.593
Revised Buckberry and Chamberlain surface texture	0.578	0.566
Ischial tuberosity	**0.745**	**0.745**
Suchey-Brooks pubic symphysis	**0.620**	0.441
Lovejoy auricular surface (original)	0.554	0.554
Buckberry and Chamberlain auricular surface (original)	0.388	0.388
Sternum articular face on manubrium	0.280	0.270

Those that had Spearman's rank correlation coefficient values between 0.500 and 0.600 provided criteria in independent age stages of skeletal degeneration that could divide the assessed individuals into broad, often open-ended ranges (e.g. younger, middle and older). These included all of the individual cervical vertebrae studies, lateral clavicle, manubrium facet on the sternal end of the clavicle, the auricular surface of the ilium (excluding the original Buckberry and Chamberlain criteria), and the iliac crest in males. These regions of the skeleton are influenced by other external factors that have suggested to have affected the correlation between trait expression and age. For example, they are susceptible to higher degrees of movement (i.e. the cervical vertebrae and the consistent movement of the head and neck, lateral clavicle and the function of the rotator cuff), weight-bearing (i.e. auricular surface), or provide structural support for the human body (i.e. the iliac crest is an anchoring place for muscles that support movements of the abdomen).

Methods found to have a Spearman's rank correlation coefficient (r_s) smaller than 0.500 were only able to provide information on the extremes of trait expression (e.g. if the most severe expressions were present, it indicated an individual of advanced age than those that did not display the trait). With the exception of the Buckberry and Chamberlain (2002) auricular surface ageing criteria, the methods that were found to have these r_s vales were all in female individuals. Recorded degeneration of pubic symphysis, iliac crest, articular facet of the dens process and clavicular facet on the sternal surface of the clavicle in females were all included in this Spearman's rank correlation coefficient category. As previously suggested, this may be the result of the discrepancy in trait expression between gracile females and those of larger body size. The deficiency with the Buckberry and Chamberlain (2002) assessment of the auricular surface was due entirely to the non-signification relationship (i.e. $P > 0.05$) of many of the individual surface traits that are recorded in this method.

8.3.9.1 Age Ranges

Ageing techniques must meet three criteria. They must be able to predict the true age of the individual under study (i.e. be accurate), estimate age within a reasonable age range (i.e. be precise) and have criteria that are easily applied by all researchers (i.e. be repeatable; low intra- and interobserver errors). With primary focus on the first two criteria, as they are inter-linked, much thought was put into how to state the age estimations incurred from the developed methods. As has been consistently proven, the utmost importance of adult skeletal ageing is to reflect the true variability in the ageing process observed between individuals of equivalent ages. As a result, both the 95% confidence intervals and the broader suggested age ranges were blind tested for each of the developed criteria.

The blind test results indicated that although very precise (i.e. able to estimate age within a small range of ages), the 95% confidence intervals derived for all methods were too narrow to accurately estimate age (commonly less than 30% of the Spitalfields collection were accurately aged). It is acknowledged that in addition to the recorded traits, factors also effecting this narrow range are the use of a truncated sample (40+ years), or the large sample sizes. In contrast, the blind test results found the suggested age ranges to predict much more accurately, with commonly over 85% of the Spitalfields sample provided with an accurate assessment of age. However, these accurate results were provided with much less precise (i.e. given within broad, often open-ended age ranges).

A conflict arose: is it better to produce ageing criteria with decreased precision (i.e. age estimates provided in wider age ranges) but are highly accurate (i.e. more frequently predicting the true age), or to develop a technique with a great deal of precision (i.e. age estimates provided in concise ranges) but provide a decreased accuracy (i.e. the true age is less frequently correctly estimated). It is acknowledged that a narrow age estimate gives a good impression of a highly correlated relationship between the method and age-at-death, however, in practice, if the criteria does not accurately describe the individual under study, does it really matter how precise the method is? Researchers such as Rissech et al. (2012:151) criticise the "sacrifice of precision for accuracy", however, an incorrect answer provides misleading information for the skeletal individual under study. This is a dangerous statement, as choosing precision over accuracy will do little more than perpetuate the inaccuracy of all aspects of adult ageing, as found in biological anthropology today. As a result, the 95% confidence intervals are not to be stated as the age estimates for the developed criteria. The suggested age ranges allow for the full extent of inter-personal and inter-populational variability to be accounted for, which is of the utmost importance in adult ageing.

In the past, age intervals were presented as suggested ranges, while in recent years, ageing methods have provided 95% confidence intervals to increase the accuracy of their methods. These 95% ranges provide information on the variation of the ageing process in the human skeleton, yet have been subjected to much criticism over the broadness of age ranges. Many researchers have commented that the accuracy of the Brooks and Suchey (1990) and Buckberry and Chamberlain (2002) techniques is solely due to the width of the estimated intervals. But what is the point of having a very precise method (e.g. Lovejoy's age ranges of 5 to 10 years), if it is inaccurate?

For the purposes of this study, focus was placed on the production of ageing criteria that were accurate and reproducible. Age ranges were proposed based on the variability observed in each method within each assessed age stage. Where possible, the minimum and maximum limits were clearly distinct in each stage of degeneration. The first stage of each method provides an upper age limit for "no degeneration" to be observed. The last stage sets a minimum age limit for the age when the most severe expressions of degeneration begin. If possible, further stages were suggested.

8.3.9.2 Adulthood

In biological anthropology today there is great variation in the way ages are stated worldwide (Falys and Lewis, 2011). In Europe, adulthood is most commonly divided into four age categories: 16 years to 25 years, 26 years to 35 years, 36 years to 45 years, and 46+ years. Following the findings of this study, these stages have been extended. It is proposed the new age ranges are: 16–25 years, 26–39 years, 40–59 years, 60+ years. In some individuals it may be proven possible to estimate age as 70+ years.

Skeletal development allows confident identification of age under 30 years, between the ages of 20 years and 30 years, the crowns of the third molars have usually emerged and their roots are complete, the long bone epiphyses have fused to their corresponding metaphyses (e.g. the head of the femur). The late fusing epiphyses, sternum (sternebrae), iliac crest, ischial tuberosity, and vertebral end plates display varying degrees of union, and are commonly fused by the age of 25 years. The medial clavicle and first and second sacral vertebrae complete fusion by 30 years and 35 years, respectively, which signify skeletal maturation is complete. These appearances can be compared against the surface morphology of the pubic symphysis and auricular surface.

Once all fusions are complete, degenerative processes accumulate in severity at differing rates, depending on several interactive factors (e.g. genetics, health, nutrition, manual labour etc). In response, resultant age estimations, as shown by this study, must acknowledge the variability by broadening the age range. Between the ages of 30 and 45 years, all elements have finished development, and the only areas of degeneration observed are located in the pubic symphysis and auricular surface. However, current methods have been shown to overage individuals in the 30–40 year age group, and underage older individuals. Revisions of ageing methods were not included in this study. Failing revision of current ageing methods across the entire adult life span, the only suggestion is to collapse age ranges into one large bracket (i.e. 35–60 years).

It may be possible to identify those aged 45 to 60 years, as the results of this study have suggested that the pubic symphysis can be used to identify a maximum age of 40 years (Phase VI). The auricular surface has been shown to reach peak degeneration at 60 years (Stage 8). Between these ages, the lateral clavicle displays slight to moderate degeneration, but no or minimal changes are found in the sternal clavicle, ischium, iliac crest and cervical vertebrae. Using aspects of the current study, slight increases in degenerative processes can aid in the identification of age over 45, 50, and 55 years.

Between the ages of 60 and 70, the auricular surface and lateral clavicle have reached peak degeneration, and age estimation depends on the sternal clavicle, iliac crest, ischium and cervical spine, which commonly display slight to moderate alterations.

