Polymorphism of cranial suture obliteration in adult crania

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"What you get by achieving your goals
is not as important as
what you become by achieving your goals."

Zig Ziglar

Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution to Manisha Dayal and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Date: __________________________________

In memory of my Uncle and Aunt,

Parbhoo Kunvar
1954-2008
&
Pushpa Kunvar
1957-2007

Abstract

Cranial sutures are fibrous joints of the skull which allow for growth in young individuals. The sutural ligament is the fibrous connective material found between the two joint surfaces which can be divided into a number of different layers. During embryonic development and growth, ossification centres in the skull allow for the growth and development of the flat bones in the skull. Sutures are the areas where these ossification centres eventually meet. Some sutures like the frontal suture normally disappear at the age of two years, but it has been shown that this suture can persist in adulthood and is then called the metopic suture. Torgersen (1950) has shown that the obliteration pattern of the metopic suture is the same for skulls belonging to common inheritance trajectories. Cranial suture closure has thus been shown to be controlled by genes. In physical anthropology, obliteration of cranial sutures has been used as an age-at-death indicator since 1542. However, in 1890, Dwight rejected the notion that there was any relationship between age and obliteration patterns. Despite this, there have been a number of studies that have continued to use this method to estimate age-at-death from skeletal remains. These methods are currently still being used. The aim of this study was to investigate cranial suture obliteration patterns in adult crania. A total of 490 randomly selected modern black and white South African skulls from the Dart Collection were used to collect data. The ages of the individuals ranged from 19 to 98 years. Two methods previously used to estimate age from skeletal remains were used to assess the final obliteration status of the sutures. The scores assigned to these sutures were then subjected to statistical analyses to explore any relationship between age, sex and population affinity. The results show that considerable polymorphism in the obliteration pattern of the cranial vault sutures exist. The endocranial scores are bimodal while the ectocranial aspects using both the Acsádi & Nemeskéri (1970) and Meindl & Lovejoy (1985) method are multimodal. Bimodality and multimodality are direct indications of polymorphism. No significant relationship was found between obliteration and age. Thereafter the two methods initially used to assess the sutures were used to estimate the age of the skulls to test these methods. The results show that both these methods are not useful as age estimators when used on individuals drawn from the South African black and white populations. Since the large majority of variation in cranial suture obliteration is not explainable by age, it is hypothesized that patterns of the cranial vault suture obliteration are the result of epigenetic variation similar to that occurring elsewhere on the skeleton, and not a regular result of aging.

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Chapter One: Introduction

Sutures also called suturae, which means 'seams' in Latin (Taylor et al., 1988), are defined as a link between bones that are joined by connective tissue in vertebrate crania (Chopra, 1957; Standring et al., 2005). The first descriptions of cranial sutures are found in "The Oldest Surgical Treatise" (http://www.touregypt.net/edwinsmithsurgical.htm) dated to around 1600 BC, written in Egyptian language. In 1954, Moss defined a suture as the soft tissue that is present between the bones while calling the adjacent bone areas and the overlying soft tissue the "sutural area." However, cranial sutures are generally accepted as the joint between the flat bones of the skull in most textbooks of anatomy (Woodburne & Burkel, 1994; Standring et al., 2005; Saladin, 2007).

Cohen (1993) however, emphasizes that when we speak about sutures we mean the "open, functional status of the suture and not their eventual closure" (Cohen, 1993; p 582). This definition, as accepted by clinicians who study craniosynostosis in young individuals and other associated conditions, is not recognized by anthropologists who study the dry state of bones of individuals of all ages, and thus is used to describe the joints even when they are partially or near completely fused.

In biological anthropology cranial sutures have for many years been thought to be an indicator of age at death (Todd & Lyon, 1924; 1925a; 1925b; 1925c; Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1985; Krogman & İşcan, 1986; Masset, 1989). Since 1542 (Masset, 1989), the status of cranial sutures was categorized and used to find the approximate age of the individual in physical anthropology, paleoanthropology and most recently in forensic anthropology cases. This is especially the case when only the skull is available for study. The most influential study is that of Todd and Lyon, who in 1924 studied the skeleton for indicators of age-at-death. Their study on cranial sutures is still used today, albeit in a modified version (Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1985), in biological anthropology and especially in forensic anthropology where the biological profile determination is so imperative (Krogman & İşcan, 1986).

Cranial sutures are synarthrodial joints which contain only fibrous tissue between the bones (Christensen et al., 1960; Basmajian, 1978; Cunningham, 1981; Hollinshead & Rosse, 1985; Langebartel, 1977; Leeson & Leeson, 1972; Lockhart et al., 1965). The sutures are generally primary bone sites during the development and growth of the skull but also create a firm bond between the bones of the cranium (Baer, 1954; Moss, 1954; Mednick & Washburn, 1956; Pritchard et al., 1956, Hubbard et al., 1971; Opperman, 2000). When mature, they allow little or no movement to take place in adults (Jacob et al.,1978; Lever, 1980). At birth, however, the future sutural sites (fontanelles) allow for the overlap of the calvarial bones during delivery of the baby as it passes through the birth canal. The bones are then brought back to their normal position through the growth of the calvarium (Cohen, 1993).

During growth and development of the skull, a number of tissue interactions take place (Ogle et al., 2004). Depending on the interactions that take place at these sites, cranial sutures often fuse prematurely (Cohen, 1993; Ogle et al., 2004). In addition to their use for the estimation of age of the skeletal remains in forensic anthropology (Dwight, 1890; Todd & Lyon, 1924; 1925a; 1925b; 1925c; Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1985; Krogman & İşcan, 1986; Masset, 1989), cranial sutures have also been used as an individual identification tool using the sutural patterns that are highly varied between individuals (Chandra-Sekharan, 1985; Rogers & Allard, 2004).

The cranial sutures will be discussed in more detail in the proceeding sections under the following sequential headings: i) macroscopic anatomy of adult sutures; ii) microscopic anatomy of adult sutures; iii) embryologic development; and iv) suture closure.

1.1 Macroscopic anatomy of sutures

The sutures most commonly used for age estimation are those of the vault of the skull. These sutures gained prominence in forensic literature and were found to be used more often than sutures in other parts of the skull. The cranial vault consists of eight bones which are connected by cranial sutures. The three most prominent vault sutures are the coronal, sagittal and lambdoid. The coronal suture is found on the anterior aspect of the skull, the lambdoid in the posterior aspect, while the sagittal suture lies between the coronal and the lambdoid along the median plane of the skull. The coronal suture found in the coronal plane is the junction of the frontal and the paired parietal bones (Standring et al., 2005).

Another prominent vault suture found in individuals less than two years of age is the frontal suture (sutura interfrontalis), which is found between the two frontal bones. Generally this suture fuses completely or almost completely in most individuals but sometimes remains patent until adulthood and throughout life. It is then called the metopic suture (Krogman & İşcan, 1986; Standring et al., 2005). The metopic suture is considered to be an epigenetic trait which is found in different populations ranging in frequencies of approximately zero to 16% in adults (Hauser & De Stefano, 1989).

The sagittal suture as its name suggests is found in the sagittal plane between the two parietal bones. This suture extends from the bregma (junction of the coronal and sagittal sutures) to the lambda (junction between the sagittal and the lambdoid sutures) (Standring et al., 2005). The lambdoid suture connects the two parietal bones to the occipital bone.

Other cranial vault sutures include the spheno-frontal, spheno-temporal, spheno-parietal and occipito-mastoid sutures. These sutures are sometimes referred to as the circum-meatal sutures. Non-cranial vault sutures that are present in the human skull include those that connect to the facial region and the base of the skull. These include the sutures such as the zygomatico-maxillary, fronto-nasal, fronto-maxillary and many more (Standring et al., 2005). Some of these non-cranial vault sutures, like the palatine sutures have also been used for age determination (Mann et al., 1987; Gruspier & Mullen, 1991; Mann et al., 1991; Ginter, 2005). However, the spheno-frontal and the spheno-temporal sutures (Meindl & Lovejoy, 1985; Dorandeu et al., 2008) have also been used to investigate age. Though attempts to relate still other cranial suture closure to age are being made, this study only considers the three most prominent cranial vault sutures and parts of the spheno-temporal and spheno-frontal sutures.

The classification of sutures is generally based on their articulation of the two edges of bone (Saladin, 2007), but sutures can also be classified according to the degree of complexity they possess (Herring, 1972). Under the articulation classification, sutures can either be described as simple or overlapping. These classifications are based on the orientation of the two surfaces (Saladin, 2007). Thus simple sutures would have both the surfaces in the same or very similar plane while an overlapping suture would allow two surfaces from two different planes to articulate. Simple sutures, are also called end-to-end, butt, flat or plane sutures and are generally found in the sagittal plane (Cohen, 1993; De Costa et al., 2007; Saladin, 2007). An example of this type of suture would be the palatine suture (Mann et al., 1987; Gruspier & Mullen, 1991; Mann et al., 1991; Ginter, 2005).

An overlapping suture, sometimes also called bevelled or squamous (*Latin*: scaly) suture (Frick et al., 1991) can be compared to tiles on a roof where the surface area of the articulating surface is increased thus offering more resistance at the sutural edge (Herring, 1972). The squamous suture, which is found between the parietal and temporal bones is a good example of an overlapping suture, where the two articulating surfaces (parietal and temporal) are in two different planes (Saladin, 2007).

Sutures can also be classified based on the number of inter-digitations that are found in the suture pattern (Herring, 1972). A simple suture would have less inter-digitations while a serrated suture would have a jagged appearance with an increase in the number of inter-digitations. Sometimes sutures are only classified as three types which include plane, serrated or lap sutures (Saladin, 2007). Herring (1972), however, studied suture morphology and evaluated the appearance of the suture and the degree of inter-digitation. A four-stage scale ranging from straight to very inter-digitated, with varying grades of slightly inter-digitated and inter-digitated was suggested (Herring, 1972; Cohen, 1993).

Sutures cover a large area and have been shown to differ along their length (Krogman & İşcan, 1986). Thus a single suture can be classified differently along its length. Initially it was suggested that all sutures start off as simple sutures and thereafter become highly inter-digitated (Wagemans et al., 1988; Cohen, 1993). This observation was later criticized as other investigators found that some sutures in their formation are serrated. Remmelink (1985) in a doctoral thesis (Wagemans et al.,

1988) and more recently Wu and colleagues (2007) have shown that the sagittal suture increases in complexity up until the age of 10 years. Thus sutures are said to become more irregular and increase in complexity with age (Cohen, 1993; Sun et al., 2004). It should, however, be noted that this only occurs in younger humans and no further complexity changes have been observed with increasing age (Wu et al., 2007). The complexity of the coronal suture, however, was shown to increase with age in male rats and the bevelling of the suture was also shown to increase (Smith & McKeown, 1974). There was great variation in the sutural pattern (Smith & McKeown, 1974).

Endocranial and ectocranial sutures have also been shown to differ in their pattern and complexity. Ectocranial suture patterns are diverse in their pattern with an integration of simple and complex patterns. The endocranial sutures found on the inner aspect of the skull, are not as complicated as those of the ectocranial. The endocranial sutures are simpler and homogenous in their pattern (Shapiro & Janzen, 1960; Hauser & De Stefano, 1989).

1.2 Microscopic anatomy of sutures

The sutural ligament (Singer, 1953) is the ligament that binds the cranial bones at the site of the suture (Standring et al., 2005). This ligament is comprised of soft tissue and it can be distinguished by a number of layers (Standring et al., 2005). The study that is most quoted is that of Pritchard et al. (1956) in which sutures of six different species (including humans) were studied through the sequential stages of development. These authors described their results for five different stages of development, which include: 1) stage of approaching bone territories; 2) stage of meeting of the bone territories; 3) early growing stage; 4) late growing stage; and finally 5) adult stage (Pritchard et al., 1956; Wagemans et al., 1988).

Other investigators have also tried to describe the microscopic structure of sutures but there seems to be no real consensus as to the number of layers found between the adjacent bones in the joint (Pritchard et al., 1956). Comparisons between studies are difficult as the methodology employed differs between studies. Cohen (1993) criticises the studies that involve only dry skulls (Todd & Lyon, 1924; Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1986) adding that these studies were not as reliable as histological studies, as the internal part of the suture could not be studied. There is also no consensus about the number of layers that exist since the definition of a layer is not stated and most of these studies do not investigate the sutures at different developmental times. This poses a major problem when investigating such a structure, as it is also known that within a single suture there is developmental variation (Gardner et al., 1975).

Since different species and types of animals were used and the histological techniques differed from experiment to experiment, some structures and cells are shown more clearly than other structures (Wagemans et al., 1988). Thus, it is no surprise that there is no agreement between the studies. Pritchard and associates (1956) described five different layers of the sutural ligament which include: a cambial layer found on either side of the sutural aspect of the bone containing osteogenic cells. The next layer, more medial to the cambial layer on either side, is a fibrous capsular layer. The middle layer is a highly vascular layer (Fig 1.1).

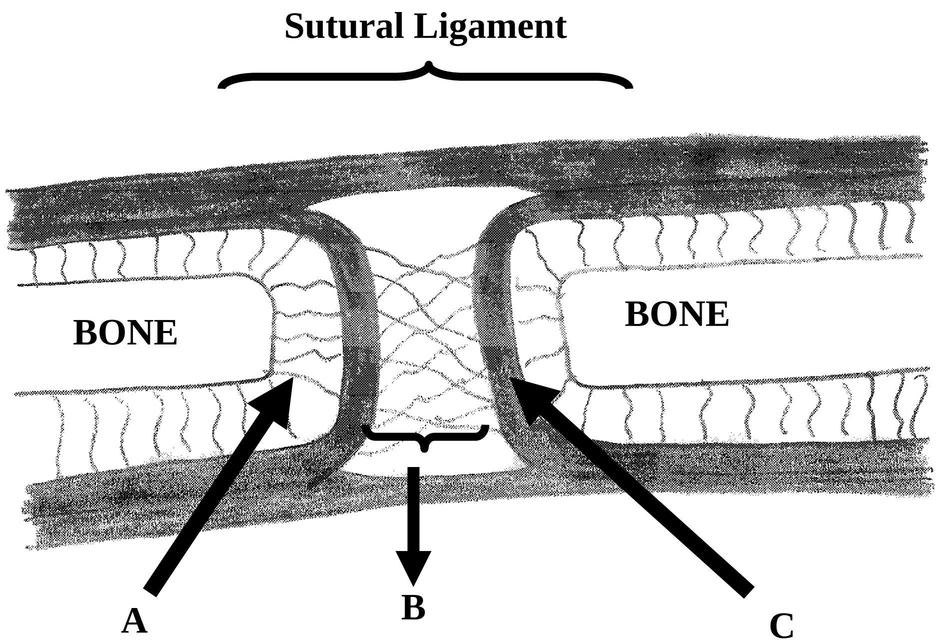


Figure 1.1. Schematic diagram of the different layers of the sutural ligament (redrawn from Standring et al., 2005). A = Cambial layer, B = Middle layer, C = Capsular layer.

The cambial and fibrous capsular layers, are equivalent and continuous with the periosteum found internally and externally on the skull at the sutural margin (Pritchard et al., 1956; Moss, 1960). The layer found at the centre of the sutural ligament (vascular layer) is suggested to vary in width with age. This layer contains all the blood vessels and the nerves that supply the joint and surrounding structures. The veins that are present in this layer also communicate with the diploic veins, the venous sinuses found intracranially and the external veins of the scalp (Pritchard et al., 1956; Cohen, 1993; Standring et al., 2005; Proff et al., 2006).

An earlier study by Sitsen in 1933, as summarized by Pritchard et al. (1956) only describes three layers. In this study the human lambdoid sutures were described. Other investigations by Bernstein (1933) (see Pritchard et al., 1956), Weinmann & Sicher (1955) and Johansen & Hall (1982) seem to favour a three layered sutural ligament. The only study that considers that the sutural ligament is a four-layered structure is that of Scott (1954).

Moss (1954), however, was able to explain that in actual fact all these theories of the numbers of layers are correct except that these layers have been identified at different times of development. He criticizes the fact that some researchers would only examine a histological slice on a single section of the suture (Moss 1954). Skull sutures have also been shown to differ in structure in a single skull and even in a single suture itself (Wagemans et al., 1988).

The major criticism of studies of cranial sutures is that these are not longitudinal studies where the status of suture obliteration is followed (Christensen et al., 1960). The second downfall is that most biological anthropology studies only assess the ectocranial aspect of the suture without any consideration of the status of the endocranial aspects of the sutures (Cohen, 1993) as the latter are sometimes inaccessible.

1.3 Embryology of suture formation

The skull vault forms part of the membranous neuro-cranium which is derived from mesenchyme (mesoderm), specifically from the "primitive meninx" found around the developing neural tube. The primitive meninx is divided into an ectomeninx (found externally) and an endomeninx (found internally) (Harrison, 1978). The endomeninx gives rise to the pia and arachnoid mater of the brain, while the ectomeninx gives rise to the dura mater and the bones of the skull vault. Initially the part that gives rise to the bones is a superficial membrane which undergoes intramembranous ossification to form the frontal, parietal and supra-occipital bones, as well as the squamous region of the temporal bone. These bones appear to contain numerous needle-like structures when viewed microscopically (Harrison, 1978; Langman, 1981).

At the eighth embryonic week, the ossification centres begin to appear (Harrison, 1978; Hauser & De Stefano, 1989). These ossification centres allow bone growth in a radial direction from the centre towards the periphery of the bone (Harrison, 1978; Hauser & De Stefano, 1989). Initially, however, the bones are connected to each other by a layer of dense connective tissue, which is the site of future sutures. The edges of the bones do not fuse thus allowing for the bones of the skull vault to overlap each other during the birthing process so that the large skull of the neonate can pass through the relatively narrow pelvis of the mother (Cohen, 1993).

In certain regions of the skull the areas that separate the bones from each other are much larger and these areas are referred to as fontanelles (Beck et al., 1973; Dryden, 1978; England, 1996; Langman, 1981). At birth a number of fontanelles are present that close at different times. The large anterior fontanelle that is found between the two parts of the frontal bone and the two parietal bones is usually the last of the fontanelles to close; normally around the age of two years. The other fontanelles are said to close before the end of the first year (Beck et al., 1973; Dryden, 1978; England, 1996; Langman, 1981; Scheuer & Black, 2000).

The major function of the fontanelles is to allow the skull vault to expand during the first year of life. The growth of the bones of the skull is directed by the growth of the brain but there are also other factors which include the tissue interactions that take place at the sutural sites, the mechanical signalling of the forces produced by the swift expansion of the skull and also by the signalling of the dura mater through specific cells that keep sutures patent during growth and development (Ogle et al., 2004). These factors account for the growth of the flat bones of the skull (Beck et al., 1973; Dryden, 1978; England, 1996; Langman, 1981).

The expansion of the skull occurs through two different mechanisms: bone remodelling and growth. Firstly the apposition of a new layer of bone on the external surface and simultaneously the resorption of bone at the internal surface allows the skull to grow but also makes sure that the bones do not become too thick. The second mode is the growth of the bones at the sutural edge allowing the space between the bones to narrow (Langman, 1981; Cormack, 2001).

As the bones of the cranial vault grow, the fontanelles become smaller and form the sites for skull sutures. Although there are primary ossification centres found within the flat bones of the skull to allow for the growth of the bones, secondary ossification centres are found at the edges of the bones where the sutures are present (Hauser & De Stefano, 1989).

At birth the bones of the skull are not yet differentiated into the two layers of compact bone separated by a layer of cancellous bone (Retzlaff et al., 1979). The bones are unilammelar with no diploë. The formation of the sutures occurs during the first and second years of extra-uterine life. After that age the appearance of sutures does not change significantly until adulthood. The bones interlock at the sutures by tongue-shaped processes that are called “lingulae” (Oudhof, 1982; van Doorenmaalen, 1984; Hauser & De Stefano, 1989). At the external and internal surface of the skull the lingulae are developed differently. At the external surface the lingulae are much more flattened and become less flattened for the central and the internal parts. The lesser complexity of the endocranial sutures serves as evidence for this happening. Lingulae are also more intensely developed in areas where bone growth is extreme (Oudhof, 1982; van Doorenmaalen, 1984; Hauser & De Stefano, 1989).

1.4 Closure of cranial sutures

There are many studies that offer reasons for the closure of the cranial sutures while some studies offer reasons that the sutures remain patent (Pritchard et al., 1956; Kokich, 1986; Wagemans et al., 1988; Cohen, 1993). In physical anthropology, however, only the final state of the cranial suture is investigated (Todd & Lyon, 1924; 1925a; 1925b; 1925c; Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1985; Krogman & İşcan, 1986). Since the closure of cranial sutures is not a simple process, physical anthropologists would benefit from a more extensive study of the sutures.

The process of cranial sutures closure is dependent on a number of interactions that are triggered by different hormones, although the process is still not fully understood. Sutures were considered to close and obliterate once the growth and development of the skull ceases (Kokich, 1986). The sutures change their structure during growth thus the structural composition and arrangement of the sutural ligament is altered. The cambial layers become thinner as the bone edges grow closer together. This layer eventually becomes a single layer. The other layers of the sutural ligament also change as the capsular layers increase in density and the middle layer becomes more vascular (Pritchard et al., 1956).

The study of the fusion of cranial sutures, however, has been extensively dominated by the investigation of craniosynostosis, which is the premature fusion of one or more of the sutures in the skull (Bolk, 1915; Bertelsen, 1958; Kimonis et al., 2007; Slater et al., 2008). This allows investigators to study the process in a quicker time frame and to investigate which factors contribute to the premature closure. The causes and underlying biology of craniosynostosis are not yet known thus making the investigations of these studies even more difficult (Cohen, 1993; Bradley et al., 1996).

It has been shown that in some animals, like New World monkeys, the circum-meatal (parieto-squamosal, parieto-mastoid, occipito-mastoid, spheno-temporal, spheno-frontal and spheno-parietal) sutures remain patent all through life (Chopra, 1957). In Peccaries (pig-like mammals), however, who use their snout at a very early age to search for food, the sutures fuse early so that the structure can maintain its firmness (Herring, 1974). There are many discussions that are still taking place considering whether there is actual fusion of the suture once the growth and development has stopped (Kokich, 1986). Current research shows that there are also many factors that cause sutures to close such as tissue interactions at the microscopic level with the mechanical tension found in the skull (Cohen, 1993; Ogle et al., 2004).

When animal models are used to investigate the fusion patterns of sutures a wide individual variation in the time of suture closure is seen (Wang et al., 2006). The same trend is seen in humans when the cranial sutures are used as age indicators (Dwight, 1890; Powers, 1962). In some individuals the cranial vault sutures are open in 80 year olds while the same sutures in other individuals are completely obliterated before the age of 50 years (Dwight, 1890; Eränkö & Kihlberg, 1955). Despite all the knowledge that there is an erratic pattern of fusion of sutures, efforts are still being made to use them as age indicators (Sahni et al., 2005; Dorandeu et al., 2008). The endocranial sutures, however, have been shown to close more often and much earlier than the ectocranial sutures (Mitchell & Patterson, 1967).

The wide variation in the pattern of suture obliteration in individuals of the same age indicates that sutures may not be closing regularly with age. Other explanations accounting for the cause of the polymorphic nature of suture closure and its variation in the obliteration status are to be investigated.

The aim of this work was to test the hypothesis that the degree of obliteration of cranial vault sutures in adults is not substantially related to age and to offer an alternative explanation for the polymorphism in suture obliteration. This was carried out by testing the current methods of Acsádi and Nemeskéri (1970) and Meindl and Lovejoy (1985) on a South African skeletal sample. This sample was best suited for this purpose as it consists of individuals of both sexes from different genetic backgrounds who lived in the same geographic region and it covers a wide range of adult ages.

Chapter Two: Epigenetic traits in skeletal biology

Epigenetic traits in skeletal biology have been defined as the minor skeletal variations that are seen on the skull and on the postcranial skeleton. The term epigenetics is defined as “that branch of biology which deals with the casual analysis of development” and was first defined by Waddington in 1940 (Rieger et al., 1968; p 150). It derives from the term “epigenesis” meaning the “process of progressive determination and differentiation of cells and tissues, as a result of the original genetic instructions operating in a progression of environments” (Hauser & De Stefano, 1989; p 1).

Biological anthropologists applied the term many years ago to morphological traits which were considered to be as close to genetics as possible. These traits were called epigenetic as they were shown to be genetic in nature but needed the correct environment for development. In skeletal biology only traits that were visible on the skeleton were investigated. These included morphological traits that were regarded to be “present” or “absent” on the skeleton (Berry & Berry, 1967; Berry, 1975; Hauser & De Stefano, 1989).

As the definition of these traits was not clear, the names given to these morphological traits were numerous. These included terms like quasi-continuous traits, minor skeletal variants, non-metrical variants (Finnegan, 1978), discrete traits (Corruccini, 1974), discontinuous and discrete traits (Hertzog, 1968; Kellock & Parsons, 1970; Ossenberg, 1976; Hauser & De Stefano, 1989, Manzi et al., 1996; Hanihara & Ishida, 2001a; 2001b). This terminology was used interchangeably (Berry & Berry, 1967; Berry, 1975; Hauser & De Stefano, 1989).

The work of Berry and Berry (1967) was the foundation of studies of these morphological traits. This study highlighted the traits that were seen in the human skull. Most of the traits that were scored in this study are based on the work of Wood-Jones (1931a; 1931b; 1931c; 1933), who published a series of papers in his study of the skeleton to identify race from certain markers in the skeleton. Other epigenetic traits that were used by Berry and Berry (1967) were introduced by Brothwell in 1963.

An excellent summary in the form of a comprehensive text called: “Epigenetic variants of the human skull” by Hauser and De Stefano (1989) has been the cumulative work of most of these traits. This text summarises the history of epigenetic traits in the human skull, and also acts as an atlas of all the traits that are visible on the human skull (Hauser & De Stefano, 1989).

The degree of development of the epigenetic traits depends on the environment that the trait is allowed to develop within. These traits have also been shown to be sexually dimorphic and vary amongst populations, while there are also differences seen on both sides of the body. This makes the assessment of these traits more difficult as the interpretation of the degree of development of a structure is not always concordant amongst researchers (Berry & Berry, 1967). This was clearly demonstrated by Berry and Berry (1967) when the palatine torus frequencies were shown to have large discrepancies between populations. They concluded that there are probably two different areas that are being labelled as the palatine torus.

A study even earlier than this was carried out by Gruneberg (1954) on mice. This study showed that some of these minor skeletal variants were only present in certain populations of mice. Other populations sometimes showed a grading difference for the same trait (Gruneberg, 1954).

Epigenetic traits can also occur during a particular developmental stage, for example the appearance of sutural bones. The sutural bones develop as a result of an extra ossification centre developing during the growth of the skull. In addition to ossification centres in the skull, it has also been shown that there are ossification centres found within the sutures (Hauser & De Stefano, 1989). Thus, sutural bones develop as a result of these ossification centres found within the sutures if the environment for its development is correct. Sutural bones can be seen in young and mature skulls. Epigenetic traits have a threshold that allows them to develop depending on the conditions around the trait. These conditions include the environment that the trait is found in. The sutural bones were generally scored based on whether they were present or absent in the suture (Hauser & De Stefano, 1989). Other traits are scored according to their grade of development (Hauser & De Stefano, 1989).

In the skull the epigenetic traits that have been identified range from the sinuses found within the skull, the spines, depressions, foramina, sutural (wormian) bones to even some sutures like the metopic sutures.

2.1 Metopic sutures

Metopic sutures were identified as epigenetic traits of the skull. Failure of the frontal suture to close in infants and its persistence into adulthood is called metopism (Hess 1945; Bademci et al., 2007). The frontal bone is normally found in two parts with two ossification centres. It has been accepted for many years that during growth and development, the two halves unite in the first and second year of life to form a single frontal bone in the adult (Bolk, 1917; Skrzat et al., 2004). However, in many cases it was noticed that the frontal suture that separates these two halves does not close thus becoming a metopic suture. The metopic suture is associated with brachycephalic skulls (Bryce & Young, 1917; Hauser & De Stefano, 1989).

The metopic fissure, investigated by Schultz (1929), was suggested to decrease the growth of the frontal bone and was also suggested to have a “hereditary tendency.” The metopic suture, however, was shown to be a hereditary trait by Torgersen in 1950. Torgersen found that in a single family the metopic suture seemed to be inherited, although in different forms from the parents to children thus making this characteristic one controlled by genetics but further developed depending on the environment (Torgersen, 1950). This was observed using the skulls of many individuals and their families. The metopic suture was found in five cases in individuals with cleft lip and also showed that it was hereditary when examining the skulls of their parents and siblings. In one family which contained monozygotic twins, the metopic suture was present in both twins and the father. When a family of dizygotic twins were assessed all members of the family displayed the suture except one of the daughters (Torgersen, 1951a).

Torgersen later found a few more families that showed the metopic suture to be hereditary (Torgersen, 1951b). When 50 pairs of twins were examined, the metopic suture was found in eight pairs of the twins. In a pair of dizygotic twins, one twin displayed a metopic suture but also included a sutural bone. The other twin did not display a metopic suture but did display a sutural bone in exactly the same position (Torgersen, 1951b). Further investigation into the x-rays of the families of the other twins who showed no metopism, supernumerary bones were found in the twins while a metopic suture was found in the father. These supernumerary bones were in the same place that the metopic suture was observed in the father. These examples illustrate the heritability of the metopic suture from parents to siblings, however, the manifestation of variations of the metopic suture in the form of sutural bones demonstrate that these hereditary traits are influenced by other factors. These factors include the environment allowing this trait to develop within a certain threshold. These criteria resemble that of epigenetic traits.

Torgersen (1951b) also suggested that there were probably two genes that were responsible for the sutural patterns (Torgersen, 1951b). One gene would control the site of the ossification centres while the other gene would be responsible for the rate of the obliteration of the suture. Further investigation into this being a recessive trait has been undertaken and thus the metopic suture is now considered an epigenetic trait (Hauser & De Stefano, 1989).

Many studies have been carried out to report the incidences of metopic sutures in various populations (Jit & Shah, 1948; Das et al., 1973; Agarwal et al., 1979; Ajmani et al., 1983; Baaten et al., 2003; Bilodi et al., 2003). The incidence of the metopic suture was said to be greater in higher races, meaning Europeans (Bryce & Young, 1917), but later it was found that the metopic suture incidence differs from population to population (Hauser & De Stefano, 1989).

The above-mentioned studies should probably have investigated the incidence of the metopic sutures in the families of the cases that were found. This, however, is sometimes not possible as most of these studies were performed on skeletal material whose families were not known. Future studies into this trait would benefit by studying this trait in living families.

The metopic suture was recorded as either present or absent in the skull. If the metopic suture was found to be present then it would be graded according to the length of the metopic suture, presence at the coronal suture end or its persistence at the nasal end. The pattern of the metopic suture was also used to report the incidences. The patterns that were recorded included the “H” shaped or “W” shaped suture (Hauser & De Stefano, 1989). The metopic suture is a typical skeletal trait that has been linked to genetics by Torgersen (1951a; 1951b) thus illustrating the need for these traits to be included in reports when physical and biological anthropologists analyse a skull.

Chapter Three: Background to the usage of cranial suture obliteration as a method to estimate age from skeletal remains

A large volume of literature is available on the application of the obliteration of cranial sutures for estimating age in physical and forensic anthropological work (Dwight, 1890; Todd & Lyon, 1924; Genoves & Messmacher, 1959; Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1985; Krogman & İşcan, 1986; Key et al., 1993). These methods have also been extended to other primates (Falk et al., 1989; Cray et al., 2008). Other elements of the skeleton that can also be used for the estimation of age using macroscopic methods include the articular surface of the pubic symphysis (Brooks, 1955), the occusal surface of the teeth (Molnar, 1971; Kim, 2000), the sternal ends of ribs (İşcan et al., 1984), and the internal structure of long bones (Acsádi & Nemeskéri, 1970; Krogman & İşcan, 1986). The estimation of age based on the obliteration of cranial vault sutures has notoriously been labelled as an inaccurate method (Dwight, 1890; Singer, 1953; Powers, 1962). This skeletal trait, however, is currently still being used to investigate any significant relationship that it might have with the age of the individual so that it can be used as a method to estimate age (Key et al., 1994; Ritz-Timme et al., 2000; Bednarek et al., 2005; Lefevre et al., 2005; Sahni et al., 2005; Rösing et al., 2007; Dorandeu et al., 2008; O'Brien & Sensor, 2008).

The history of this method goes back to the late 16th century (Todd & Lyon, 1924; Masset, 1989). However, the most well-known study on using the obliteration of cranial sutures for aging is probably the study carried out by Todd and Lyon in 1924 and 1925 using different populations. This study was based upon the concept of the obliteration of the three major sutures of the cranial vault with age. The skull is more often regarded as the element that can be used to gather the most information but has also shown to be the skeletal element that survives most often in the archaeological record (Brooks, 1955). Thus the obliteration of skull sutures has been the most popular method that is commonly used.

As the method of age estimation is a morphological one, which does not involve complex equations or other comparative material, suture closure gained momentum as an age indicator (Dorandeu et al., 2008). Many anthropologists over the years used to examine the cranial sutures with the naked eye and would deduce from this whether the skull is that of a younger or older individual. This was based on the assumption that closure of cranial sutures progressed with age (Todd & Lyon, 1924; 1925a; 1925b; 1925c).

With time, however, this indicator has been shown to be unreliable when it comes to estimating age (Dwight, 1890; Singer, 1953; Brooks, 1955; Powers, 1962). Despite all warnings from several researchers, the method is still used today (Sahni et al., 2005; Dorandeu et al., 2008), either on its own or as part of a more complex method (Acsádi & Nemeskéri, 1970), to estimate the age of skeletal remains in forensic and archaeological cases (Acsádi & Nemeskéri, 1970; Sahni et al., 2005).

3.1 History of the method of estimating age using cranial suture closure

Most of the early literature on the history of cranial suture closure was published in languages other than English (Broca, 1861; Frédéric, 1906). Thus the research of the Americans Todd and Lyon, who in 1924 and 1925 published a series of papers in the American Journal of Physical Anthropology in English on the use of this method to estimate age, is probably the most quoted study today. Todd & Lyon (1924), in their introductory paper gave an overview of the research that was carried out before 1924. Another source which relayed this information is a chapter by Masset (1989) titled: “Age estimation on the basis of cranial sutures.” in the book edited by İşcan (1989) titled “Age markers in the human skeleton.” Singer (1953) also gave a brief overview of the history of the estimation of age from cranial suture closure.

It was in 1542 when the first statement was made by Vesale, as quoted by Masset (1989), regarding the relationship of cranial suture closure and age. Later, in 1861, Broca in his paper on the volume and the form of the brain conveyed that skulls of 50 year olds showed sutures that had not begun closure. In 1866, however, Welcker was able to classify skulls into four age groups based on the closure of the cranial sutures. Similarly Ferraz de Macedo (1892) found that he could classify 1000 skulls into 10-year categories, based upon the obliteration of the cranial sutures (Todd & Lyon, 1924).

In earlier literature the entire skull or different aspects of the skull were described in a single paper. Cranial sutures were not the main focus of the research but were instead described by the authors as a matter-of-fact or in a passing comment (Broca, 1861; Frédéric, 1906). This would explain why so many early papers did not include the detail of skull sutures. Initially the variations of the closure of the different parts of the sutures were not observed but were described in relation to the sequence of each of the sutures as a whole in different skulls. Others compared the skulls of “lower and higher races” (Dwight, 1890).

From Todd & Lyon’s 1924 summary of previous literature, the first references to suture closure were made in the first century A.D., when Celsus compared skulls during his medical teaching and found that sutures were not seen in those skulls in warmer climates. Arranius later agreed with him when he worked on Ethiopians.

These populations were seen as a “lower race” and there was a belief that in “lower races” sutures started closure at a much earlier age. Pommerol (1869) in his thesis on the synostosis of cranial sutures found that in whites the onset of cranial suture closure began at the ages between 40 and 45 years. Topinard, (1885), on the other hand found that there was a great variation in the timing of the closure of the sutures. He reported that if there were any open sutures, the individual was 35 years or less, if there was closure in the sagittal suture the individual was probably around 40 years, and if the coronal suture had started closure it would point to someone over the age of 50 years. However, if the temporal suture showed signs of closure, an age of 66 years would be estimated (Todd & Lyon, 1924).

Five years later Dwight (1890) found that the patterns of closure of the cranial sutures were so erratic that he warned against using these indicators as an aging technique. He did not state the order of closure of the cranial sutures but gave a few generalizations in terms of closure of cranial sutures. He found that closure began from the inside and then moved towards the ectocranial aspects which confirmed previous observations. He also observed that in general the posterior end of the sagittal suture was more often obliterated than the lateral ends of the coronal suture. Interestingly, he found that in skulls of older individuals, when the coronal suture did not close early, the lambdoid was more often closed than the coronal on the ectocranial aspects. He, however, concluded that: “It must not be forgotten that there are other guides to the age of the skull; and I am not prepared to assert that, taken together with them, the sutures are absolutely worthless in the hands of the experienced anatomist. I am sure that to any one else the rules in question are misleading and dangerous” (Dwight, 1890; p 392).

This statement from Dwight (1890) probably led Todd & Lyon (1924) to reconsider the relationship of age and suture closure during Todd's research on aging of the skeleton. Dwight (1890) suggested that there was no association between age and suture closure. However, there were limitations to Dwight's study as in some cases he only studied the ectocranial aspects while in other cases he included the endocranial aspects in his assessment. Another question that Dwight raised of his own research was the reliability of the recorded ages of the individuals. While the ages of the individuals were given, they may be questioned as the skulls were mostly those that belonged to paupers; hence the reported ages might be unreliable (Dwight, 1890).

Following Dwight's research Parsons and Box (1905) were against the use of ectocranial sutures as a method of age estimation. They, however, agreed that the endocranial (entocranial as used in their paper) aspects could be used for this purpose. An important observation made by them, which they considered a rule, is: "The simpler the suture the earlier its closure," (Parsons & Box, 1905; p 37).

This concept was also seen in Frédéric's (1906) paper where a method to score the complexity of the sutures was given (Figure 3.1). The score for the complexity of the suture ranged from one to five with one having the least complexity and five the most complexity (the number of inter-digitations). This was taken directly from Broca's (1875) paper.

The work of Frédéric (1906), however, was better known as he published his results in German, which at the time was a more widely used language of science. His findings showed that when the cranial sutures were used as an aging indicator the estimates showed a difference of more than 10 years from the recorded ages (Frédéric, 1906). This reinforced the fact that there probably was no relationship between the closure of cranial sutures and age of the individual. These findings together with those of Dwight (1890) and Parsons and Box (1905), however, did not stop further investigation into the relationship of cranial suture closure with age (Todd & Lyon, 1924).

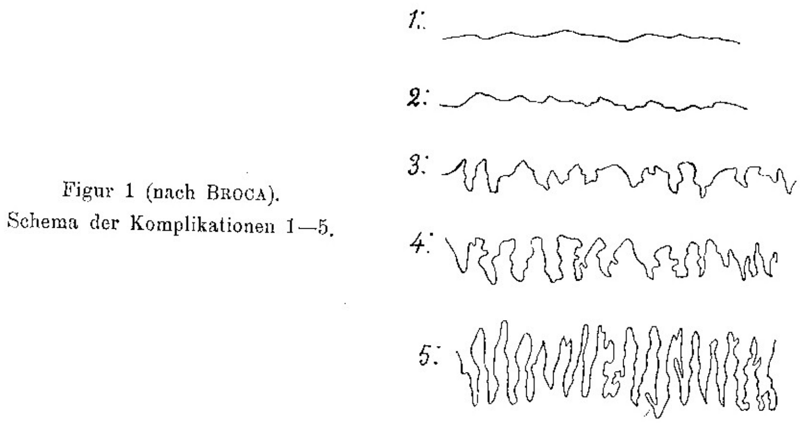


Figure 3.1 Figure appearing in Frédéric's (1906) publication as taken from Broca (1875) showing the scoring pattern of complication of the sutures. A score of one indicates a very simple suture while a score of five indicates the most complicated suture.

In the mid 1920's the series of papers published by Todd & Lyon reinforced the idea that there was a strong relationship between cranial suture closure and age (Todd & Lyon, 1924; 1925a; 1925b; 1925c). There were many limitations to this research, however, the most important limitation was the exclusion of skeletons in their sample that did not fit into the pattern of cranial suture obliteration with age. A justification was made in their original article for the removal of these specimens stating that any skeleton which showed an anomaly of the relationship with age was removed as well as all those that showed the growth deviation in the pubic symphyses (Todd & Lyon, 1924).

These limitations led many others to doubt the scientific basis of their study (Singer, 1953; Brooks, 1955; Eränkö & Kihlberg, 1955; Powers, 1962). Research into the unreliability of cranial suture closure in estimating age led to many studies being carried out to test the method either on the same population as that of Todd & Lyon (1924) or on other populations (Singer, 1953; Brooks, 1955; Eränkö & Kihlberg, 1955; Powers, 1962). But many other studies were also carried out to prove the unreliability of the closure of cranial sutures as an aging indicator. Singer (1953) examined the skulls of Cape Coloureds, Bantu, White Germans, North American Indians and Eskimos. Working on such a variety of populations he found that estimating age from cranial suture closure was totally unreliable. He thus concluded his publication with: “Evidence is provided that, with techniques available at present, an assessment regarding the precise age at death of any individual, gauged only on the degree of closure of the vault sutures of the skull, is a hazardous and unreliable procedure” (Singer, 1953; p 59).