Individuals aged 70+ years can be identified by severe degeneration of the sternal clavicle and ischium, and moderate or severe changes to the iliac crest and cervical spine.

8.3.9.2.1 Standardisation of Age Categories

As was highlighted in Falys and Lewis (2011), it is imperative that age estimates are stated using standardised terms (i.e. same age ranges or descriptive terms). Suggestions have been made above as to how to numerically state age, however, there is discrepancy in the age and stage of skeletal development at which individuals were determined to be adult (Falys and Lewis, 2011), and relatedly, at what age or skeletal degeneration, should an individual be considered "old". As discussed in Chapter 3, using current descriptive terminology, individuals aged 46+ years are called "old", "older", "mature", "elderly", or "senile".

This study proposes that adulthood can be divided into four stages based on skeletal development and degeneration, with an individual considered "adult" from the age or skeletal development of 20 years:

- <u>20+ years:</u> the epiphyses of the long bones have fused to the metaphyses.
- <u>20 to 40 years:</u> the skeleton completes development as late-fusing epiphyses unite. The only identifiable areas of degeneration are limited to the pelvis (i.e. pubic symphysis and auricular surface).
- <u>40 to 60 years:</u> the pubic symphysis displays peak surface breakdown. Degeneration of extra-pelvis regions of the skeleton begin to show, in absence of pathological alteration, minimal to slight evidence of degeneration (e.g. the clavicle, cervical vertebrae bodies and facets).
- <u>60+ years:</u> the auricular surface displays peak degeneration, and can display ankylosis of the sacro-iliac joint in some individuals (primarily male). Moderate to severe degenerative changes can be identified in the cervical spine, and lateral end of the clavicle, and iliac crest. Ankylosis of two or more cervical vertebral bodies may be present.
- <u>70+ years:</u> the sternal end of the clavicle, clavicular notch of the manubrium, and ischial tuberosity display complete surface breakdown.

It is essential that a reliable physiological baseline is established from which theoretical questions can be developed regarding the life course and identify any cultural differences that may exist. It is proposed that "old age" in osteological terms occurs at the point when the regions of the skeleton outside of the pelvic region begin to show clear signs of degeneration (i.e. at the approximate age of 60 years).

8.3.9.3 Further Research

Criteria-specific suggestions for further research were provided in the previous section. There are, however, general suggestions that apply to all methods developed here. It is essential that the findings of this study substantiated. Investigations should include:

- evaluation of these traits in adult individuals of all ages, not just 40+ years, or from the time of epiphyseal fusion (where applicable; i.e. sternal end of the clavicle, iliac crest, ischial tuberosity).
- individuals from documented skeletal collection of differing geographical regions, ancestries, time periods.

- evaluation of the relationship between activity and degeneration for the skeletal regions that demonstrated statistically significant differences between left and right skeletal elements, as well as in the cervical vertebrae.
- evaluate the applicability of the developed criteria (i.e. written descriptions and photographs), through assessment of the intra- and inter-observer errors. Although criteria were developed to be as user-friendly as possible (i.e. using well-established terminology, separating surface degeneration into a series of individual aspects, not mixing all traits into a single description of a degenerative phase, e.g. Lovejoy's auricular surface), some traits are not able to be adequately quantified and remain dependent on the observer's experience (e.g. osteophyte formation). The productions of three-dimensional models that allow comparison of traits are essential to decreasing the inter- and intra-observer errors of ageing methods.
- study samples derived from archaeological contexts should be employed to assess if all traits can be confidently identified (i.e. can the surface trait of porosity (antemortem) easily distinguishable from the preservation-related erosive lesions; are osteophytic growths commonly undamaged).
- revision of the scoring system may be beneficial to the interpretation of surfaces, with focus on the distribution of nodule formation (perhaps should be modified similar to that of porosity, which is based on the percentage of the surface affected, rather than present or absent, as currently scored).
- produce criteria using weighted surface traits. Although degeneration of surfaces all display an interrelation of all three traits: change in surface topography, porosity and osteophyte formation, and all developed criteria were found to be statistically significantly correlated with age-at-death, surface topography commonly preformed better (i.e. higher r_s values). It is proposed that future revision of these methods place weighted emphasis on this trait.
- once/if the criteria is validated by application to adults of all age, Bayesian analyses must be undertaken to remove the bias introduced into the resultant age stages by the age structures of the reference samples, and developmental outliers.
- it is also imperative to investigate the effects "bone formers" and "bone losers" have on the ageing process, expression of age, and displays of pathology (e.g. osteoarthritis and DISH).

CHAPTER NINE
CONCLUSIONS

The purpose of this study was to develop new, accurate and reproducible criteria to identify the "elderly" in past populations. This was accomplished through the re-evaluation and revision of established skeletal age indicators in attempt to alleviate the current trend of underageing, and by developing innovative methods of age estimation based on the degeneration of differing skeletal regions that had previously not been investigated in adult ageing. At the cost of precision, this study ensured the full range of skeletal variation experienced in the ageing process between individuals and populations was acknowledged. Despite this variation, discernable patterns of progressive degeneration were identified, which challenge the assumption that individuals did not live into old age in past populations. It is an unfortunate fact that this lack of precision (i.e. narrow age estimates) will render these techniques inapplicable to forensic contexts, however, they yield great potential for advancements of many aspects of archaeological investigation.

The primary outcomes of this study were:

- revisions of the pubic symphysis and auricular surface criteria.
- development of criteria that have the ability to provide age estimations for males and females utilizing the clavicle, manubrium, and ischium.
- development of supplementary criteria that help establish the young old person from the oldest, based on the cervical spine and iliac crest.
- identification of regions of the skeleton that are problematic and do not contribute to the investigation of adult age (i.e. arachnoid granulations, manubriosternal articular facets).
- differences between males and females in the ageing process.
- development of new age ranges within "adulthood" to be integrated into the standardised osteological ageing criteria. Named categories were not suggested to avoid inducing cultural biases to future studies.
- presented three new potential methods, to be established with further analysis, for identifying those in new elderly categories:
    - clavicle (sternal and lateral ends)
    - clavicular notch of the manubrium
    - ischial tuberosity

With reference to the biases stated in the beginning of this study, three concepts have previously limited the life course study of the elderly: intellectual, methodological, and taphonomic. This thesis has acknowledged and sought to rectify methodological biases present in current adult ageing techniques, and has ultimately proposed new ways of linking biological and chronological ages of older adult individuals. Identifying these features in a skeleton will allow the "elderly" to be identified in the archaeological record, provide a sufficiently broad age range, and ultimately allowing assessment of the life course and significance of social age. Unfortunately, the third bias (preservation), as previously suggested, will only be identified once the first two biases are rectified, as only through the identification of the elderly, can their presence and absence in skeletal populations be qualified and quantified.

This study has provided numerous avenues of further research for both biological anthropology and social archaeology through the development of new ways to assess advancing age. It is essential that other researchers re-evaluate and revise each of the developed ageing criteria to maximize the accuracy and reproducibility of each technique. The implications of this study for the wider study of human remains may help alleviate the current bias towards the underageing of older individuals. It provides great potential for skeletal remains that were previously deemed to be 46+ years, to be aged beyond this current limit. It will also validate or refute assumptions such as that all past peoples died young compared to modern trends, and that skeletal elements of older individuals are less well preserved in the burial context. Finally, with the ability to identify the very old in archaeological populations comes the potential of examination of the bioarchaeology of a previously unidentifiable phase in life. Life course studies can be extended into adulthood and beyond, allowing recognition of long-lived lives, as the "elderly" in archaeological populations can finally be acknowledged and emerge from the shadows of time.

REFERENCES

Achenbaum, WA (1996) Historical perspectives on aging. In Binstock, RH and George, LK (eds.) *Handbook of Aging and the Social Sciences.* Fourth edition. New York: Academic Press, pp. 137-152.

Acsádi, G and Nemeskéri, J (1970) *History of Human Life Span and Mortality*. Budapest: Akadémiai Kaidó.

Aktas, E, Koçak, A, Aktas, S and Yemisçigil, A (2004) Intercostal variation for age estimation - Are the standards for the right 4th rib applicable for other ribs? *Collegium Antropologicum* **28** Suppl. 2: 267-272.

Albert, AM (1998) The use of vertebral ring epiphyseal union for age estimation in two cases of unknown identity. *Forensic Science International* **97**: 11-20.

Albert, AM and Maples, WR (1995) Stages of epiphyseal union for thoracic and lumbar vertebral centra as a method of age determination for teenage and young adult skeletons. *Journal of Forensic Sciences* **40**: 623-633.

Albert, AM and McCallister, K (2004) Estimating age at death from thoracic and lumbar vertebral ring epiphyseal union data. *American Journal of Physical Anthropology* **Suppl. 38**: 51.

Albert, AM, Mulhern, D, Torpey, M and Boone, E (2010) Age estimation using thoracic and first two lumbar vertebral ring epiphyseal union. *Journal of Forensic Sciences* **55**: 287-294.

Alesbury, HS, Ubelaker, DH and Bernstein, R (*in press*) Utility of the frontonasal suture for estimating age at death in human skeletal remains. *Journal of Forensic Sciences*.

Appleby, JEP (2010) Why we need an archaeology of old age, and a suggested approach. *Norwegian Archaeological Review* **43**: 145-168.

Appleby, JEP (2011) Bodies, burials and ageing: accessing the temporality of old age in prehistoric societies. *Oxford Journal of Archaeology* **30**: 231-246.

Arber, S and Evandrou, M (eds.) (1993a) *Ageing, Independence and the Life Course.* London: Jessica Kingsley Publishers.

Arber, S and Evandrou, M (1993b) Mapping the territory: ageing, independence and the life course. In Arber, S and Evandrou, M (eds.) *Ageing, Independence and the Life Course.* London: Jessica Kingsley Publishers, pp. 9-26.

Arber, S and Ginn, J (1991) *Gender and Later Life*. London: Sage.

Arber, S and Ginn, J (1995) *Connecting Gender and Ageing: A Sociological Approach.* Buckinham: Open University Press.

Arking, R (1998) *Biology of Aging.* Sunderland, MA, USA: Sinauer Associates, Inc.

Arlet, J and Ficat, P (1958) Osteo-arthritis of the sterno-clavicular joint. *Annals of the Rheumatic Diseases* **17**: 97-100.

Aykroyd, RG, Lucy, D, Pollard, AM and Solheim, T (1997) Technical note: regression analysis in adult age estimation. *American Journal of Physical Anthroplogy* **104**: 259-265.

Aykroyd, RG, Lucy, D, Pollard, AM and Roberts, CA (1999) Nasty, brutish, but not necessarily short: a reconsideration of the statistical methods used to calculate age at death from adult human skeletal and dental age indicators. *American Antiquity* **64**: 55-70.

Baccino, E, Ubelaker, DH, Hayek, LC and Zerilli, A (1999) Evaluation of seven methods of estimating age at death from mature human skeletal remains. *Journal of Forensic Sciences* 44: 931-936.

Bang, G and Ramm, E (1970) Determination of age in humans from root dentin transparency. *Acta Odontologica Scandinavica* **28**: 3-35.

Baker, M (1997) Invisibility as a symptom of gender categories in archaeology. In Moore, J and Scott, E (eds.) *Invisible People and Processes.* London: Leicester University Press, pp. 183-191.

Barber, G (1997) A Study of the Age Related Changes on the Endocranial Surface of the Skull. Unpublished PhD Thesis. University of Bristol, Bristol.

Barber, G, Shepstone, L and Rogers, J (1995) A methodology for estimated age at death using arachnoid granualtion counts. *American Journal of Physical Anthropology* **38**: 61.

Basmajian, JV (1952) The depressions for the arachnoid granulations as a criterion of age. *The Anatomical Record* **112**: 843-846.

Bass, WM (1995) *Human Osteology. Fourth edition.* Columbia: Special Publication No. 2 of the Missouri Archaeological Society.

Baxter, PTW and Almagor, U (1978) Observations about generations. In La Fontaine, J (ed.) *Age and Sex as Principles of Social Differentiation.* London: Academic Press, pp. 159-181.

Beall, CM (1984) Theoretical dimensions of a focus on age in physical anthropology. In Kertzer, DI and Keith, J (eds.) *Age and Anthropological Theory.* London: Cornell University Press, pp. 82-95.

Beauthier, J, Lefevre, P, Meunier, M, Orban, R, Polet, C, Werquin, J and Quatrehomme, G (2010) Palatine sutures as age indicator: a controlled study in the elderly. *Journal of Forensic Sciences* **55**: 153-158.

Bedford, ME, Russell, KF and Lovejoy, CO (1989) *The auricular surface ageing technique: 16 color photographs with descriptions.* Kent.

Bedford, ME, Russell, KF, Lovejoy, CO, Meindl, RS, Simpson, SW and Stuart-MacAdam, PL (1993) Test of the multifactorial aging method using skeletons with known ages-at-death from the Grant collection. *American Journal of Physical Anthropology* **91**: 287-297.

Belcastro, MG, Rastelli, E and Mariotti, V (2008) Variation of the degree of sacral vertebral body fusion in adulthood in two European modern skeletal collections. *American Journal of Physical Anthropology* **135**: 149-160.

Bello, SM, Thomann, A, Signoli, M, Dutour, O and Andrews, P (2006) Age and sex bias in the reconstruction of past population structures. *American Journal of Physical Anthropology* **129**: 24-38.

Berg, GE (2008) Pubic bone age estimation in adult women. *Journal of Forensic Sciences* **53**: 569-577.

Bocquet-Appel, JP and Masset, C (1982) Farewell to palaeodemography. *Journal of Human Evolution* **11**: 321-333.

Borkan, GA, Hults, DE and Mayer, PJ (1982) Physical anthropological approaches to aging. *Yearbook of Physical Anthropology* **25**: 181-202.

Borkan, GA (1986) Biological age assessment in adulthood. In Bittles, AH and Collins, KJ (eds.) *The Biology of Human Ageing.* Cambridge: Cambridge University Press, pp. 81-94.

Bradley, R (1988) Status, wealth and the chronological ordering of cemeteries. *Antiquity* **54**: 327-329.

Brooke, R (1924) The sacro-iliac joint. *Journal of Anatomy* **58**: 299-305.

Brooks, ST (1955) Skeletal age at death: the reliability of cranial and pubic age indicators. *American Journal of Physical Anthropology* **13**: 567-597.

Brooks, ST and Suchey, JM (1990) Skeletal age determination based on the os pubis: a comparison of the Acsádi & Nemeskéri and Suchey-Brooks methods. *Human Evolution* **5**: 227-238.

Brothwell, DR (1981) *Digging Up Bones. Third edition.* Oxford Oxford University Press.

Buckberry, JL and Chamberlain, AT (2002) Age estimation from the auricular surface of the ilium: a revised method. *American Journal of Physical Anthropology* **119**: 231-239.

Buikstra, JE and Ubelaker, DH (1994) *Standards for Data Collection from Human Skeletal Remains.* Fayetteville: Arkansas Archaeological Survey.

Buikstra, JE and Beck, LA (eds.) (2006) *Bioarchaeology: The Contextual Analysis of Human Remains.* New York: Academic Press.

Calce, SE (2012) A new method to estimate adult age-at-death using the acetabulum. *American Journal of Physical Anthropology* **148**: 11-23.