Like Todd in the 1920’s, Brooks in the 1950’s decided to approach the problem of aging of the skeleton as well. Brooks (1955) worked on the cranial sutures and the pubic symphyses. She basically tested the methods set forth by Todd & Lyon (1924) for the obliteration of the cranial sutures. She had also correlated the ages that were estimated from the cranial sutures with those estimated by using the pubic symphyses. She found that when she tested the methods on skeletons at the Western Reserve University (the same series was used earlier by Todd), there were no correlations between estimations based upon the cranial suture closure and the known age. As for age estimation from the pubic symphysis, she recommended not using this trait alone for age estimation either.

Abbie (1950) studied 206 Australian Aboriginal skulls to investigate the time of closure of the sutures. The outcome of this study was that closure of cranial sutures occurred in certain regions rather than in a single suture. This study included juveniles and adolescents (Abbie, 1950).

"So erratic is the onset and progress of closure that an adequate series will provide just about any pattern at any age level..... suture closure, as either direct or supportive evidence for skeletal age identification, is generally unreliable," (McKern & Stewart, 1957; p 37). This was the conclusion that McKern and Stewart reached in 1957 after they studied the American soldiers from the Korean War. As the ages of the soldiers were known, there was no doubt about the accuracy of the data. This American soldier sample was also that of an elite group of individuals within a specified age group. Due to the great variability in closure of the sutures, the authors once again cautioned against the use of these traits as indicators of age (McKern & Stewart, 1957).

This was the same message that was reported when Eränkö and Kihlberg (1955) and Powers (1962) set out to test the idea of a strong relationship between age and cranial suture closure. Ninety five Finnish crania were assessed on the ectocranial and endocranial aspects in the former study (Eränkö & Kihlberg, 1955). The initial results were not satisfactory, so they carried out further analyses with more complicated statistics but eventually asserted: "Therefore, it may safely be concluded that the estimation of age on the degree of suture closure will in the best case remain a method hardly better than tossing a coin" (Eränkö & Kihlberg, 1955; p 30).

Powers (1962) studied skulls of soldiers from many European countries and found large discrepancies between the known age and the estimated age. Skulls of very young and very old individuals were used (Powers, 1962). Powers (1962) found many young individuals with closed sutures while many individuals around and over the age of 100 years have shown completely open sutures (Dwight, 1890; Powers, 1962). This same trend was evident in Dwight's (1890) sample.

By the 1960's the method of age estimation using cranial sutures was being considered as a very unreliable method. This, however, did not steer many other investigators away from still trying to find a relationship between age and cranial suture closure (Acsádi & Nemeskéri, 1970; Perizonius, 1984; Meindl & Lovejoy, 1985; Sahni et al., 2005; Dorandeu et al., 2008).

A well-known study by Acsádi & Nemeskéri (1970) using the multivariate method to estimate age in a skeleton is still currently being used by practitioners. This study does not differ from the concept that Todd & Lyon (1924) had put forward but gave it a more practical basis in that the authors provided a table to estimate age from the closure of endocranial suture scores. This made it easier for anyone trying to use the method in an archaeological and forensic case where an age range was needed when composing a profile of the skeletal remains.

Following Acsádi & Nemeskéri's (1970) work, other important studies have modified the methods to be of practical use in the field. These include the work of Perizonius (1984) and Meindl & Lovejoy (1985). Perizonius (1984) kept to the original idea of dividing the vault sutures into parts and scoring them but soon realised that for individuals below the age of 50 years and those over the age of 50 years there seemed to be a discrepancy in the rate at which closure occurs. Thus two tables are provided to estimate age when using the method, but the practitioner needed to decide whether the individual is under or over the age of 50. This is circular reasoning as the practitioner was required to estimate the age of an individual before attempting to assess it using the closure of cranial sutures.

Meindl & Lovejoy's (1985) study on the cranial sutures was very different from the traditional studies in that instead of using the entire suture to estimate age, they used only a one centimetre fragment of different areas of the ectocranial sutures. Two systems resulted from their findings, the lateral anterior system and the vault system. This study was the latest to be used in the estimation of age for demographic purposes (Meindl & Lovejoy, 1985).

A more recent study by Nawrocki (1998) that uses a one centimetre section of the suture like that instituted by Meindl & Lovejoy (1985) uses regression formulae to estimate age from the closure of cranial sutures. In this study, however, the endocranial aspect and the palatine sutures were assessed as well. A number of regression equations were derived, and it was concluded that using more areas of the skull probably produces better results than only using the ectocranial aspects (Nawrocki, 1998). Johnson (1976) had similar conclusions from the study carried out on cranial sutures and tooth wear that used discriminant function equations to estimate age. It was shown that a multi-factorial method is more favoured than only using a single skeletal trait for estimating age.

In 1994 Key and colleagues tested the three major methods on a skeletal sample from Christ Church in the Spitalfields, London. This study was carried out on a sample of 183 excavated skulls of known age testing the Acsádi and Nemeskéri (1970), Perizonius (1984) and Meindl and Lovejoy (1985) methods of estimating age from the ectocranial and endocranial aspects of the skull (Key et al., 1994). The results of this study state that the methods that had been widely used on all populations do not always work on some populations. Sexual dimorphism of the closure of cranial sutures was also detected during their study. The final conclusion of the study was that age estimation from the closure of cranial sutures had low accuracy

(Key et al., 1994). The authors, however, constructed a new scoring method based also on certain sites instead of the entire suture. This was in agreement with that of Meindl and Lovejoy who suggested ten sites in two different systems (Meindl & Lovejoy, 1985). The main reason for persisting on using the sutures was that the skull often survives intact more than the rest of the skeleton (Key et al., 1994). The authors also suggested that the main reason for pursuing this pathway was that since the function of sutures is not well known, the aging technique will always be unreliable (Key et al., 1994).

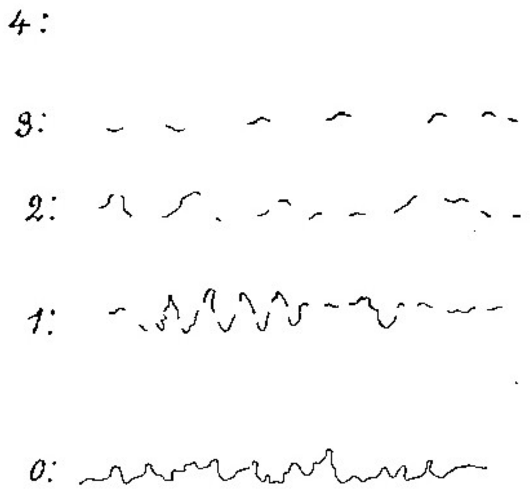
Due to the large volume of literature now building up on the negative results of age estimation from suture closure, further investigative studies started emerging to test the methods that had been proposed. One of the studies was that of Galera and colleagues (1998) who investigated four methods of age estimation using the closure of cranial sutures on 963 skulls from the Terry Collection. The four methods included those of Acsádi and Nemeskéri (1970), Meindl and Lovejoy (1985), Masset (1982) and Baker (1984). After analyses of the data, none of the methods were recommended on their own to estimate age. It was thus concluded that the four methods probably worked best in different age categories. This study also found sexual and population differences when using these methods (Galera et al., 1998).

Unlike basic linear measurements of dry bones currently used in biological and forensic anthropology to determine the profile of unknown skeletal remains, cranial suture patterns do not have a basic pattern that can be measured easily. Thus in 1907, Oppenheim suggested that the shape and the size of the pattern be scored descriptively. A scoring of one to four was suggested for the shape while a score between one and ten was recommended for the size. Thereafter a sutural index was calculated which could vary between 170 and 1130.

Recently however, Hauser and colleagues (1991) suggested a third dimension that should be taken into account. This dimension still relates to shape but the extension of the pattern is now considered. The size of the pattern is scored by observing the complexity of the pattern in a defined area. The scoring is based on the breadth of the pattern. If the looping of the suture is absent, then a score of one is assigned, while if the looping extends more than 10mm a score of six is given. The scores in-between relate to the gradual increase in the looping of the suture (Hauser et al., 1991).

The second criterion suggested to describe the sutures was the basic configuration of the pattern. Once again a score of one suggested that the configuration was simple while a score of five suggested a narrow looped configuration. The configurations were classified as simple, dentate or looped in the wide and narrow categories. The last criterion that was assessed was the secondary protrusion of the pattern. This was scored on whether it is absent, weakly expressed, well expressed or strongly expressed (Hauser et al., 1991).

Another method used to score sutures related to the degree of obliteration of the sutures. This method was introduced by Broca in 1875 as quoted by Frederic (1906) and was later used by Martin (1928). A score of zero indicated that the suture was still open while a score of four indicated that the suture had completely obliterated. The scores of one, two and three were progressive scores towards the complete obliteration of the suture (Figure 3.2). A score of one suggested that less than 25% of the suture had obliterated, while a score of two suggested that around half of the suture had obliterated. A score of three indicated that more than 75% of the suture had obliterated. This scoring system was probably the most widespread of the scoring systems used for assessing sutures (Acsádi & Nemeskéri, 1970).



Figur 2 (nach Broca).
Schema des Verwachungszustands.
0 = nicht verwachsen,
1 = weniger als halb verwachsen,
2 = halb verwachsen,
3 = mehr als halb verwachsen,
4 = ganz verwachsen.
In Figur 2 sind die von Broca ursprünglich gegebenen Zahlen umgekehrt. Broca bezeichnete mit 0 = ganz verwachsen, mit 4 = nicht verwachsen u.s.w.)

Figure 3.2 Scores representing the obliteration status of the sutures as presented by Broca (1875). A score of zero suggests an open suture while a score of four suggests a completely obliterated suture. This figure appeared in Frederic’s (1906) publication.

Meindl and Lovejoy (1985) used the same concept as Martin but introduced a four degree scale with the scores ranging from zero to three, instead of a five degree scale. Once again a score of zero indicated no closure of the suture, one indicated less than 50 % of the suture has closure, while a score of two indicated that most of the suture has obliterated but there were still parts of the suture that could be seen, while a score of three indicated that the entire suture had obliterated (Meindl & Lovejoy, 1985). This scoring was based upon that of Martin (1928) but had the original score of two and three combined, thus instead of a five category scale, it now became a four category scale (Meindl & Lovejoy, 1985).

These methods of scoring a suture, however, are not based on a biological concept like the formation or development of the suture but are artificial and mechanistic for ease of method. Human vault sutures tend to be heterogeneous in their pattern in a single skull and even in a single suture (Beresford, 1993). Thus if the above mentioned scoring systems were applied to the sutures, the sutures need to be divided to represent a certain part. The most logical division of the sutures was suggested by Ribbe (1855). This division of the sutures was further used by Frédéric (1906) but was defined eventually by Oppenheim in 1907. The classical pattern of divisions of the vault sutures has appeared almost in all textbooks and published papers that investigate the relationship of sutures with age. It was however, Meindl and Lovejoy, in 1985, who suggested that we move away from the traditional divisions and just score certain areas of the vault sutures. This was based upon the heterogeneity of a single suture and also the reasoning that some areas on the sutures showed a better relationship with age than other areas.

The vault sutures were most often scored but in some studies other sutures of the skull were also included (Todd & Lyon, 1924; 1925a; 1925b; 1925c; Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1985). The three major vault sutures were generally divided into three or four parts each (Todd & Lyon, 1924; 1925a; 1925b; 1925c; Singer, 1953; Eränkö & Kihlberg, 1955; McKern & Stewart, 1957; Acsádi & Nemeskéri, 1970). The classic divisions recommended by Oppenheim (1907) included three parts for the coronal, four for the sagittal and three for the lambdoid. All divisions were based upon the change in the complexity of the sutures. The coronal and the lambdoid sutures, being sutures found in the coronal plane of the body were initially divided into a left and right side. Thereafter each side was divided into three parts (Oppenheim, 1907).

The coronal suture, from medial to lateral, had the following named parts: *pars bregmatica*, *pars complicata* and *pars pterica* (Singer, 1953; McKern & Stewart, 1957; Perizonius, 1984). The *pars pterica* was initially called the pars temporalis (Martin, 1928) or the *pars stephanica* (Comas, 1960). The *pars bregmatica* was considered simple while the *pars complicata* had a greater complexity than that of the *pars bregmatica*. The *pars complicata* ended at the temporal line, and the *pars pterica* was the most lateral part of the suture (Perizonius, 1984). Eränkö and Kihlberg (1955) however, divided the coronal suture into four parts as did Singer (1953) and McKern and Stewart (1957) (Figure 3.3).

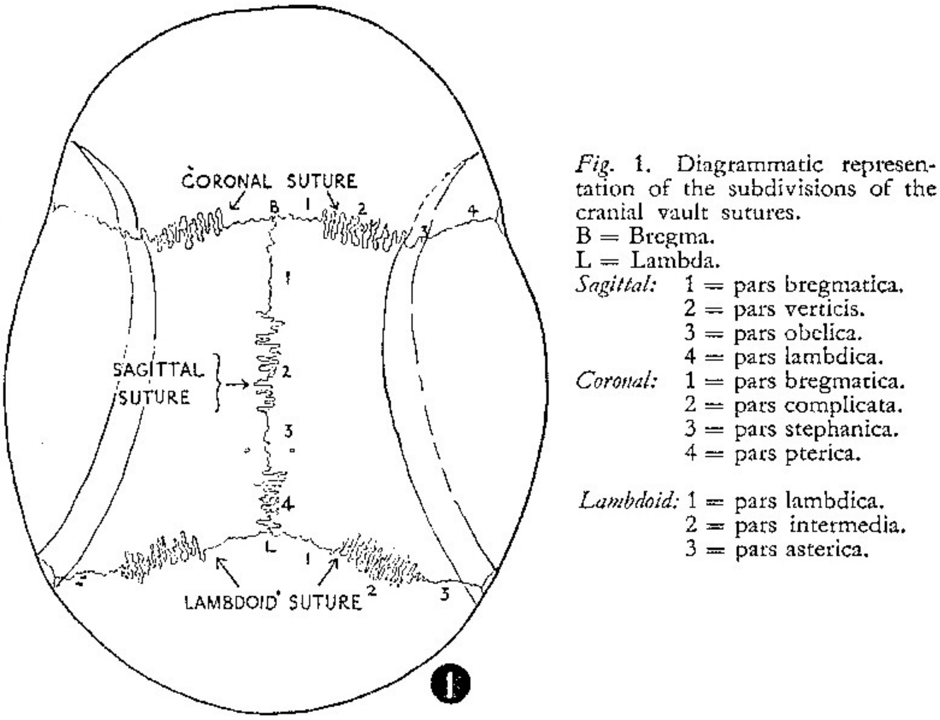


Figure 3.3 Diagram of skull vault sutures indicating the divisions of each of the sutures for scoring the obliteration of the sutures. Note the four divisions of the coronal suture indicated here. This figure appeared in Singer's (1953) publication.

The sagittal suture was divided into four parts extending from anterior to posterior: *pars bregmatica*, *pars vertices*, *pars obelica* and *pars lambdica*. The *pars lambdica* was also called the *pars postica* (Martin, 1928). The pattern of the *pars bregmatica* was similar to that of the *pars bregmatica* of the coronal suture. The *pars vertices* was the highest part of the skull. The *pars obelica*, was considered by many to be one of the parts of the skull sutures that most often obliterated. This section lies between the parietal foramina found in the posterior section of the parietal bones. The section of the sagittal suture closest to the lambdoid suture was the *pars lambdica* (Oppenheim, 1907). The lambdoid suture was divided into three parts on either side of the sagittal suture. The most medial of the parts was the *pars lambdica*, then the *pars intermedia* followed by the *pars asterica* (Oppenheim, 1907). Eränkö and Kihlberg (1955) divided both the left and right lambdoid suture into two parts only.

The scores of each of the sutures are then determined either by averaging out the scores or by totalling all the scores of the sutural parts. These averaged or totalled scores are then related to the age of the individual (Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1985).

It is interesting that the authors advocating the use of cranial sutures obliteration for aging and also those opposing it, despite acknowledging great individual variation in patterns of suture closure, have not offered, nor tested any hypotheses explaining this variation by factors other than age. The fact that from early on the papers opposing the use of cranial sutures obliteration as an age indicator were ineffective in conveying their message, may result from this shortcoming. Stating that a certain factor does not explain observed variation without offering an alternative explanation, can easily be overlooked as just an attempt at trying to improve precision of aging methods. An alternative to the age explanation of the pattern of cranial suture closure is needed.

Previous nay-sayers like Dwight (1890), Singer (1953), Powers (1962), and many others have reiterated that the obliteration of cranial sutures was not a good indicator of age. Thus the current methods need to be tested to either concur with this or to discard this theory.

Chapter Four: Materials and Methods

4.1 Material

Material from the Raymond Arthur Dart Collection of Human skeletons (thereafter referred to as the "Dart Collection"), housed at the University of the Witwatersrand, Johannesburg was used to collect data for the present study.

History of the Raymond Arthur Dart Collection of Human Skeletons

The Dart Collection is located in the basement at the Medical School at the University of the Witwatersrand, Johannesburg, South Africa. This collection is named after Raymond Arthur Dart, who first arrived in Johannesburg, South Africa in 1923 to take up the position as Head of Department of Anatomy (Tobias, 1989). Being a bright and gifted anatomist, and also a great scientist, Dart started many collections at this department. One such collection, being of great interest and value today is the Raymond A Dart Collection of Human Skeletons (Tal and Tau, 1983). Dart visited the United States of America as a Rockefeller Fellow in 1921 (Tobias, 1989) and it was there that he was introduced to human skeletal collections with known sex and age. These two major collections are the Terry Collection found at Washington University and the Hamman-Todd Collection which is housed at Case Western Reserve University (Tobias, 1985). Dart saw the value of collecting skeletons for scientific and research purposes and introduced the same concept in South Africa.

Skeletons that make up the Dart Collection come generally from cadavers used in the teaching of medical and allied health students. These cadavers are collected under the South African Human Tissues Act (Act 65 of 1983) and previously under other Anatomy Acts. Initially these were unclaimed bodies from Transvaal Provincial hospitals but currently most of the bodies are donated to the Anatomy department for science and research as part of the bequeathal program. However, there are still a number of unclaimed bodies that are given to the department (Dayal et al., 2009).

The cadavers are embalmed in the anatomy department and dissected by students who study anatomy. Once the cadavers are completely dissected, they are skeletonised and then added to the Dart Collection. These skeletons make up the major part of the Dart Collection, which is the cadaver-based section of the Dart Collection, while the non-cadaver derived part of the collection is made up of archaeological material and skeletal donations (Dayal et al., 2009). In the present study however, only the cadaver-derived skeletons were used.

Considering the previous history of South Africa under the rule of "Apartheid," which literally means keeping apart; the people of South Africa for many years were kept apart by law thus creating isolated populations. There was probably very little mixture between populations and between tribes. This served as an advantage in using this collection for this study as similarities and differences between populations could be noted but also individual variation within each group could be assessed. Thus the Dart Collection was an ideal collection to use for the present study.

Inventory of the specimens in the Raymond Dart Collection

The Dart Collection consists of approximately 3039 skeletons and there are skeletons still being added to the collection. This includes all the skeletons of the cadavers that were donated to the School, those acquired through archaeological excavation and also includes skeletons that were randomly found by the public and donated to the School. The majority of the skeletons have been acquired through the dissection hall and therefore the collection is mostly cadaver-based (Table 4.1).

TABLE 4.1. Inventory of the specimens in the Raymond Dart Collection of Human Skeletons

Population Group	Cadaver	Ex Situ			Total
		Archaeological	Donated	No Provenance	
South African Blacks	1818	182	120	37	2157
Other African Blacks	168	1	2		171
South African Whites	479		7		486
South African Indians	5			5	10
South African "Coloureds"	118				118
Bushman (San)	2	6	25	7	40
Hottentot	11				11
Other	2		42		44
Unknown	2				2
Total	2605	189	196	49	3039

Information available for these skeletons includes the sex, age, population affinity, date of death, stature or body length and also in some cases the cause of death. Most of this information is recorded from the death certificates or hospital records of the individuals. In the case of paupers the age of the individual was recorded by the attending nurse or doctor by asking the patient their age on admission to hospital. This may have resulted in some unreliable estimates as the spoken language of the medical staff may have differed from that of the patient. It is unlikely, however, that true age would differ substantially from the reported one in such circumstances since patient’s appearance (young or old) would have to agree roughly with the reported age. The recorded age of the skeletons in the Dart collection ranges from 0 to 108 years (Figures 4.1a & b).

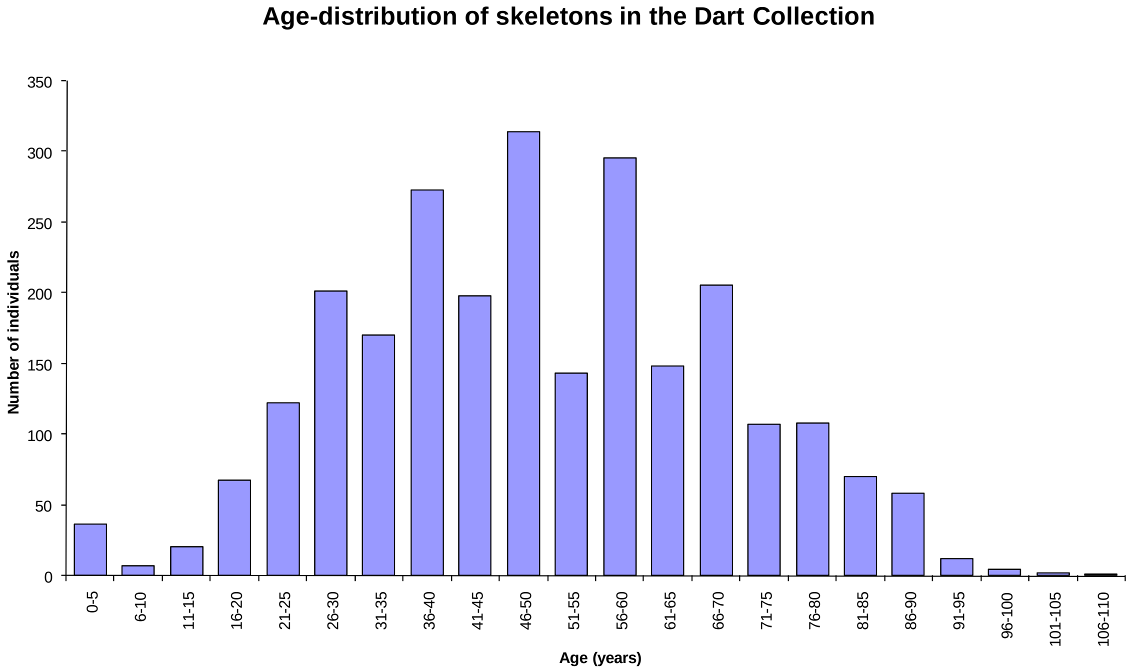


Figure 4.1a. Age distribution of the skeletons in the Dart Collection (five year age intervals).

Stature, on the other hand, is recorded as a recumbent post mortem length measured by the technician in the anatomy department. The population affinity of the individuals is recorded as *Euro* for whites, *Ind* for the Indians, and *Mixed* for the people of mixed origin in South Africa. In the case of the blacks, however, each tribe was initially recorded as the group they belonged to (i.e. their population affinity) but now all blacks are recorded as South African Negro (S.A.N). The tribes that were originally recorded include: Zulu, Sotho, Xhosa, Tswana, Venda, Tsonga, Swazi, Shangaan, Rots, Rolo, Pondo, Pedi, Nyik, Ndebele, Hottentot, Hlube, Fing, Coan, and Baca. The largest group contributing to the collection is that of the S.A.N (70%). The percentage that each of the other populations contributes to the collection is as follows: white 18%, Indians 0.2%, Mixed 4.5%. In the present study the term black is used to collectively refer to the South African Negro population and the term whites is a reference to the European skeletal sample. Only these two population groups are used in the present study.

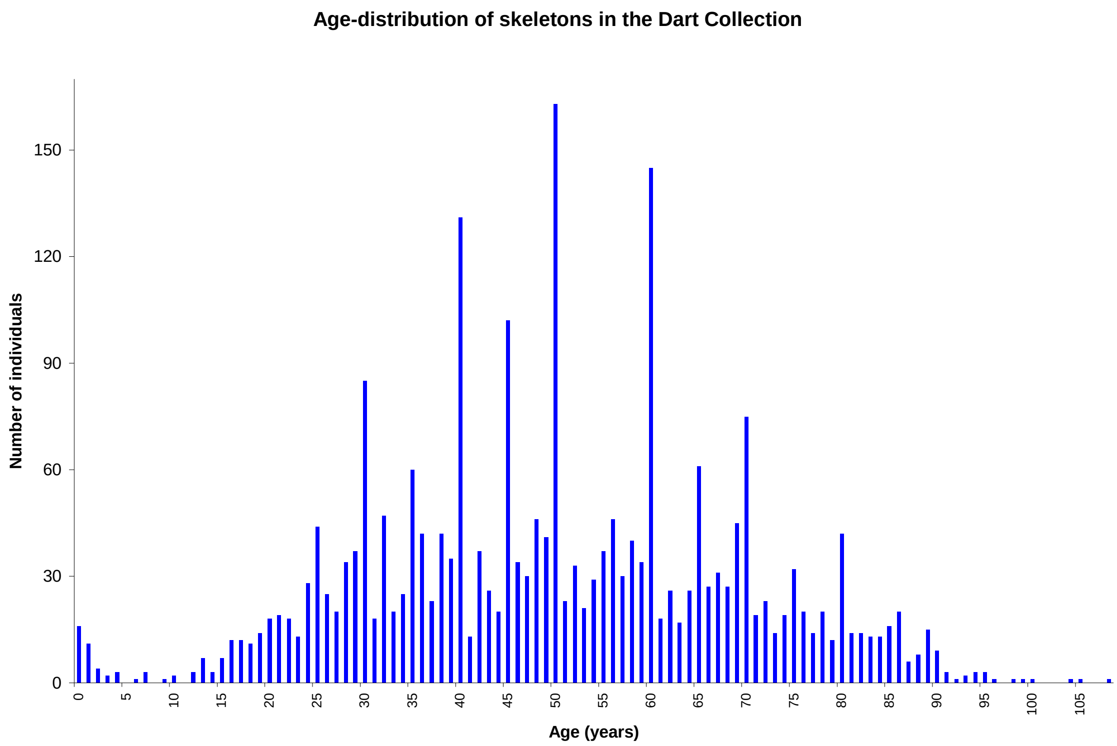


Figure 4.1b. Age distribution of the skeletons in the Dart Collection (one year intervals). Please note obvious peaks at round-age categories. These are a result of age reporting by medical personnel or next-of-kin when no birth certificate or similar record of birth date was available.

Material used in this study

A total of 486 skulls of both sexes of blacks and whites were assessed in this study. In the initial design of the project it was anticipated to assess an equal number of skulls with at least 100 in each group. Random sampling was carried out to achieve the final numbers as follows. Initially the electronic database, that contains all the demographic information, was used to calculate the number of potential skulls that could be used in the study for each group. This was done to eliminate any skulls that were less than 18 years old. A serial number was than assigned to each of the skulls that the sample would be chosen from. A table of random numbers was generated for each of the groups using a standard random table depending on the number of potential skulls available for study. The first 100 random numbers were then matched to the serial numbers of the skulls. These skulls were finally assessed and included 113 black males, 130 black females, 123 white males and 120 white females. The ages of the skulls that were used in this study ranged from 18 to 98 years. All skulls were inspected macroscopically for any visible signs of abnormality or pathology and these were not included in the study. If there were too many skulls eliminated from the random sample initially drawn up, then another random table was generated to achieve an equal number in each group.

4.2 Procedure

Most of the skulls in the Dart Collection are cut circumferentially around the vault to allow for brain to be removed from the cadaver in the interest of brain dissection. Thus many of the skulls that were used in this study had removable calottes which served as an advantage as this allowed for easy access to view and study the endocranial sutures.

Some of the skulls, however, remained intact. This made it slightly more difficult to assess the endocranial sutures. In these cases the endocranial sutures were assessed by placing the skull in bright light and looking through the foramen magnum or by using a flashlight which was shone into the skull onto the endocranial aspect through the foramen magnum. Some skulls, however, were not assessed on the endocranial aspect as these sutures were extremely difficult to identify.

A number of skulls were initially laid out on the bench with the demographic information concealed (Fig 4.2). A separate data sheet for each of the skulls was used to collect data. An example of the data collection sheet can be seen in Appendix A. This was done to allow the study to be carried out as a blind study to avoid any potential biases. The sutures were then scored based upon two established methods (Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1985) of assessing cranial suture obliteration, originally developed for ageing of skeletons.

Figure 4.2. Photograph of the working area in the Raymond Dart Collection illustrating the collection of data as a blind study.

The scores were either assigned to the entire vault suture which was divided into parts (Acsádi & Nemeskéri, 1970); or to only a specific centimetre of the suture (Meindl & Lovejoy, 1985). Both these methods are based on the principle that sutures obliterate with age (Todd & Lyon, 1924). In the present study the following terms:

parts, sections and sites will be used interchangeably to refer to the divisions and sites of the sutures.

Division and naming of parts of the sutures

The vault sutures (where the entire suture was scored) for the Acsádi and Nemeskéri (1970) method were divided as follows: for both the coronal and lambdoid sutures the midline sagittal suture was used to divide the sutures into a left and right side. The sutures were thereafter divided into three parts namely: from medial to lateral: *pars bregmatica* (C1), *pars complicata* (C2) and *pars pterica* (C3) for the coronal suture and *pars lambdica* (L1), *pars intermedia* (L2) and *pars asterica* (L3) for the lambdoid suture. The sagittal suture was divided into four parts, from anterior to posterior: *pars bregmatica* (S1), *pars vertices* (S2), *pars obelica* (S3) and *pars lambdica* (S4). These divisions and names are taken from Oppenheim (1907) and can be found in Martin's *Lehrbuch der Anthropologie* (1928) and other studies (Gottlieb, 1978). An adaptation of Oppenheim's figure can be seen in Figure 4.3. In the present study both the ectocranial and endocranial aspects of the skull were scored.

In the attempt by Meindl and Lovejoy (1985) to improve the method of cranial suture obliteration as an ageing method, the authors decided to only use parts of the suture. In their study only a one centimetre section of each suture was scored. Using this method, only the ectocranial aspect of the skull was assessed. The ten sites included for scoring the sutures involved the coronal, sagittal, lambdoid and squamous sutures. These include: midlambdoid (1), lambda (2), obelion (3), anterior sagittal (4), bregma (5), midcoronal (6), pterion (7), sphenofrontal (8), inferior sphenotemporal (9) and superior sphenotemporal (10) as seen in Fig 4.4.

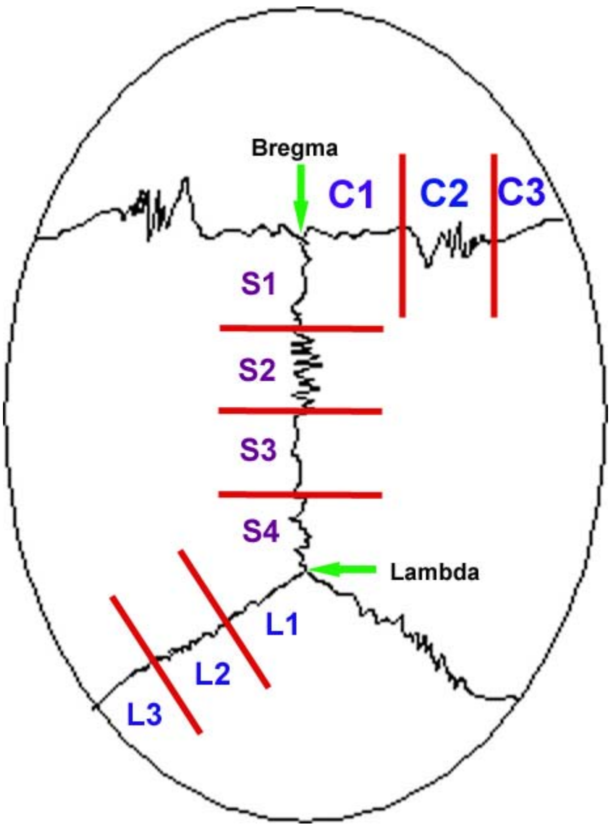


Figure 4.3. An adaptation of the original drawing illustrating the divisions and names of the sections on the ectocranial and endocranial aspects of the skull.

The first seven sites are found on the three major vault sutures, and are considered as part of the vault system. The last three sites are situated on the accessory sutures of the skull making up the lateral anterior system. This system also included the two sites: midcoronal (6) and pterion (7). The numbers at the end of each site in parentheses indicate the numbers given by Meindl and Lovejoy (1985) in their original publication. Figure 4.4 is a reproduction of the original diagram found in the Meindl and Lovejoy (1985) paper.

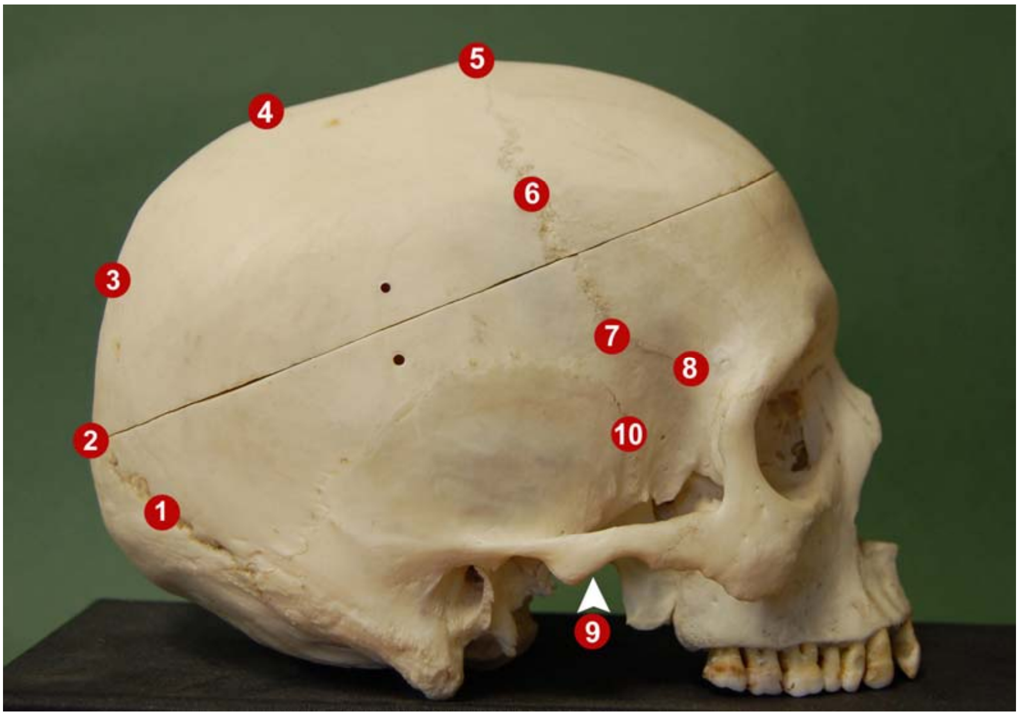


Figure 4.4. Photograph of skull showing the ten sites that were assessed using the Meindl & Lovejoy (1985) method. Numbers: 1 = midlambdoid; 2 = lambda; 3 = obelion; 4 = anterior sagittal; 5 = bregma; 6 = midcoronal; 7 = pterion; 8 = sphenofrontal; 9 = inferior sphenotemporal; and 10 = superior sphenotemporal

Scoring of the sutures

The scoring of each section was carried out using a progressive scale. When the Acsádi and Nemeskéri (1970) method was used, a five-category scale (0-4) introduced in Martin's textbook (1928) was employed. The following definitions of the scores were used: 0 – indicates that the suture is open, 1 – the beginning of closure, 2 – suture in process of closure/obliteration, 3 – suture in advanced state of closure, 4 – completely closed suture. A graphical representation of these scores is shown in Table 4.2.

Meindl and Lovejoy (1985), however, introduced a four category scoring system. This system of scoring when compared to that of Acsádi and Nemeskéri

(1970) basically combines scores two and three, resulting in one score less. The description of each of the scores as illustrated by them is as follows (Meindl & Lovejoy, 1985; p 58):

0 Open; there is no evidence of any ectocranial closure at the site;

1 Minimal closure; some closure has occurred. This score is given for any minimal to moderate closure, i.e., from a single bony bridge across the suture to about 50% synostosis at the site;

2 Significant closure; there is a marked degree of closure but some portion of the site is still not completely fused;

3 Complete obliteration; the site is completely fused.

4.3 Data Analyses

A Microsoft® Office Excel 2003 spreadsheet was used to record the data and also to analyse some of the data. The SPSS® 11.5 program was used to analyse the data using statistical methods not available on the Excel program. The information that was included into the spreadsheet included the accession number of the skeleton, the recorded age of the skeleton as provided by the collection database, the sex of the skeleton as recorded, and the scores as assigned to the cranial sutures using the two different methods. The results for the ectocranial and endocranial aspects of the skull were separated from each other when using the Acsádi and Nemeskéri (1970) method while the results of the left and right sides of the skull were also separated when using the Meindl and Lovejoy (1985) method. In the following sections, the results of the repeatability tests are reported following an explanation of statistical analyses used.

TABLE 4.2. Graphical representation of the suture scores

Score	Suture morphology	Description
0		Suture open
1		Incipient closure, less than half suture length obliterated
2		Closure in process, approximately half suture length obliterated
3		Advanced closure, more than half suture length obliterated
4		Closed suture

Repeatability

Repeated observations were carried out to ensure that the data collected were reliable (Tables 4.3 to 4.11). Initially samples of five skulls of each group (totalling 20 skulls and 320 observations) were used for the repeatability observations to ensure consistency in scores (degrees of obliteration) before actual data were collected. Thereafter further repeatability observations were carried out throughout the study. All scores of the subsample were recorded and the exercise was repeated the following day. Bias was unlikely considering the vast number of observations that were recorded on any given day. All repeatability observations were intra-observer scores. A total of 70 skulls (14%), representing all groups, were eventually used in the repeatability tests. Only 66 of the 70 skulls were accessible for endocranial inspection, even after trying the flashlight method.

The test of repeatability was carried out by counting the number of times the original score was the same as the repeated score, i.e. 0-0, 1-1, 2-2, etc. This is presented in tables (Table 4.3- 4.11) which show the frequencies of the scores that match the original score (numbers shaded in grey) and also the frequencies of the scores when the original score differed from that of the repeated score. These tables also give the number of times the repeated score was either less than or greater than the original score. Scores that differed by more than two degrees were eventually discarded. That part was re-assessed and a final score was recorded. In most cases when these special cases were revisited, the problem was found to be the division of the sutures into its component parts.

The tables are presented with the first row of the table presenting the original score and the second score presented in the first column of the table. The grey shaded areas show the number of cases that were the same for the first and second observation. An example from Table 4.3 shows that when the *pars bregmatica* was scored on the left side, a total of 28 cases were assigned a score of zero for both the first and second observations. Thus, a total of 56 (out of 70) cases had the same score for the first and the second observation.

Tables 4.3 to 4.5 represent the scores given using the Acsádi and Nemeskéri (1970) method on the ectocranial aspect of the skull. Each table represents each of the major vault sutures, coronal, sagittal and lambdoid for both the left and right sides of the skull. The next three tables also represent the scores when using the Acsádi and Nemeskéri (1970) method but these are scores given to the endocranial aspect. Tables 4.9 to 4.11 represent the repeatability scores when using the Meindl and Lovejoy (1985) method. Table 4.9 represents the unilateral sites (bregma, anterior sagittal, obelion and lambda), while the next two tables represent the scores for the bilateral sites.

The results of the repeatability tests when using the Acsádi and Nemeskéri (1970) method show that many of the repeated observations either are the same as the first observation or most of the time are only one score away from the original observation (Table 4.3 to 4.8). On the ectocranial aspect the coronal suture observations (Table 4.3) show that the majority of the observations are in concordance with the original score.

Table 4.3. Frequencies of repeated measures of the coronal suture sectional scores on the ectocranial aspect using the Acsádi & Nemeskéri (1970) method

Ectocranial

Left

	Pars Bregmatica	**First Observation**					
		0	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**28**	2	-	-	-	30
	1	3	**12**	2	-	-	17
	2	-	3	**3**	1	-	7
	3	-	-	1	**6**	2	9
	4	-	-	-	-	**7**	7
	Total	31	17	6	7	9	70

Right

	Pars Bregmatica	**First Observation**					
		0	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**32**	1	-	-	-	33
	1	5	**7**	2	-	-	14
	2	-	2	**5**		-	7
	3	-	-	1	**6**		7
	4	-	-	-	1	**8**	9
	Total	37	10	8	7	8	70

Left

	Pars Complicata	**First Observation**					
		0	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**34**	2	-	-	-	36
	1	1	**8**	1	-	-	10
	2	-	3	**5**	3	-	11
	3	-	-	2	**5**	3	10
	4	-	-	-	1	**2**	3
	Total	35	13	8	9	5	70

Right

	Pars Complicata	**First Observation**					
		0	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**36**	2	-	-	-	38
	1	2	**2**	-	-	-	4
	2	2	3	**4**	4	-	13
	3	-	-	3	**6**	1	10
	4	-	-	1	-	**4**	5
	Total	40	7	8	10	5	70

Left

	Pars Pterica	**First Observation**					
		0	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**4**	1	-	-	-	5
	1	2	**13**	2	-	-	17
	2	-	2	**3**	1	2	8
	3	-	2	1	**3**	5	11
	4	-	-	-	1	**28**	29
	Total	6	18	6	5	35	70

Right

	Pars Pterica	**First Observation**					
		0	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**6**	1	-	-	-	7
	1	1	**9**	1	-	1	12
	2	-	1	**4**	1	1	7
	3	-	3	2	**2**	3	10
	4	-	-	-	3	**31**	34
	Total	7	14	7	6	36	70

Table 4.4. Frequencies of repeated measures of the sagittal suture sectional scores on the ectocranial aspect using the Acsádi & Nemeskéri (1970) method

Ectocranial

Pars Bregmatica		**First Observation 0**	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**27**	4	-	-	-	31
	1	3	**10**	1	-	-	14
	2	-	1	**4**	1	-	6
	3	-	-	2	**6**	-	8
	4	-	-	-	1	**10**	11
	Total	30	15	7	8	10	70

Pars Vertices		**First Observation 0**	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**17**	1	1	-	-	19
	1	3	**6**	2	1	-	12
	2	1	-	**6**	2	-	9
	3	-	-	1	**8**	7	16
	4	-	-	-	3	**11**	14
	Total	21	7	10	14	18	70

Pars Obelica		**First Observation 0**	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**14**	2	-	-	-	16
	1	1	**5**	2	-	-	8
	2	-	2	**4**	3	-	9
	3	-	-	4	**9**	8	21
	4	-	-	-	3	**13**	16
	Total	15	9	10	15	21	70

Pars Lambdica		**First Observation 0**	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**16**	-	-	-	-	16
	1	5	**10**	2	-	-	17
	2	-	2	**3**	2	-	7
	3	-	-	-	**10**	6	16
	4	-	-	-	2	**12**	14
	Total	21	12	5	14	18	70

Table 4.5. Frequencies of repeated measures of the lambdoid suture sectional scores on the ectocranial aspect using the Acsádi & Nemeskéri (1970) method

Ectocranial

Left

	Pars Lambdica	**First Observation 0**	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**24**	2	-	-	-	26
	1	2	**8**	-	-	-	10
	2	-	-	**6**	2	-	8
	3	-	-	4	**7**	2	13
	4	-	-	-	3	**10**	13
	Total	26	10	10	12	12	70

	Pars Intermedia	**First Observation 0**	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**30**	3	1	-	-	34
	1	1	**6**	2	-	-	9
	2	-	-	**2**	1	-	3
	3	-	-	2	**9**	1	12
	4	-	-	-	-	**12**	12
	Total	31	9	7	10	13	70

	Pars Asterica	**First Observation 0**	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**40**	2	1	-	-	43
	1	1	**9**	2	-	-	12
	2	-	4	**4**	-	-	8
	3	-	1	1	**1**	-	3
	4	-	-	-	-	**4**	4
	Total	41	16	8	1	4	70

Right

	Pars Lambdica	**First Observation 0**	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**23**	3	-	-	-	26
	1	2	**8**	-	-	-	10
	2	-	-	**7**	3	-	10
	3	-	-	3	**9**	1	13
	4	-	-	-	-	**11**	11
	Total	25	11	10	12	12	70

	Pars Intermedia	**First Observation 0**	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**25**	3	1	-	-	29
	1	6	**9**	2	-	-	17
	2	-	1	**2**	-	1	4
	3	-	-	1	**10**	1	12
	4	-	-	-	-	**8**	8
	Total	31	13	6	10	10	70

	Pars Asterica	**First Observation 0**	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**37**	2	-	-	-	39
	1	5	**4**	5	-	-	14
	2	-	3	**5**	-	1	9
	3	-	1	3	**-**	-	4
	4	-	-	-	-	**4**	4
	Total	42	10	13	0	5	70

Table 4.6. Frequencies of repeated measures of the coronal suture sectional scores on the endocranial aspect using the Acsádi & Nemeskéri (1970) method

Endocranial

Left

Pars Bregmatica		First Observation 0	1	2	3	4	Total
Second observation	0	**9**	-	-	-	-	9
	1	-	**6**	-	-	-	6
	2	-	1	**1**	-	-	2
	3	-	-	-	**1**	1	2
	4	-	-	-	-	**47**	47
	Total	9	7	1	1	48	66

Right

Pars Bregmatica		First Observation 0	1	2	3	4	Total
Second observation	0	**9**	1	-	-	-	10
	1	-	**5**	-	-	-	5
	2	-	1	**1**	2	-	4
	3	-	-	-	**-**	-	0
	4	-	-	-	-	**47**	47
	Total	9	7	1	2	47	66

Left

Pars Complicata		First Observation 0	1	2	3	4	Total
Second observation	0	**8**	-	-	-	-	8
	1	-	**2**	-	-	-	2
	2	-	-	**1**	1	-	2
	3	-	-	-	**-**	2	2
	4	-	-	-	1	**51**	52
	Total	8	2	1	2	53	66

Right

Pars Complicata		First Observation 0	1	2	3	4	Total
Second observation	0	**9**	-	-	-	-	9
	1	-	**1**	1	-	-	2
	2	-	-	**-**	1	1	2
	3	-	-	-	**1**	2	3
	4	-	-	-	-	**50**	50
	Total	9	1	1	2	53	66

Left

Pars Pterica		First Observation 0	1	2	3	4	Total
Second observation	0	**10**	-	-	-	-	10
	1	-	**4**	-	-	-	4
	2	-	1	**-**	-	-	1
	3	-	-	-	**2**	1	3
	4	-	-	-	-	**48**	48
	Total	10	5	0	2	49	66

Right

Pars Pterica		First Observation 0	1	2	3	4	Total
Second observation	0	**9**	-	-	-	-	9
	1	-	**4**	-	-	-	4
	2	1	-	**-**	-	1	2
	3	-	-	-	**2**	1	3
	4	-	-	-	1	**47**	48
	Total	10	4	0	3	49	66

Table 4.7. Frequencies of repeated measures of the sagittal suture sectional scores on the endocranial aspect using the Acsádi & Nemeskéri (1970) method

Endocranial

Pars Bregmatica		**First Observation**					
		0	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**11**	1	-	-	-	12
	1	-	**3**	1	-	-	4
	2	-	1	**-**	1	1	3
	3	-	-	-	**1**	2	3
	4	-	-	-	1	**43**	44
	Total	11	5	1	3	46	66

Pars Vertices		**First Observation**					
		0	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**10**	-	-	-	-	10
	1	1	**3**	1	-	-	5
	2	-	1	**5**	-	3	9
	3	-	-	-	**4**	-	4
	4	-	-	-	1	**37**	38
	Total	11	4	6	5	40	66

Pars Obelica		**First Observation**					
		0	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**11**	1	-	-	1	13
	1	1	**5**	1	-	1	8
	2	1	1	**2**	1	1	6
	3	-	-	1	**1**	3	5
	4	-	-	-	1	**33**	34
	Total	13	7	4	3	39	66

Pars Lambdica		**First Observation**					
		0	**1**	**2**	**3**	**4**	**Total**
Second observation	**0**	**9**	-	-	-	-	9
	1	-	**5**	2	-	-	7
	2	-	-	**4**	-	1	5
	3	-	-	-	**1**	-	1
	4	-	-	-	1	**43**	44
	Total	9	5	6	2	44	66

Table 4.8. Frequencies of repeated measures of the lambdoid suture sectional scores on the endocranial aspect using the Acsádi & Nemeskéri (1970) method

Endocranial

Left

Pars Lambdica		First Observation 0	1	2	3	4	Total
Second observation	**0**	**12**	-	1	-	-	13
	1	-	**6**	2	-	-	8
	2	-	1	**7**	1	-	9
	3	-	-	2	**3**	3	8
	4	-	1	-	3	**24**	28
	Total	12	8	12	7	27	66

Pars Intermedia		First Observation 0	1	2	3	4	Total
Second observation	**0**	**13**	-	-	-	-	13
	1	-	**3**	1	-	1	5
	2	-	1	**-**	-	1	2
	3	-	-	-	**-**	1	1
	4	-	-	-	-	**45**	45
	Total	13	4	1	0	48	66

Pars Asterica		First Observation 0	1	2	3	4	Total
Second observation	**0**	**16**	1	1	-	1	19
	1	-	**3**	-	1	-	4
	2	-	-	**1**	-	-	1
	3	-	-	-	**1**	2	3
	4	-	-	-	-	**39**	39
	Total	16	4	2	2	42	66

Right

Pars Lambdica		First Observation 0	1	2	3	4	Total
Second observation	**0**	**12**	-	-	-	-	12
	1	-	**6**	3	-	-	9
	2	-	1	**5**	3	-	9
	3	-	-	1	**3**	3	7
	4	-	1	1	4	**23**	29
	Total	12	8	10	10	26	66

Pars Intermedia		First Observation 0	1	2	3	4	Total
Second observation	**0**	**12**	-	-	-	-	12
	1	-	**3**	1	1	-	5
	2	-	-	**-**	1	-	1
	3	-	-	-	**-**	-	0
	4	-	1	-	1	**46**	48
	Total	12	4	1	3	46	66

Pars Asterica		First Observation 0	1	2	3	4	Total
Second observation	**0**	**14**	2	-	-	-	16
	1	-	**4**	1	1	-	6
	2	-	-	**1**	-	-	1
	3	-	-	-	**-**	2	2
	4	-	1	-	-	**40**	41
	Total	14	7	2	1	42	66

There are only 12 (2.85%) observations from a total of 420 on the entire suture (both left and right) that are more than one score different from the first observation. The *pars bregmatica* and the *pars complicata* have greater frequencies in the lower scores while the *pars pterica* has scores in the higher range. There is no discrepancy between the left and right sides of the coronal sutures with the frequencies being very similar to each other.

The sagittal suture, however, had only two observations that were more than one score away from the original score (Table 4.4, *pars vertices*). Except for the *pars bregmatica*, the other three parts of the sagittal sutures had a fair spread of the scores. Interesting to note that the *pars vertices, pars obelica* and the *pars lambdica* had a greater number of scores that were first observed as four and the repeated observation was three. The lambdoid suture observations were also highly repeatable with only seven observations recorded being more than one score away from the original score (Table 4.5).

On the endocranial aspect there were 18 observations that differed from the original for the coronal suture and three observations that were more than one score from the original (Table 4.6). The *pars obelica* on the sagittal suture seemed to have a few observations that were three scores different (Table 4.7). The lambdoid suture (Table 4.8), however, had many (41) observations that were very different from the original scores.

When the Meindl and Lovejoy's (1985) scoring system was used (Tables 4.9 to 4.11), with only four scores to assign to the suture and a one centimetre section of the suture scored, the results were similar to those using the Acsádi and Nemeskéri (1970) scaling method. The midline sutures once again were highly repeatable with only two observations that are more than one score different from the original observation (Table 4.9). There were, however, almost as many observations that were one score different from the original. Other sites on the coronal and lambdoid sutures (Table 4.10) had 11 (out of 420) that were more than one observation from the original but the majority (311) of the sites were highly repeatable. The sites on the accessory sutures (spheno-frontal, inferior and superior spheno-temporal) (Table 4.11) showed a similar degree of repeatability as all the other sites. A large number (10) of the original observations which were scored as a zero were then recorded as one in the superior spheno-temporal site on the right side (Table 4.11).

The summary of the repeatability tests (Table 4.12) showed that the endocranial aspect was the most repeatable which had 94.7%, 87.5% and 86.4% accuracy in the coronal, sagittal and lambdoid sutures respectively. The ectocranial sutures, however, when using both the Acsádi and Nemeskéri (1970), and Meindl and Lovejoy (1985) methods displayed values that were not greater than 79.6% for the first and second observation being the same. For observations that were one score away between the original and the repeated, the ectocranial aspects were once again similar. The endocranial aspect of the skull showed the greatest percentage of cases that were more than one score from the original. The coronal suture fared the best among all the sutures on the endocranial aspect with the largest number of cases that fell into the exact category than the one score away category and finally the lowest percentage for more than one score.

Table 4.9. Frequencies of repeated measures of the midline sectional scores on the ectocranial aspect using the Meindl & Lovejoy (1985) method

Bregma		First Observation 0	1	2	3	Total
Second observation	**0**	**34**	5	-	-	39
	1	2	**11**	3	-	16
	2	-	1	**5**	1	7
	3	-	-	1	**7**	8
	Total	36	17	9	8	70

Anterior Sagittal		First Observation 0	1	2	3	Total
Second observation	**0**	**22**	3	-	-	25
	1	3	**7**	4	-	14
	2	2	2	**7**	3	14
	3	-	-	2	**15**	17
	Total	27	12	13	18	70

Obelion		First Observation 0	1	2	3	Total
Second observation	**0**	**12**	2	-	-	14
	1	1	**6**	2	-	9
	2	-	6	**15**	5	26
	3	-	-	4	**17**	21
	Total	13	14	21	22	70

Lamba		First Observation 0	1	2	3	Total
Second observation	**0**	**23**	6	-	-	29
	1	4	**7**	-	-	11
	2	-	2	**9**	4	15
	3	-	-	2	**13**	15
	Total	27	15	11	17	70

Table 4.10. Frequencies of repeated measures of the midcoronal, pterion and midlambdoid sectional scores on the ectocranial aspect using the Meindl & Lovejoy (1985) method

Left

		First Observation				
Midcoronal		**0**	**1**	**2**	**3**	**Total**
Second observation	**0**	**37**	2	1	-	40
	1	7	**5**	3	-	15
	2	1	3	**5**	2	11
	3	-	-	2	**2**	4
	Total	45	10	11	4	70

		First Observation				
Pterion		**0**	**1**	**2**	**3**	**Total**
Second observation	**0**	**5**	3	-	-	8
	1	4	**7**	1	1	13
	2	-	4	**7**	4	15
	3	-	1	5	**28**	34
	Total	9	15	13	33	70

		First Observation				
Midlambdoid		**0**	**1**	**2**	**3**	**Total**
Second observation	**0**	**30**	6	-	-	36
	1	1	**5**	2	-	8
	2	-	1	**6**	1	8
	3	-	1	1	**16**	18
	Total	31	13	9	17	70

Right

		First Observation				
Midcoronal		**0**	**1**	**2**	**3**	**Total**
Second observation	**0**	**37**	1	1	-	39
	1	8	**4**	1	-	13
	2	-	2	**8**	2	12
	3	2	-	1	**3**	6
	Total	47	7	11	5	70

		First Observation				
Pterion		**0**	**1**	**2**	**3**	**Total**
Second observation	**0**	**6**	2	1	-	9
	1	3	**6**	2	-	11
	2	-	4	**6**	5	15
	3	-	-	4	**31**	35
	Total	9	12	13	36	70

		First Observation				
Midlambdoid		**0**	**1**	**2**	**3**	**Total**
Second observation	**0**	**31**	3	1	-	35
	1	1	**9**	1	-	11
	2	1	2	**5**	2	10
	3	-	-	2	**12**	14
	Total	33	14	9	14	70

Table 4.11. Frequencies of repeated measures of the spheno-frontal, superior and inferior spheno-temporal sectional scores on the ectocranial aspect using the Meindl & Lovejoy (1985) method

Left

	Spheno-frontal	First Observation 0	1	2	3	Total
Second observation	**0**	**3**	6	-	-	9
	1	2	**11**	5	2	20
	2	-	5	**7**	2	14
	3	-	1	-	**26**	27
	Total	5	23	12	30	70

	Inferior Spheno-temporal	First Observation 0	1	2	3	Total
Second observation	**0**	**38**	4	-	-	42
	1	7	**6**	-	-	13
	2	-	1	**2**	-	3
	3	1	1	-	**10**	12
	Total	46	12	2	10	70

	Superior Spheno-temporal	First Observation 0	1	2	3	Total
Second observation	**0**	**46**	2	1	-	49
	1	5	**4**	-	1	10
	2	-	4	**1**	1	6
	3	-	-	-	**5**	5
	Total	51	10	2	7	70

Right

	Spheno-frontal	First Observation 0	1	2	3	Total
Second observation	**0**	**3**	2	1	-	6
	1	4	**10**	4	-	18
	2	-	2	**8**	5	15
	3	-	1	1	**29**	31
	Total	7	15	14	34	70

	Inferior Spheno-temporal	First Observation 0	1	2	3	Total
Second observation	**0**	**37**	3	1	-	41
	1	4	**8**	2	1	15
	2	-	-	**1**	-	1
	3	-	-	1	**12**	13
	Total	41	11	5	13	70

	Superior Spheno-temporal	First Observation 0	1	2	3	Total
Second observation	**0**	**40**	5	-	-	45
	1	10	**4**	-	-	14
	2	1	2	**-**	-	3
	3	-	-	-	**8**	8
	Total	51	11	0	8	70

TABLE 4.12. Summary results of the repeatability tests (in percentage)

		Exact	± 1	± 2/3
Ectocranial	Coronal	76.9	20.2	2.9
	Sagittal	71.8	27.1	1.1
	Lambdoid	79.5	18.8	1.7
Endocranial	Coronal	94.7	4.5	0.8
	Sagittal	87.5	9.1	3.4
	Lambdoid	86.4	10.3	3.3
Ectocranial	Midline	75.0	24.3	0.7
	Peripheral	74.1	23.3	2.6
	Circummeatal	75.9	21.2	2.9

Method of analysis and interpretation

Once it was established that the method was repeatable, the following statistics and analyses were carried out. The mean, median, standard deviation, range, 5th and 95th percentiles for the recorded age (Table 5.1) were calculated, while the mean, standard deviation and sample size for the individual sutural scores were calculated (Tables 5.2 to 5.4). The left and right sides of the scores were separated and are presented separately. The individual scores were kept separate for the four groups to assess the sexual and population differences.

The tables are presented with the scores that were obtained using the Acsádi and Nemeskéri (1970) method first followed by the Meindl and Lovejoy (1985) method. The ectocranial aspects are displayed before the endocranial aspects when the Acsádi and Nemeskéri (1970) method was used. The scores for the coronal suture were separated from those of the sagittal and the lambdoid but they appear on the same table for the Acsádi and Nemeskéri (1970) method. In the case of the Meindl and Lovejoy (1985) method all sites that related to the coronal, the sagittal and lambdoid sutures were each grouped separately. The sites on the accessory sutures were added to the bottom of the table. This was done so that an easy comparison could also be made across the two methods. A paired student's T-test was used to evaluate the differences.

Thereafter the frequencies (Figures 5.1 to 5.9) of the individual scores were calculated and represented on a graph as a percentage. Each graph represents a part of or site of the suture again separating the left and right sides. The graphs are presented in the same way as the descriptive statistics with the frequencies of the coronal suture parts first using the Acsádi and Nemeskéri (1970) method and then the other parts following with the ectocranial aspects displayed first and then the endocranial aspects. The graphs represent the percentage of individuals that displayed a score between zero and four for each of the sections of the suture on both the left and right sides when the Acsádi and Nemeskéri (1970) scoring method was used, while the scores for the Meindl and Lovejoy (1985) only ranged from zero to three.

Following this procedure, the distributions of the total scores (Figures 5.10 to 5.15) were calculated to ascertain whether the samples were normally distributed. The maximum total for the Acsádi and Nemeskéri (1970) scoring method for the sixteen parts equals 64 while that of the Meindl and Lovejoy (1985) method for the ten sites equals 30. Initially the frequencies were calculated for the entire sample and thereafter the sample was divided into three age groups based on recorded age. The first age group included all individuals less than and equal to 39 years, the second group included all individuals with a recorded age between 40 and 69 years, while the last group included all individuals older than and equal to 70 years. This manner of dividing the groups would give an indication of the effect of age, if any, when considering the total score distributions. The groups were divided according to this pattern as many of the age determination tables using other skeletal indicators consider the ageing process to be the same after the age of 70 years. As many victims of crime are not always less than 70 years, in this study the obliteration status of the sutures was investigated in individuals older than 70 years as well. The 18-60 group was then further divided into an 18-39 year group and a 40-69 group to track any age changes that might occur in these groups. A Kolmogorov-Smirnov one sample test was then carried out to determine if the recorded age data adhered to a normal distribution (Table 5.5) by assessing the degree to which the observed pattern of categorical age frequencies differed from the pattern that would be expected on the null hypothesis in each of the groups and also between groups.

The patterns of variation of the obliteration scores were then explored to investigate the polymorphic nature of suture closure. This was done by initially investigating the suture closure scores without reference to age. Thereafter the patterns of the obliteration scores were grouped according to the ages of the individuals. This was achieved by sorting the data according to the obliteration pattern scores in the coronal, sagittal and lambdoid sutures. Within each of these categories the scores of each of sutures (coronal, sagittal & lambdoid) were then sorted according to the closure of the different sites. Due to the high number of variations that were possible regarding the number of permutations that would be expected, the data were then subjected to only three categories describing the suture to be open, closed or not closed. This resulted in 27 different patterns. These patterns, however, averaged the scores so that most of the cases were reported as the middle pattern, while the other cases were reported at the extreme ends of the scores either being zero or the total score.

The original obliteration patterns were then compared between males and females and also between the population groups. There were no consistent patterns with age or without age between any of the groups. There were a great number of patterns that needed documentation with almost every specimen showing a different pattern. These patterns were not pursued further as there was no cumulative results to show obliteration patterning in groups. Thus frequency distributions were then used to illustrate the polymorphic nature of the obliteration patterns and comparisons of the frequencies between sex/population groups were carried out to suggest that there may be epigenetic differences.

Scatter plots (Figures 5.16 to 5.23) were then constructed to investigate whether there was any relationship between the total obliteration score and the recorded age using both the Acsádi and Nemeskéri (1970) and the Meindl and Lovejoy (1985) method. This was achieved by correlating the total score of the individual to the recorded age of the individual. Initially the entire sample was used to investigate the relationship between the total scores and the recorded ages but thereafter the sample was divided into the sex/population groups to investigate whether there were any other differences that were probably related to the different groups. The relationship between each of the scores and the recorded age were further investigated by calculating the Spearman’s rank correlation coefficient for each of the suture sites (Tables 5.6 to 5.8). In this analysis the correlations for the entire sample were calculated thereafter the sample was separated into males and females.

The correlation of the scores between the left and right sides of the skull were then compared to assess the fluctuating asymmetry of the sample (Figures 5.24 to 5.32). In the case of the Acsádi and Nemeskéri (1970) method the coronal and lambdoid sutures were compared while for the Meindl and Lovejoy (1985) method the bilateral sites (mid-coronal, pterion, mid-lambdoid, spheno-frontal, inferior and superior spheno-temporal) were compared. Initially the correlations were calculated for the entire sample, thereafter the correlation between the left and right sides were calculated for each age grouping when the score frequencies were carried out. The fluctuating asymmetry (Table 5.9) was calculated by using Van Valen's formula: $(1-r^2)$, where r is the correlation coefficient between the two sides.

The Acsádi and Nemeskéri (1970) method and the Meindl and Lovejoy (1985) method were developed to determine the age of a specimen. Both these methods are based upon the hypothesis that there is a linear relationship between age and the obliteration status of the sutures. To use this hypothesis to estimate age the mean or total obliteration scores were used. Both these methods present a table that can be used to read off values after scoring the sutures.

The Acsádi and Nemeskéri (1970) method calculated the mean scores of the parts of the major sutures to estimate age. Five stages representing an increase in the mean scores were given. For each stage a range of the mean scores was given with the corresponding mean age of that group. The standard deviations of the mean ages were also given with the number of individuals in each stage. Finally a range of the actual ages for each stage are presented. In the original study only the scores for the endocranial aspects were published as they found that the obliteration status of the ectocranial aspects was too erratic for age estimation (Acsádi & Nemeskéri, 1970). When a mean score was calculated then the age of the individual could be estimated by taking the age range of the stage. Key et al. (1994) also used the same table to draw up corresponding values found in their study. In the present study, a comparison was made with the Acsádi and Nemeskéri (1970) and Key et al. (1994) studies by constructing the same table (Table 5.9) and adding in the corresponding values obtained from the data collected in this study. In addition the values for the ectocranial aspects were added to examine the differences.

When the Meindl and Lovejoy (1985) method was used to estimate age, two systems (lateral anterior and vault) were used. These systems used a number of the ten sites that were used for scoring the sutures. The vault system included the mid-coronal, pterion, bregma, anterior sagittal, obelion, lambda and mid-lambdoid sites. The lateral anterior system included the mid-coronal, pterion, spheno-frontal, inferior spheno-temporal and superior spheno-temporal sites. In this method the composite or total score for each system was used to estimate age.

Seven stages of obliteration were presented including the range of the composite scores, the mean age of each stage, the standard deviation of the age, the sample size for that stage and the age range for the lateral anterior (Table 5.10) and the vault (Table 5.12) system. Key et al. (1994) once again compared their results by drawing up the same table with their corresponding values. In the present study the left and right sides of the skull were kept separated, but for the purposes of this table, averages between the sides were calculated to compare the results of the Meindl and Lovejoy (1985) and the Key et al. (1994) studies. The findings for the left and right sides were added to a separate table (Table 5.11, 5.13).

Finally both methods, Acsádi and Nemeskéri (1970) and Meindl and Lovejoy (1985) were tested to assess the accuracy of the age estimation methods on a different population using the data from the present study. The estimated ages were calculated for each of the individuals from the scores obtained from the present study. These estimates were then compared to the recorded age of the individual as recorded on the database using scatter plots (Figures 5.33 to 5.38). Both the ectocranial and endocranial aspects were used for the Acsádi and Nemeskéri (1970) methods and treated separately, while both the left and right side skull scores were used for the Meindl and Lovejoy (1985) method.

Using the Acsádi and Nemeskéri (1970) method for estimating age, the mean score of the ectocranial and endocranial aspects were calculated. All individuals that had scores of less than 0.4 as a mean were excluded from the sample as the table only provided for individuals with mean scores of 0.4 or higher (Table 5.9 as adapted from Acsádi & Nemeskéri, 1970). The estimated mean age was then read off from the table and scattergrams were drawn to illustrate how the estimated mean age correlated to the recorded age.

The estimated minimum and maximum age estimates were determined from the same table and the recorded age was compared to the maximum and minimum estimated age. If the recorded age of the individual fell below the minimum estimated age, the method over-estimated the age of the individual. If the recorded age fell between the minimum and maximum estimated age, it was correctly estimated, while if the recorded age was above the maximum estimated age, it was under-estimated. As the age ranges for each of the scores were very large, most of the individuals were expected to fall into the correctly estimated category. This assumed, however, that the cranial sutures obliterated with age. Histograms were then drawn to illustrate the number of individuals that fell into the three categories (Figures 5.39 to 5.52).

When the Meindl and Lovejoy (1985) method was used to estimate age, the composite scores for the lateral anterior and vault systems were calculated. All individuals with total scores of zero for both the systems were removed, while all individuals with a total score for the vault system of 21 and for the lateral anterior system of 15 were also excluded from the sample as the table provided by Meindl and Lovejoy (1985) does not include some minimum and maximum estimated ages. As with the Acsádi and Nemeskéri (1970) method, the estimated mean age was then read off from the table and scatter plots were drawn to illustrate how the estimated mean age correlated to the recorded age. Thereafter the estimated minimum and maximum estimated ages were read off the same tables. The same procedure was then followed to test whether the method had under-estimated, correctly estimated or over-estimated the recorded age. Histograms were also drawn for these procedures.

Chapter Five: Results and Discussion

This chapter is organised into sections. The descriptive statistics for the recorded age and the sutural sites are displayed initially followed by the frequencies of the individual scores for the ectocranial and endocranial aspects using both the Acsádi and Nemeskéri (1970) and Meindl and Lovejoy (1985) methods. The score distributions are then displayed in the form of histograms. The relationship between the obliteration scores and recorded age is then investigated. The correlation between the left and right sides of the skull is then studied to assess the fluctuating asymmetry in this sample. Lastly tables are presented, using the data from the present study, to match those that were previously shown by Acsádi and Nemeskéri (1970), and Meindl and Lovejoy (1985) to illustrate the similarities and differences using the same methods. Finally, the differences between the estimated and recorded ages are graphed to assess the applicability of the previous methods.

5.1 Descriptive statistics

Recorded age

The mean ages in different groups ranged from 43.74 years (black females) to 71.71 years (white females) (Table 5.1). The standard deviations of the recorded ages were greater in the blacks than in the whites. The 5th percentile values were fairly different for the groups while the 95th percentile was similar in all the groups. All differences in mean age were significant at $p \leq 0.05$ when the t-test was used.

TABLE 5.1. Descriptive statistics of Recorded Age (in years)

	n	***Mean***	***Median***	***Std Dev***	***Range***	***5th Percentile***	***95th Percentile***
Black Males	113	54.99	56	17.64	18-98	22	88
Black Females	130	43.74	40	16.58	19-87	20	71
White Males	123	68.07	70	13.78	28-95	40	88
White Females	120	71.71	75	13.15	19-95	50	89

Only adult skulls were used in this study to eliminate the effect of growth and development in the skull. Skeletons with recorded ages less than 18 years normally show unfused epiphyses which indicates incomplete growth (Krogman & İşcan, 1986). The age range of the present study parallels most other studies (Acsádi & Nemeskéri, 1970; Perizonius, 1984; Meindl & Lovejoy, 1985; Hershkovitz et al. 1997; Galera et al., 1998; Dorandeu et al., 2008), while the sample size was comparable to many studies that considered cranial sutures (Singer, 1953; Meindl & Lovejoy, 1985; Dorandeu et al., 2008).

The lowest sample size was that of the black males, despite being the largest represented group in the collection. As was mentioned before, in the initial design of the study an equal number of skulls was anticipated for the project but during the data collection stage too many skulls from the black male group did not meet the inclusion criteria. Thus any sample size greater than 100 was accepted as initially projected.

The 5^{th} percentiles for the groups vary with black males and females having a 5^{th} percentile in the second decade of life while the white females had the oldest 5^{th} percentile of 50 years. This difference may have an effect on the obliteration patterning.

TABLE 5.1a. Number of individuals found in each decade according to sex and population affinity

Age	*Black Males*	*Black Females*	*White Males*	*White Females*	*Total*
18-19	1	3	0	1	5
20-29	10	26	1	1	38
30-39	14	34	3	0	51
40-49	9	19	12	3	43
50-59	30	17	12	16	75
60-69	23	20	31	29	103
70-79	16	8	36	30	90
80-89	7	3	25	35	70
90-99	3	0	3	5	11
Total	113	130	123	120	486

Table 5.1a gives the results when the complete sample is divided according to age (in decades). It is clear from this table that there are many more individuals in the younger group for black females while white females have the highest number of individuals in the 80-89 year old group.

Sutural scores

The mean, standard deviation and number of observations for each of the parts of the coronal, sagittal and lambdoid sutures in all groups are shown in Tables 5.2 to 5.4. These descriptive statistics are based on the scores using the method of Acsádi and Nemeskéri (1970), where the scores ranged from zero to four. The method based on the Meindl and Lovejoy (1985) study had scores ranging from zero to three only. The results using Acsádi and Nemeskéri (1970) method are presented first (ectocranial and then endocranial). Thereafter the results using the Meindl and Lovejoy (1985) method are presented.

Ectocranial aspect (Acsádi & Nemeskéri, 1970, method)

Black males

The parts of the coronal suture on the ectocranial aspect (Table 5.2) displayed a unique arrangement of obliteration scores with the *pars pterica* (left: 3.02, right 3.16) always showing a higher mean value compared to the rest of the coronal suture, while the *pars bregmatica* and *pars complicata* had means similar to each other.

When parts of the sagittal suture were compared, the *pars obelica* had the largest mean score (2.50) while the *pars bregmatica* had the lowest mean score (1.81). The suture obliteration pattern for the lambdoid suture, however, showed a pattern opposite to that of the coronal suture with the *pars asterica* on the left side (0.95) displaying the lowest mean value for the entire suture. There was no consistency when the mean values of the left and right sides of both the coronal and the lambdoid sutures were compared. Except for the *pars bregmatica*, the right side means were always greater than the left side.

Paired student T-tests were carried out to detect any differences between the left and right sides of the parts of the coronal suture. These results are shown in Appendix B. No statistically significant differences were found for any of the parts of the coronal suture at $p \leq 0.05$. When each part of the sagittal suture was compared to the other parts of the same suture using a paired T-test (Appendix B) the only part that was not significantly different from the *pars vertices* was the *pars lambdica* at $p \leq 0.05$. The comparisons between the mean values of the left and right sides of the lambdoid suture did not yield any statistically significant differences (Appendix B).

Black females

The black females showed a similar suture obliteration arrangement on the ectocranial aspect as that of the black males for the coronal suture (Table 5.2). The difference, however, was that the mean values of all the parts were lower than those of the males. While the scores of the left and right *pars pterica* (coronal suture) of the black males ranged from 3.02 to 3.16, those of the black females were 2.67 and 2.58 for the left and right sides respectively.

The mean scores of the other parts of the coronal suture also showed means that were less than those of the black males. The sagittal suture obliteration pattern was also similar to that of black males but not as pronounced. The *pars obelica* again displayed the highest mean value for the entire suture but there was no significant difference between this part and the *pars lambdica* of the same suture. The mean scores for the *pars asterica* of the lambdoid suture for black females, however, showed values of less than or equal to 0.75 (Table 5.2).

A comparison of the left and right sides showed that there was a significant difference between the left and right sides of the *pars bregmatica* of the coronal suture as seen in Appendix B, while the other parts of the suture showed no significant differences. When the sections of the sagittal suture were compared to each other the *pars obelica* and the *pars lambdica* were the only sections that showed no significant differences. None of the parts of the lambdoid suture showed any significant differences between the left and right sides in the black females (Appendix B).

TABLE 5.2. Mean, standard deviation (std dev), and sample size (n) for the obliteration scores of parts of the coronal, sagittal and lambdoid suture on the ectocranial aspect using the Acsadi & Nemeskeri (1970) method

	Black Males			**Black Females**			**White Males**			**White Females**		
Variable	**mean**	**std dev**	**n**	**mean**	**std dev**	**n**	**mean**	**std dev**	**n**	**mean**	**std dev**	**n**
Age (in years)	54.99	17.64	113	43.74	16.58	130	68.07	13.78	123	71.71	13.15	120
Coronal												
Pars Bregmatica-Left	1.60	1.39	113	1.41	1.47	130	1.21	1.26	123	1.66	1.47	120
Pars Bregmatica-Right	1.57	1.38	113	1.25	1.33	130	1.17	1.25	123	1.68	1.49	120
Pars Complicata-Left	1.75	1.41	113	1.44	1.55	130	1.05	1.21	123	1.24	1.24	120
Pars Complicata-Right	1.79	1.43	113	1.45	1.44	130	0.90	1.20	123	1.30	1.34	120
Pars Pterica-Left	3.02	1.45	113	2.67	1.52	130	3.61	0.88	123	3.01	1.22	120
Pars Pterica-Right	3.16	1.33	113	2.58	1.55	130	3.64	0.77	123	3.07	1.20	120
Sagittal												
Pars Bregmatica	1.81	1.47	113	1.07	1.38	130	1.84	1.43	123	1.91	1.58	120
Pars Vertices	2.27	1.48	113	1.22	1.40	130	2.40	1.33	123	2.38	1.39	120
Pars Obelica	2.50	1.36	113	1.45	1.45	130	2.80	1.21	123	2.43	1.31	120
Pars Lambdica	2.24	1.45	113	1.39	1.47	130	2.46	1.32	123	2.27	1.48	120
Lambdoid												
Pars Lambdica-Left	1.83	1.46	113	1.02	1.40	130	2.00	1.53	123	1.77	1.51	120
Pars Lambdica-Right	1.86	1.44	113	1.02	1.37	130	2.09	1.43	123	1.78	1.46	120
Pars Intermedia-Left	1.51	1.51	113	1.04	1.39	130	1.54	1.47	123	1.83	1.54	120
Pars Intermedia-Right	1.61	1.47	113	1.05	1.40	130	1.59	1.47	123	1.74	1.53	120
Pars Asterica-Left	0.95	1.31	113	0.75	1.25	130	1.16	1.25	123	0.96	1.13	120
Pars Asterica-Right	1.00	1.37	113	0.73	1.24	130	1.11	1.23	123	1.14	1.18	120

White males

The mean scores of the left and right sides of the *pars pterica* of the coronal suture had the largest mean scores compared to all parts of all sutures as well as when the mean was compared to all other parts of all groups (Table 5.2). Here again, the *pars pterica* of the coronal suture was the part that was more often closed than it was open while the *pars bregmatica* was the second part which was more often closed than open. The *pars complicata* of the coronal suture, however, displayed mean values around 1.00 which were the least values when compared to all other groups. The obliteration pattern in the lambdoid suture for this group was the same as that of both the black males and females. It is interesting that, despite their older average age, white males had closure scores lower than black males. The *pars lambdica* of the lambdoid suture once again was found to be more often closed than it was open when compared to other parts of the suture.

There was a significant difference only between the left and right sides of the middle sections of the coronal suture (Appendix B). Most sections of the sagittal suture when compared to each other displayed significant differences in the white males except for a comparison between the *pars vertices* and the *pars lambdica*. Once again, like the previous two groups, there were no significant differences between the scores of the left and right sides of the lambdoid sutures (Appendix B).

White females

The obliteration score means for the white females showed the same arrangement as that of the white males (Table 5.2). The *pars pterica* of the coronal suture on both the left and right sides showed that this part of the suture was more often closed than it was open, when compared to the other parts of the coronal suture. The obliteration pattern of the sagittal suture showed that the *pars bregmatica* of this suture was open more often than the other parts of the suture. The only part of the lambdoid suture that had a mean value below one was the *pars asterica* on the left side (Table 5.2).

There were no significant differences between the left and right sides of any of the parts of the coronal suture (Appendix B), however, significant differences were found between the left and right sides of the *pars asterica* of the lambdoid suture and between selected parts of the sagittal suture (Appendix B).

Pattern of obliteration from the most to the least obliterated:

Ectocranial aspect (Acsádi & Nemeskéri, 1970, method)

Coronal suture:

Black males: *pars pterica, pars complicata, pars bregmatica*

Black females: *pars pterica, pars complicata, pars bregmatica*

White males: *pars pterica, pars bregmatica, pars complicata*

White females: *pars pterica, pars bregmatica, pars complicata*

Sagittal suture:

Black males: *pars obelica, pars vertices, pars lambdica, pars bregmatica*

Black females: *pars obelica, pars lambdica, pars vertices, pars bregmatica*

White males: *pars obelica, pars lambdica, pars vertices, pars bregmatica*

White females: *pars obelica, pars vertices, pars lambdica, pars bregmatica*

<u>Lambdoid suture:</u>

Black males: *pars lambdica, pars intermedia, pars asterica*

Black females: *pars lambdica, pars intermedia, pars asterica*

White males: *pars lambdica, pars intermedia, pars asterica*

White females: *pars lambdica, pars asterica, pars intermedia*

The patterns of obliteration in the coronal suture were population specific with the *pars bregmatica* being the section least obliterated in blacks while the *pars complicata* was the least obliterated section in the whites. The *pars pterica*, which generally lies under the temporal muscle, was the section of the coronal suture that was most often obliterated in all groups. McKern and Stewart (1957) specifically followed Singer's (1953) practice by dividing the coronal suture into four parts on either side of the sagittal suture to investigate whether the temporalis muscle might have an influence on the closure of the lateral aspects of the coronal suture. However, they did not mention any trend that was visible in their study. In the present study the coronal suture was only divided into three equal parts. A difference was visible between the obliteration scores as the *pars pterica* was the part that was most often obliterated rather than any other part of the coronal suture. This finding was in agreement with that of Dwight (1890) where he noted that the most lateral aspects of the coronal suture were more often obliterated like the posterior aspects of the sagittal suture.

In the present study, the sagittal suture showed the same pattern of obliteration in both black males and white females. The *pars obelica* was the least obliterated while the *pars bregmatica* was the section of the sagittal suture that was found to be the most obliterated in all groups. The *pars vertices* and the *pars lambdica* lie between these two sections and were not consistent in their obliteration in all groups. The *pars obelica* was the part of the sagittal suture that was most obliterated as noticed by so many previous investigators, e.g. Dwight (1890).

When the pattern of the lambdoid suture obliteration was compared, the white females differed from the other groups. The obliteration scores increased from medial to lateral for the three other groups but in the white females the *pars asterica* obliterated more often than the *pars intermedia*.

No previous study records each part of the suture as a separate entity. Most studies had initially found an average of the left and right sides of the suture and thereafter found an average of the entire suture (Eränkö & Kihlberg, 1955; Acsádi & Nemeskéri, 1970; Perizonius, 1984). Other studies considered the degree of obliteration of the entire suture and averaged it out (McKern & Stewart, 1957), but if there were any signs of closure of the suture, an average obliteration score would only reflect the incipient closure (McKern & Stewart, 1957). McKern and Stewart (1957) eventually suggested that the sutures not be divided into different parts but rather scored as a whole.

Endocranial aspect (Acsádi & Nemeskéri, 1970, method)

Black males

The obliteration scores of the suture sections were higher than they were on the ectocranial aspect (Table 5.3). There were no major discrepancies between the different parts of the same suture in the coronal, sagittal and lambdoid suture. The *pars obelica* of the sagittal had the lowest score compared to all the other parts of the sagittal suture which is opposite to what was seen on the ectocranial aspect. This section also had the lowest score of all the sections. The means for the coronal suture sections ranged between 3.06 and 3.43, while the means for the lambdoid suture sections ranged from 2.27 to 2.88.

When the left and right sides of the different sections of the coronal and lambdoid sutures were compared, only the *pars bregmatica* with p = 0.01 (Appendix C) showed any significant differences. The comparisons between the different parts of the sagittal suture illustrated significant differences between all parts except between the *pars bregmatica* and *pars lambdica* (Appendix C).

Black females

The mean scores for the black females were less than those of the black males (Table 5.3). This same trend was seen on the ectocranial aspect when using the Acsádi & Nemeskéri (1970) method. The pattern of obliteration, however, was still the same with the scores of the lambdoid sutures being the lowest (1.20) amongst the three sutures. The *pars lambdica* of the sagittal suture had the greatest mean while the *pars obelica* of the same suture had the lowest mean. The only comparisons between sections of the sagittal suture that showed significant difference were found between the *pars obelica* and the *pars lambdica* (Appendix C).