Calce, SE and Rogers, TL (2011) Evaluation of age estimation technique: testing traits of the acetabulum to estimate age at death in adult males. *Journal of Forensic Sciences* **56**: 302-311.

Cardoso, HFV (2008a) Age estimation of adolescent and young adult male and female skeletons II, epiphyseal union at the upper limb and scapular girdle in a modern Portuguese skeletal sample. *American Journal of Physical Anthropology* **137**: 97-105.

Cardoso, HFV (2008b) Epiphyseal union at the innominate and lower limb in a modern Portuguese skeletal sample, and age estimation in adolescent and young adult male and female skeletons. *American Journal of Physical Anthropology* **135**: 161-170.

Chamberlain, A (2000) Problems and prospects in palaeodemography. In Cox, M and Mays, S (eds.) *Human Osteology in Archaeology and Forensic Science.* London: Greenwich Medical Media, Ltd., pp. 101-115.

Chamberlain, A (2006) *Demography in Archaeology.* Cambridge: Cambridge University Press.

Chapman, R and Randsborg, K (1981) Approaches to the archaeology of death. In Chapman, R, Kinnes, I and Randsborg, K (eds.) *The Archaeology of Death.* Cambridge: Cambridge University Press, pp. 1-24.

Charles, DK, Condon, K, Cheverud, JM and Buikstra, JE (1986a) Cementum annulation and age determination in Homo sapiens. I. Tooth variability and observer error. *American Journal of Physical Anthropology* **71**: 311-320.

Charles, DK, Condon, K, Cheverud, JM and Buikstra JE (1986b) Cementum annulation and age determination in Homo sapiens. II. Estimates and accuracy. *American Journal of Physical Anthropology* **71**: 321-330.

Chen, X, Zhang, Z, Zhu, G and Tao, L (2011) Determining the age at death of females in the Chinese Han population: using quantitative variables and statistical analysis from pubic bones. *Forensic Science International* **210**: 278.e271-278.e278.

Chen, X, Zhang, Z and Tao, L (2008) Determination of male age at death in Chinese Han population: Using quantitative variables statistical analysis from pubic bones. *Forensic Science International* **175**: 36-43.

Cohen, R (1984) Age and culture as theory. In Kertzer, DI and Keith, J (eds.) *Age and Anthropological Theory.* London: Cornell University Press, pp. 234-249.

Cokayne, K (2003) *Experiencing Old Age in Ancient Rome.* London: Routledge.

Cokayne, K (2007) Age and aristocratic self-identity: activities for the elderly. In Harlow, M and Laurence, R (eds.) *Age and Ageing in the Roman Empire.* Portsmouth: Journal of Roman Archaeology, Supplementary Series Number 65, pp. 209-220.

Coqueugniot, H and Weaver, TD (2007) Brief communication: Infracranial maturation in the skeletal collection from Coimbra, Portugal: New aging standards for epiphyseal union. *American Journal of Physical Anthropology* **134**: 424-437.

Corsini, M, Schmitt, A and Bruzek, J (2005) Aging process variability on the human skeleton: artificial network as an appropriate tool for age at death assessment. *Forensic Science International* **148**: 163-167.

Cox, M (2000) Ageing adults from the skeleton. In Cox, M and Mays, S (eds.) *Human Osteology in Archaeology and Forensic Science.* London: Greenwich Medical Media Ltd, pp. 61-81.

Crews, DE and Garruto, RM (eds.) (1994) *Biological Anthropology and Aging.* New York: Oxford University Press.

DePalma, AF (1957) *Degenerative Changes in the Sternoclavicular and Acromioclavicular Joints.* Springfield: Charles C Thomas.

DiGangi, EA, Bethard, JD, Kimmerle, EH and Konigsberg, LW (2009) A new method for estimating age-at-death from the first rib. *American Journal of Physical Anthropology* **138**: 164-176.

Djurić, M, Djonić, D, Nikolić, S, Popović, D and Marinković, J (2007) Evaluation of the Suchey-Brooks method for aging skeletons in the Balkans. *Journal of Forensic Sciences* **52**: 21-23.

Dorandeu, A, Coulibaly, B, Piercecchi-Marti, M, Bartoli, C, Gaudart, J, Baccino, E and Leonetti, G (2008) Age-at-death estimation based on the study of frontosphenoidal sutures. *Forensic Science International* **177**: 47-51.

Dorandeu, A, Lorin de la Grandmaison, G, Coulibaly, B, Durigon, M, Piercecchi-Marti, M, Baccino, E and Leonetti, G (2009) Value of histological study in the fronto-sphenoidal suture for the age estimation at the time of death. *Forensic Science International* **191**: 64-69.

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

Duray, SM and Martel, SS (2006) A quantitative method for estimation of volume changes in arachnoid foveae with age. *Journal of Forensic Sciences* **51**: 238-243.

Ericksen, MF (1976) Some aspects of aging in the lumbar spine. *American Journal of Physical Anthropology* **45**: 575-580.

Ericksen, MF (1978a) Aging in the lumbar spine. II. L1 and L2. *American Journal of Physical Anthropology* **48**: 241-245.

Ericksen, MF (1978b) Aging in the lumbar spine. III. L5. *American Journal of Physical Anthropology* **48**: 247-250.

Falys, CG and Lewis, ME (2011) Proposing a way forward: A review of standardisation in the use of age categories and ageing techniques in osteological analysis (2004–2009). *International Journal of Osteoarchaeology* **21**: 704-716.

Falys, CG, Schutkowski, H and Weston, DA (2005) The distal humerus - a blind test of Rogers' sexing technique using a documented skeletal collection. *Journal of Forensic Sciences* **50**: 1289-1293.

Falys, CG, Schutkowski, H and Weston, DA (2006) Auricular surface ageing: worse than expected? A test of the revised method on a documented historic skeletal assemblage. *American Journal of Physical Anthropology* **130**: 508-513.

Fanton, L, Gustin, M, Paultre, U and Malicier, D (2010) Critical study of observation of the sternal end of the right 4th rib. *Journal of Forensic Sciences* **55**: 467-472.

Featherstone, M and Wernick, A (eds.) (1995a) *Images of Aging.* London: Routledge.

Featherstone, M and Wernick, A (1995b) Introduction. In Featherstone, M and Wernick, A (eds.) *Images of Aging.* London: Routledge, pp. 1-15.

Ferembach, D, Schwidetzky, I and Stoukal, M (1980) Recommendations for age and sex diagnoses of skeletons. *Journal of Human Evolution* **9**: 517-549.

Ferrant, O, Rougé-Maillart, C, Guittet, L, Papin, F, Clin, B, Fau, G and Telmon, N (2009) Age at death estimation of adult males using coxal bone and CT scan: a preliminary study. *Forensic Science International* **186**: 14-21.

Foner, N (1984) Age and social change. In Kertzer, DI and Keith, J (eds.) *Age and Anthropological Theory.* London: Cornell University Press, pp. 195-216.

Forbes, TR (1972) Mortality books for 1820 to 1849 from the parish of St. Bride, Fleet Street, London. *Journal of the History of Medicine* **27**: 15-29.

Fortes, M (1984) Age, generation, and social structure. In Kertzer, DI and Keith, J (eds.) *Age and Anthropological Theory.* London: Cornell University Press, pp. 99-122.

Fry, CL (1996) Age, aging, and culture. In Binstock, RH and George, LK (eds.) *Handbook of Aging and the Social Sciences.* New York: Academic Press, pp. 118-136.

Galera, V, Ubelaker, DH and Hayek, LC (1998) Comparison of macroscopic cranial methods of age estimation applied to skeletons from the Terry collection. *Journal of Forensic Sciences* **43**: 933-939.