White males

The mean scores in this group were much greater than those of the previous two groups (Table 5.3). The *pars pterica* of the coronal suture on the left side had a mean score which was the closest to the maximum score of four. Once again the *pars* *obelica* of the sagittal suture displayed the lowest mean (2.64). The standard deviations for the parts in this group were also much lower than in the previous two groups (Table 5.3). In this group there were no significant differences between the left and right sides of the coronal suture (Appendix C). All parts of the sagittal suture showed significant differences, while only the pars asterica of the lambdoid suture showed any significant differences between the two sides.

White females

The suture obliteration arrangement for the white females, once again was similar to that of the white males with the mean scores being very close to the maximum score of four (Table 5.3). The lowest mean, however, was not that of the *pars obelica* of the sagittal suture but that of the *pars lambdica* of the lambdoid suture, which showed a significant difference between the left and right sides ($p = 0.04$) with the right side more often obliterated than the left (Appendix C). The coronal suture once again showed no significant differences between the left and right sides (Appendix C).

TABLE 5.3. Mean, standard deviation (std dev), and sample size (n) for the obliteration scores of parts of the coronal, sagittal and lambdoid suture on the endocranial aspect using the Acsadi & Nemeskeri (1970) method

	Black Males			**Black Females**			**White Males**			**White Females**		
Variable	***mean***	***std dev***	***n***	***mean***	***std dev***	***n***	***mean***	***std dev***	***n***	***mean***	***std dev***	***n***
Age (in years)	54.99	17.64	113	43.74	16.58	130	68.07	13.78	123	71.71	13.15	120
Coronal												
Pars Bregmatica-Left	3.19	1.37	113	2.19	1.81	130	3.77	0.81	123	3.75	0.86	120
Pars Bregmatica-Right	3.06	1.51	113	2.20	1.86	130	3.80	0.69	123	3.81	0.74	120
Pars Complicata-Left	3.43	1.26	113	2.65	1.08	130	3.89	0.56	123	3.76	0.87	120
Pars Complicata-Right	3.39	1.33	113	2.59	1.82	130	3.86	0.59	123	3.82	0.71	120
Pars Pterica-Left	3.34	1.38	113	2.42	1.85	130	3.91	0.53	123	3.75	0.92	120
Pars Pterica-Right	3.35	1.38	113	2.42	1.88	130	3.90	0.49	123	3.76	0.87	120
Sagittal												
Pars Bregmatica	3.04	1.51	113	1.90	1.87	130	3.73	0.80	123	3.73	0.85	120
Pars Vertices	2.58	1.58	113	1.87	1.83	130	3.21	1.14	123	3.53	0.98	120
Pars Obelica	2.20	1.66	113	1.82	1.81	130	2.64	1.40	123	3.23	1.21	120
Pars Lambdica	3.14	1.41	113	2.07	1.84	130	3.50	0.97	123	3.51	1.06	120
Lambdoid												
Pars Lambdica-Left	2.35	1.52	113	1.20	1.56	130	2.95	1.29	123	2.83	1.44	120
Pars Lambdica-Right	2.27	1.53	113	1.24	1.56	130	2.94	1.28	123	2.95	1.37	120
Pars Intermedia-Left	2.81	1.64	113	1.62	1.80	130	3.80	0.78	123	3.35	1.33	120
Pars Intermedia-Right	2.88	1.63	113	1.58	1.79	130	3.84	0.63	123	3.43	1.26	120
Pars Asterica-Left	2.48	1.76	113	1.38	1.75	130	3.69	0.92	123	3.08	1.55	120
Pars Asterica-Right	2.50	1.77	113	1.38	1.75	130	3.78	0.73	123	3.20	1.44	120

Pattern of obliteration from the most to the least obliterated:

Endocranial aspect (Acsádi & Nemeskéri, 1970, method)

Coronal suture:

Black males: *pars complicata, pars pterica, pars bregmatica*

Black females: *pars complicata, pars pterica, pars bregmatica*

White males: *pars pterica, pars complicata, pars bregmatica*

White females: *pars complicata, pars bregmatica, pars pterica*

Sagittal suture:

Black males: *pars lambdica, pars bregmatica, pars vertices, pars obelica*

Black females: *pars lambdica, pars bregmatica, pars vertices, pars obelica*

White males: *pars bregmatica, pars lambdica, pars vertices, pars obelica*

White females: *pars bregmatica, pars vertices, pars lambdica, pars obelica*

Lambdoid suture:

Black males: *pars intermedia, pars asterica, pars lambdica*

Black females: *pars intermedia, pars asterica, pars lambdica*

White males: *pars intermedia, pars asterica, pars lambdica*

White females: *pars intermedia, pars asterica, pars lambdica*

On the endocranial aspect, the pattern of obliteration for the entire skull was the same for both black males and females. The white males, however, showed a different pattern from that of the white females and the blacks. The *pars complicata* of the coronal suture had the least obliteration score for the black males, black females and the white males. The *pars pterica* of the coronal suture was the part that was least obliterated in the white males. Contrary to this Todd and Lyon (1924), showed that the *pars pterica* was one of the least obliterated parts of the coronal suture but eventually reached complete closure around the age of 41 in some individuals, while the rest of the coronal suture showed complete obliteration earlier.

The pattern of obliteration of the sagittal suture was the same for the black males and females, but differed in the white males and females. The *pars lambdica* of the sagittal suture was the most obliterated in the blacks while in the whites the *pars bregmatica* was the most obliterated. These two regions are at opposite ends of the sagittal suture. The *pars obelica* on the sagittal suture, which was the region most obliterated on the ectocranial aspect, was the least obliterated on the endocranial aspect in all groups. This finding was in disagreement with that of Parson and Box (1905) who found that on the endocranial aspect the *pars obelica* was one of the most obliterated parts of the sagittal suture followed by the anterior aspect of the suture and finally the posterior aspect. In some cases the posterior aspect had been shown to be patent even in older individuals (Parsons & Box, 1905).

The lambdoid suture had the same pattern of obliteration in all groups. In the present study the lambdoid suture on the endocranial aspect was more often open than closed compared to the other sutures. This was in agreement with Parsons and Box (1905) who only found five specimens that showed closure in the lambdoid suture on the endocranial aspect.

<u>Ectocranial aspect (Meindl & Lovejoy, 1985, method)</u>

The ten sites suggested by Meindl and Lovejoy (1985) were clustered to represent the coronal, sagittal and lambdoid for easy comparison to the method suggested by Acsádi and Nemeskéri (1970). The following sites were included into the different sutures: for the coronal suture: sites six and seven, from lateral to medial; sagittal suture: sites five, four and three from anterior to posterior; and lambdoid suture: sites two and one, from lateral to medial. The accessory suture scores were included at the end of the table (Table 5.4).

Black males

The pterion mean scores on both the left and right sides showed a greater value than the mid-coronal part (Table 5.4). This was in synchronisation with the mean of the *pars pterica* on the coronal suture (Table 5.2). The parts of the sagittal suture also showed that the obelion in this case was more often closed than the anterior sagittal or bregma. The lambda, which is the junction of the sagittal and lambdoid sutures showed a greater mean than the mid-lambdoid part. The spheno-frontal part displayed a mean score close to that of the pterion while the superior spheno-temporal had the lowest mean score of all the parts. There were only significant differences between parts of the sagittal suture at $p \leq 0.05$ (Appendix D), while there were no differences between the coronal, lambdoid and accessory sutures.

Black females

The pattern of obliteration in this group was the same as that of the black males (Table 5.4). The difference though is that the black females displayed lower mean scores for each of the suture sites when compared to the black males. Despite a difference of the mean ages for this group being lower than that of the black males by 11 years, the obliteration scores only showed an average difference of 0.4 which is a fraction of the total score. This pattern is the same as that seen on the ectocranial aspect when the Acsádi and Nemeskéri (1970) method was used. The means for the spheno-temporal parts were the lowest (0.46) on the left. The obelion was significantly different from the bregma, anterior sagittal and lambda while the left and right pterions were significantly different (Appendix D).

White males

The mean values for the mid-coronal part in this group were the lowest of all groups including the white females (Table 5.4), while the superior spheno-temporal mean scores were much greater than in all the other groups. Like the other groups, however, the pterion was the part that was more often closed than the other parts of the skull. The spheno-frontal mean was also very close to the pterion mean. All parts were significantly different from each other when examining the midline sutures, while the superior and inferior spheno-temporal parts differed significantly on either side (Appendix D).

White females

Like the white males, the mid-coronal parts showed a lower mean than both the black males and females (Table 5.4), but the scores of obliteration in the accessory sutures were lower than all other groups. Despite there being a low average difference of 4 years in the mean ages of the white females compared to the white males, there still existed a difference on average of 0.5 of the total score of 4. Significant differences were found with the parts at the anterior and posterior aspects of the sagittal suture (Appendix D).

It is interesting that white males, and sometimes females, have some scores lower than blacks, especially males, despite the average age difference in opposite direction. This indicates that factors other than age may be responsible for obliteration of sutures.

TABLE 5.4. Mean, standard deviation (std dev), and sample size (n) for the obliteration scores of parts of the sutures using Meindl & Lovejoy's (1985) method- their labels in parentheses

	Black Males			Black Females			White Males			White Females		
Variable	***mean***	***std dev***	***n***	***mean***	***std dev***	***n***	***mean***	***std dev***	***n***	***mean***	***std dev***	***n***
Age (in years)	54.99	17.64	113	43.74	16.58	130	68.07	13.78	123	71.71	13.15	120
Coronal												
Mid-coronal-Left (6)	1.29	1.13	113	0.99	1.12	130	0.54	0.90	123	0.69	0.94	120
Mid-coronal-Right (6)	1.27	1.13	113	0.94	1.08	130	0.50	0.88	123	0.74	1.03	120
Pterion-Left (7)	2.27	1.10	113	1.91	1.07	130	2.74	0.64	123	2.21	0.96	120
Pterion-Right (7)	2.25	1.04	113	2.08	1.06	130	2.78	0.51	123	2.23	0.96	120
Sagittal												
Bregma (5)	1.18	1.02	113	0.78	0.92	130	0.89	0.97	123	1.14	1.11	120
Anterior Sagittal (4)	1.68	1.16	113	0.85	1.07	130	1.66	1.11	123	1.71	1.18	120
Obelion (3)	2.02	1.11	113	1.24	1.19	130	2.30	0.91	123	1.80	1.10	120
Lambdoid												
Lambda (2)	1.26	1.06	113	0.75	0.99	130	1.46	1.08	123	1.31	1.16	120
Midlambdoid-Left (1)	1.17	1.11	113	0.81	1.10	130	1.33	1.20	123	1.34	1.23	120
Midlambdoid-Right (1)	1.16	1.08	113	0.76	1.06	130	1.35	1.21	123	1.33	1.20	120
Accessory												
Spheno-frontal-Left (8)	2.17	1.03	113	1.96	1.12	130	2.71	0.67	123	1.93	1.08	120
Spheno-frontal-Right (8)	2.19	1.03	113	2.04	1.09	130	2.71	0.64	123	1.98	1.05	120
Inf. Spheno-temporal-Left (9)	1.20	1.20	113	0.75	1.04	130	1.65	1.23	123	0.48	0.83	120
Inf. Spheno-temporal-Right (9)	1.33	1.21	113	0.74	0.99	130	1.82	1.24	123	0.52	0.87	120
Sup. Spheno-temporal-Left (10)	0.71	0.94	113	0.46	0.79	130	1.41	1.27	123	0.21	0.45	120
Sup. Spheno-temporal-Right (10)	0.78	1.02	113	0.50	0.82	130	1.66	1.29	123	0.18	0.42	120

Pattern of obliteration from the most to the least obliterated:

Ectocranial aspect (Meindl & Lovejoy, 1985, method)

Coronal region:

Black males: pterion, mid-coronal

Black females: pterion, mid-coronal

White males: pterion, mid-coronal

White females: pterion, mid-coronal

Sagittal region:

Black males: obelion, anterior sagittal, bregma

Black females: obelion, anterior sagittal, bregma

White males: obelion, anterior sagittal, bregma

White females: obelion, anterior sagittal, bregma

Lambdoid region:

Black males: lambda, mid-lambdoid

Black females: mid-lambdoid, lambda

White males: lambda, mid-lambdoid

White females: mid-lambdoid, lambda

Accessory sutures:

Black males: spheno-frontal, inferior, superior spheno-temporal

Black females: spheno-frontal, inferior, superior spheno-temporal

White males: spheno-frontal, inferior, superior spheno-temporal

White females: spheno-frontal, inferior, superior spheno-temporal

The pattern of obliteration when only a part of the suture was examined showed very similar patterns for all regions. Almost all the patterns were the same for all the groups, except for the lambdoid region which was sexually dimorphic. Males demonstrated that the lambda obliterated more often than the mid-lambdoid region while the reverse was true for females.

When the patterns of obliteration using the Acsádi and Nemeskéri (1970) method and the Meindl and Lovejoy (1985) method are compared the following observations were made: the lateral aspect of the coronal suture obliterated more often than the other parts of the suture in both methods. The sagittal suture also showed the same results when the patterns were compared. Here once again, there was closure in the obelion area more often than the middle parts of the suture and the anterior aspects of the suture were the least obliterated. Finally the lambdoid suture showed sexual dimorphism when using the Meindl and Lovejoy (1985) method. The males displayed obliteration at the lambda area more often than in the mid-lambdoid part of the lambdoid suture.

5.2 Frequencies of scores

The obliteration scores, which ranged from zero to four for the Acsádi and Nemeskéri (1970) method were calculated as percentages for each of the parts of the coronal, sagittal and lambdoid sutures. The scores for the Meindl and Lovejoy (1985) method, which ranged from zero to three were calculated as percentages for each of the ten sites. These were then displayed as graphs for each part (Figures 5.1- 5.9). All groups were combined to represent a single group. A Chi-squared test was used to assess any significant differences between the frequencies at each site. The actual frequencies of the scores and the Chi-squared tests can be viewed in Appendices D, E & F.

Ectocranial aspect (Acsádi & Nemeskéri, 1970, method)

There is a great tendency for the *pars pterica* to be more often closed than the other parts of the coronal suture (Fig 5.1). Both the *pars bregmatica* and the *pars complicata*, on both the left and right sides showed that the score of zero was observed more often than any other score. The sagittal suture showed an equal number of individuals score across the range (Fig 5.2), while the lambdoid suture showed an opposite pattern of obliteration with the suture staying open more often than the other parts. This is true for all parts of the lambdoid suture (Fig 5.3). All frequencies were significantly different except for the pars vertices on the ectocranial aspect (Appendix E).

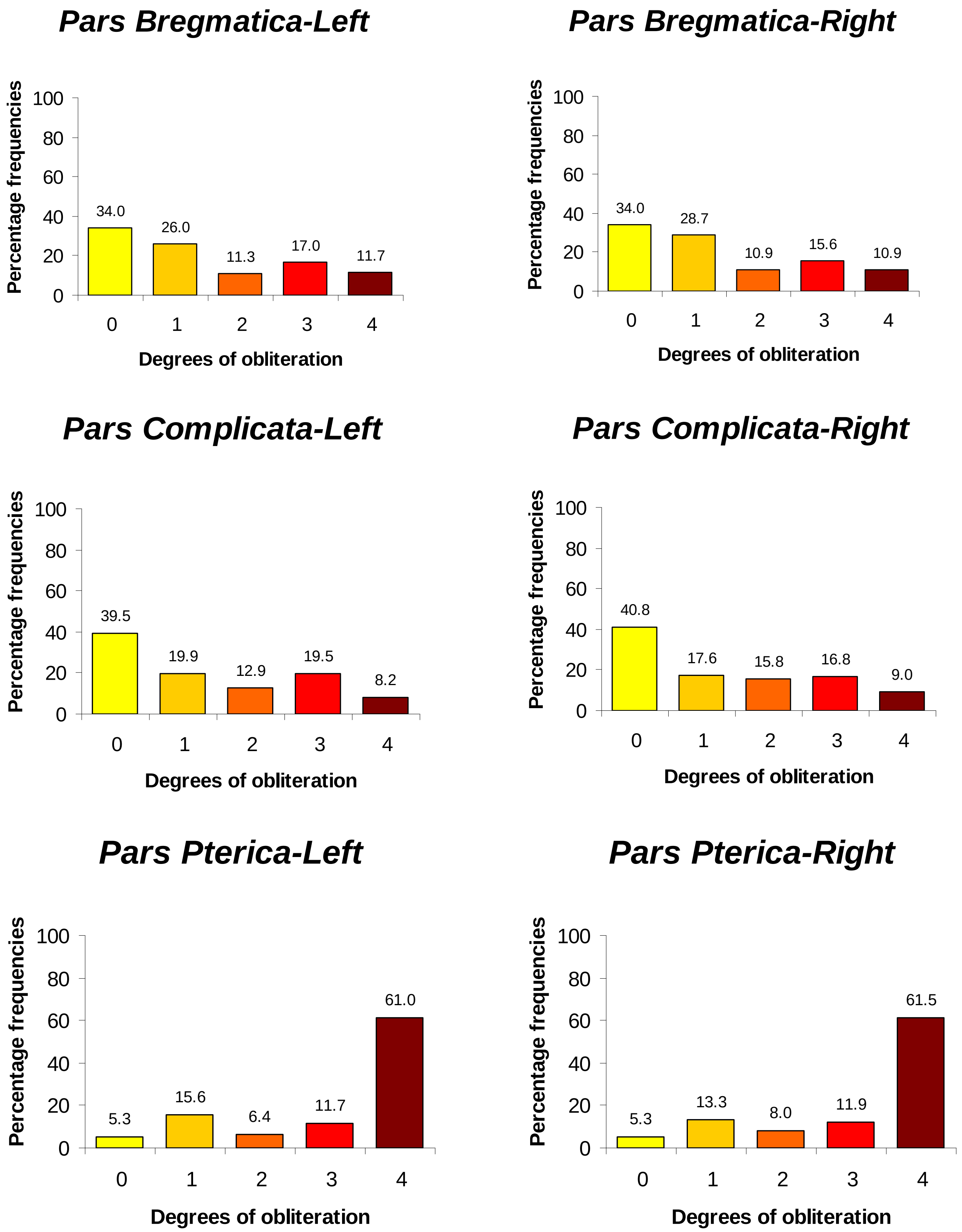


Figure 5.1. Frequency distribution of obliteration scores for the coronal suture using the Acsádi & Nemeskéri (1970) method for all individuals, on the ectocranial aspect.

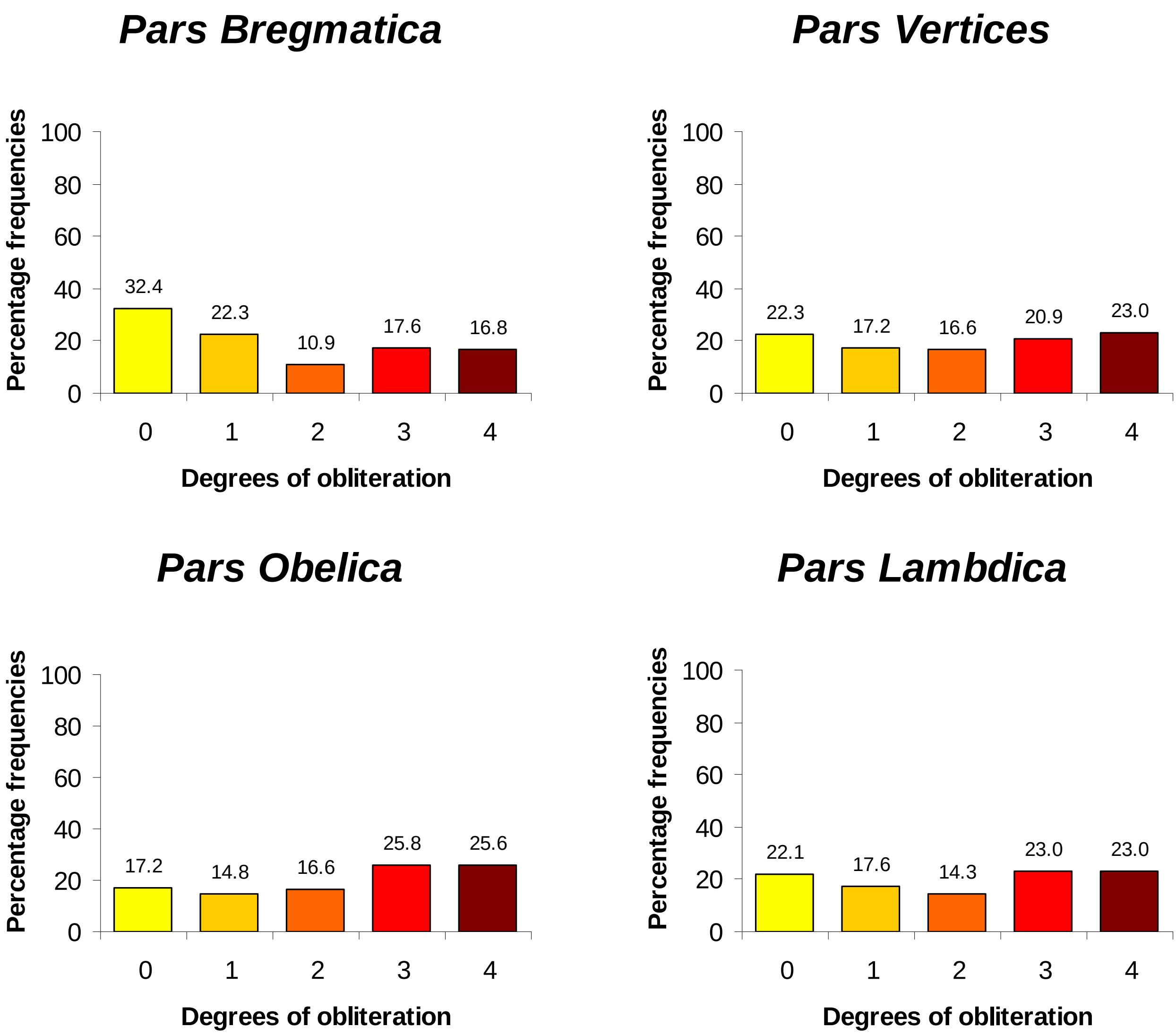


Figure 5.2. Frequency distribution of obliteration scores for the sagittal suture using the Acsádi & Nemeskéri (1970) method for all individuals, on the ectocranial aspect.

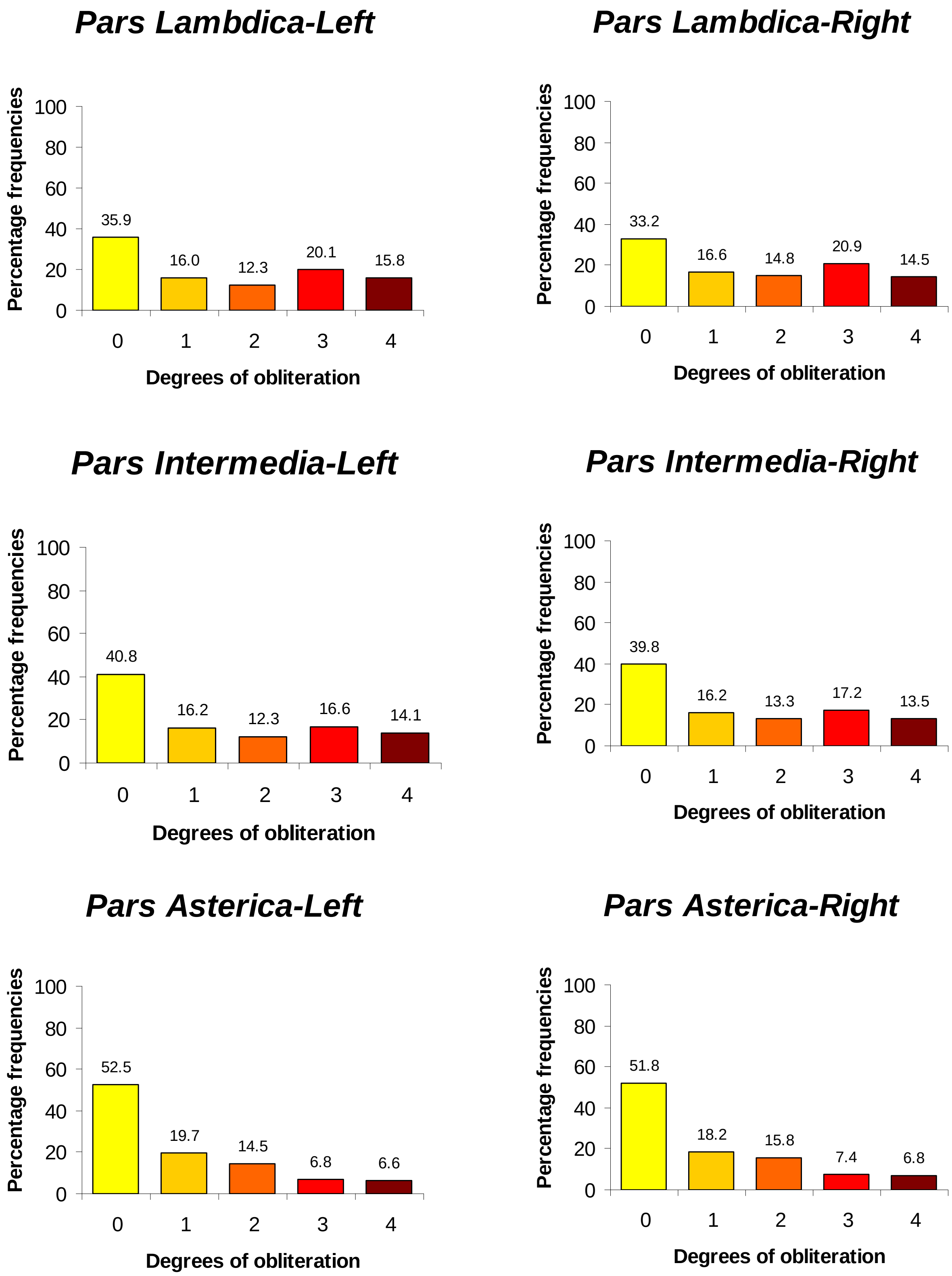


Figure 5.3. Frequency distribution of obliteration scores for the lambdoid suture using the Acsádi & Nemeskéri (1970) method for all individuals, on the ectocranial aspect.

Endocranial aspect (Acsádi & Nemeskéri, 1970, method)

The last scoring category was the most prominent in all sutures on the endocranial aspect. The frequencies for the coronal suture ranged from 73.4 to 81.4% (Fig 5.4), while those of the sagittal (45.1- 70.5%, Fig. 5.5) and lambdoid (38.5-66.4%, Fig. 5.6) sutures were not as high as that of the coronal suture. The frequencies of the other scores were not greater than 25%. All frequencies were statistically significant at the $p \leq 0.05$ level if the expected frequencies of the categories are equal (Appendix F).

Ectocranial aspect (Meindl & Lovejoy, 1985, method)

The frequencies of the scores when using the Meindl and Lovejoy (1985) method also showed a similar pattern to that seen on the ectocranial aspect of the skull when using the Acsádi and Nemeskéri (1970) method. The pterion can be compared to the *pars pterica*, where the majority of the parts were given a score of three (Fig. 5.7). The mid-coronal, however, followed the same pattern as the mid-lambdoid with a large percentage of the cases awarded a score of zero. The lambda and the bregma both had scores of zero and one more often than scores of two and three (Fig. 5.8). The score of three, at the obelion, however, accounted for 40% of the scores in this area. The spheno-frontal part of the accessory sutures tended to be more often closed than the superior and inferior spheno-temporal parts (Fig. 5.9). All frequencies of the sites on the ectocranial aspect of the skull showed a significant difference at $p \leq 0.05$ if the expected frequencies of each category were 20% (Appendix G).

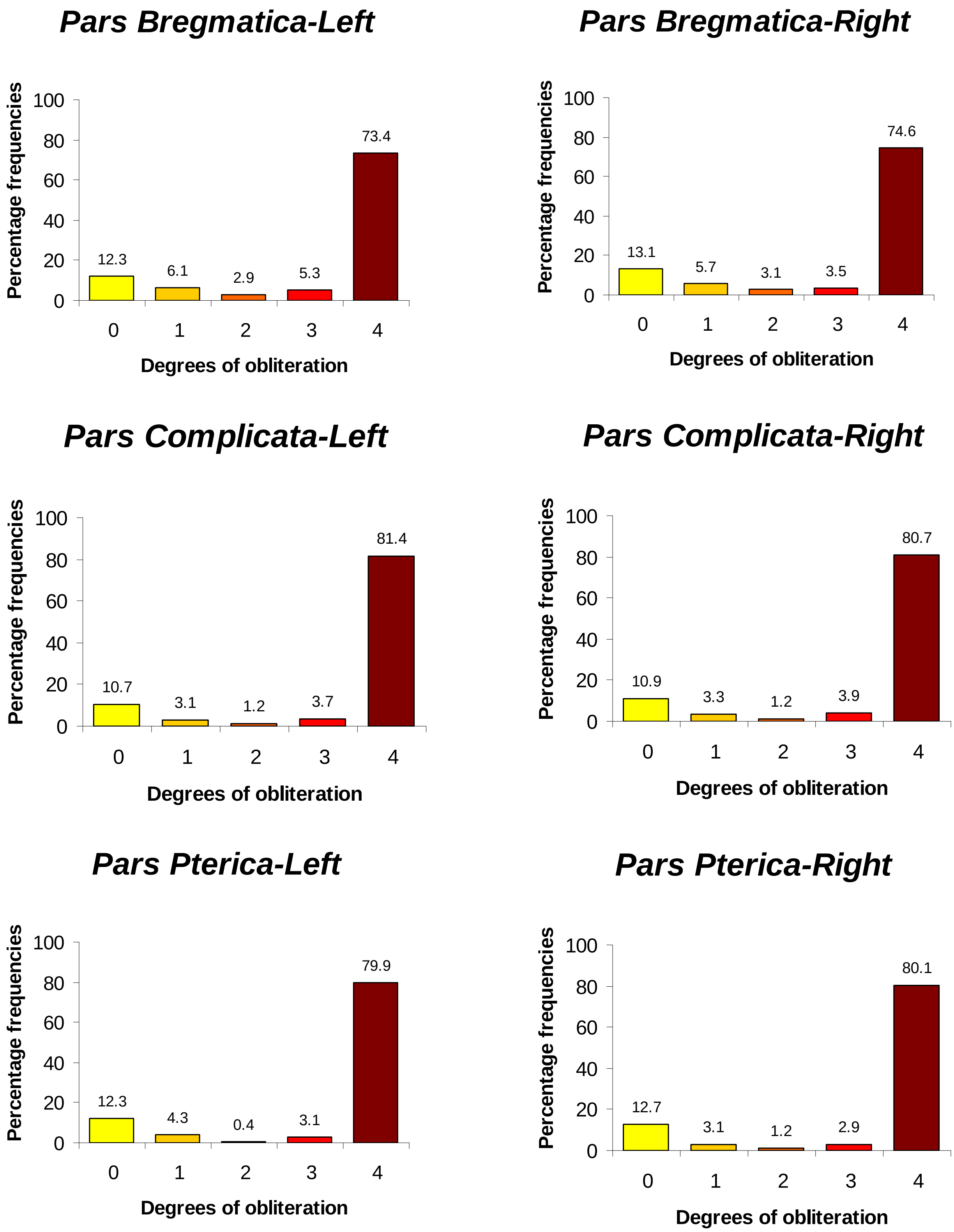


Figure 5.4. Frequency distribution of obliteration scores for the coronal suture using the Acsádi & Nemeskéri (1970) method for all individuals, on the endocranial aspect.

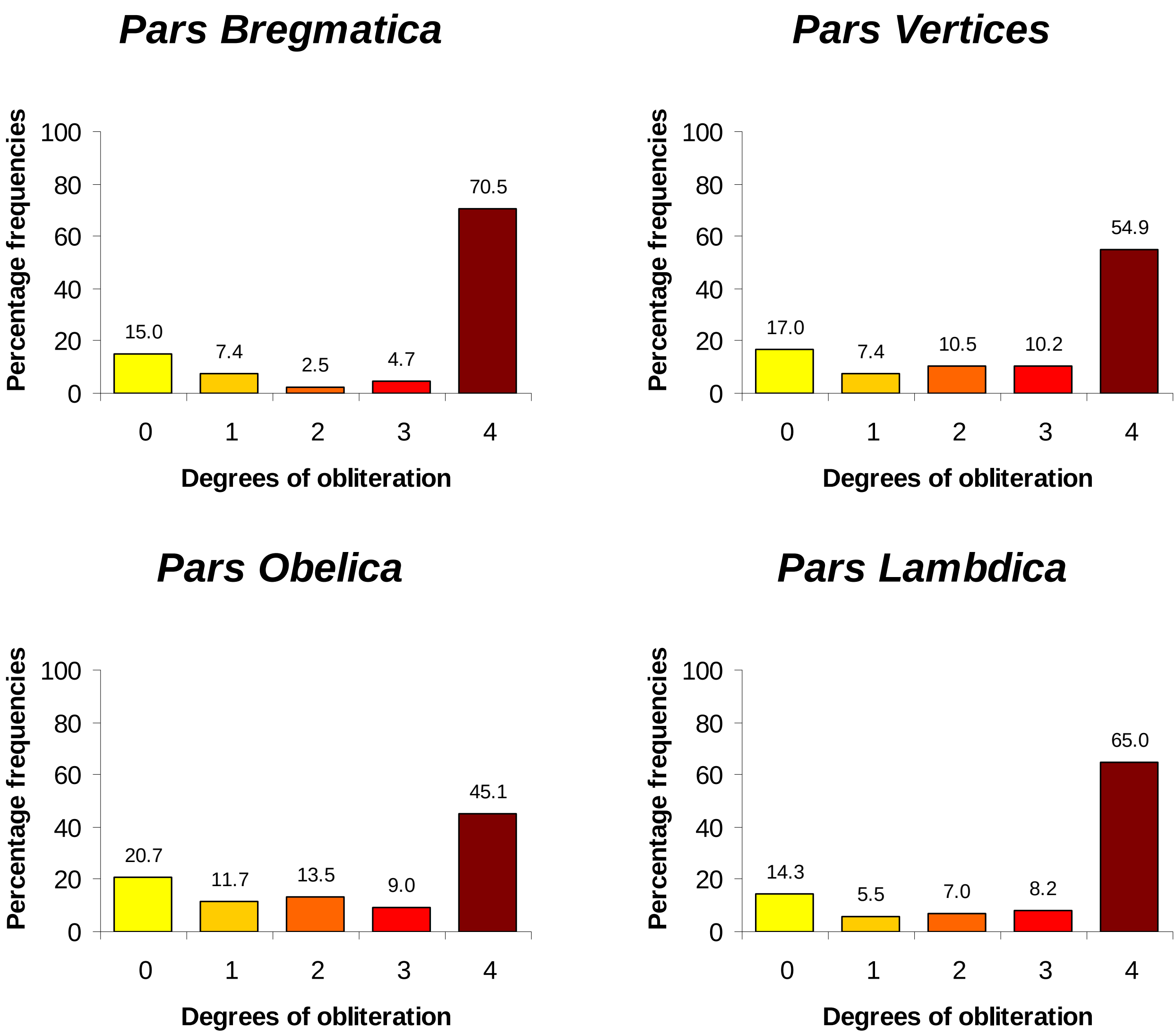


Figure 5.5. Frequency distribution of obliteration scores for the sagittal suture using the Acsádi & Nemeskéri (1970) method for all individuals, on the endocranial aspect.

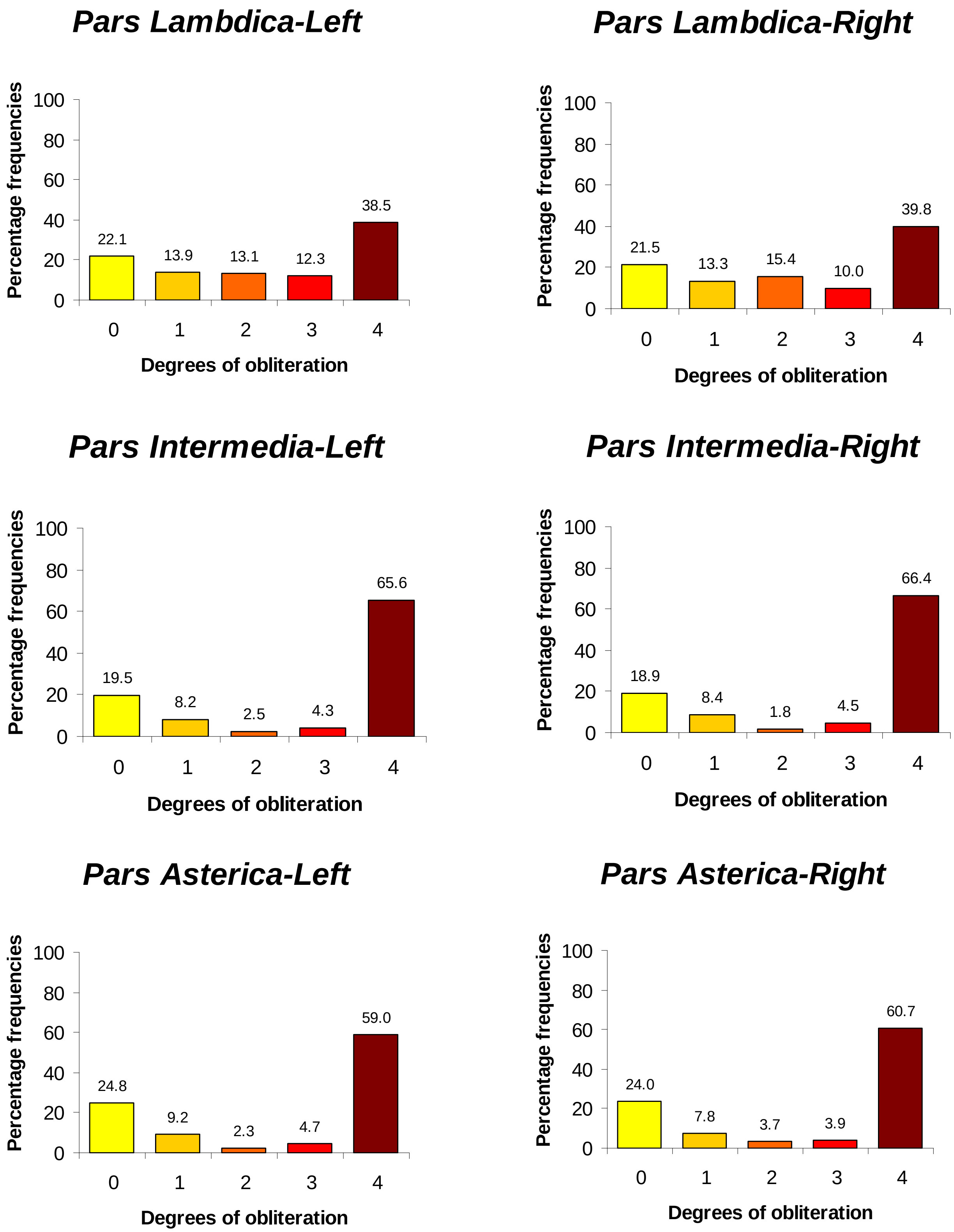


Figure 5.6. Frequency distribution of obliteration scores for the lambdoid suture using the Acsádi & Nemeskéri (1970) method for all individuals, on the endocranial aspect.

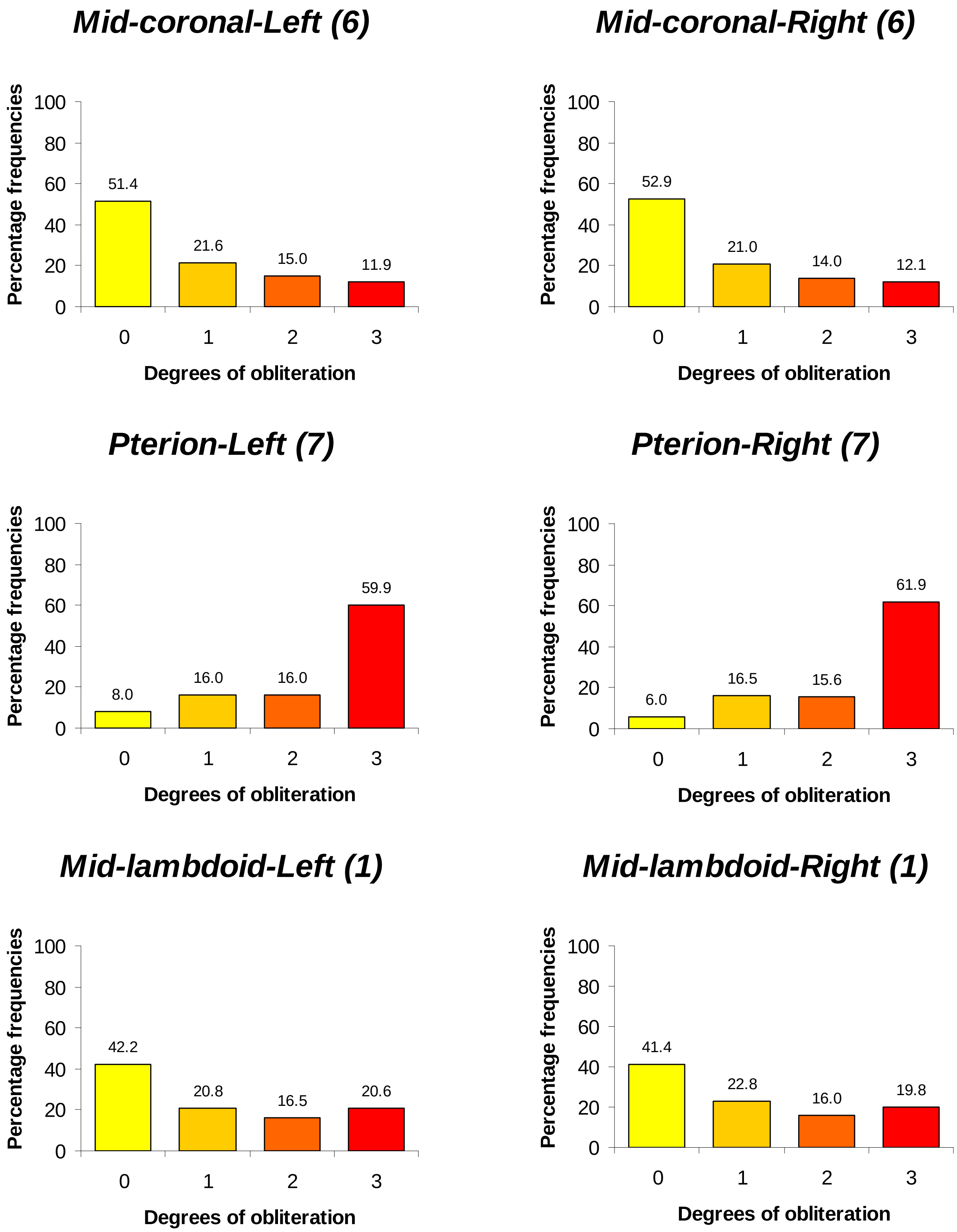


Figure 5.7. Frequency distribution of obliteration scores for the mid-coronal, pterion and mid-lambdoid areas using the Meindl & Lovejoy (1985) method for all individuals, on the left and right aspect.

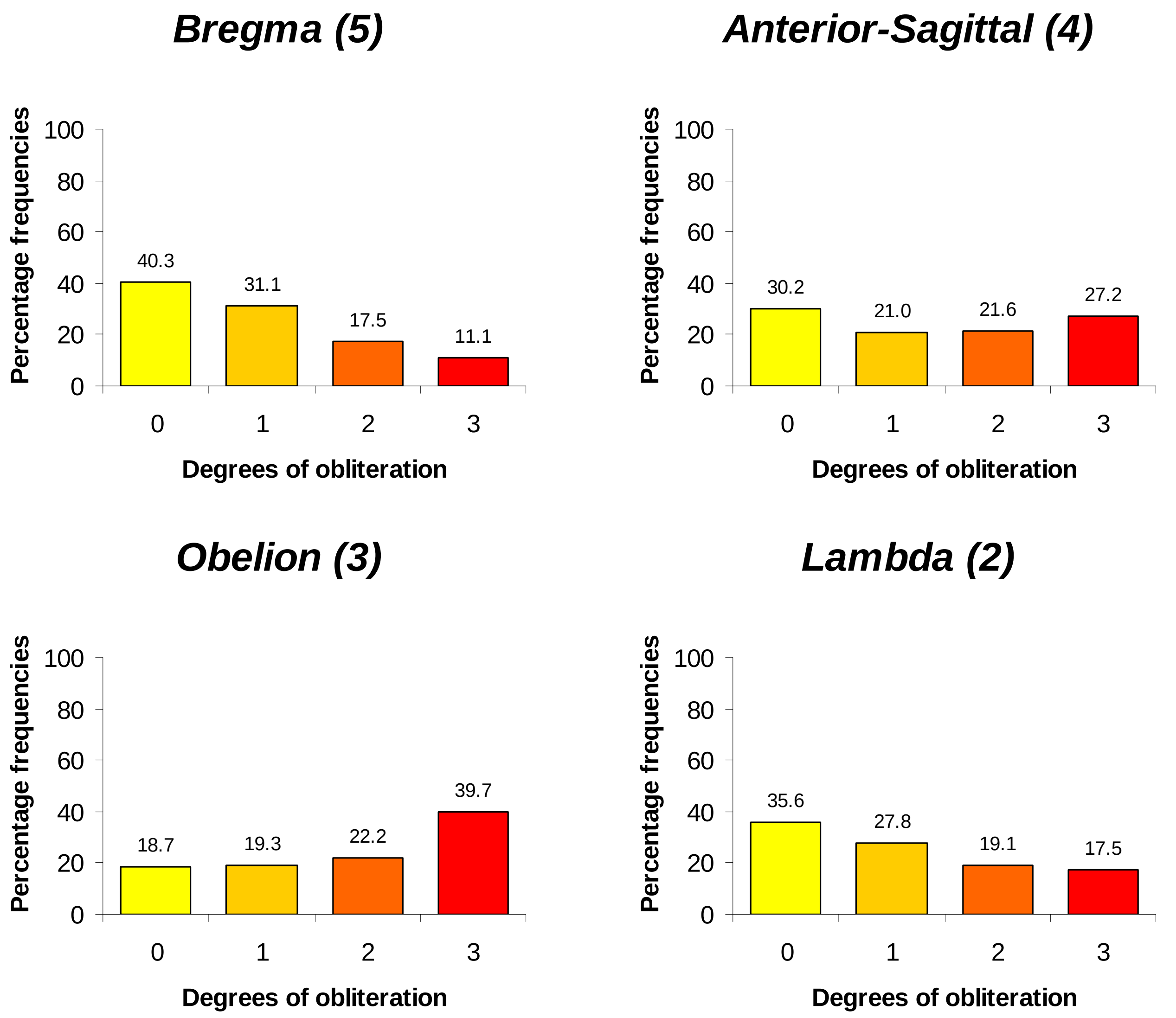


Figure 5.8. Frequency distribution of obliteration scores for the bregma, anterior sagittal, obelion and lambda sutural areas using the Meindl & Lovejoy (1985) method for all individuals.

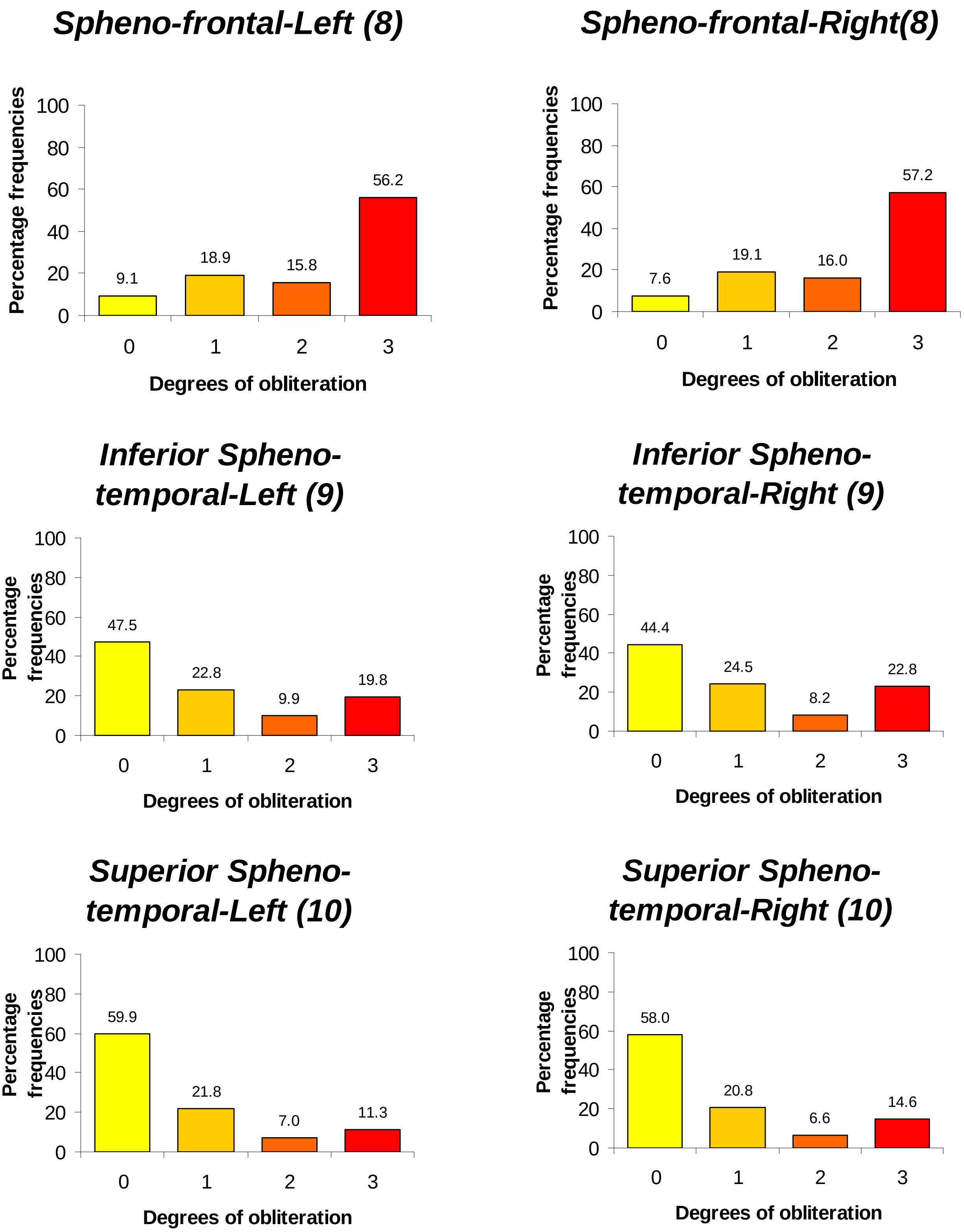


Figure 5.9. Frequency distribution of obliteration scores for the Spheno-frontal, superior and inferior Spheno-temporal sutural areas using the Meindl & Lovejoy (1985) method for all individuals, on the left and right aspect.

5.3 Distribution of total scores

The scores for the ectocranial and endocranial aspects, as well as the left and right sides of the skull, were then totalled to observe the distribution of the scores for all individuals in the sample (Figures 5.10 to 5.13). Thereafter the sample was divided into individuals that have a recorded age of: a) less than and equal to 39 years, b) between 40 and 69 years, and c) greater than and equal to 70 years. A Kolmogorov-Smirnov one-sample test was used to check whether the total scores were normally distributed in each sample (Table 5.5).

Entire sample

The distribution of the total scores was very close to the normal curve with a few scores in the lower range that were greater than the normal for ectocranial scores (Figure 5.10). The distributions for the endocranial scores, however, were very different with majority of the endocranial total scores being much higher than the normal curve (Figure 5.11). The total scores when using the Meindl and Lovejoy (1985) method on the left and right sides of the skull also showed a normal distribution of the scores (Figures 5.12 & 5.13). The p-values for the Kolmogorov-Smirnov one-sample test, however, showed that all total scores distributions were not normal at the $p \leq 0.05$ level (Table 5.5).

Age categories

Figures 5.14-5.15 display the distribution of total scores when dividing the sample into different age groups. The scores on the endocranial aspect for individuals $\leq$ 39 years illustrated that the lower scores are much more frequent than the higher scores.

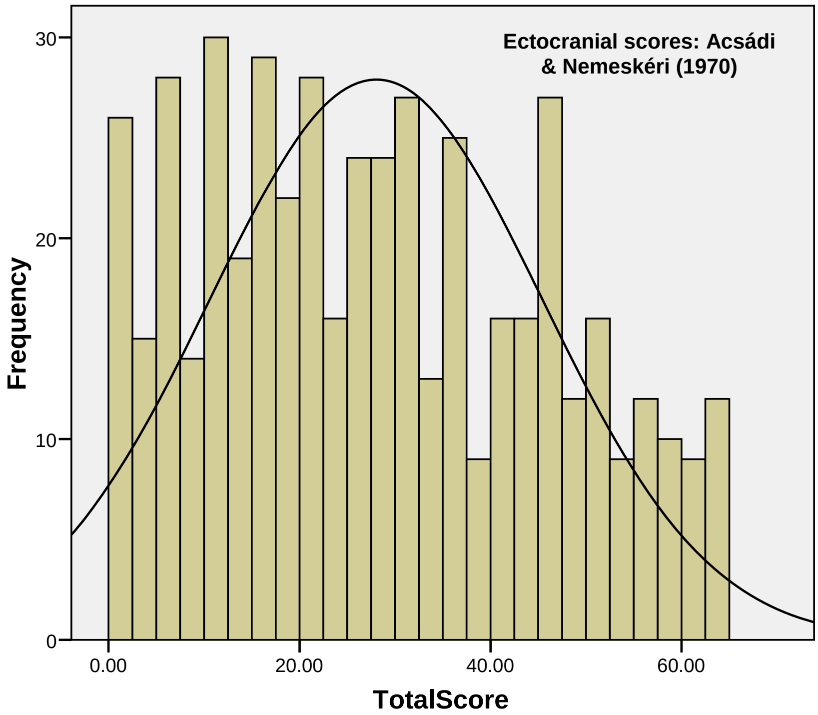


Figure 5.10. Distribution of total ectocranial scores for the entire sample

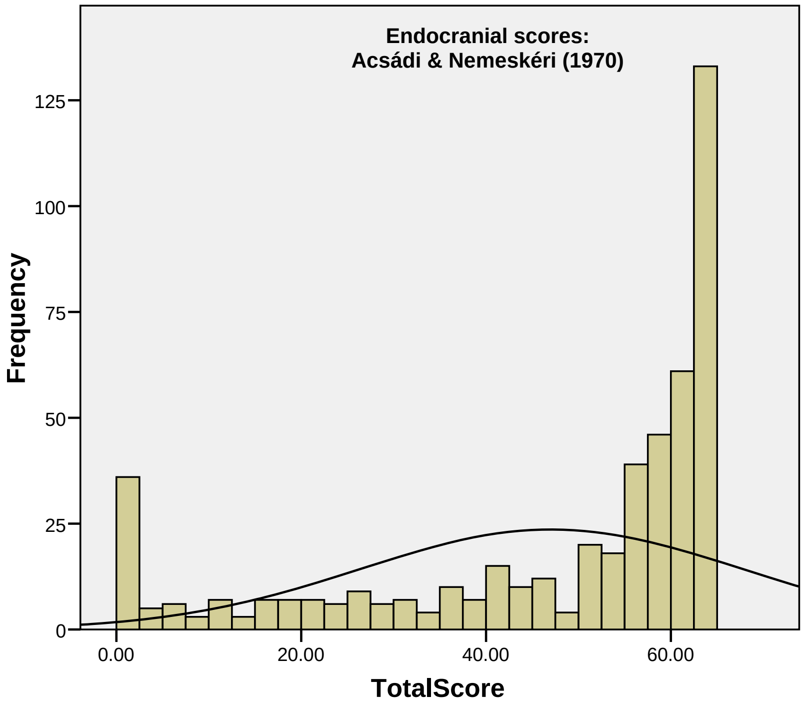


Figure 5.11. Distribution of total endocranial scores for the entire sample

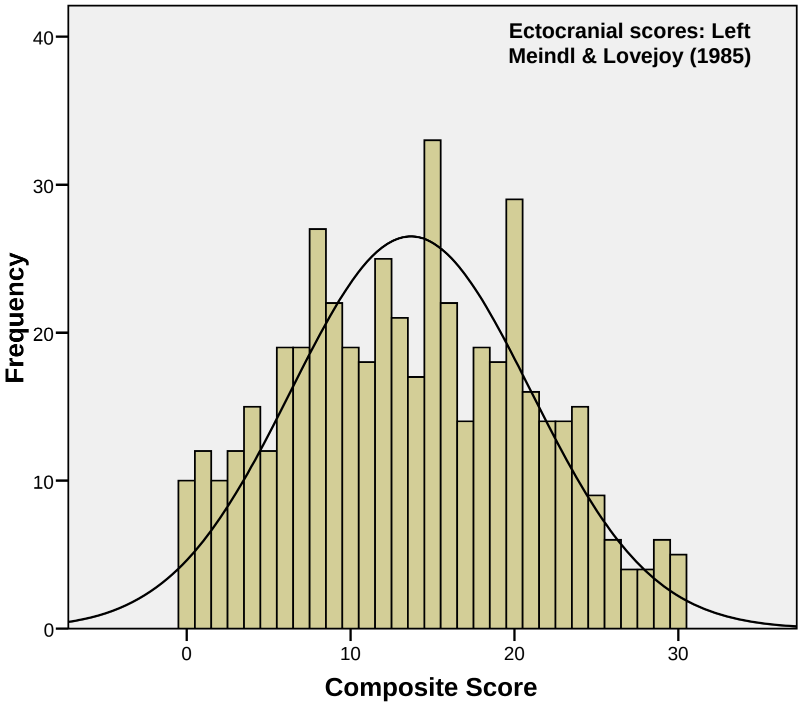


Figure 5.12. Distribution of the total scores computed from the left side of the skull

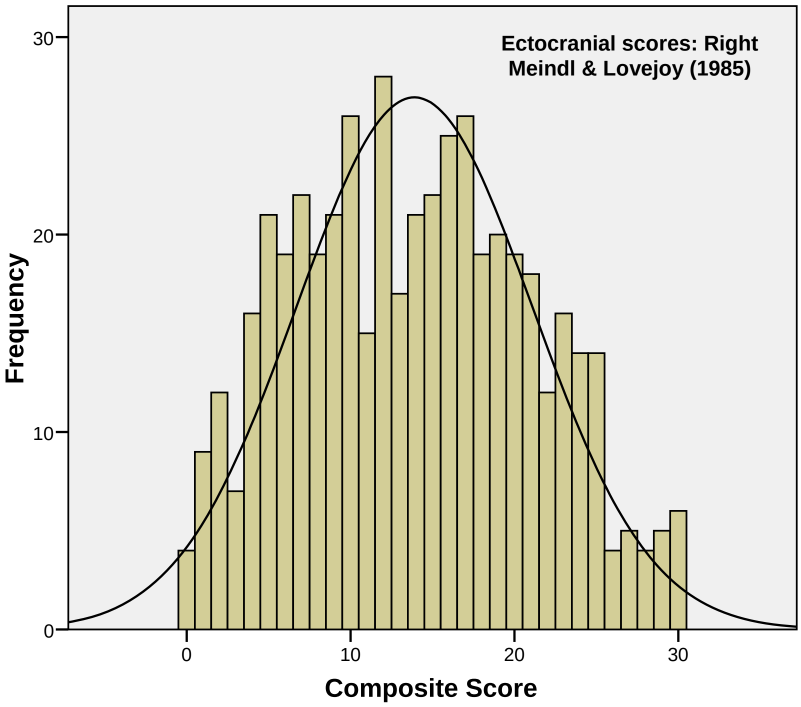


Figure 5.13. Distribution of the total scores computed from the right side of the skull

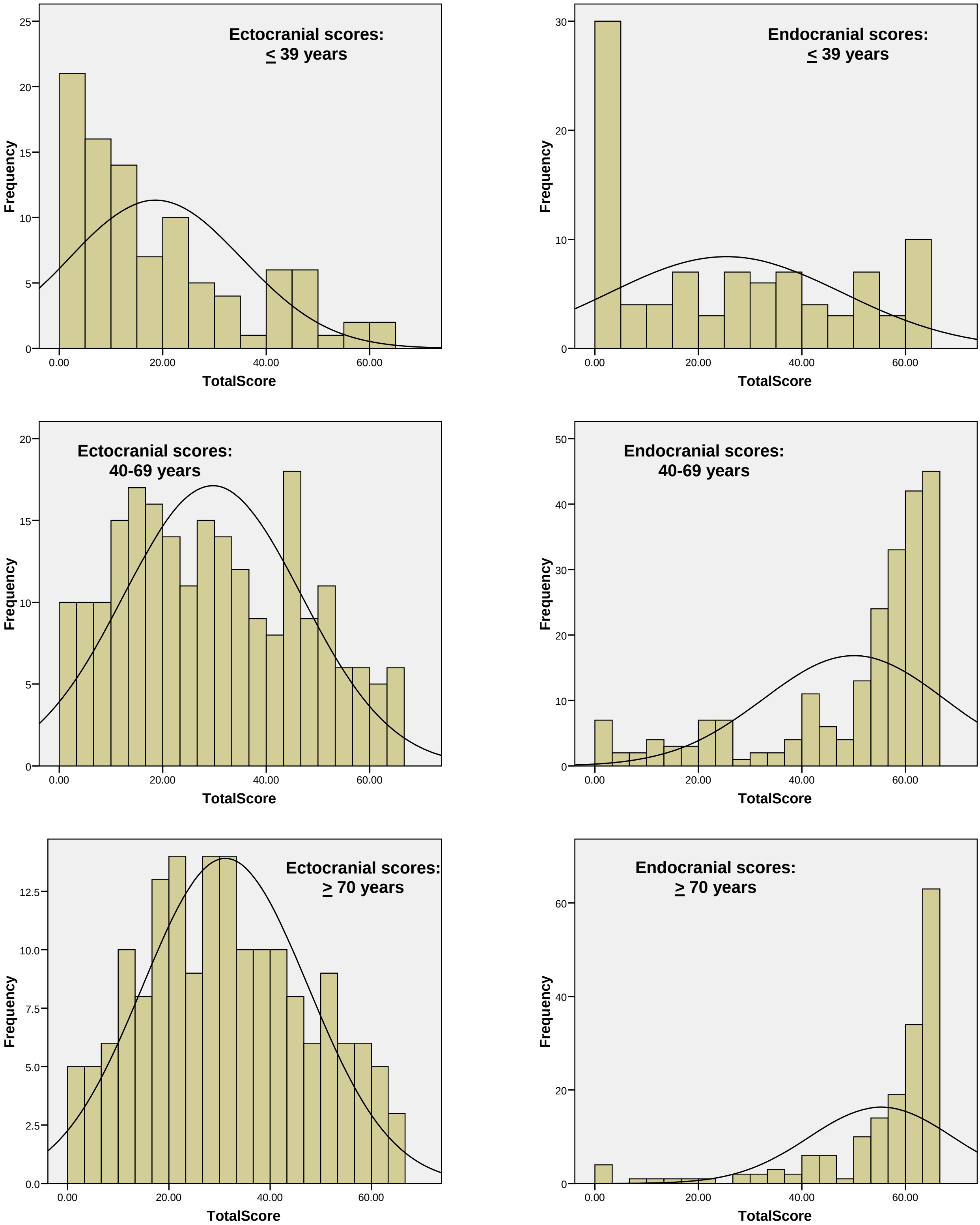


Figure 5.14. Distribution of total scores for individuals ≤ 39 years, those between 40 and 69 years and those ≥ 70 years from top to bottom with the graphs for ectocranial scores on the left side and endocranial scores on the right side.

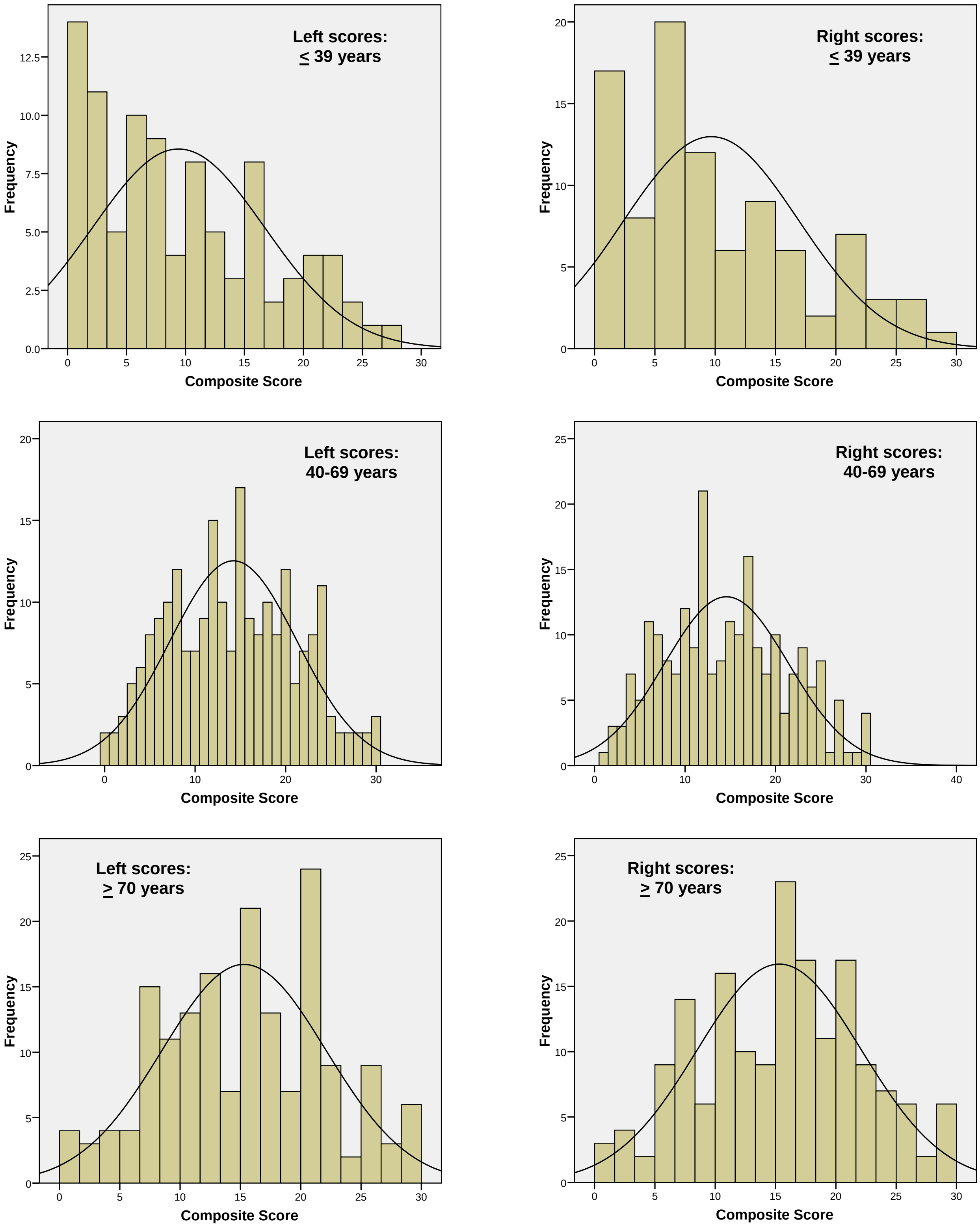


Figure 5.15. Distribution of total scores for individuals ≤ 39 years, those between 40 and 69 years and those ≥ 70 years from top to bottom with the graphs for left total scores on the left side and right total scores on the right side.

As the individual recorded ages increased, the scores increased as well, showing a possible correlation of age to endocranial scores. On the ectocranial aspect, however, there was no great shift in the scores when the recorded ages increase. Only the individuals in the youngest category seemed to have lower scores with the graphs showing that there were no differences between the individuals older than 40 years. The same can be seen in the graphs for the left and right sides of the skull. This was expected as these are also on the ectocranial aspect. It seems that with endocranial scores there is a “on-off” effect: below 40 years they are basically open, after 40 closed. This indicates an abrupt event of closure rather than a gradual prolonged slow progress of obliteration. The endocranial aspects of the composite scores were not normally distributed as the p-values for the Kolmogorov-Smirnov one-sample test (Table 5.5) were all less than 0.05. The scores for the left side were normally distributed for each individual age group but when the entire sample was pooled the result was significant indicating that the scores did not adhere to a normal distribution. This is indicated in the table (Table 5.5) with all the numbers in bold indicating that these distributions of the total scores were not normally distributed as one would expect. The ectocranial aspect and the right side are normally distributed for all ages above 40 years.

TABLE 5.5. Testing for normality of score distributions.
P-values for Kolmogorov-Smirnov one sample test

	All	***< 39 years***	***40-69 years***	***> 70 years***
Ectocranial	**0.01**	**0.03**	0.09	0.76
Endocranial	**0.00**	**0.04**	**0.00**	**0.00**
Left	**0.04**	0.14	0.23	0.47
Right	**0.02**	**0.04**	0.07	0.50

Numbers in bold indicate statistical significance

5.4 Relationship of obliteration scores to recorded age

Scatter plots of the total scores when using the Acsádi & Nemeskéri (1970) method and the Meindl and Lovejoy (1985) method were drawn to investigate any significant relationship to age. Typically, a linear correlation would be drawn to calculate the extent of the relationship of these two variables. As it was found that the data were scattered as a cluster, a "best fit" polynomial curve was fitted to the data points to achieve the best R^2 value. The graphs thus contain a polynomial curve of the second degree for all the data points except for those of the endocranial aspect. Here a polynomial to the 5^{th} degree best fitted the data (Figs 5.17 and 5.21).

Total obliteration scores

Scatter plots of total score versus recorded age showed that there was practically no significant correlation between these two variables (Figures 5.16 to 5.19). The best relationship was seen in Figure 5.17 where the endocranial score increased, to a certain degree, with an increase in recorded age (r^2= 0.349). However, even for this result the percentage of variance explained was small. Just above one third of the total could be explained by this relationship. This may have been the reason why many previous researchers recommended that only the endocranial aspect of the skull should be used when using cranial sutures for the determination of age. This advice, however, would still lead to poor prediction. It is clearly apparent that even at ages greater than 70 years, at least three individuals displayed scores of zero, while some individuals below the age of 40 years had maximum or close to maximum scores on the ectocranial aspect (Figure 5.16).

This finding was in keeping with that of Eränkö and Kihlberg (1955). Although in their study the average closure score was plotted against the recorded age of the individual there was a wide range of data points throughout the area of the graph. An average score of four, which describes a closed suture, was found in individuals whose age ranged from below 30 to 90 years (Eränkö & Kihlberg, 1955).

When using parts of the suture to calculate the total score of a suture (method of Meindl & Lovejoy, 1985), the same pattern was seen (Figures 5.18 & 5.19). When the groups are separated, there was still no considerable improvement in the correlation. The whites showed a very poor correlation while the black females showed the best correlation compared to all other groups from all aspects, except on the endocranial aspect (Figures 5.20-5.23). This may be the result of many individuals in this group being less than 40 years old.

The results of the same analysis by Key et al. (1994) (Figure 4 in their study) showed a large scatter of the data as well. The score of zero was assigned to individuals with a recorded age between zero and eighty in both systems (Key et al., 1994).

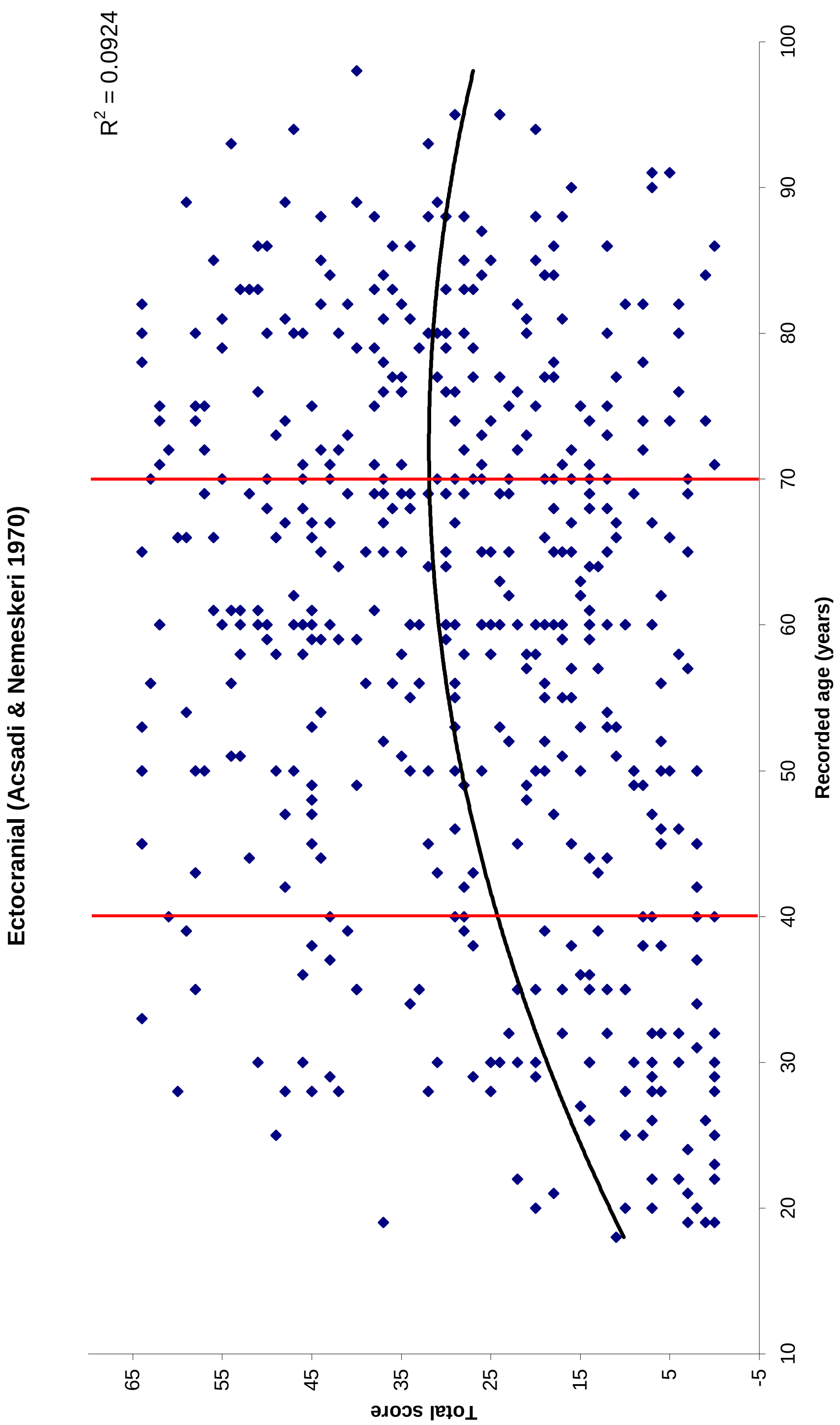


Figure 5.16. Scatter plot of recorded age vs total ectocranial score using Acsádi & Nemeskéri's (1970) method.

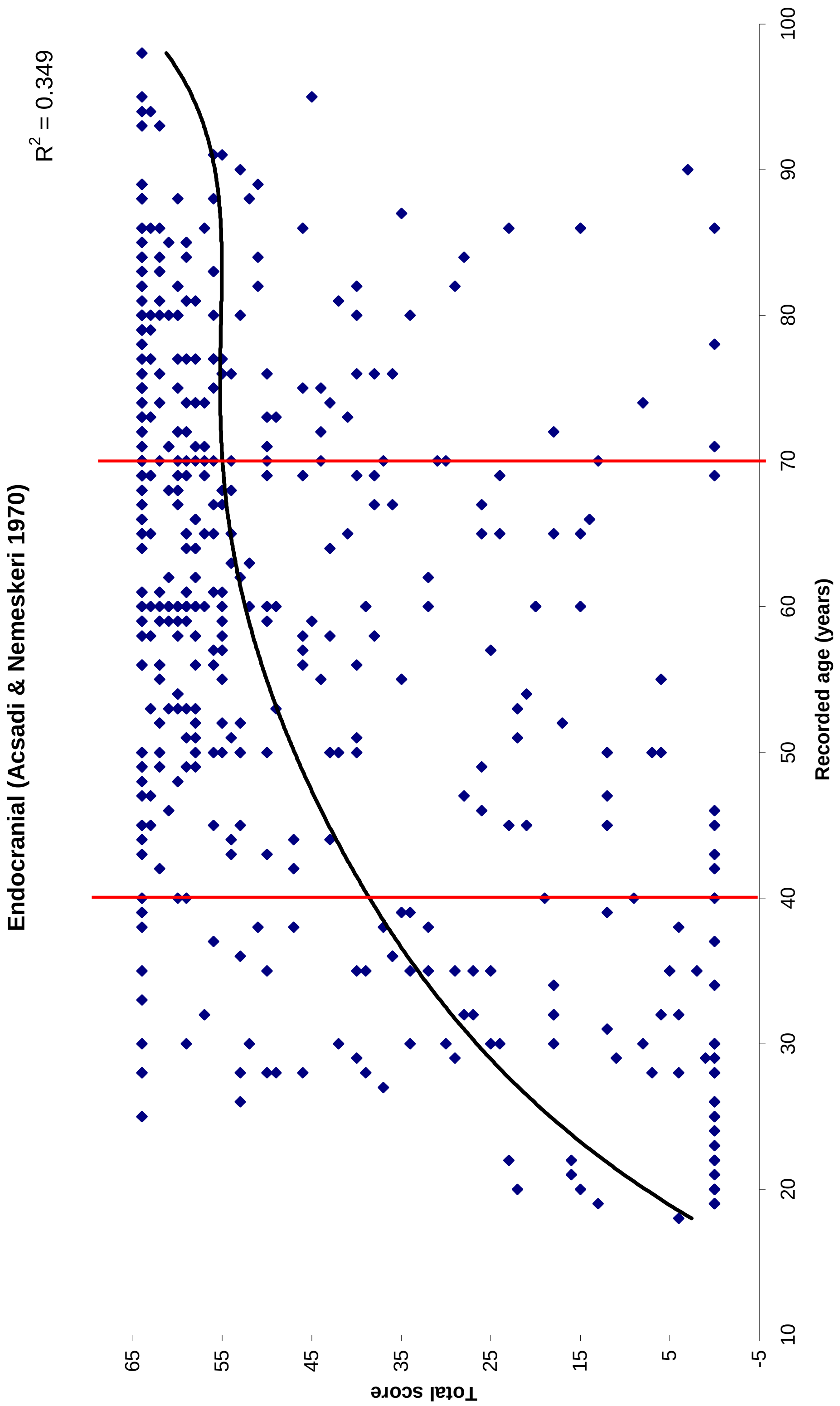


Figure 5.17. Scatter plot of recorded age vs total endocranial score using Acsádi & Nemeskéri's (1970) method.

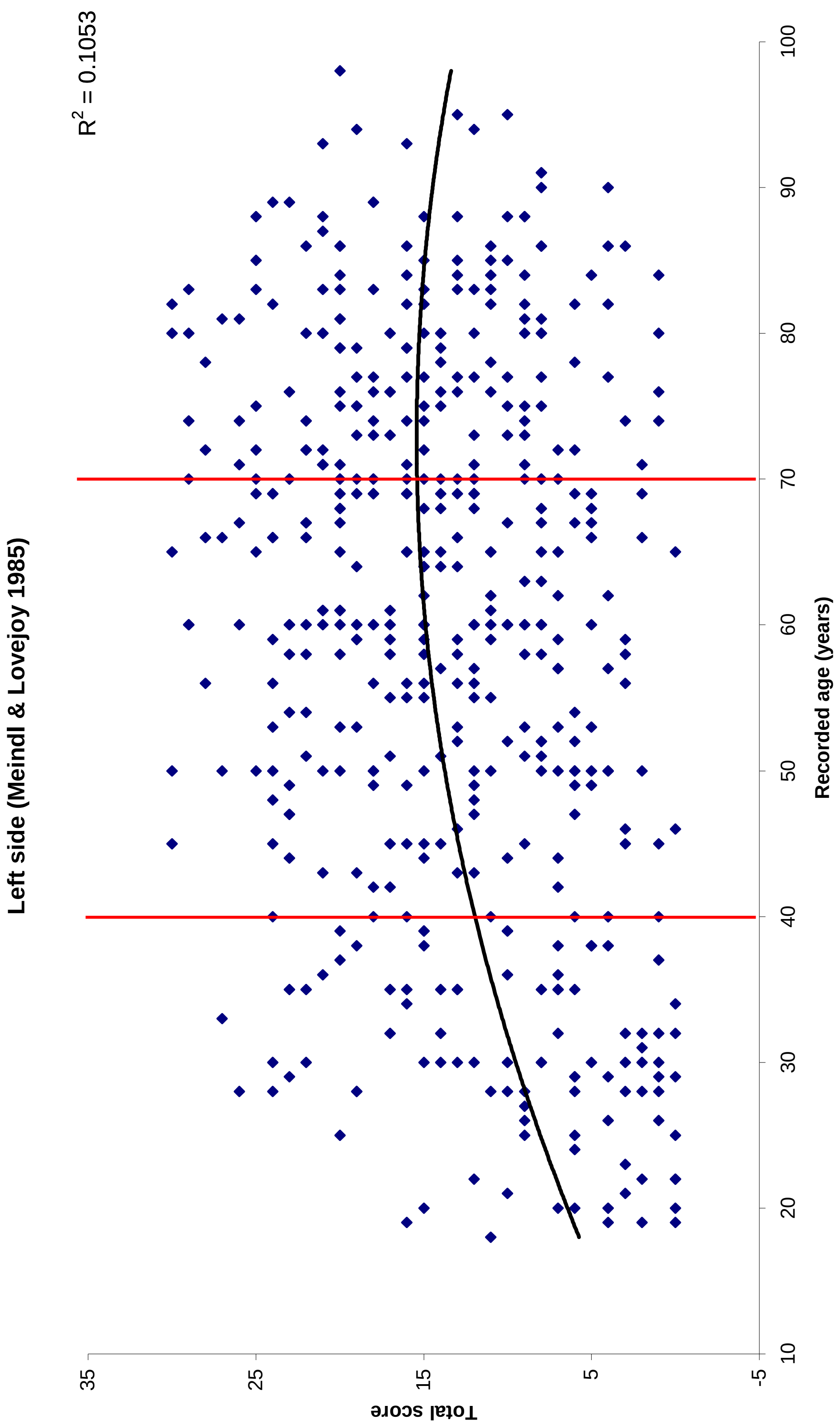


Figure 5.18. Scatter plot of recorded age vs total score, on the left side of the skull, using Meindl & Lovejoy's (1985) method.