Gilbert, BM (1973) Misapplication to females of the standard for aging th male *os pubis*. *American Journal of Physical Anthropology* **38**: 39-40.

Gilbert, BM and McKern, TW (1973) A method for aging the female *os pubis*. *American Journal of Physical Anthropology* **38**: 31-38.

Gilchrist, R (1994) *Gender and Material Culture. The Archaeology of Religious Women.* London: Routledge.

Gilchrist, R (1999) *Gender and Archaeology*. London: Routledge.

Gilchrist, R (2000) Archaeological biographies: realizing human lifecycles, -courses and -histories. *World Archaeology* **31**: 325-328.

Gilchrist, R (2004) Archaeology and the life-course: a time and age for gender. In Meskell, L and Preucel, R (eds.) *A Companion to Social Archaeology*. Oxford: Blackwell Publishing, pp. 142-160.

Gilchrist, R (2012) *Medieval Live: Archaeology and the Life Course*. Woodbridge: Boydell.

Ginter, J (2005) A test of the effectiveness of the revised maxillary suture obliteration method in estimating adult age at death. *Journal of Forensic Sciences* **50**: 1303-1309.

Gowland, R (2006) Ageing the past: examining age identity from funerary evidence. In Gowland, R and Knusel, C (eds.) *Social Archaeology of Funerary Remains.* Oxford: Oxbow Books, pp. 143-154.

Gowland, R (2007a) Age, ageism and osteological bias: the evidence from late Roman Britain. *Journal of Roman Archaeology; Supplementary Series* **65**: 153-169.

Gowland, R (2007b) Beyond ethnicity: symbols of social identity from the fourth to sixth centuries in England. *Anglo-Saxon Studies in Archaeology and History* **14**: 56-65.

Graves, WW (1922) Observations on age changes in the scapula: a preliminary note. *American Journal of Physical Anthropology* **5**: 21-33.

Halcrow, SE and Tayles, N (2008) The bioarchaeological investigation of childhood and social age: problems and perspectives. *Journal of Archaeological Method and Theory* **15**: 190-215.

Hanihara, K and Suzuki, T (1978) Estimation of age from the pubic symphysis by means of multiple regression analysis. *American Journal of Physical Anthropology* **48**: 233-240.

Hareven, TK (1995) Changing images of aging and the social construction of the life course. In Featherstone, M and Wernick, A (eds.) *Images of Aging.* London: Routledge, pp. 119-134.

Harlow, M and Laurence, R (2002) *Growing Up and Growing Old in Ancient Rome: A Life Course Approach.* London: Routledge.

Harlow, M and Laurence, R (eds.) (2007) *Age and Ageing in the Roman Empire.* Journal of Roman Archaeology, Supplementary Series 65.

Hartnett, KM (2010a) Analysis of age-at-death estimation using data from a new, modern autopsy sample—Part I: pubic bone. *Journal of Forensic Sciences* **55**: 1145-1151.

Hartnett, KM (2010b) Analysis of age-at-death estimation using data from a new, modern autopsy sample—Part II: sternal end of the fourth rib. *Journal of Forensic Sciences* **55**: 1152-1156.

Hens, SM, Rastelli, E and Belcastro, G (2008) Age estimation from the human os coxa: a test on a documented Italian collection. *Journal of Forensic Sciences* **53**: 1040-1043.

Hens, SM and Belcastro, MG (2012) Auricular surface aging: A blind test of the revised method on historic Italians from Sardinia. *Forensic Science International* **214**: 209.e201-209.e205.

Hershkovitz, I, Latimer, B, Dutour, O, Jellema, L, Wish-Baratz, S, Rothschild, C and Rothschild, BM (1997) Why do we fail in ageing from the skull from the sagittal suture? *American Journal of Physical Anthropology* **103**: 393-399.

Hoppa, RD (2000) Population variation in osteological aging criteria: an example from the pubic symphysis. *American Journal of Physical Anthropology* **111**: 185-191

Hoppa, RD and Saunders, S (1998) Two quantitative methods for rib seriation in human skeletal remains. *Journal of Forensic Sciences* **43**: 174-177.

Hoppa, RD and Vaupel, JW (eds.) (2002) *Paleodemography: Age Distributions from Skeletal Samples*. Cambridge.

Hurcombe, L (1997) A viable past in the pictorial present? In Moore, J and Scott, E (eds.) *Invisible People and Processes.* London: Leicester University Press, pp. 15-24.

Igarashi, Y, Uesu, K, Wakebe, T and Kanazawa, E (2005) New method for estimation of adult skeletal age at death from the morphology of the auricular surface of the ilium. *American Journal of Physical Anthropology* **128**: 324-339.

İşcan, MY (1989) Assessment of age at death in the human skeleton. In İşcan, MY (ed.) *Age Markers in the Human Skeleton.* Springfield: Charles C. Thomas, pp. 5-18.

İşcan, MY and Loth, SR (1989) Estimation of age and determination of sex from the sternal rib. In Reichs, KJ (ed.) *Forensic Osteology: Advances in the Identification of Human Remains.* Springfield: Charles C. Thomas, pp. 68-89.

İşcan, MY, Loth, SR and Wright, RK (1984a) Age estimation from the rib phase analysis: white males. *Journal of Forensic Sciences* **29**: 1094-1104.

İşcan, MY, Loth, SR and Wright, RK (1984b) Metamorphosis at the sternal rib end: a new method to estimate age at death in white males. *American Journal of Physical Anthropology* **65**: 147-156.

İşcan, MY, Loth, SR and Wright, RK (1985) Age estimation from the rib phase analysis: white females. *Journal of Forensic Sciences* **30**: 853-863.

İşcan, MY, Loth, SR and Wright, RK (1993) *Casts of age phases from the sternal end of the rib for white males and females.* Fort Collins: France Casting.

Jackes, M (1992) Paleodemography: Problems and techniques. In Saunders, S and Katzenberg, M (eds.) *Skeletal Biology of Past Peoples: Research Methods.* New York: Wiley-Liss, pp. 189-224.

Katz, D and Suchey, JM (1986) Age determination of the male os pubis. *American Journal of Physical Anthropology* **69**: 427-435.

Keith, J (1980) "The best is yet to be": toward an anthropology of age. *Annual Review of Anthropology* **9**: 339-364.

Keith, J and Kertzer, DI (1984) Introduction. In Kertzer, DI and Keith, J (eds.) *Age and Anthropological Theory.* London: Cornell University Press, pp. 19-61.

Kemkes-Grottenthaler, A (2002) Aging through the ages: historical perspectives on age indicator methods. In Hoppa, RD and Vaupel, JW (eds.) *Palaeodemography: Age distribution from skeletal samples.* Cambridge: Cambridge University Press, pp. 48-72.

Kerley, ER and Ubelaker, DH (1978) Revisions in the microscopic method of estimating age at death in human cortical bone. *American Journal of Physical Anthropology* **49**: 545-546.

Kern, KF (2006) T. Wingate Todd: pioneer of modern American physical anthropology. *Kirtlandia* **55**: 1-42.

Kertzer, DI and Keith, J (eds.) (1984) *Age and Anthropological Theory.* London: Cornell University Press.

Key, CA, Aiello, LC and Molleson, T (1994) Cranial suture closure and its implications for age estimation. *International Journal of Osteoarchaeology* **4**: 193-207.

Kimmerle, EH, Konigsberg, LW, Jantz, RL and Baraybar, JP (2008a) Analysis of age-at-death estimation through the use of pubic symphyseal data. *Journal of Forensic Sciences* **53**: 558-568.

Kimmerle, EH, Prince, DA and Berg, GE (2008b) Inter-observer variation in methodologies involving the pubic symphysis, sternal ribs, and teeth. *Journal of Forensic Sciences* **53**: 594-600.