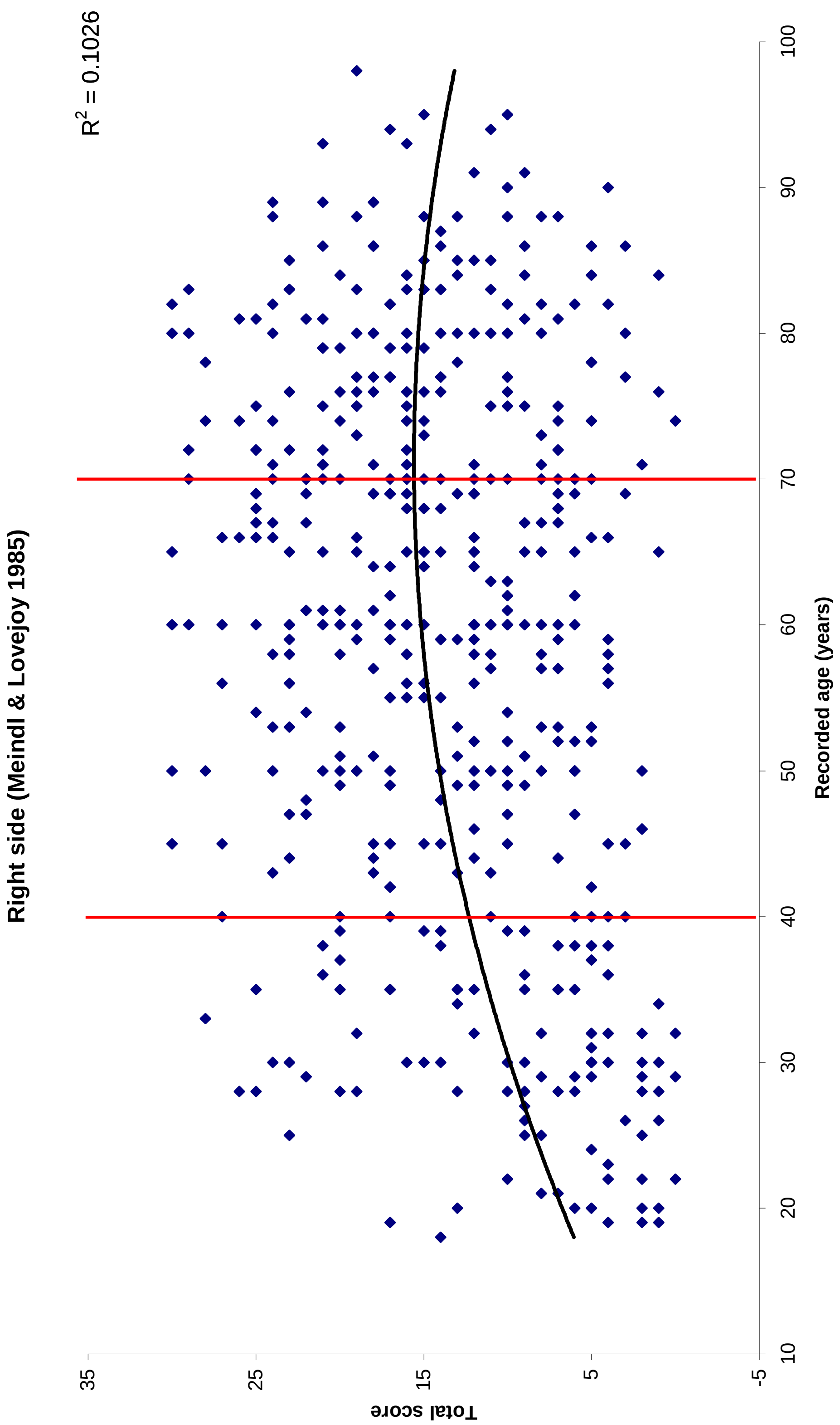


Figure 5.19. Scatter plot of recorded age vs total score, on the right side of the skull, using Meindl & Lovejoy's (1985) method.

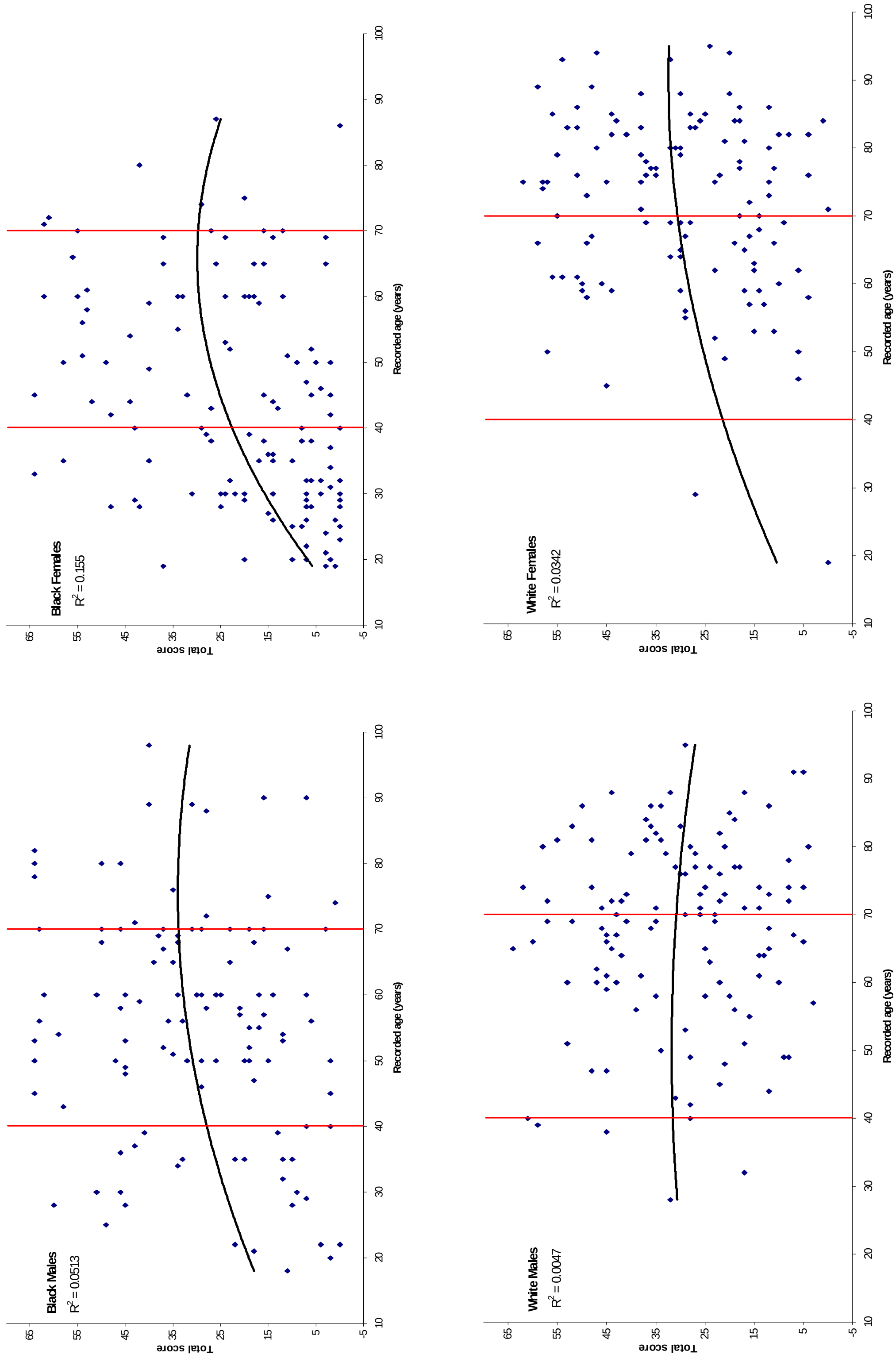


Figure 5.20. Scatter plots of recorded age vs total ectocranial score using Acsádi & Nemeskéri's (1970) method.

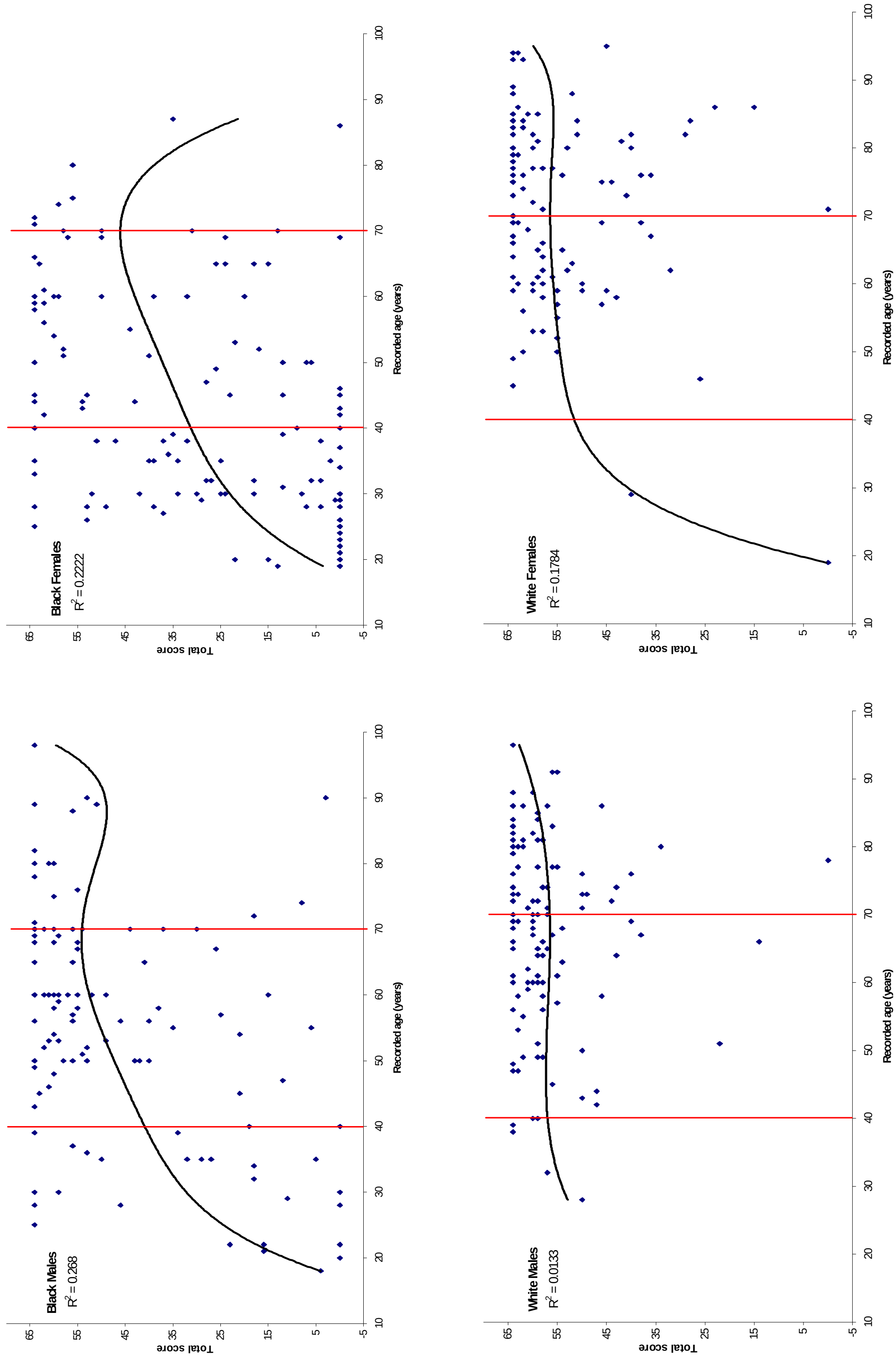


Figure 5.21. Scatter plots of recorded age vs total endocranial score using Acsádi & Nemeskéri's (1970) method.

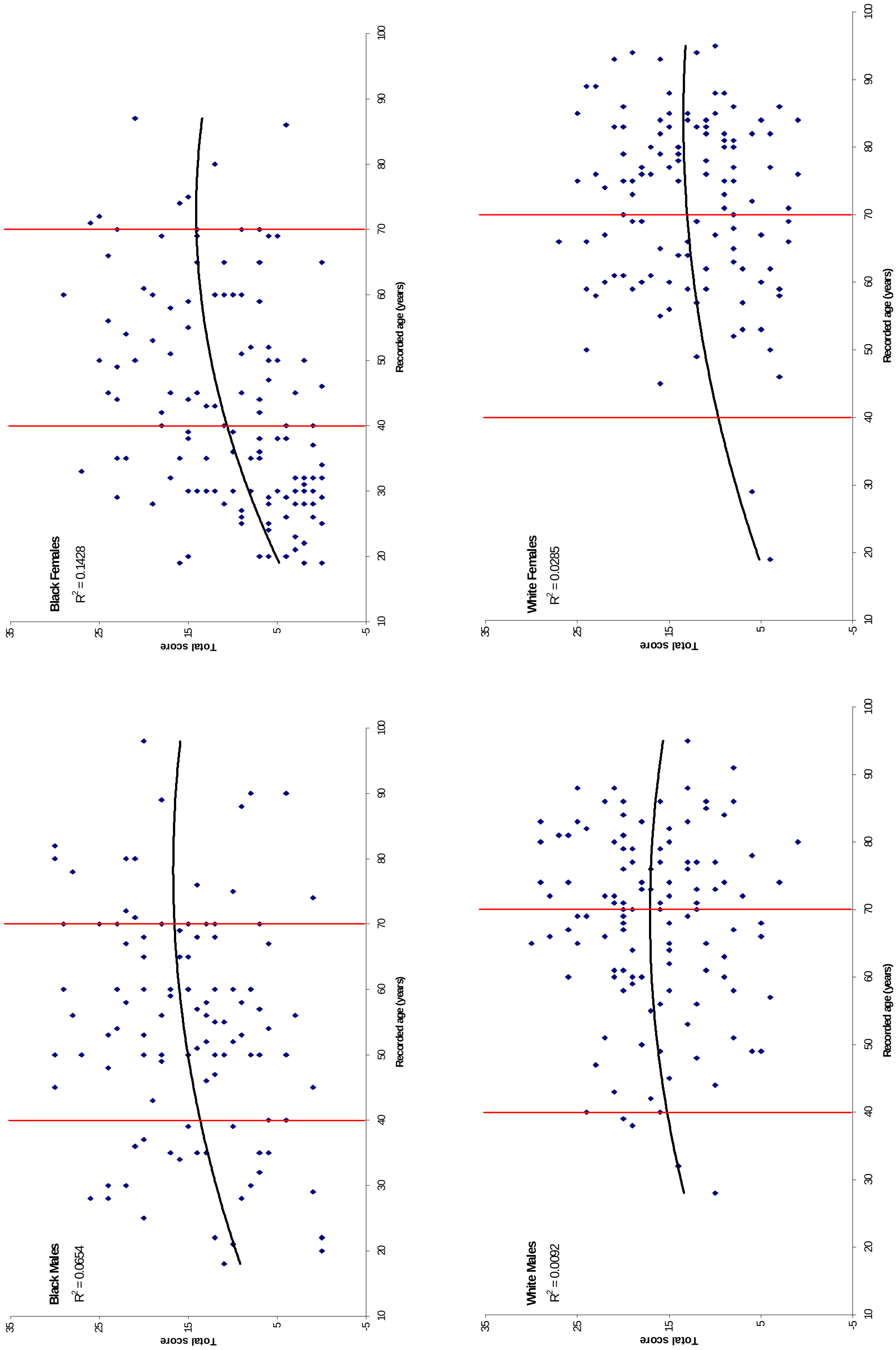


Figure 5.22. Scatter plots of recorded age vs total score, on the left side of the skull, using Meindl & Lovejoy's (1985) method.

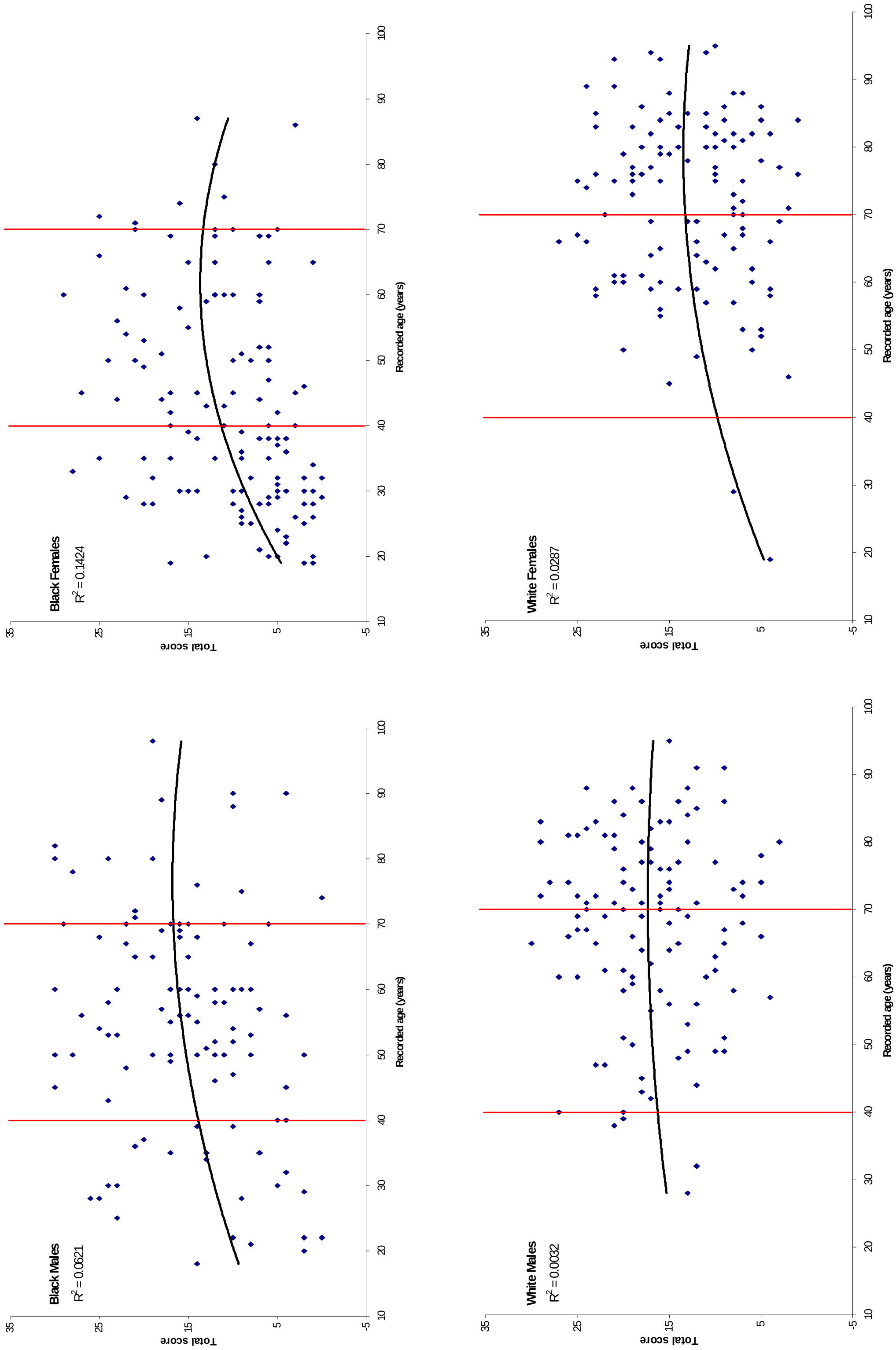


Figure 5.23. Scatter plots of recorded age vs total score, on the right side of the skull, using Meindl & Lovejoy's (1985) method.

Suture sites

As the relationship between recorded age and total scores did not show a clear trend, the scores of the parts of the sutures were then examined using the Spearman's rank correlation. The coefficients for various parts of the sutures on the ectocranial and endocranial aspects are given in Tables 5.6 to 5.8. Initially all groups were investigated, thereafter the sample was divided into males and females so that a comparison could be made to other studies that had followed the same procedure, for example Key et al., 1994. Correlations were considered significant at the 0.05 level.

The *pars asterica* was the only part of the lambdoid suture on the ectocranial aspect that showed a significant correlation when the entire sample was analysed (Table 5.6). None of the values were greater than 0.29 when the entire sample was analysed. The males showed no significant correlations in any of the sites, and the correlation coefficients were much less than those seen in the entire sample. The females, however, displayed significant correlations with age only in the *pars complicata* of the coronal suture. The correlation coefficients in certain aspects were greater than for the males and the entire sample. This might be due to the high number of individuals that were younger than 40 years in this group.

The endocranial aspect (Table 5.7) did not display any significant correlation coefficients but the correlations were much higher than those seen on the ectocranial aspect. The range for the entire sample was from 0.32 to 0.42. The values for the males and females were also greater than those seen on the ectocranial aspect. The largest correlation coefficients for the females were 0.52 for the *pars bregmatica* and the *pars vertices*, while the lowest correlation found was that of the males at the *pars obelica (0.18).*

TABLE 5.6. Correlation with recorded age using the Spearman's rank correlation coefficient (rho) for ectocranial suture sites when using Acsadi & Nemeskeri's (1970) method

Suture Site	All Crania		Males		Females	
	rho	*n*	*rho*	*n*	*rho*	*n*
Coronal						
Pars Bregmatica-Left	0.15	486	0.03	236	0.25	250
Pars Bregmatica-Right	0.13	486	0.01	236	0.24	250
Pars Complicata-Left	0.06	486	-0.06	236	**0.15**	250
Pars Complicata-Right	0.03	486	-0.07	236	**0.13**	250
Pars Pterica-Left	0.27	486	0.26	236	0.26	250
Pars Pterica-Right	0.27	486	0.27	236	0.26	250
Sagittal						
Pars Bregmatica	0.21	486	0.04	236	0.31	250
Pars Vertices	0.29	486	0.08	236	0.44	250
Pars Obelica	0.27	486	0.11	236	0.39	250
Pars Lambdica	0.25	486	0.07	236	0.36	250
Lambdoid						
Pars Lambdica-Left	0.21	486	0.07	236	0.29	250
Pars Lambdica-Right	0.20	486	0.04	236	0.30	250
Pars Intermedia-Left	0.19	486	0.03	236	0.30	250
Pars Intermedia-Right	0.18	486	0.05	236	0.28	250
Pars Asterica-Left	**0.11**	486	-0.03	236	0.21	250
Pars Asterica-Right	0.14	486	-0.02	236	0.27	250

Numbers in bold indicate correlation is significant at the 0.05 level (2-tailed)

When one centimetre sections of the sutures were evaluated and correlated to age, the results differed when compared to the results using the Acsádi and Nemeskéri (1970) method (Table 5.8). The left and right inferior spheno-temporal sites were the only sites where a significant correlation was found. The correlation coefficients were not as high as those of the ectocranial and endocranial aspects. The males only showed a significant correlation at the 0.05 level for the left superior spheno-temporal site. The females on the other hand showed significant correlations for the pterion and the left spheno-frontal sites. The correlation coefficients in some cases were also much lower than those of the ectocranial and endocranial aspects when the Acsádi and Nemeskéri (1970) method was used.

TABLE 5.7. Correlation with recorded age using the Spearman's rank correlation coefficient (rho) for endocranial suture sites when using Acsadi & Nemeskeri's (1970) method

	All Crania		***Males***		***Females***	
Suture Site	***rho***	***n***	***rho***	***n***	***rho***	***n***
Coronal						
Pars Bregmatica-Left	0.42	486	0.27	236	0.51	250
Pars Bregmatica-Right	0.42	486	0.30	236	0.49	250
Pars Complicata-Left	0.39	486	0.29	236	0.44	250
Pars Complicata-Right	0.36	486	0.21	236	0.45	250
Pars Pterica-Left	0.43	486	0.27	236	0.51	250
Pars Pterica-Right	0.40	486	0.24	236	0.48	250
Sagittal						
Pars Bregmatica	0.42	486	0.25	236	0.52	250
Pars Vertices	0.42	486	0.28	236	0.52	250
Pars Obelica	0.32	486	0.18	236	0.44	250
Pars Lambdica	0.39	486	0.23	236	0.48	250
Lambdoid						
Pars Lambdica-Left	0.40	486	0.27	236	0.47	250
Pars Lambdica-Right	0.40	486	0.28	236	0.47	250
Pars Intermedia-Left	0.41	486	0.27	236	0.48	250
Pars Intermedia-Right	0.41	486	0.27	236	0.48	250
Pars Asterica-Left	0.38	486	0.27	236	0.43	250
Pars Asterica-Right	0.41	486	0.30	236	0.45	250

Numbers in bold indicate correlation is significant at the 0.05 level (2-tailed)

The correlation coefficients of the present study were extremely low when compared to those in the study carried out by Key et al. (1994) (see Table 6 in Key et al., 1994). The correlations ranged from 0.32 to 0.94 for the entire sample in the Key et al. (1994) study while in the present study there were a few negative values. The correlations for females in the Key et al. (1994) study, however, were closer to the results of the present study but also had a much higher range (Key et al., 1994).

The correlations of the present study compared well with those of Perizonius (1994). Although the correlations of the entire suture were calculated, the values were much closer than those for the study by Key et al. (1994).

TABLE 5.8. Correlation with recorded age using the Spearman's rank correlation coefficient (rho) for suture sites when using Meindl & Lovejoy's (1985) method

	All Crania		Males		Females	
Suture Site	***rho***	***n***	***rho***	***n***	***rho***	***n***
Coronal						
Mid-coronal-Left (6)	-0.01	486	-0.11	236	0.08	250
Mid-coronal-Right (6)	-0.02	486	-0.09	236	0.04	250
Pterion-Left (7)	0.30	486	0.32	236	0.27	250
Pterion-Right (7)	0.22	486	0.28	236	**0.15**	250
Sagittal						
Bregma (5)	0.15	486	0.02	236	0.24	250
Anterior Sagittal (4)	0.25	486	0.05	236	0.39	250
Obelion (3)	0.23	486	0.09	236	0.33	250
Lambdoid						
Lambda (2)	0.22	486	0.10	236	0.29	250
Midlambdoid-Left (1)	0.17	486	0.02	236	0.27	250
Midlambdoid-Right (1)	0.17	486	0.02	236	0.28	250
Accessory						
Spheno-frontal-Left (8)	0.22	486	0.32	236	**0.12**	250
Spheno-frontal-Right (8)	0.18	486	0.26	236	0.09	250
Inf. Spheno-temporal-Left (9)	**0.12**	486	0.22	236	-0.04	250
Inf. Spheno-temporal-Right (9)	**0.11**	486	0.23	236	-0.07	250
Sup. Spheno-temporal-Left (10)	0.02	486	**0.17**	236	-0.20	250
Sup. Spheno-temporal-Right (10)	0.05	486	0.20	236	-0.18	250

Numbers in bold indicate correlation is significant at the 0.05 level (2-tailed)

5.5 Fluctuating asymmetry

The advantage of having an observation for both sides of the skull enables correlation coefficients to be calculated between the left and right sides of the same skull. Such correlation coefficients can then be used to assess the fluctuating asymmetry (Table 5.9). The correlations between the left and right sides of the skull for the entire skeletal sample are illustrated in Figures 5.24 to 5.26. Both the coronal and lambdoid sutures are shown on the same graph when the sutures are divided according to the Acsádi and Nemeskéri (1970) method (Fig 5.24 and 5.25) while the correlation of the sections of the sutures using the Meindl & Lovejoy (1985) method is shown in Figure 5.26. Bar charts have been drawn here to illustrate the correlation of the right and left sides of the skull. The correlation is represented by the coloured part of the bar while the black strip is the representation of the amount of deviation that might be explained by other factors like the environment.

On the ectocranial aspect (Fig 5.24) the correlation decreased from the medial to lateral part of the coronal suture while the parts of the lambdoid suture showed a similar correlation to each other when dividing the suture into three equal parts. All these correlations on the ectocranial aspect were greater than 0.8.

On the endocranial aspect (Figure 5.25) the *pars bregmatica* and the *pars pterica* had the same correlation while the *pars complicata* showed a correlation much less than the former two parts. The parts of the lambdoid suture showed similar correlations to each other, with all values above 0.9. A totally different pattern (Figure 5.26) is seen when parts of the ectocranial suture are examined using the sites suggested by Meindl and Lovejoy (1985). The highest correlation between the left and right sides were that of the mid-coronal site, which had a correlation coefficient of 0.9

and the lowest correlation between the two sides was illustrated at the spheno-frontal suture (0.75).

When the samples were divided into the age categories used previously, a difference was noticed in the correlation coefficients for the different groups (Figure 5.27 to 5.32). The ectocranial and endocranial aspects of the coronal suture are presented first (Figures 5.27 and 5.28) using the Acsádi and Nemeskéri (1970) method and then the aspects of the lambdoid suture (Figures 5.29 and 5.30) using the same method.

The best correlation of the *pars bregmatica* was found in the under 39 years age group (Figure 5.27). The *pars complicata* had a slightly lower value than the *pars bregmatica* but the *pars pterica* had the least value of the three parts of the coronal suture on the ectocranial aspect. The *pars complicata* was the only part that showed a decrease in correlation with an increase in age. On the endocranial aspect the same trend, showing a decrease in the correlation coefficient with age, was visible for the *pars bregmatica* and the *pars pterica* (Fig 5.28). This pattern was opposite to that of the ectocranial aspect, which showed an increase in the correlation with age for these two parts. The lambdoid suture on the ectocranial aspect (Fig 5.29) showed a higher correlation between the left and right sides with the correlations decreasing as the ages increased. On the endocranial aspect all correlations were around 0.9 (Fig 5.30).

When one centimetre sections of the suture were scored and correlated between the left and right sides, the pterion, spheno-frontal, inferior and superior spheno-temporal parts (Fig 5.31- 5.32) showed a much lower correlation compared to the parts of the suture when dividing the entire suture into three equal parts (Figure 5.27 to 5.30). The mid-coronal and mid-lambdoid, however, showed correlations comparable to those of the previous section (Fig 5.31).

Asymmetry of the closure of cranial sutures has previously been shown on a few populations like Europeans and East African Bantus (Zivanovic, 1983). This study showed that the patterns of suture closure between the right and left side of the skull are almost never the same. This is in agreement with the present study as none of the correlations between the right and left side of the skull gives a value of one minus the error or one minus the correlation between the first and second score of the same site.

The fluctuating asymmetry of the coronal and lambdoid sutures was assessed with the results presented in Table 5.9. The fluctuating asymmetry indices for the ectocranial aspects, when using the Acsádi and Nemeskéri (1970) method are generally lower than the ectocranial sites when using the Meindl and Lovejoy (1985) method. Since the latter method only assesses a certain section of the suture, other factors play a greater role in the final state of the obliteration. On the endocranial aspect the indices are lower than the ectocranial aspect (Table 5.9). The reason for this artefact could be related to the fact that endocranial sutures have been shown to close more often than the ectocranial aspects.

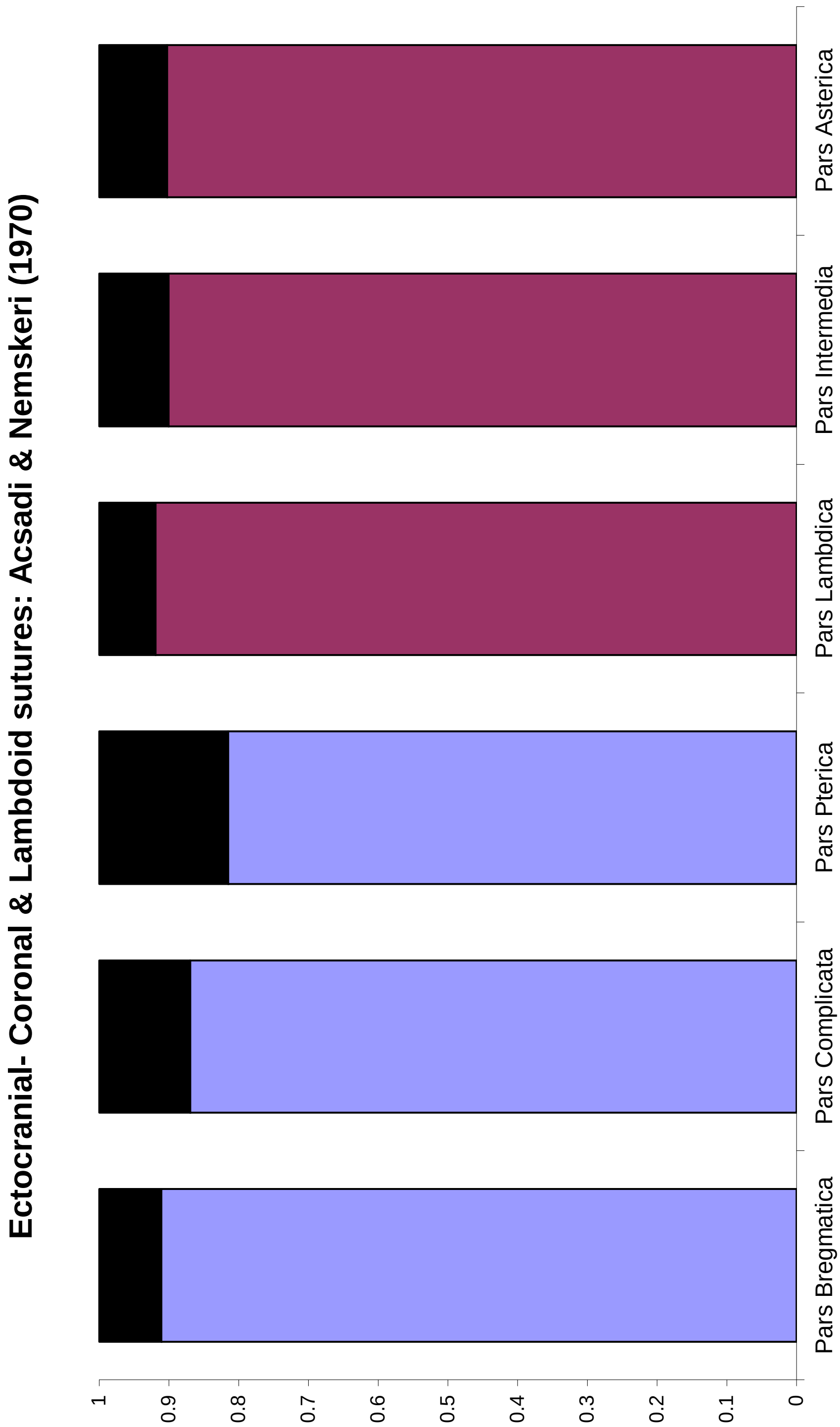


Figure 5.24. Correlation between left and right obliteration scores to indicate fluctuating asymmetry on the ectocranial aspect for the entire sample using Acsádi & Nemeskéri's (1970) method. The coloured bar represents the correlation while the black strip represents the amount of deviation that might be explained by other factors.

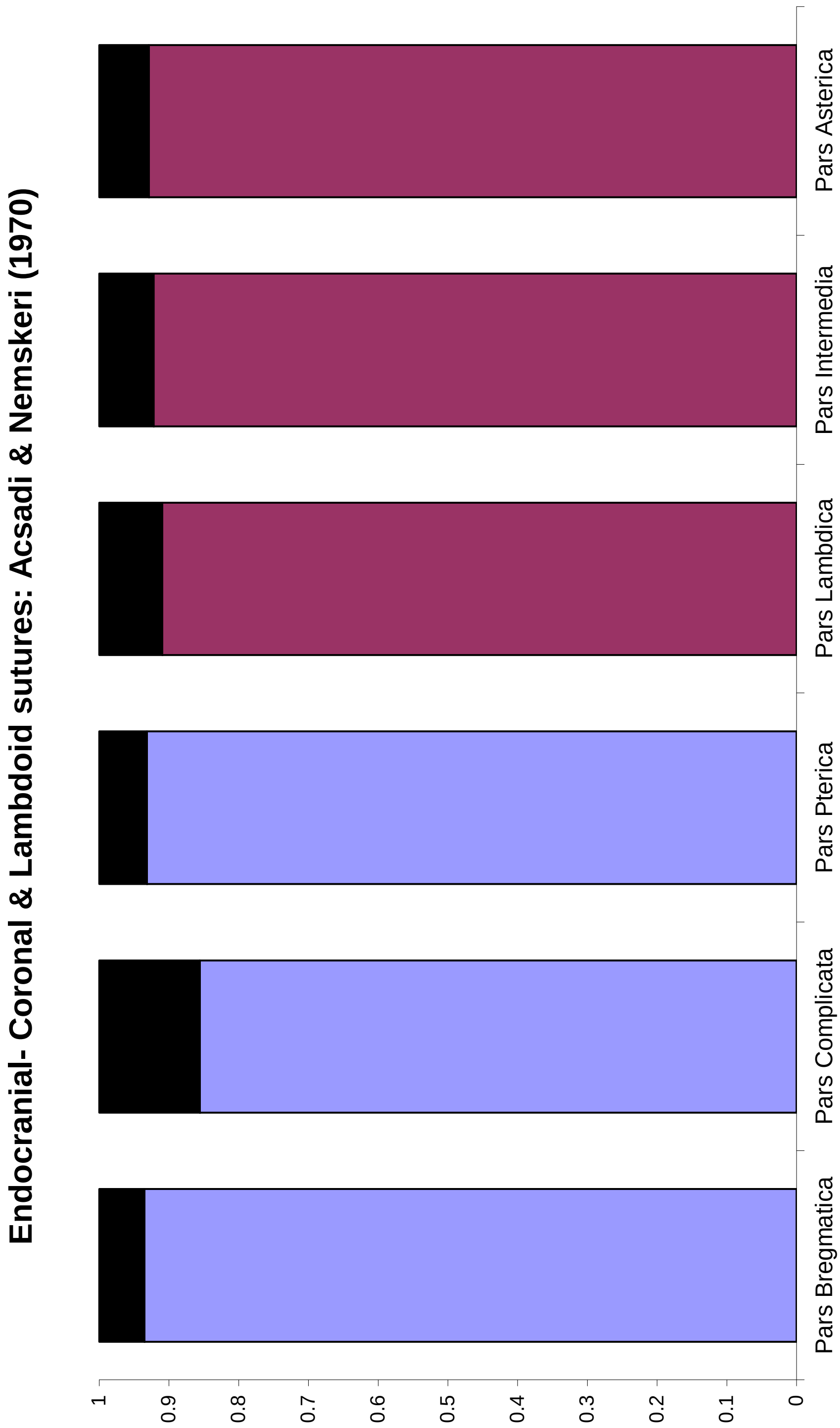


Figure 5.25. Correlation between left and right obliteration scores to indicate fluctuating asymmetry on the endocranial aspect for the entire sample using Acsádi & Nemeskéri's (1970) method. The coloured bar represents the correlation while the black strip represents the amount of deviation that might be explained by other factors.

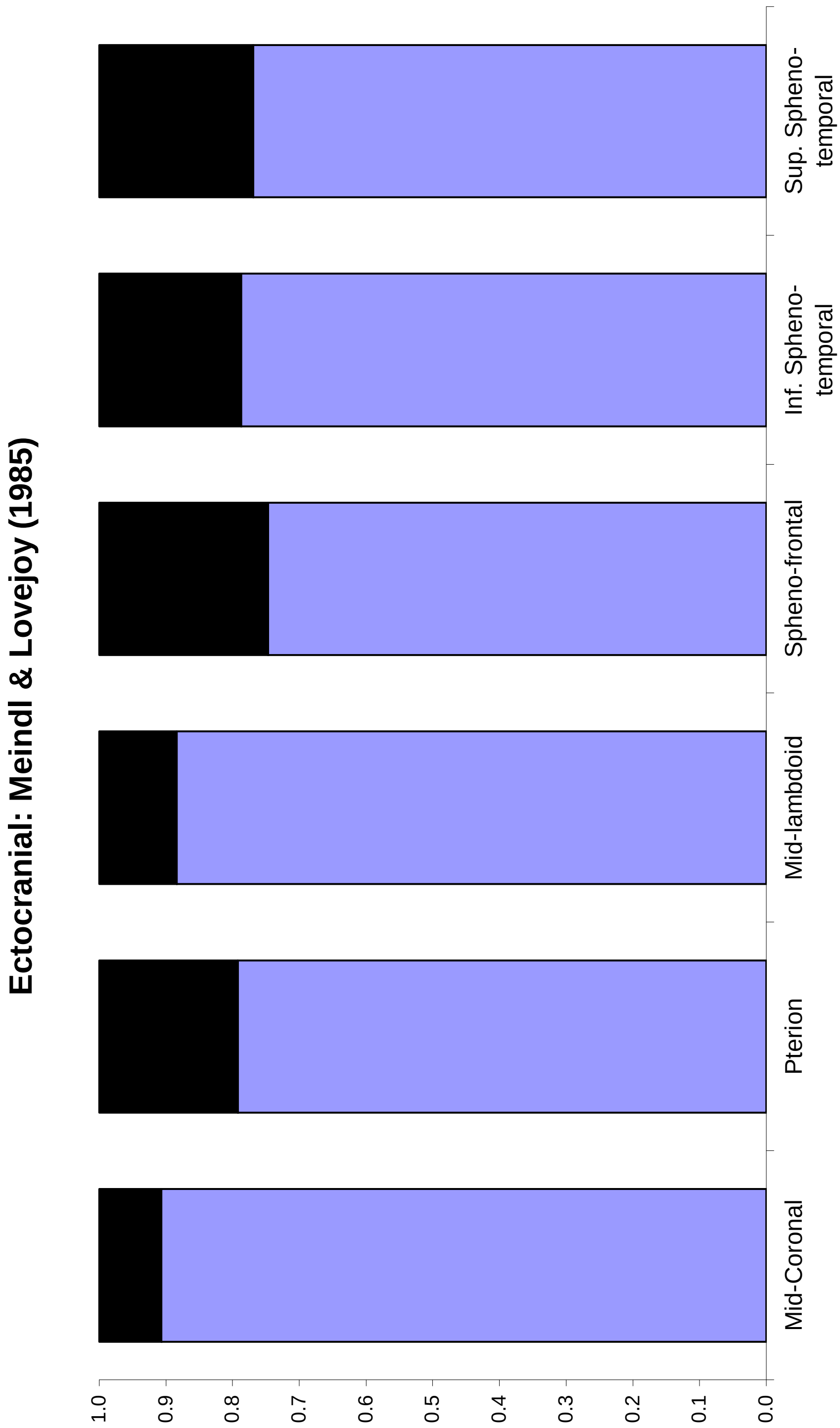


Figure 5.26. Correlation between left and right obliteration scores to indicate fluctuating asymmetry on the ectocranial aspect for the entire sample using Meindl & Lovejoy's (1985) method. The coloured bar represents the correlation while the black strip represents the amount of deviation that might be explained by other factors.

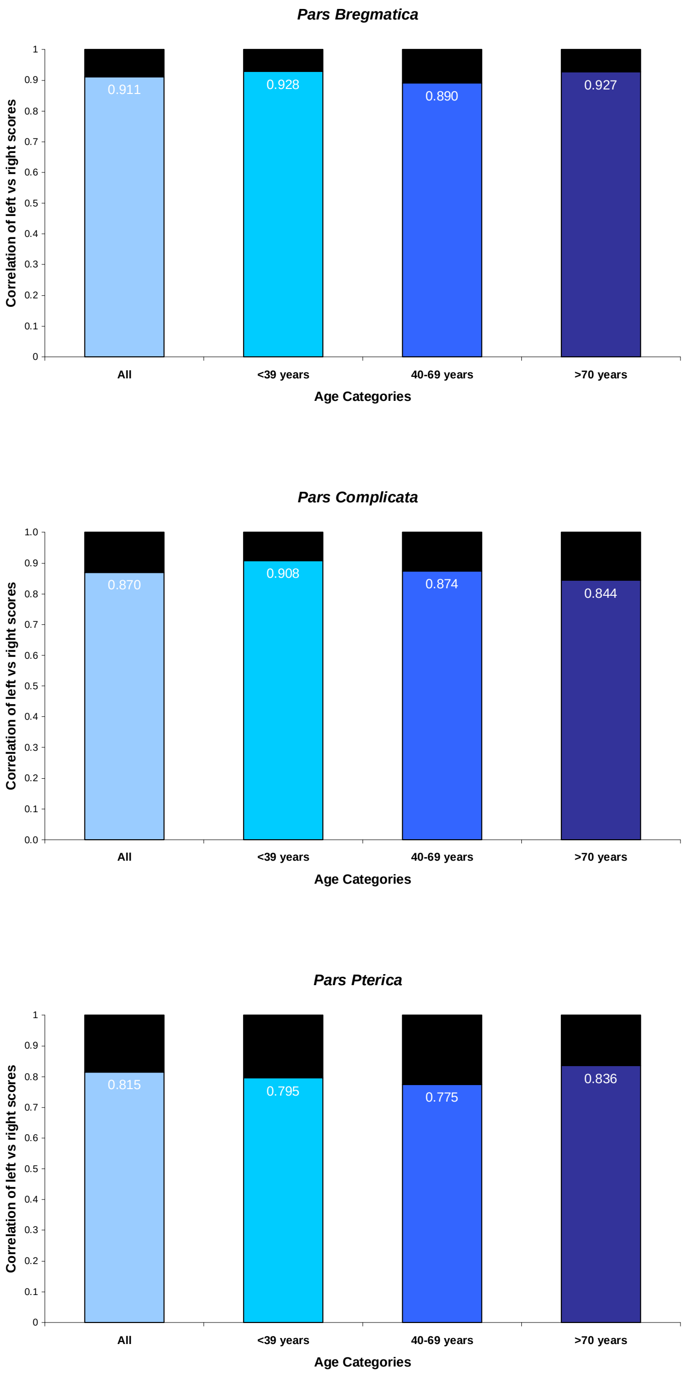


Figure 5.27. Correlation between left and right obliteration scores to indicate fluctuating asymmetry for the coronal suture parts on the ectocranial aspect for the entire sample. The coloured bar represents the correlation while the black strip represents the amount of deviation that might be explained by other factors.

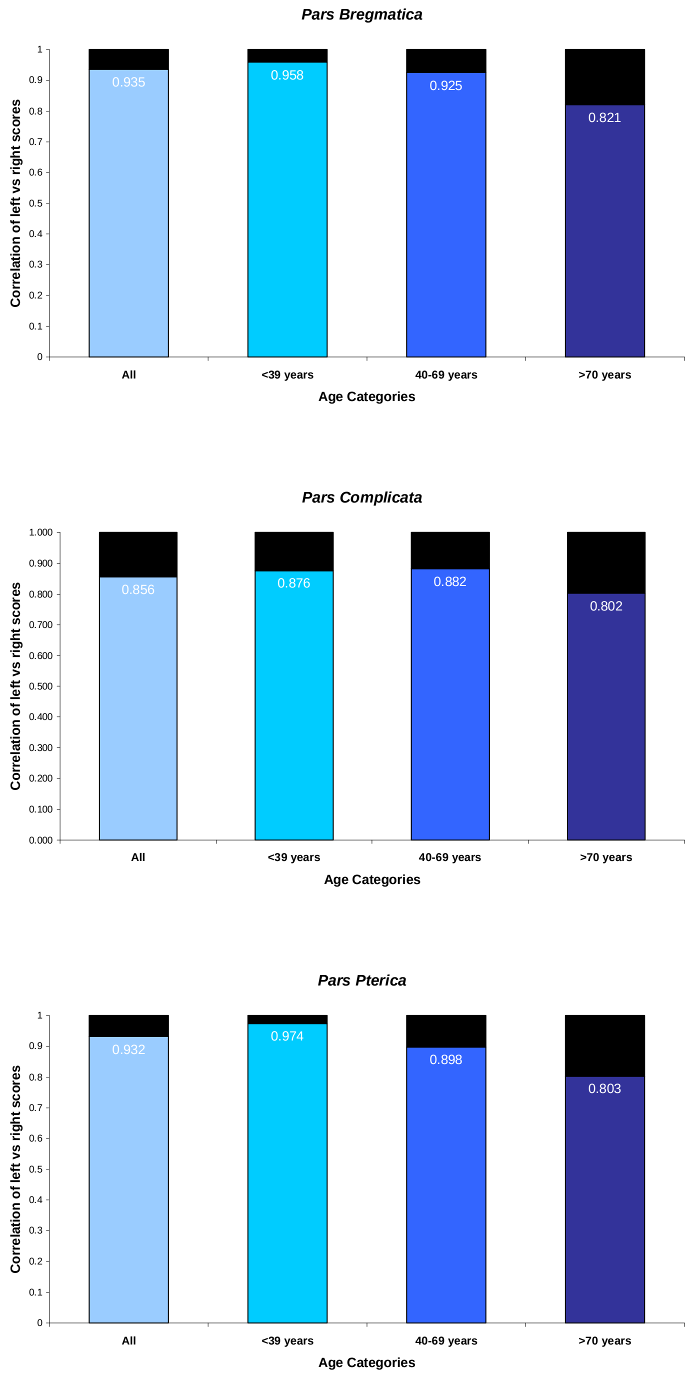


Figure 5.28. Correlation between left and right obliteration scores to indicate fluctuating asymmetry for the coronal suture parts on the endocranial aspect for the entire sample. The coloured bar represents the correlation while the black strip represents the amount of deviation that might be explained by other factors.

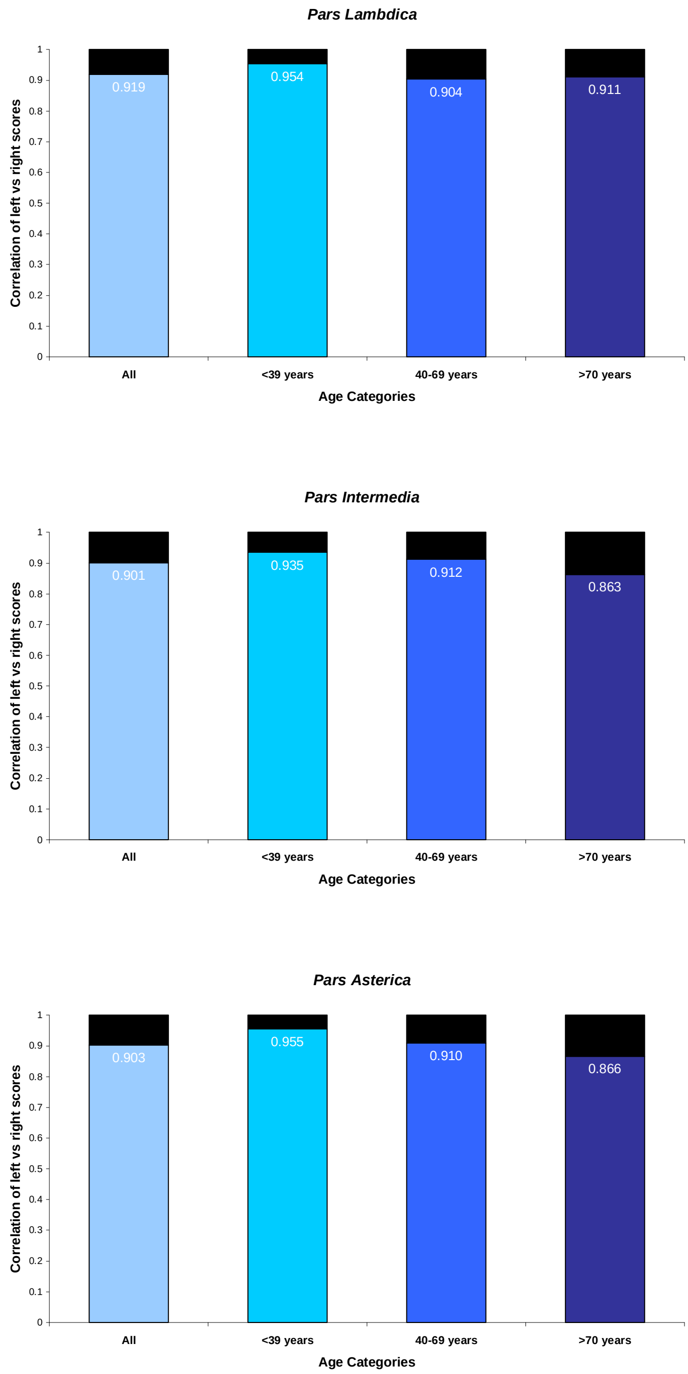


Figure 5.29. Correlation between left and right obliteration scores to indicate fluctuating asymmetry for the lambdoid suture parts on the ectocranial aspect for the entire sample. The coloured bar represents the correlation while the black strip represents the amount of deviation that might be explained by other factors.

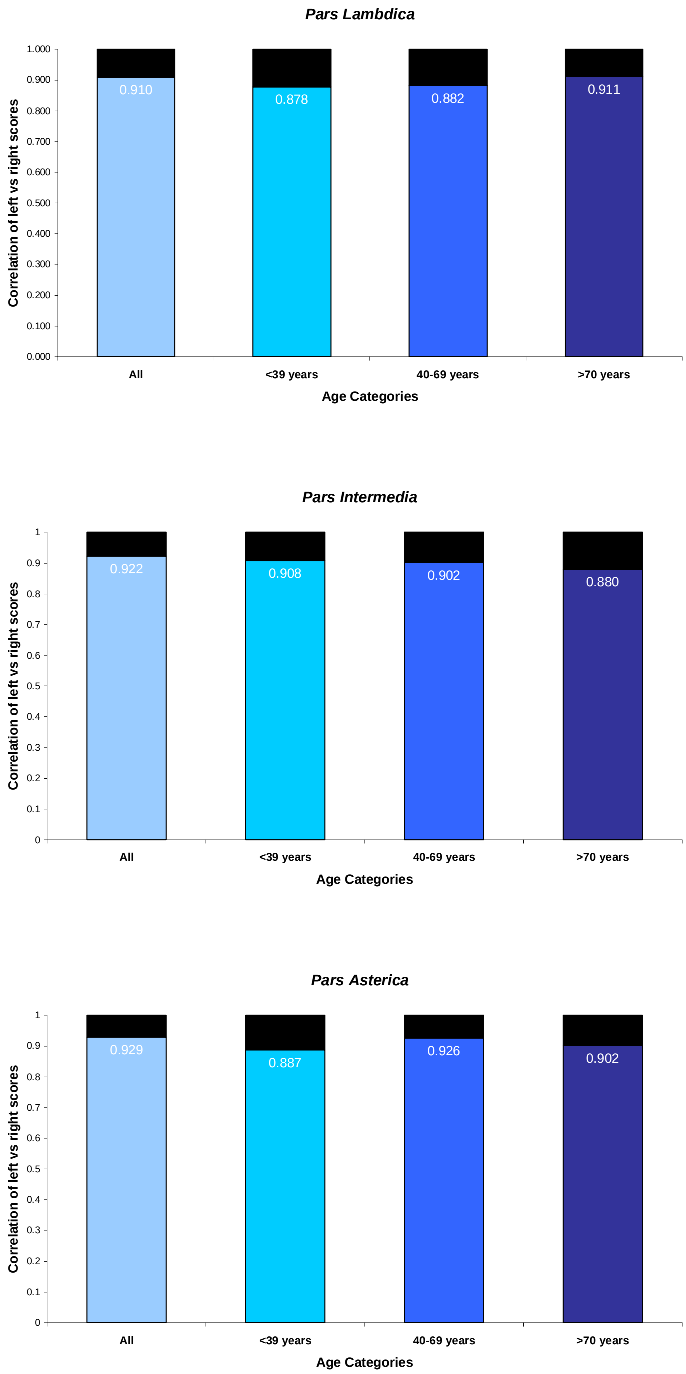


Figure 5.30. Correlation between left and right obliteration scores to indicate fluctuating asymmetry for the lambdoid suture parts on the endocranial aspect for the entire sample. The coloured bar represents the correlation while the black strip represents the amount of deviation that might be explained by other factors.

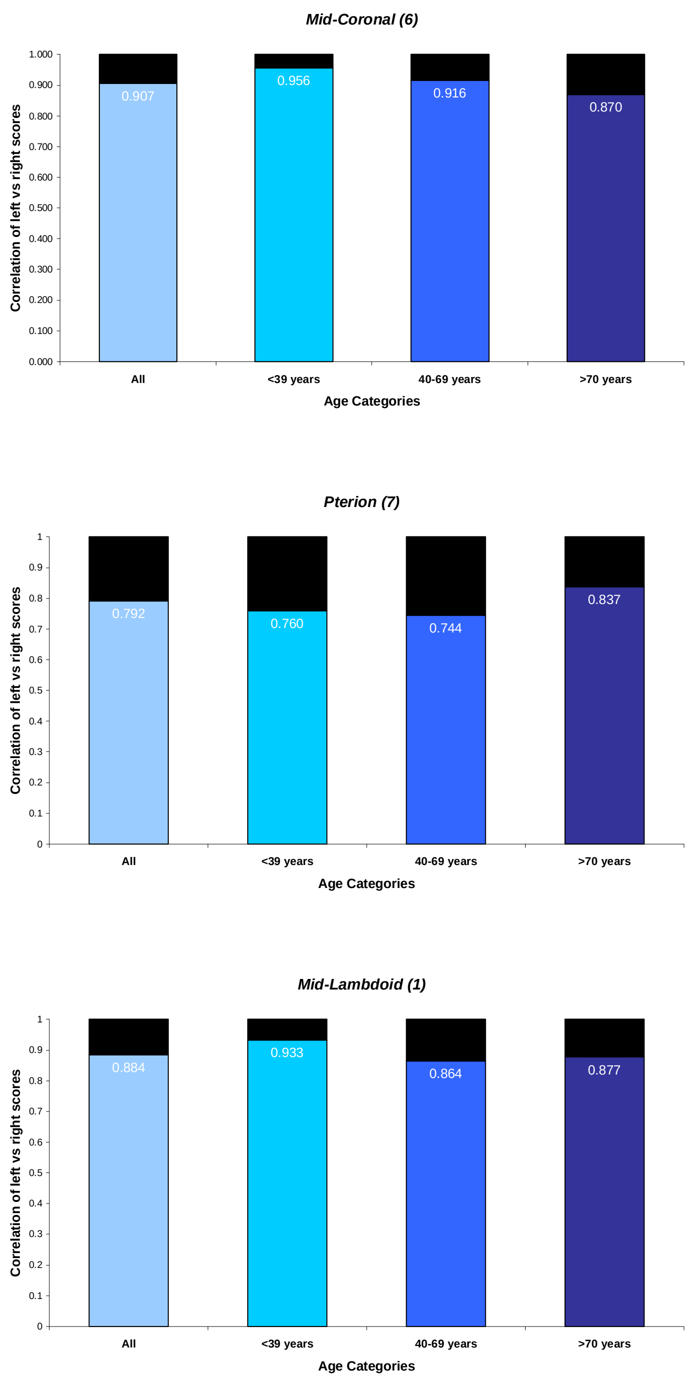


Figure 5.31. Correlation between left and right obliteration scores to indicate fluctuating asymmetry for the mid-coronal, pterion and mid-lambdoid sections on the ectocranial aspect for the entire sample. The coloured bar represents the correlation while the black strip represents the amount of deviation that might be explained by other factors.

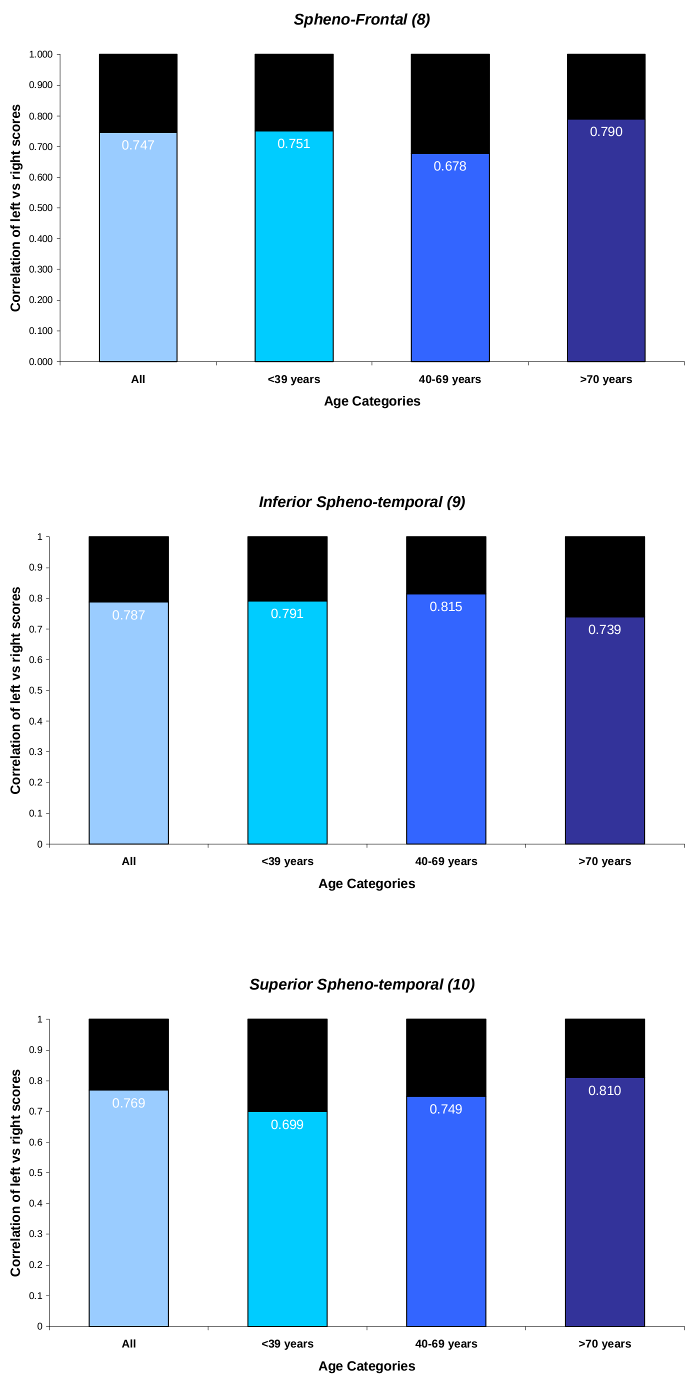


Figure 5.32. Correlation between left and right obliteration scores to indicate fluctuating asymmetry for the spheno-frontal, superior and inferior spheno-temporal sections on the ectocranial aspect for the entire sample. The coloured bar represents the correlation while the black strip represents the amount of deviation that might be explained by other factors.

TABLE 5.9. Fluctuating asymmetry indices for bilateral sites.

	Acsadi & Nemeskeri (1970)					Meindl & Lovejoy (1985)	
	Ectocranial		Endocranial			Ectocranial	
	r	$1 - r^2$	r	$1 - r^2$		r	$1 - r^2$
Pars Bregmatica					***Mid-coronal (6)***		
All	0.911	0.170	0.935	0.126	***All***	0.907	0.177
≤ 39 years	0.928	0.139	0.958	0.082	***≤ 39 years***	0.956	0.086
40-69 years	0.890	0.208	0.925	0.144	***40-69 years***	0.916	0.161
≥ 70 years	0.927	0.141	0.821	0.326	***≥ 70 years***	0.870	0.243
Pars Complicata					***Pterion (7)***		
All	0.870	0.243	0.856	0.267	***All***	0.792	0.373
≤ 39 years	0.908	0.176	0.876	0.233	***≤ 39 years***	0.760	0.422
40-69 years	0.874	0.236	0.882	0.222	***40-69 years***	0.744	0.446
≥ 70 years	0.844	0.288	0.802	0.357	***≥ 70 years***	0.837	0.299
Pars Pterica					***Midlambdoid (1)***		
All	0.815	0.336	0.932	0.131	***All***	0.884	0.219
≤ 39 years	0.795	0.368	0.974	0.051	***≤ 39 years***	0.933	0.130
40-69 years	0.775	0.399	0.898	0.194	***40-69 years***	0.864	0.254
≥ 70 years	0.836	0.301	0.803	0.355	***≥ 70 years***	0.877	0.231
Pars Lambdica					***Spheno-frontal (8)***		
All	0.919	0.155	0.910	0.172	***All***	0.747	0.442
≤ 39 years	0.954	0.090	0.878	0.229	***≤ 39 years***	0.751	0.436
40-69 years	0.904	0.183	0.882	0.222	***40-69 years***	0.678	0.540
≥ 70 years	0.911	0.170	0.911	0.170	***≥ 70 years***	0.790	0.376
Pars Intermedia					***Inf. Spheno-temporal (9)***		
All	0.901	0.188	0.922	0.150	***All***	0.787	0.381
≤ 39 years	0.935	0.126	0.908	0.176	***≤ 39 years***	0.791	0.374
40-69 years	0.912	0.168	0.902	0.186	***40-69 years***	0.815	0.336
≥ 70 years	0.863	0.255	0.880	0.226	***≥ 70 years***	0.739	0.454
Pars Asterica					***Sup. Spheno-temporal (10)***		
All	0.903	0.185	0.929	0.137	***All***	0.769	0.409
≤ 39 years	0.955	0.088	0.887	0.213	***≤ 39 years***	0.699	0.511
40-69 years	0.910	0.172	0.926	0.143	***40-69 years***	0.749	0.439
≥ 70 years	0.866	0.250	0.902	0.186	***≥ 70 years***	0.810	0.344

5.6 Comparison of the application tables of the method of estimating age

Acsádi and Nemeskéri (1970) method

The age estimation table that was given in Acsádi & Nemeskéri (1970) and the comparison table created by Key and colleagues (1994) were replicated here to compare those tables to the results of the present study (Table 5.10). Acsádi and Nemeskéri (1970) had originally collected data from both the endocranial and ectocranial aspect but eventually suggested only using the endocranial aspect as they found the pattern of obliteration on the ectocranial aspect was too erratic to use as an aging technique. The table is organized with the results using the endocranial aspects of the skull initially for both the Acsádi and Nemeskéri (1970), Key et al., (1994) and the present study and then the results using the ectocranial aspects from the present study only.

The table shows the five stages of closure (Table 5.10) including the range of the mean scores, the mean age of each stage, the standard deviation of each stage, the number of individuals that fell into each stage and finally the range of the ages of each stage. In the present study an extra stage has been added to represent the mean score of 0-0.3. This stage was not present in either the Acsádi and Nemeskéri (1970) nor the Key et al., (1994) studies but the present study found a large number of individuals in this category and therefore it was added as stage zero in the table.

TABLE 5.10. Comparison of the mean ages using the mean closure scores as first described by Acsadi & Nemskeri (1970)

Acsadi & Nemeskeri (1970) (Endocranial)

	Mean closure score			Mean Age		Sample size		Age
Stage number	Min	Max	Difference	(in years)	SD	n	n (%)	Range
1	0.4	1.5	1.1	28.6	13.1	16	5.6	**15-40**
2	1.6	2.5	0.9	43.7	14.5	29	10.2	**30-60**
3	2.6	2.9	0.3	49.1	16.4	17	6.0	**35-65**
4	3.0	3.9	0.9	60.0	13.2	162	56.8	**45-75**
5	4.0	4.0	0.0	65.4	14.1	61	21.4	**50-80**

Key, Aiello, Molleson (1994) (Endocranial)

	Mean closure score			Mean Age		Sample size		Age
Stage number	Min	Max	Difference	(in years)	SD	n	n (%)	Range
1	0.4	1.5	1.1	30.9	11.6	8	6.4	**18-55**
2	1.6	2.5	0.9	52.9	16.3	14	11.2	**27-79**
3	2.6	2.9	0.3	59.7	18.0	9	7.2	**39-86**
4	3.0	3.9	0.9	60.9	13.1	33	26.4	**31-88**
5	4.0	4.0	0.0	65.6	12.5	61	48.8	**35-92**

Current study (Endocranial)

	Mean closure score			Mean Age		Sample size		Age
Stage number	Min	Max	Difference	(in years)	SD	n	n (%)	Range
0	0.0	0.3	0.3	35.0	18.2	*42*	*8.6*	***18-90***
1	0.4	1.5	1.1	46.6	18.1	45	9.3	**19-86**
2	1.6	2.5	0.9	52.4	18.7	52	10.7	**27-87**
3	2.6	2.9	0.3	59.9	16.6	27	5.6	**28-95**
4	3.0	3.9	0.9	64.3	14.5	202	41.6	**26-94**
5	4.0	4.0	0.0	67.6	16.7	118	24.3	**25-98**

Current study (Ectocranial)

	Mean closure score			Mean Age		Sample size		Age
Stage number	Min	Max	Difference	(in years)	SD	n	n (%)	Range
0	0.0	0.3	0.3	45.6	22.4	*45*	9.3	***19-91***
1	0.4	1.5	1.1	56.4	19.2	181	37.2	**18-95**
2	1.6	2.5	0.9	65.6	16.8	128	26.3	**19-98**
3	2.6	2.9	0.3	60.5	16.7	52	10.7	**28-94**
4	3.0	3.9	0.9	64.1	16.1	70	14.4	**25-93**
5	4.0	4.0	0.0	58.1	17.1	10	2.1	**33-82**

All endocranial studies showed an increase in mean age with an increase in stage, while no trend was detected for the ectocranial aspect. It was also evident that there were no consistent differences of the mean scores of each stage. The differences were 1.1 in the first stage, 0.9 in stage two and four, while stage three was only from 2.6 to 2.9. The standard deviations for each of the stages ranged from 13.1 to 16.4 years for the Acsádi and Nemeskéri (1970) study while that of the Key et al., (1994) ranged from 11.6 to 18.0 years. The present study, however, had the greatest standard deviations ranging from 14.5 to 18.7 years for endocranial sutures. The greatest standard deviation was seen in stage zero of the ectocranial scores which had the widest age range as well.

Most of the individuals in the Acsádi and Nemeskéri (1970) sample had a mean score that fell between 3.0 and 3.9 while the Key et al. (1994) study had the greatest number of individuals that had a mean score of 4.0. In the present study most individuals fell into stage four (mean score between 3.0 and 3.9), like that of Acsádi and Nemeskéri (1970) and the second largest group had a mean score of 4.0. On the ectocranial aspect the largest group was that of stage one with 181 individuals in that stage and 128 individuals in stage two.

The mean ages for stage one for both the previous studies were similar (28.6 years and 30.9 years) while that of the present study was much greater (46.6 years). The mean ages for stages two and three were similar in the Key et al. (1994) paper and the present study while the Acsádi and Nemeskéri (1970) study showed mean ages that were much less. The mean ages for the last two stages were once again similar in the previous studies while that of the present study showed greater mean ages than both the Acsádi and Nemeskéri (1970) and Key et al. (1994) studies. The age ranges for each stage also showed a large overlap. The present study displayed ranges that were almost from the minimum to the maximum for each of the stages meaning that there were individuals of all ages in each stage.

Meindl and Lovejoy (1985) method

This method involved two separate systems namely the lateral anterior system and the vault system. Once again the tables that were originally published by Meindl and Lovejoy (1985) and Key et al. (1994) were replicated for easy comparison to the present study. Tables 5.11 and 5.12 represent the comparison of the lateral anterior system while Tables 5.13 and 5.14 displays the results for the vault system. Meindl and Lovejoy (1985) in their study did not mention which side of the skull was used to collect data, while Key et al. (1994) used an average of the two sides. In the present study both sides of the skull were investigated and like Key et al. (1994) an average (mean of left and right) was calculated. A table showing the observations on the left and the right side are also added to Table 5.14 for comparison.

The tables contain the composite scores of the sites that were specified for each system. The vault system included the first seven sites as described by Meindl and Lovejoy (1985) while the lateral anterior system included the mid-coronal (6), pterion (7), sphenofrontal (8), and inferior (9) and superior (10) sphenotemporal. The mean age, standard deviation, sample size and range for each stage are also given in the tables.

TABLE 5.11. Comparison of the mean ages using the composite closure scores as first described by Meindl & Lovejoy (1985) using the lateral anterior system

Lateral Anterior system

Meindl & Lovejoy (1985)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
1	1	32.0	8.3	18	9.3	**19-48**
2	2	36.2	6.2	18	9.3	**25-49**
3	3-5	41.1	10.0	56	29.0	**23-68**
4	6	43.4	10.7	17	8.8	**23-63**
5	7-8	45.5	8.9	31	16.1	**32-65**
6	9-10	51.9	12.5	29	15.0	**33-76**
7	11-14	56.2	8.5	24	12.4	**34-68**

Key, Aiello, Molleson (1994)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
1	1	54.8	16.1	17	13.6	**21-85**
2	2	68.7	16.0	12	9.6	**37-92**
3	3-5	58.5	14.3	29	23.2	**34-86**
4	6	66.5	10.9	12	9.6	**48-80**
5	7-8	63.5	10.8	24	19.2	**47-77**
6	9-10	65.9	14.6	26	20.8	**34-85**
7	11-14	71.2	9.4	5	4.0	**60-81**

Current study (Average)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
0	*0*	*42.4*	*23.4*	*7*	*1.4*	***22-84***
1	1	50.2	25.0	20	4.1	**19-86**
2	2	51.3	19.0	26	5.3	**19-86**
3	3-5	55.0	20.1	94	19.3	**19-95**
4	6	61.4	19.6	52	10.7	**24-94**
5	7-8	61.6	18.0	101	20.8	**19-95**
6	9-10	62.5	16.7	83	17.1	**25-91**
7	11-14	62.1	17.3	92	18.9	**18-98**
8	*15*	*68.4*	*13.3*	*11*	*2.3*	***45-83***

TABLE 5.12. Comparison of the mean ages using the composite closure scores of the average of the left and right and then the left and right sides separately, as first described by Meindl & Lovejoy (1985) using the lateral anterior system

Lateral Anterior system

Current study (Average)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
0	*0*	*42.4*	*23.4*	*7*	*1.4*	***22-84***
1	1	50.2	25.0	20	4.1	**19-86**
2	2	51.3	19.0	26	5.3	**19-86**
3	3-5	55.0	20.1	94	19.3	**19-95**
4	6	61.4	19.6	52	10.7	**24-94**
5	7-8	61.6	18.0	101	20.8	**19-95**
6	9-10	62.5	16.7	83	17.1	**25-91**
7	11-14	62.1	17.3	92	18.9	**18-98**
8	*15*	*68.4*	*13.3*	*11*	*2.3*	***45-83***

Current study (Left)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
0	*0*	*42.9*	*22.1*	*21*	*4.3*	***19-86***
1	1	54.7	21.4	20	4.1	**28-86**
2	2	49.4	18.8	27	5.6	**19-84**
3	3-5	59.0	18.8	93	19.1	**19-95**
4	6	58.5	22.1	50	10.3	**20-95**
5	7-8	62.9	17.3	101	20.8	**19-94**
6	9-10	59.3	17.5	83	17.1	**18-89**
7	11-14	63.9	16.5	82	16.9	**28-98**
8	*15*	*68.9*	*14.5*	*9*	*1.9*	***45-83***

Current study (Right)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
0	*0*	*49.9*	*25.1*	*9*	*1.9*	***22-84***
1	1	54.3	22.6	20	4.1	**19-86**
2	2	48.8	21.7	33	6.8	**19-88**
3	3-5	56.9	20.5	88	18.1	**19-95**
4	6	58.3	20.2	52	10.7	**21-93**
5	7-8	61.6	16.2	107	22.0	**19-95**
6	9-10	63.9	18.0	71	14.6	**25-98**
7	11-14	61.6	16.9	97	20.0	**18-91**
8	*15*	*66.3*	*13.9*	*9*	*1.9*	***45-83***

TABLE 5.13. Comparison of the mean ages using the composite closure scores as first described by Meindl & Lovejoy (1985) using the vault system

Vault system

Meindl & Lovejoy (1985)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
1	1-2	30.5	9.6	12	6.0	**18-45**
2	3-6	34.7	7.8	30	15.1	**22-48**
3	7-11	39.4	9.1	50	25.1	**24-60**
4	12-15	45.2	12.6	50	25.1	**24-75**
5	16-18	48.8	10.5	31	15.6	**30-71**
6	19-20	51.5	12.6	26	13.1	**23-76**

Key, Aiello, Molleson (1994)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
1	1-2	51.4	21.3	16	10.7	**18-85**
2	3-6	55.3	14.7	33	22.0	**27-92**
3	7-11	59.0	16.2	43	28.7	**19-88**
4	12-15	62.0	11.7	25	16.7	**35-79**
5	16-18	64.1	13.0	19	12.7	**34-86**
6	19-20	71.9	9.1	14	9.3	**53-85**

Current study (Average)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
0	*0*	*39.3*	*23.5*	*4*	*0.9*	***22-74***
1	1-2	43.6	21.3	48	10.6	**19-90**
2	3-6	54.9	19.5	69	15.3	**20-91**
3	7-11	61.2	17.9	136	30.1	**19-95**
4	12-15	64.2	16.2	100	22.1	**28-98**
5	16-18	65.5	16.4	53	11.7	**25-94**
6	19-20	62.9	15.6	27	6.0	**28-89**
7	*21*	*62.1*	*16.4*	*15*	*3.3*	***33-89***

TABLE 5.14. Comparison of the mean ages using the composite closure scores of the average of the left and right and then the left and right sides separately, as first described by Meindl & Lovejoy (1985) using the vault system

Vault system

Current study (Average)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
0	*0*	*39.3*	*23.5*	*4*	*0.9*	***22-74***
1	1-2	43.6	21.3	48	10.6	**19-90**
2	3-6	54.9	19.5	69	15.3	**20-91**
3	7-11	61.2	17.9	136	30.1	**19-95**
4	12-15	64.2	16.2	100	22.1	**28-98**
5	16-18	65.5	16.4	53	11.7	**25-94**
6	19-20	62.9	15.6	27	6.0	**28-89**
7	*21*	*62.1*	*16.4*	*15*	*3.3*	***33-89***

Current study (Left)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
0	*0*	*38.5*	*19.6*	*15*	*3.1*	***19-80***
1	1-2	44.3	21.3	44	9.1	**19-90**
2	3-6	57.7	18.8	101	20.8	**18-91**
3	7-11	61.3	18.3	135	27.8	**19-95**
4	12-15	64.1	15.6	94	19.3	**28-98**
5	16-18	65.7	17.0	55	11.3	**25-94**
6	19-20	61.4	15.9	28	5.8	**28-89**
7	*21*	*64.1*	*14.9*	*14*	*2.9*	***45-89***

Current study (Right)

Stage number	Composite closure score	Mean Age (years)	SD	Sample size n	%	Age Range
0	*0*	*49.9*	*27.4*	*7*	*1.8*	***22-86***
1	1-2	42.8	20.9	42	10.7	**19-90**
2	3-6	56.1	19.6	112	28.4	**18-91**
3	7-11	61.2	18.0	137	34.8	**19-95**
4	12-15	38.3	7.0	4	1.0	**30-45**
5	16-18	65.0	15.6	53	13.5	**25-93**
6	19-20	62.5	16.0	23	5.8	**28-89**
7	*21*	*60.9*	*16.6*	*16*	*4.1*	***33-89***

The mean ages increased with an increase in the stage for the Meindl and Lovejoy (1985) study (Table 5.11). The same can be seen in the present study when the averages of the left and right sides are taken into account but the ages are higher in the present study than reported by Meindl and Lovejoy (1985). In the Key et al. (1994) study, stage two had a higher mean age than the third, fourth, fifth and sixth stages. The mean ages were also much greater than those of the Meindl and Lovejoy (1985) but were similar to the present study.

The age ranges once again overlapped but in this case there was no gradual increase in the minimum age as the stage of obliteration increased. In the Meindl and Lovejoy (1985) study the age range does not change greatly as the stage increased, as was evident from the last few stages with the minimum age around 33 years. However, in the Key et al. (1994) study the age range for stage seven was 60-81 years and that of the present study was 18-98 years.

The standard deviations for each of the stages were less than 12.5 years for the Meindl and Lovejoy (1985) study while that of Key et al. (1994) had a minimum of 9.4 years and a maximum standard deviation of 16.1 years. The standard deviations for the present study however were the greatest with a minimum of 13.3 years and a maximum of 25.0 years. This either indicated that the samples of the present study had, for an unknown reason, greater variability, or that samples used by other authors were selected by limiting variation within age groups.

The vault system of Meindl and Lovejoy (1985) had fewer stages of composite score in the table than that of the lateral anterior system (Table 5.11). Once again the age ranges for each of the stages were very wide and the mean ages were increasing as the stage increases giving an impression that there was probably a correlation with age as the composite score increased. The importance here was that the age ranges were wide and the standard deviations were increasing as well. The mean ages for the Key et al. (1994) study were greater than those of the Meindl and Lovejoy (1985) study but were similar to the present study.

5.7 Correlation of the estimated mean age with the recorded age

When the estimated ages of the individuals were compared to the recorded ages, the scatter plots showed a vast distribution of the points (Fig 5.33-5.38). In both the ectocranial and endocranial aspects of the skull, individuals throughout the age range had estimated ages at the lowest estimate. The ectocranial aspect predicts most of the individuals in the sample to a low estimated age while when the endocranial aspects were used to estimate age the estimates were more often assigned to the higher age group (Figures 5.33 to 5.34). The estimates based on the Meindl and Lovejoy (1985) method showed similar results to the Acsádi and Nemeskéri (1970) method. Once again there was a wide range of recorded ages in each single estimated age category (Figures 5.38 to 5.38). No trends were seen between the lateral anterior and the vault systems.

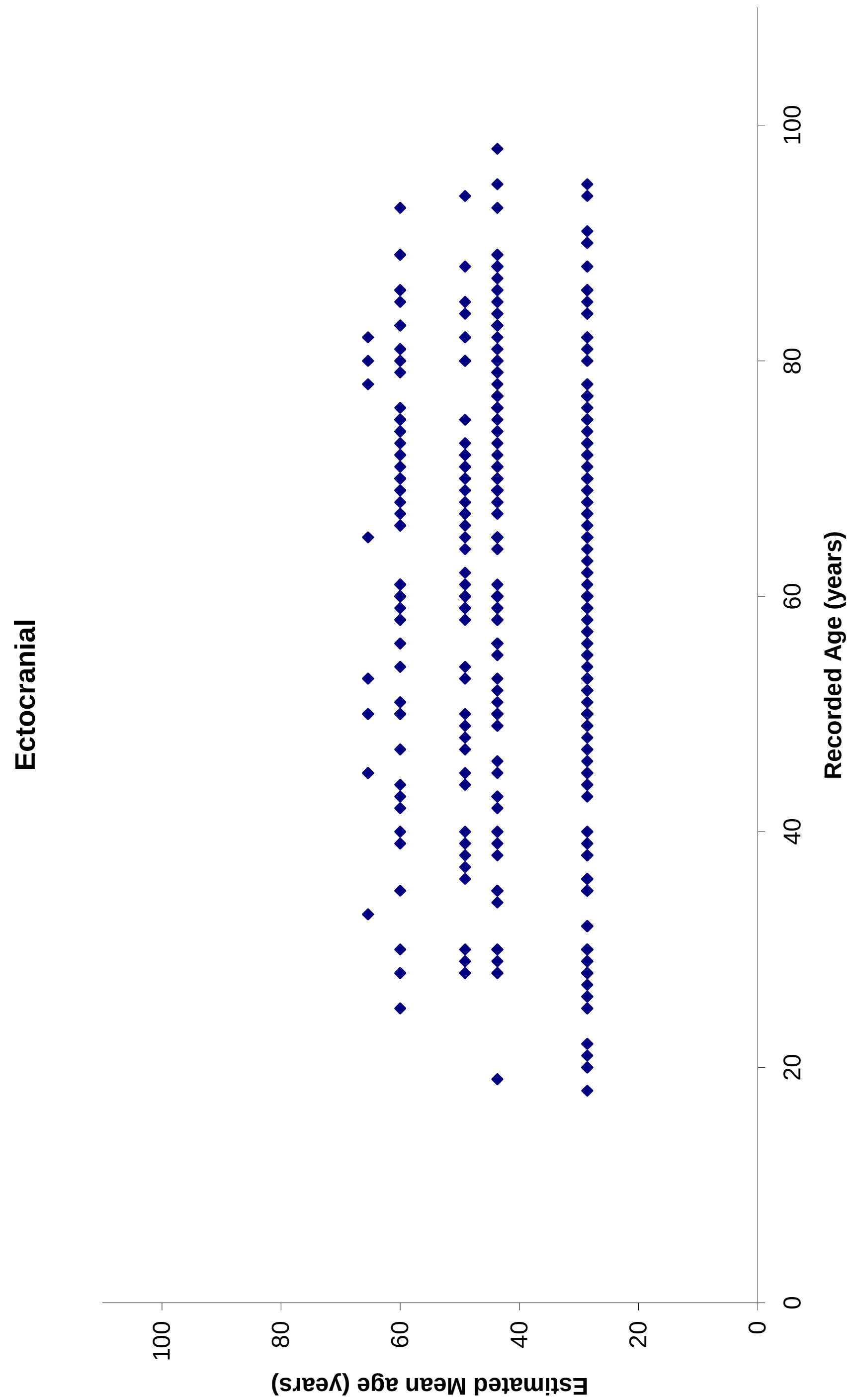


Figure 5.33. The estimated age compared to the recorded age using the Acsádi & Nemeskéri (1970) method on the ectocranial aspect.