Kirkwood, T and Austad, S (2000) Why do we age? *Nature* **408**: 233-238.
Klepinger, LL, Katz, D, Micozzi, MS and Carroll, L (1992) Evaluation of cast methods for estimating age from the os pubis. *Journal of Forensic Sciences* **37**: 763-770.

Konigsberg, LW and Frankenberg, SR (1992) Estimation of age structure in anthropological demography. *American Journal of Physical Anthropology* **89**: 235-256.

Konigsberg, LW and Frankenberg, SR (2002) Deconstructing death in paleodemography. *American Journal of Physical Anthropology* **117**: 297-309.

Kunos, CA, Simpson, SW, Russell, KF and Hershkovitz, I (1999) First rib metamorphosis: its possible utility for human age-at-death estimation. *American Journal of Physical Anthropology* **110**: 303-323.

Kurki, H (2005) Use of the first rib for adult age estimation: a test of one method. *International Journal of Osteoarchaeology* **15**: 342-350.

L'Abbé, EN, Loots, M and Meiring, JH (2005) The Pretoria Bone Collection: a modern South African skeletal sample. *HOMO* **56**: 197-205.

La Fontaine, JS (ed.) (1978) *Sex and Age as Principles of Social Differentiation.* London: Academic Press.

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

Langley-Shirley, N and Jantz, RL (2010) A Bayesian approach to age estimation in modern Americans from the clavicle. *Journal of Forensic Sciences* **55**: 571-583.

Lesick, K (1997) Re-engendering gender: some theoretical and methodological concerns on a burgeoning archaeological pursuit. In Moore, J and Scott, E (eds.) *Invisible People and Processes.* London: Leicester University Press, pp. 31-41.

Lewis, ME (2007) *The Bioarchaeology of Children*. Cambridge: Cambridge University Press.

Litten, J (1991) *The English Way of Death: the Common Funeral Since 1450.* London: Robert Hale.

Loth, SR and İşcan, MY (1994) Morphological indicators of skeletal aging: implications for paleodemography and paleogerontology. In Crews, DE and Garruto, RM (eds.) *Biological Anthropology of Aging.* New York: Oxford University Press, pp. 394-425.

Lovejoy, CO (1985) Dental wear in the Libben population: its functional pattern and role in the determination of adult skeletal age at death. *American Journal of Physical Anthropology* **68**: 47-56.

Lovejoy, CO, Meindl, RS, Mensforth, RP and Barton, TJ (1985a) Multifactorial determination of skeletal age at death: a method and blind tests of its accuracy. *American Journal of Physical Anthropology* **68**: 1-14.

Lovejoy, CO, Meindl, RS, Pryzbeck, TR and Mensforth, RP (1985b) Chronological metamorphosis of the auricular surface of the ilium: a new method for the determination of adult skeletal age at death. *American Journal of Physical Anthropology* **68**: 15-28.

Lucy, S (1997) Housewives, warriors and slaves? Sex and gender in Anglo-Saxon burials. In Moore, J and Scott, E (eds.) *Invisible People and Processes.* London: Leicester University Press, pp. 150-168.

Lucy, S (2005) The archaeology of age. In Diaz-Andreu, M, Lucy, S, Babic, S and Edwards, DN (eds.) *The Archaeology of Identity: Approaches to Gender, Age, Status, Ethnicity & Religion.* London: Routledge, pp. 43-66.

Mann, RW (1993) A method for siding and sequencing human ribs. *Journal of Forensic Sciences* **38**: 151-155.

Mann, RW, Symes, SA and Bass, WM (1987) Maxillary suture obliteration: aging the human skeleton based on intact or fragmentary maxilla. *Journal of Forensic Sciences* **32**: 148-157.

Maples, WR (1989) The practical application of age-estimation techniques. In İşcan, MY (ed.) *Age Markers in the Human Skeleton.* Springfield: Charles C. Thomas, pp. 319-324.

Marshall, VM (1996) The state of theory in aging and the social sciences. In Binstock, RH and George, LK (eds.) *Handbook of Aging and the Social Sciences.* Fouth edition. New York: Academic Press, pp. 12-30.

Maybury-Lewis, D (1984) Age and kinship: a structural view. In Kertzer, DI and Keith, J (eds.) *Age and Anthropological Theory.* London: Cornell University Press, pp. 123-140.

Mays, S (1998) *The Archaeology of Human Bones.* London: Routledge.

Mays, S, de la Rua, C and Molleson, T (1995) Molar crown height as a means of evaluating existing dental wear scales for estimating age at death in human skeletal remains. *Journal of Archaeological Science* **22**: 659-670.

McKern, TW and Stewart, TD (1957) Skeletal age changes in young American males. *Quatermaster Research and Development Command.* Natick, MA.

Meijerman, L, Maat, G, Schulz, R and Schmeling, A (2007) Variables affecting the probability of complete fusion of the medial clavicular epiphysis. *International Journal of Legal Medicine* **121**: 463-468.

Meindl, R and Russell, K (1998) Recent advances in method and theory in paleodemography. *Annual Review of Anthroplogy* **27**: 375-399.

Meindl, RS and Lovejoy, CO (1985) Ectocranial suture closure: a revised method for the determination of skeletal age at death based on the lateral-anterior sutures. *American Journal of Physical Anthropology* **68**: 57-66.

Meindl, RS, Lovejoy, CO, Mensforth, RP and Walker, RA (1985) A revised method of age determination using the os pubis, with a review and tests of accuracy of other current methods of pubic symphyseal aging. *American Journal of Physical Anthropology* **68**: 29-45.

Mensforth, RP and Latimer, BM (1989) Hamann-Todd collection aging studies: osteoporosis fracture syndrome. *American Journal of Physical Anthropology* **80**: 461-473.

Meskell, LM (2000) Writing the body in archaeology. In Rautman, AE (ed.) *Reading the Body: Representations and Remains in the Archaeological Record.* Philadelphia: University of Pennsylvania Press, pp. 13-24.

Miles, AEW (1963) Dentition in the estimation of age. *Journal of Dental Research* **42**: 255-263.

Miles, AEW (1999) A five-grade categroization of age-related change in the acromio-clavicular joint derived from the skeletal remains of early 19th century Londoners of known sex and age. *International Journal of Osteoarchaeology* **9**: 83-101.

Miles, AEW (2001) The Miles method of assessing age from tooth wear revisited. *Journal of Archaeological Science* **28**: 973-982.

Milne, G (1997) *St. Bride's Church, London: Archaeological Research 1952-60 and 1992-5.* London: English Heritage Archaeological Report 11.

Moen, P (1996) Gender, age, and the life course. In Binstock, RH and George, LK (eds.) *Handbook of Aging and the Social Sciences.* Fourth edition. New York: Academic Press, pp. 171-187.

Molleson, T and Cox, M (1993) *The Spitalfields Project Volume 2. The Anthropology. The Middling Sort.* York: C.B.A. Research Report 86.

Moore, A (2010) Age and identity in funerary contexts: the elderly in southern Roman Britain. In Moore, A, Taylor, G, Harris, E, Girdwood, P and Shipley, L (eds.) *TRAC 2009: Proceedings of the Nineteenth Annual Theoretical Roman Archaeology Conference, Which Took Place at the University of Michigan, 3-5 April 2009 and the University of Southampton, 17-18 April 2009.* Oxford: Oxbow, pp. 105-119.

Moore, J and Scott, E (eds.) (1997) *Invisible People and Processes.* London: Leicester University Press.

Mulhern, DM and Jones, EB (2005) Test of revised method of age estimation from the auricular surface of the ilium. *American Journal of Physical Anthropology* **126**: 61-65.

Murray, KA and Murray, T (1991) A test of the auricular surface aging technique. *Journal of Forensic Sciences* **36**: 1162-1169.

Nawrocki, SP (2010) The nature and sources of error in the estimation of age at death from the skeleton. In Latham, KE and Finnegan, M (eds.) *Age Estimation of the Human Skeleton.* Springfield: Charles C. Thomas, pp. 79-101.

O'Connell, L (2004) Guidance on recording age at death in adults. In Brickley, M and McKinley, JI (eds.) *Guidelines to the Standards for Recording Human Remains.* IFA Paper No 7, pp. 18-20.

O'Rand, AM (1996) The cumulative stratification of the life course. In Binstock, RH and George, LK (eds.) *Handbook of Aging and the Social Sciences.* Fourth edition. New York: Academic Press, pp. 188-207.

Osborne, DL, Simmons, TL and Nawrocki, SP (2004) Reconsidering the auricular surface as an indicator of age at death. *Journal of Forensic Sciences* **49**: 1-7.

Overbury, RS, Cabo, LL, Dirkmaat, DC and Symes, SA (2009) Asymmetry of the os pubis: Implications for the Suchey-Brooks method. *American Journal of Physical Anthropology* **139**: 261-268.

Owers, SK and Pastor, RF (2005) Analysis of quantitative methods for rib seriation using the Spitalfields documented skeletal collection. *American Journal of Physical Anthropology* **127**: 210-218.

Parker Pearson, M (1999) *The Archaeology of Death and Burial.* Stroud: Sutton Publishing Ltd.

Parkin, TG (2003) *Old Age in the Roman World.* London: The Johns Hopkins University Press.

Pavelka, MSM and Fedigan, LM (1991) Menopause: a comparative life history perspective. *Yearbook of Physical Anthropology* **34**: 13-38.

Pelling, M and Smith, RM (eds.) (1991) *Life, Death, and the Elderly.* London: Routledge.

Prescher, A (1998) Anatomy and pathology of the aging spine. *European Journal of Radiology* **27**: 181-195.

Redfern, RC (2007) The influence of culture upon childhood: an osteological study of Iron Age and Romano-British Dorset, England. In Harlow, M and Laurence, R (eds.) *Age and Ageing in the Roman Empire: Approaches to the Roman Life Course.* Portsmouth: Journal of Roman Archaeology Supplementary Series Monograph No. 65, pp. 171-190.

Revell, L (2005) The Roman life course: a view from the inscriptions. *European Journal of Archaeology* **8**: 43-63.

Ríos, L, Weisensee, K and Rissech, C (2008) Sacral fusion as an aid in age estimation. *Forensic Science International* **180**: 111.e111-111.e117.

Rissech, C, Estabrook, GF, Cunha, E and Malgosa, A (2006) Using the acetabulum to estimate age at death of adult males. *Journal of Forensic Sciences* **51**: 213-229.

Rissech, C, Estabrook, GF, Cunha, E and Malgosa, A (2007) Estimation of age-at-death for adult males using acetabulum, applied to four western European populations. *Journal of Forensic Sciences* **52**: 774-778.

Rissech, C, García, M and Malgosa, A (2003) Sex and age diagnosis by ischium morphometic analysis. *Forensic Science International* **135**: 188-196.

Rissech, C, Wilson, J, Winburn, AP, Turbón, D and Steadman, D (2012) A comparison of three established age estimation methods on an adult Spanish sample. *International Journal of Legal Medicine* **126**: 145-155.

Robb, J, Bigazzi, R, Lazzarini, L, Scarsini, C and Sonego, F (2001) Social "status" and biological "status": A comparison of grave goods and skeletal indicators from Pontecagnano. *American Journal of Physical Anthropology* **115**: 213-222.

Roberts, CA (2000) Did they take sugar? The use of skeletal evidence in the study of disability in past populations. In Hubert, J (ed.) *Madness, Disability and Social Exclusion.* London: Routledge, pp. 46-59.

Robling, AG and Stout, SD (2000) Methods of determining age at death using bone microstructure. In: Katzenberg, MA and Saunders, SR (eds.) *Biological Anthropology of the Human Skeleton*. New York: Wiley-Liss, pp. 187-205.

Rocha, MA (1995) Les collections ostéologiques humaines identifiées du Musée Anthropologique de l'Université de Coimbra. *Antropologia Portuguesa* **13**: 7-38.

Rogers, J and Waldron, T (2001) DISH and the monastic way of life. *International Journal of Osteoarchaeology* **11**: 357-365.

Rosenthal, JT (1996) *Old Age in Late Medieval England.* Philadelphia: University of Pennsylvania Press.

Rougé-Maillart, C, Jousset, N, Vielle, B, Gaudin, A and Telmon, N (2007) Contribution of the study of the acetabulum for the estimation of adult subjects. *Forensic Science International* **171**: 103-110.

Russell, KF, Simpson, SW, Genovese, J, Kinkel, MD, Meindl, RS and Lovejoy, CO (1993) Independent test of the fourth rib aging technique. *American Journal of Physical Anthropology* **92**: 53-62.

Sager, P (1969) *Spondylosis Cervicalis.* Copenhagen: Munksgaard.

Sánchez Romero, M (2008) Childhood and the construction of gender identities through material culture. *Childhood in the Past* **1**: 17-37.

Santos, AL and Roberts, CA (2001) A picture of tuberculosis in young Portuguese people in the early 20th century: a multidisciplinary study of the skeletal and historical evidence. *American Journal of Physical Anthropology* **115**: 38-49.

Sashin, D (1930) A critical analysis of the anatomy and the pathological changes of the sacro-iliac joints. *Journal of Bone and Joint Surgery* **12**: 891-910.

Saunders, SR, Fitzgerald, C, Rogers, T, Dundar, C and McKillop, H (1992) A test of several methods of skeletal age estimation using a documented archaeological sample. *Canadian Society of Forensic Sciences Journal* **25**: 97-118.

Sattenspiel, L and Harpending, H (1983) Stable populations and skeletal age. American Antiquity **48**: 489-498.

Scheuer, L and Black, S (1995) *The St. Bride's Documented Skeletal Collection.* Unpublished archive held at the Calvin Wells Laboratory at the Department of Archaeological Sciences, University of Bradford.

Scheuer, L and Black, S (2004) *The Juvenile Skeleton.* London: Elsevier Academic Press.

Schmitt, A, Murail, P, Cunha, E and Rogué, D (2002) Variability of the pattern of aging on the human skeleton: evidence from bone indicators and implications on age at death estimation. *Journal of Forensic Sciences* **47**: 1-7.

Schmitt, A (2004) Age-at-death assessment using the os pubis and the auricular surface of the ilium: a test on an identified Asian sample. *International Journal of Osteoarchaeology* **14**: 1-6.

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

Schmitt, A, Wapler, U, Couallier, V and Cunha, E (2007) Are bone losers distinguishable from bone formers in a skeletal series? Implications for adult age at death assessment methods. *HOMO* **58**: 53-66.

Scott, E (1997) Introduction: on the incompleteness of archaeological narratives. In Moore, J and Scott, E (eds.) *Invisible People and Processes.* London: Leicester University Press, pp. 1-12.

Shahar, S (1997) *Growing Old in the Middle Ages: "Winter Clothes Us in Shadow and Pain".* London: Routledge.

Shilling, C (2003) *The Body and Social Theory. Second edition.* London: SAGE.

Silberberg, M, Frank, EL, Jarrett, SR and Silberberg, R (1959) Aging and osteoarthritis of the human sternoclavicular joint. *The American Journal of Pathology* **35**: 851-865.

Silva, AM, Crubézy, E and Cunha, E (2009) Bone weight: new reference values based on a modern Portuguese identified skeletal collection. *International Journal of Osteoarchaeology* **19**: 628-641.

Sinha, A and Gupta, V (1995) A study on estimation of age from pubic symphysis. *Forensic Science International* **75**: 73-78.

Snodgrass, JJ (2004) Sex differences and aging of the vertebral column. *Journal of Forensic Sciences* **49**: 1-6.

Sofaer Derevenski, J (1997a) Age and gender at the site of Tiszapolgár-Basatanya, Hungary. *Antiquity* **71**: 875-889.

Sofaer Derevenski, J (1997b) Engendering children, engendering archaeology. In Moore, J and Scott, E (eds.) *Invisible People and Processes.* London: Leicester University Press, pp. 192-202.

Sofaer Derevenski, J (2000) Rings of life: the role of early metalwork in mediating the gendered life course. *World Archaeology* **31**: 389-406.

Sofaer, JR (2006) *The Body as Material Culture.* Cambridge: Cambridge University Press.

Sofaer, J (2011) Towards a social bioarchaeology of age. In Agarwal, SC and Glencross, BA (eds.) *Social Bioarchaeology*. Chichester: Wiley-Blackwell, pp. 285-311.

Sorg, MH, Andrews, RP and İşcan, MY (1989) Radiographic aging of the adult. In İşcan, MY (ed.) *Age Markers in the Human Skeleton.* Springfield: Charles C. Thomas, pp. 169-190.

Spirduso, WW (1995) *Physical Dimensions of Aging.* Champaign, CT: Human Kinetics.

St. Hoyme, LE and İşcan, MY (1989) Determination of sex and race: accuracy and assumptions. In Iscan, MY and Kennedy, KAR (eds.) *Reconstruction of Life from the Skeleton.* New York: Alan R. Liss, pp. 53-93.

Stevenson, PH (1924) Age order of epiphyseal union in man. *American Journal of Physical Anthropology* **7**: 53-93.

Stewart, TD (1954) Racial patterns of vertebral osteoarthritis. *American Journal of Physical Anthropology* **5**: 230-231.

Stewart, TD (1958) The rate of development of vertebral osteo-arthritis in American whites and its significance in skeletal age identification. *The Leech* **28**: 144-151.

Steyn, M, İŞcan, MY, De Kock, M, Kranioti, EF, Michalodimitrakis, M and L'Abbé, EN (2010) Analysis of ante mortem trauma in three modern skeletal populations. *International Journal of Osteoarchaeology* **20**: 561-571.

Stone, RJ and Stone, JA (1990) *Atlas of the Skeletal Muscles.* Dubuque: Wm. C. Brown Publishers.

Stoodley, N (2000) From the cradle to the grave: age organization and the early Anglo-Saxon burial rite. *World Archaeology* **31**: 456-472.

Stull, KE and James, DM (2010) Determination of age at death using the acetabulum of the os coxa. In Latham, KE and Finnegan, M (eds.) *Age Estimation of the Human Skeleton.* Springfield: Charles C. Thomas, pp. 134-146.

Suchey, J and Katz, D (1986) Skeletal age standards derived from an extensive multiracial sample of modern Americans. Abstract. *American Journal of Physical Anthropology* **69**: 269.

Suchey, JM, Brooks, ST and Katz, D (1988) Instructions for the use of the Suchey-Brooks system for age determination of the female os pubis. Instructional materials accompanying female pubic symphysial models of the Suchey-Brooks system. *Distributed by France Casting (Diane France).*

Suchey, JM and Brooks, TM (1988) Skeletal age determination based on the male os pubis. *12th International Conference of Anthropological and Ethnological Sciences.* Zagreb.

Szilvássy, J (1980) Age determination on the sternal articular faces of the clavicula. *Journal of Human Evolution* **9**: 609-610.

Todd, TW (1920) Age changes to the pubic bone: I. The white male pubis. *American Journal of Physical Anthropology* **3**: 285-334.

Todd, TW (1921) Age changes to the pubic bone: II. Pubis of male negro-white hybrid; III. Pubis of white female; IV. Pubis of female negro-white hybrid. *American Journal of Physical Anthropology* **4**: 1-17.

Todd, TW and D'Errico, J (1928) The clavicular epiphyses. *American Journal of Anatomy* **41**: 25-50.

Todd, TW and Lyon, DW (1924) Endocranial suture closure. Its progress and age relationship. Part I. Adult males of white stock. *American Journal of Physical Anthropology* **7**: 325-384.

Todd, TW and Lyon, DW (1925a) Cranial suture closure. Its progress and age relationship. Part II. Ectocranial closure in adult males of white stock. *American Journal of Physical Anthropology* **8**: 23-45.

Todd, TW and Lyon, DW (1925b) Cranial suture closure: Part III. Endocranial closure in adult males of negro stock. *American Journal of Physical Anthropology* **8**: 47-71.

Todd, TW and Lyon, DW (1925c) Cranial suture closure: Part IV. Ectocranial closure in adult males of negro stock *American Journal of Physical Anthropology* **8**: 149-168.

Van der Merwe, AE, İşcan, MY and L'Abbé, EN (2006) The pattern of vertebral osteophyte development in a South African Population. *International Journal of Osteoarchaeology* **16**: 459-464.

Van Gennep, A (1960) *The Rites of Passage.* London: Routeledge and Kegan Paul.

Van Gerven, D and Armelagos, G (1983) "Farewell to paleodemography?'' Rumors of its death have been greatly exaggerated. *Journal of Human Evolution* **12**: 353-360.

Wade, A, Nelson, A, Garvin, G and Holdsworth, DW (2011) Preliminary radiological assessment of age-related change in the trabecular structure of the human os pubis. *Journal of Forensic Sciences* **56**: 312-319.

Walker, PL, Johnshon, JR and Lambert, PM (1988) Age and sex biases in the preservation of human skeletal remains. *American Journal of Physical Anthropology* **76**: 183-188.

Walker, PL (1995) Problems of preservation and sexism in sexing: some lessons from historical collections for palaeodemographers. In Saunders, SR and Herring, A (eds.) *Grave Reflections; Portraying the Past Through Cemetery Studies.* Toronto: Canadian Scholars' Press, pp. 31-47.

Walker, RA and Lovejoy, CO (1985) Radiographic changes in the clavicle and proximal femur and their use in the determination of skeletal age at death. *American Journal of Physical Anthropology* **68**: 67-78.

Washburn, SL (1958) Review of "Skeletal age changes in young American males," by T. McKern & T. Stewart. *American Antiquity* 24: 198-199.

Watanabe, S and Terazawa, K (2006) Age estimation from the degree of osteophyte formation of vertebral columns in Japanese. *Legal Medicine* **8**: 156-160.

Waterman, J and Emery, R (2002) The diagnosis and treatment of disorders of the sterno-clavicular joint. *Current Orthopaedics* **16**: 368-373.

Webb, PAO and Suchey, JM (1985) Epiphyseal union of the anterior iliac crest and medial clavicle in a modern multiracial sample of American males and females. *American Journal of Physical Anthropology* **68**: 457-466.

Wittwer-Backofen, U, Gampe, J and Vaupel, JW (2004) Tooth cementum annulation for age estimation: results from a large known-age validation study. *American Journal of Physical Anthropology* **123**: 119-129.

Wittwer-Backofen, U, Buckberry, J, Czarnetzki, A, Doppler, S, Grupe, G, Hotz, G, Kemkes, A, Larsen, CS, Prince, D, Wahl, J, Fabig, A and Weise, S (2008) Basics in paleodemography: a comparison of age indicators applied to the early medieval skeletal sample of Lauchheim. *American Journal of Physical Anthropology* **137**: 384-396.

Yood, R and Goldenberg, D (1980) Sternoclavicular joint arthritis. *Arthritis and Rheumatism* **23**: 232-239.