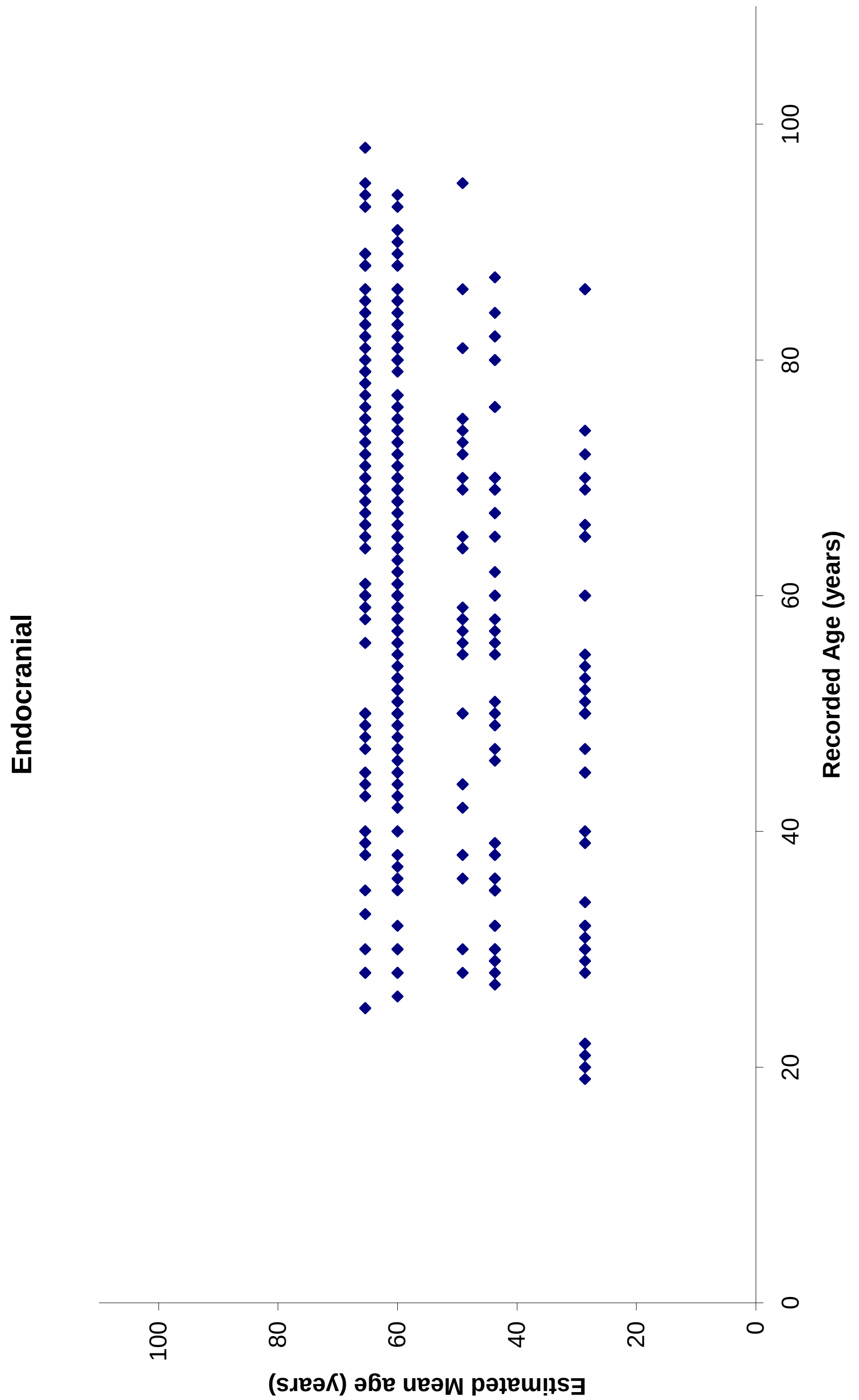


Figure 5.34. The estimated age compared to the recorded age using the Acsádi & Nemeskéri (1970) method on the endocranial aspect.

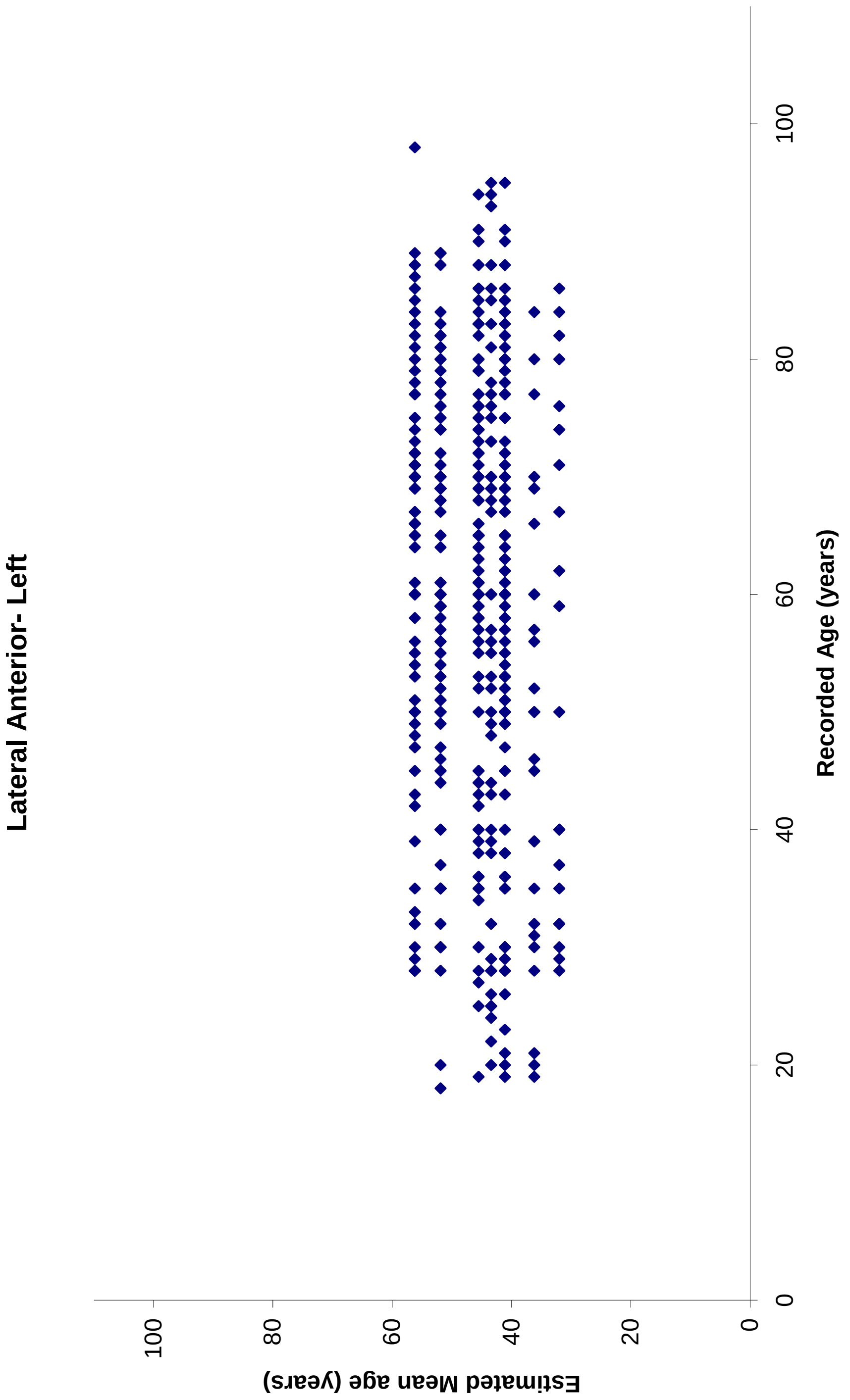


Figure 5.35. The estimated age compared to the recorded age using the Meindl & Lovejoy (1985) method of the left side for the lateral anterior system.

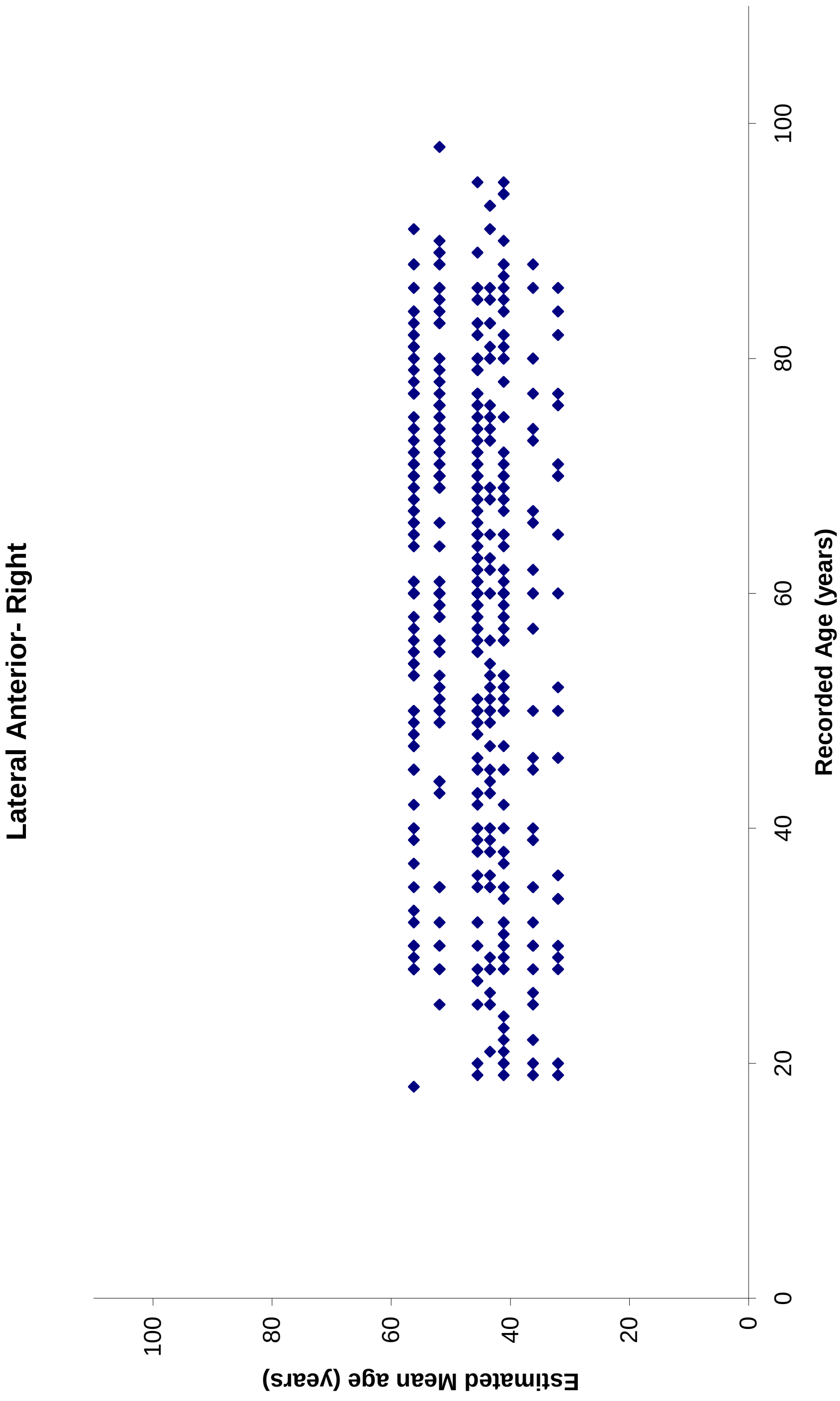


Figure 5.36. The estimated age compared to the recorded age using the Meindl & Lovejoy (1985) method of the right side for the lateral anterior system.

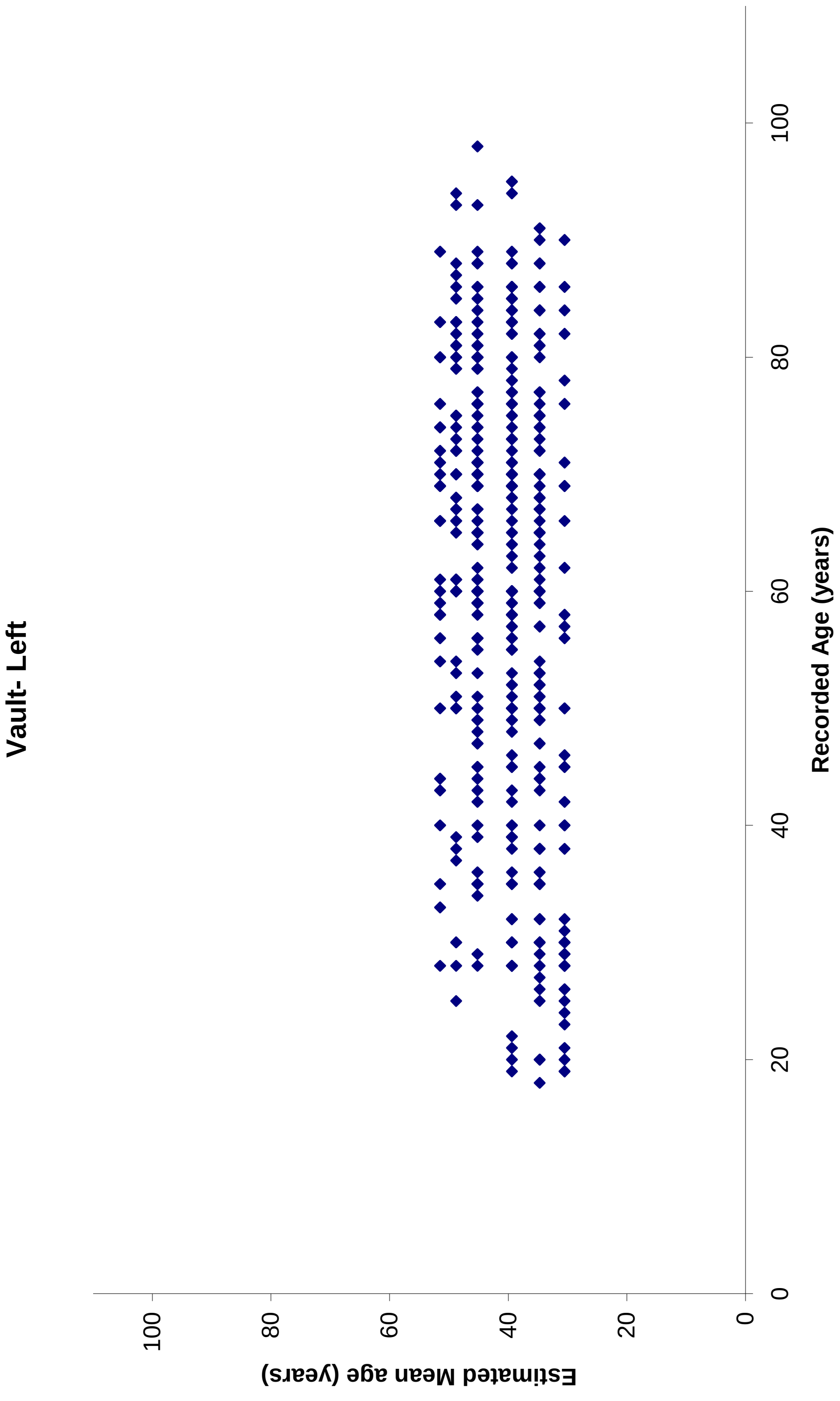


Figure 5.37. The estimated age compared to the recorded age using the Meindl & Lovejoy (1985) method of the left side for the vault system.

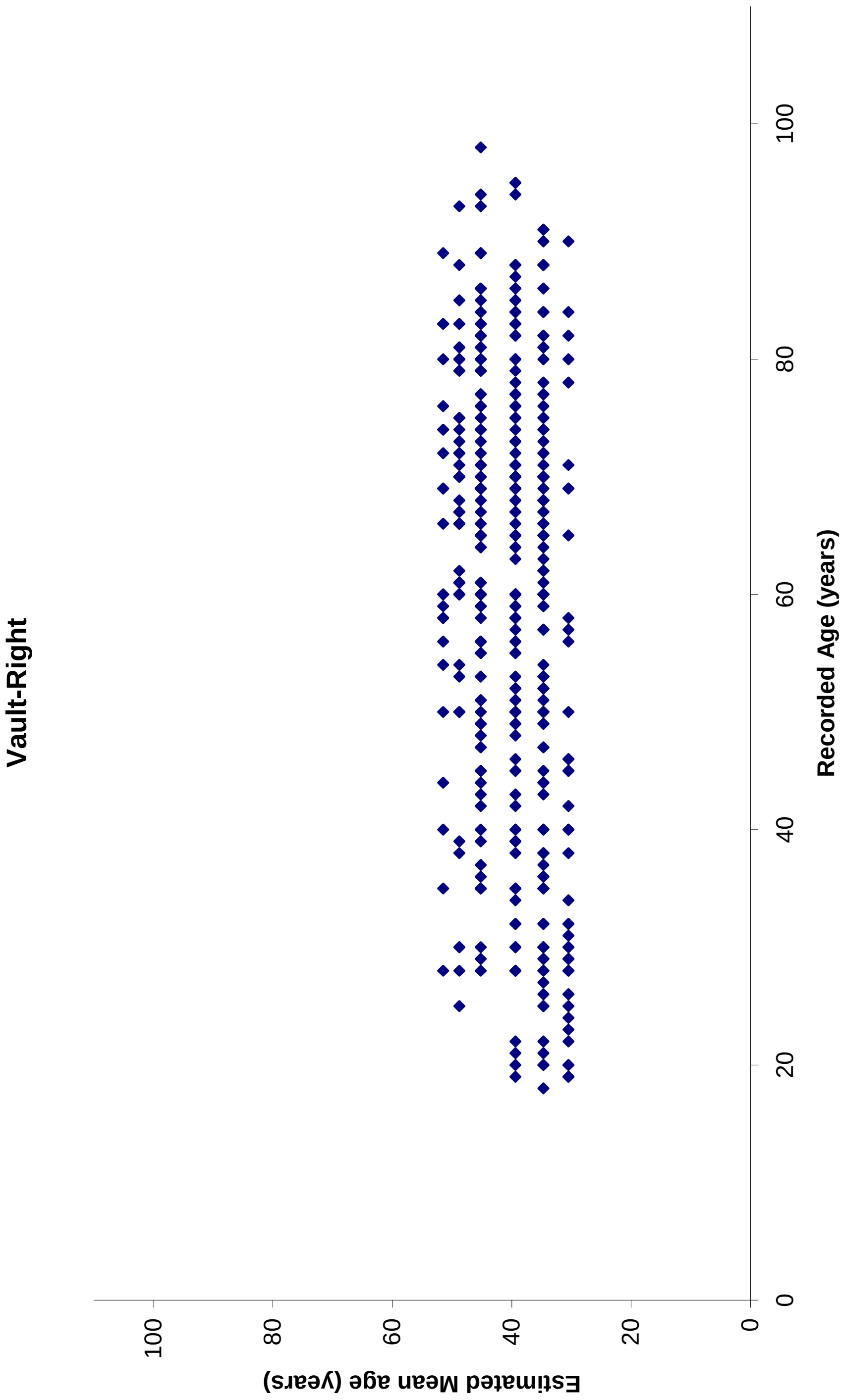


Figure 5.38. The estimated age compared to the recorded age using the Meindl & Lovejoy (1985) method of the right side for the vault system.

These results compared well to other studies when similar scatter plots were drawn (Brooks, 1955; Saunders et al. 1992; Dorandeu et al., 2008). The scatter plots drawn by Dorandeu et al. (2008) also showed similar distributions of the recorded age with a wide age range in a single age estimation group. Saunders and colleagues (1992) found a correlation of r =0.66, but in the present study the correlation was not calculated as the spread of data points was too great.

5.8 Difference between estimated sutural age and recorded age

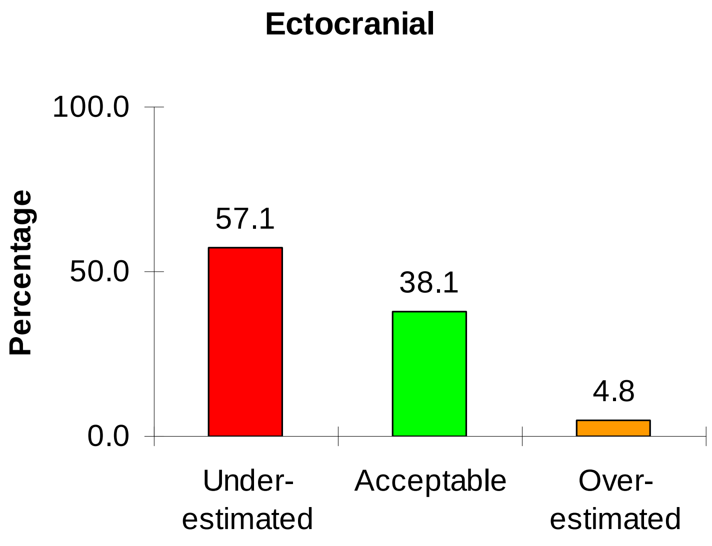
This section is based upon the accuracy of the method that was employed to estimate age from the cranial sutures. Using the tables that were previously replicated from the original studies of Acsádi and Nemeskéri (1970) and Meindl and Lovejoy (1985) (Tables 5.9, 5.10, 5.12), depending on the method used, the mean or composite score, was calculated from the recorded observations. Thereafter the recorded ages were compared to the minimum and maximum age of the stage. If the recorded age fell within the range (Tables 5.9, 5.10, 5.12) the case was considered acceptable. This meant that the actual age of the individual as recorded in the database fell within the large age range of the specified stage. If the recorded age was greater than the age range, the age was underestimated while if the recorded age was less than the age range, the age was over-estimated.

The first part of this section clusters all individuals in the sample as a single group (Figures 5.39 –5.40). Thereafter the sample was broken down into the respective sex and population groups (Figs. 5.41-5.46). Finally the sample was broken down into age groups that have been used previously, i.e. all individuals less than and equal to 39 years, individuals between the ages of 40 and 69 years, and all individuals older than 70 years (Fig. 5.47-5.52).

Entire sample (Figures 5.39-5.40)

The results from the accuracy tables showed that the method where most of the cases fell into the acceptable range was that of the Acsádi and Nemeskéri (1970) method using the endocranial aspect. This result was achieved when both the methods were compared, taking into account the endocranial, ectocranial, vault, lateral anterior systems, left and right sides of the skull.

The percentages of individuals that were found in the acceptable group were not as high as expected. Only 60.8% of the individuals in the entire sample of 486 individuals fell into the acceptable category, with 174 individuals either being under-estimated or over-estimated. The lateral anterior and the vault systems had a similar number of individuals that fell into the acceptable group while the ectocranial aspect showed a large percentage (57.1%) being under-estimated. All methods had a large percentage of individuals which fell into the under-estimated category.



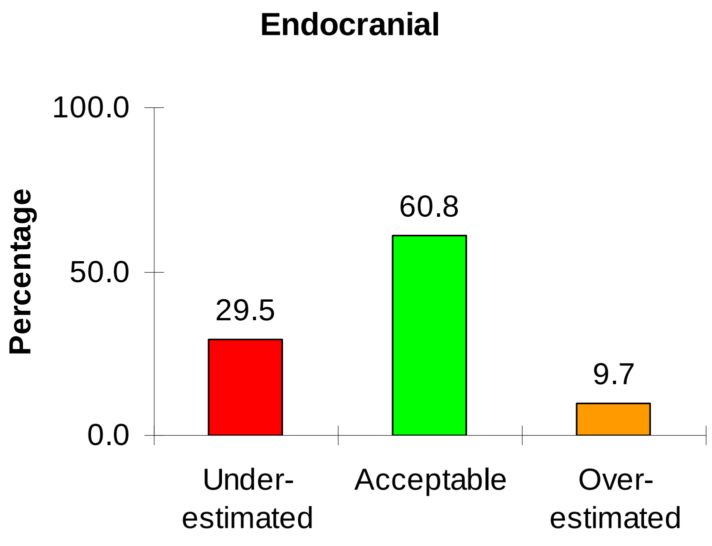


Figure 5.39. Percentage distribution of acceptable, under-estimated and over-estimated ages using the Acsádi & Nemeskéri (1970) methods on the ectocranial and endocranial aspects.

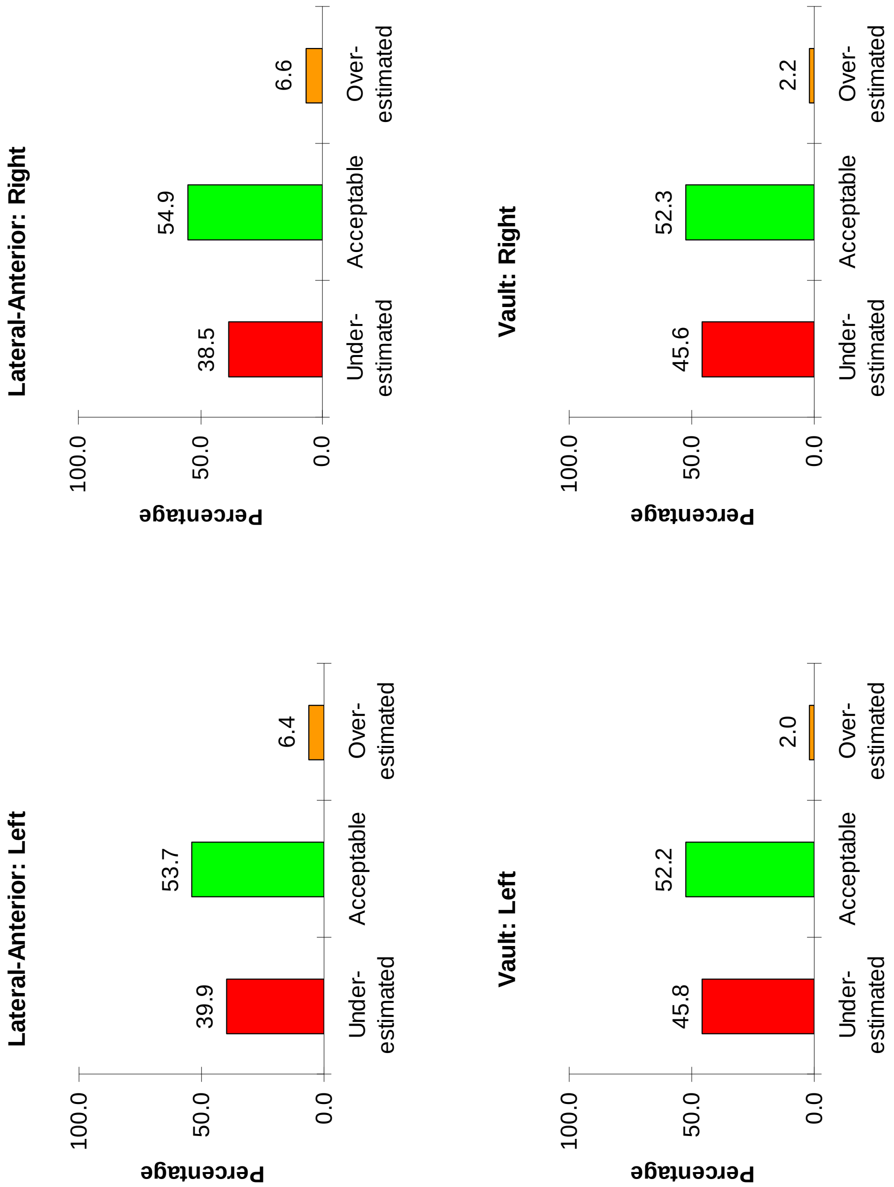


Figure 5.40. Percentage distribution of acceptable, under-estimated and over-estimated ages using the Meindl & Lovejoy (1985) methods.

Sex and population groups (Figures 5.41-5.46)

<u>Ectocranial sutures (Acsádi & Nemeskéri, 1970, method)</u>

The black females showed the highest percentage of individuals in the acceptable group while the black males had the next highest number of individuals within the acceptable age range (Figure 5.41). Both the white males and the white females had more than 72% of individuals where age was under-estimated. Recorded ages of whites were higher than those of blacks.

<u>Endocranial sutures (Acsádi & Nemeskéri, 1970, method)</u>

The number of individuals in the acceptable range for the endocranial aspect (Figure 5.42) of the skull was much greater than those of the ectocranial aspect for all groups. The black females had the same number in the acceptable range (60.2%) while the black males had 20% more individuals in this category. The white males and females, however, showed a large number of individuals in the acceptable range and fewer in the under-estimated range and there were also more individuals that had been over-estimated.

<u>Lateral anterior system (Meindl & Lovejoy, 1985, method)</u>

There was no great discrepancy in the percentage of individuals that fell into the different categories between the left and right sides of the skull when the lateral anterior system of Meindl & Lovejoy (1985) was used. Once again the black males and black females showed the higher percentage of individuals in the acceptable range while the white males and white females displayed less than 50% of individuals in this category. There were a larger number of black females (16.1%) that had been over-estimated when using the left side (Fig 5.43). A larger percent of individuals in the white males and females were in the under-estimated category than in the over-estimated category (Figs 5.43 & 5.44).

<u>Vault system (Meindl & Lovejoy, 1985, method)</u>

This system does not produce as many individuals in the acceptable range for both the white males and females as that of the lateral anterior system (Fig 5.45 & 5.46). However, none of the white males or females fell within the over-estimated age range. Once again the group that showed the highest number (77.1%) of individuals in the acceptable range was the black females when using the left side of the skull.

Age groupings

Figures 5.47- 5.52 display the percentage distribution of acceptable, under-estimated and over estimated ages for the entire sample, but the sample was divided into the three age groupings. There was a general trend in the under 39 year olds group, where a large number of individuals (57.1-89.2%) fell into the acceptable range, however, as the age increased the trend moved towards the under-estimated category. The over 70 year old group had a greater number of individuals in the under-estimated group ranging from 61.1% (endocranial aspect) to 93.3% (left lateral anterior aspect).

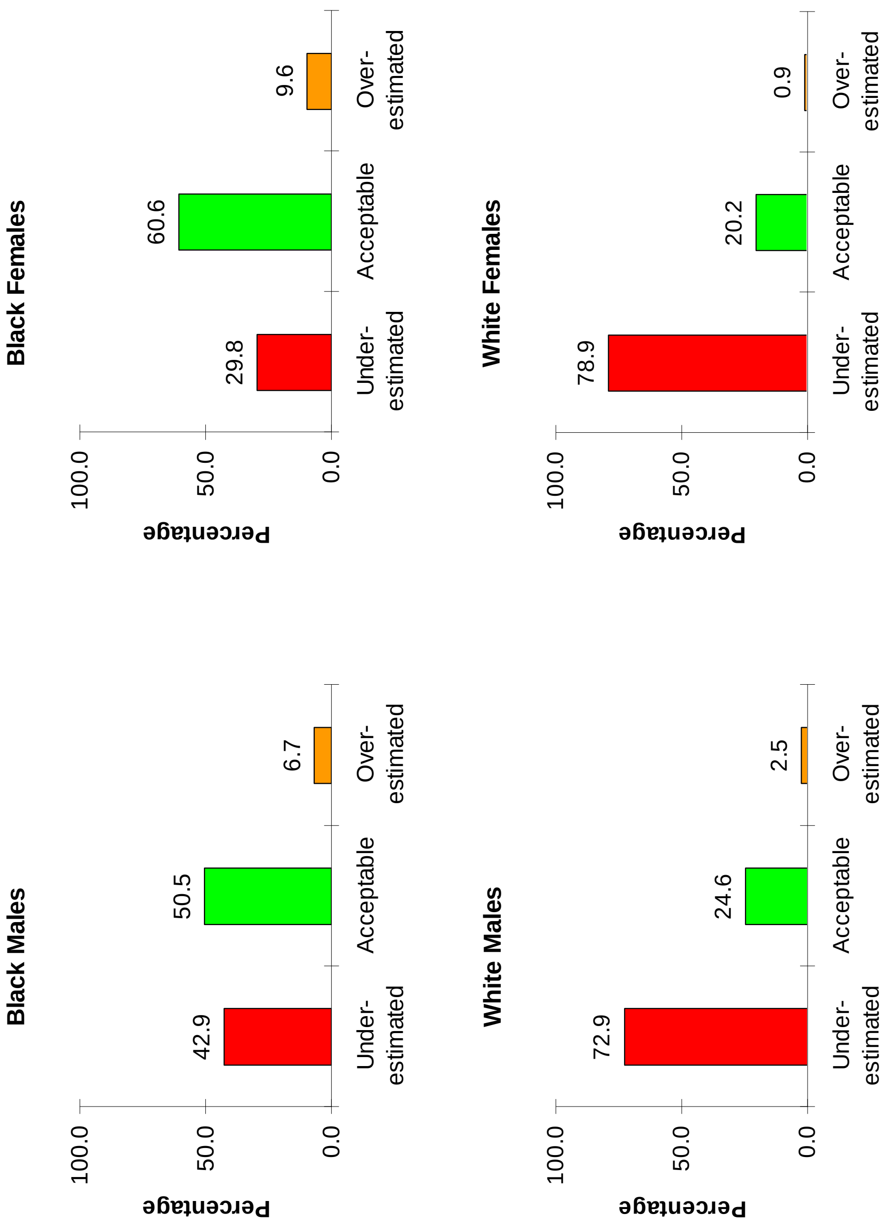


Figure 5.41. Percentage distribution of acceptable, under-estimated and over-estimated ages using the Acsádi & Nemeskéri (1970) methods of ectocranial sutures obliteration.

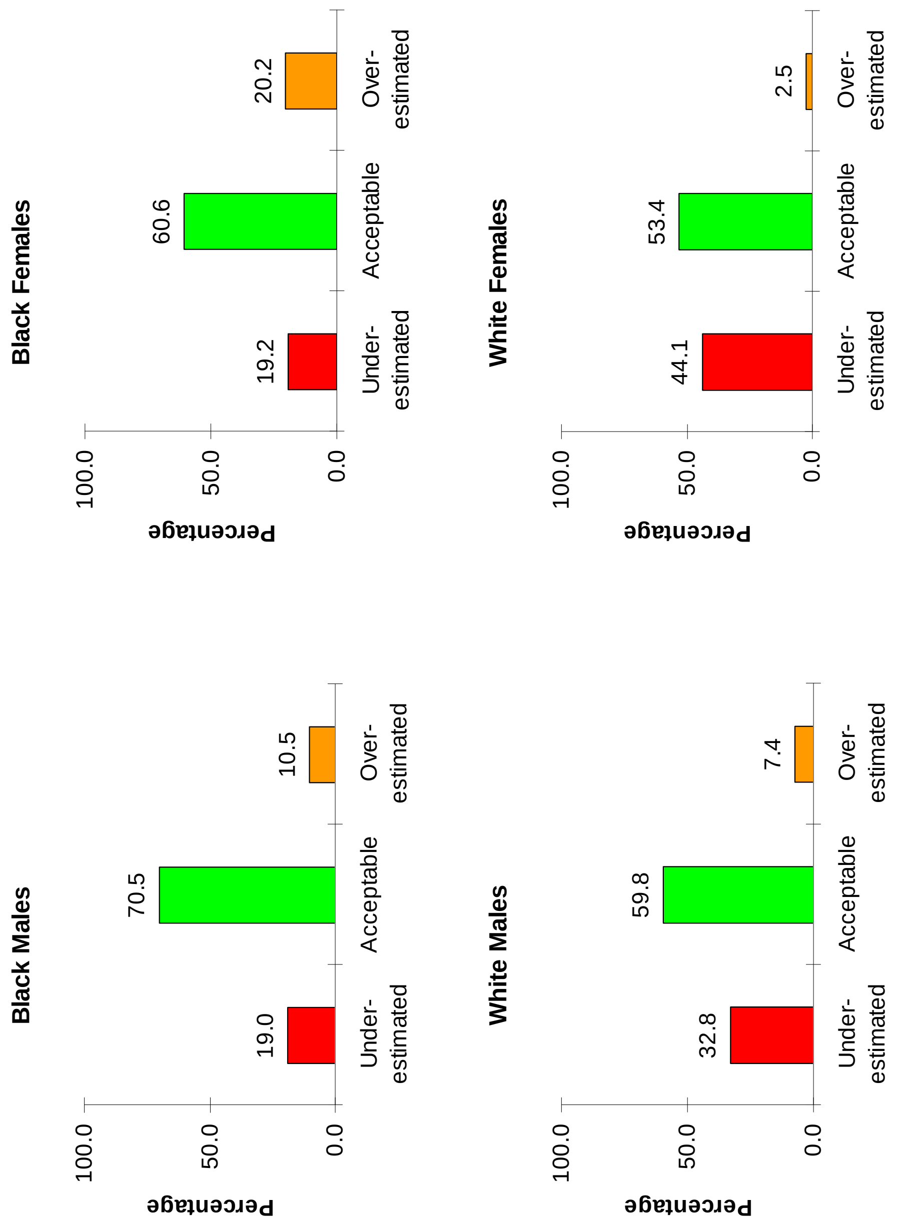


Figure 5.42. Percentage distribution of acceptable, under-estimated and over-estimated ages using the Acsádi & Nemeskéri (1970) methods of endocranial cranial sutures obliteration.

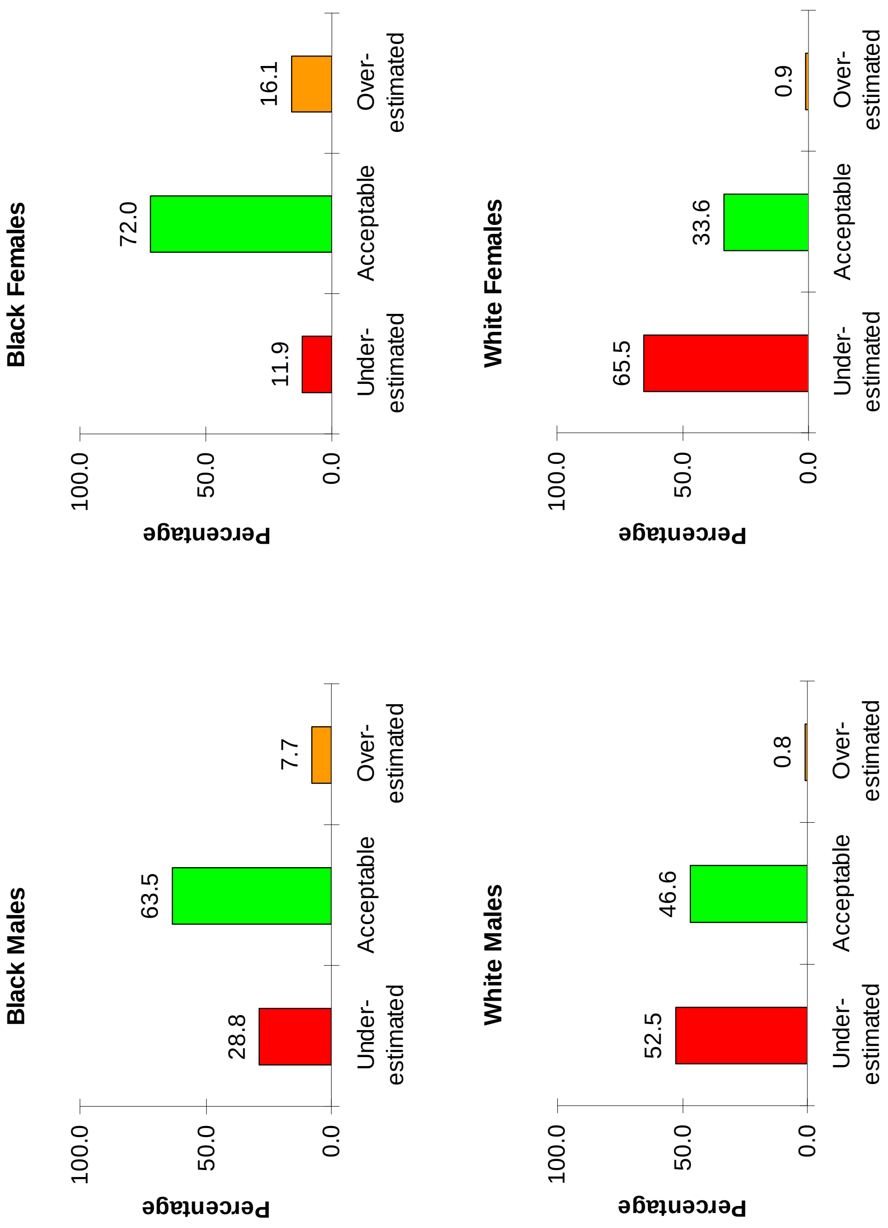


Figure 5.43. Percentage distribution of acceptable, under-estimated, and overestimated ages using the Meindl & Lovejoy (1985) method of the lateral anterior cranial sutures system on the left side.

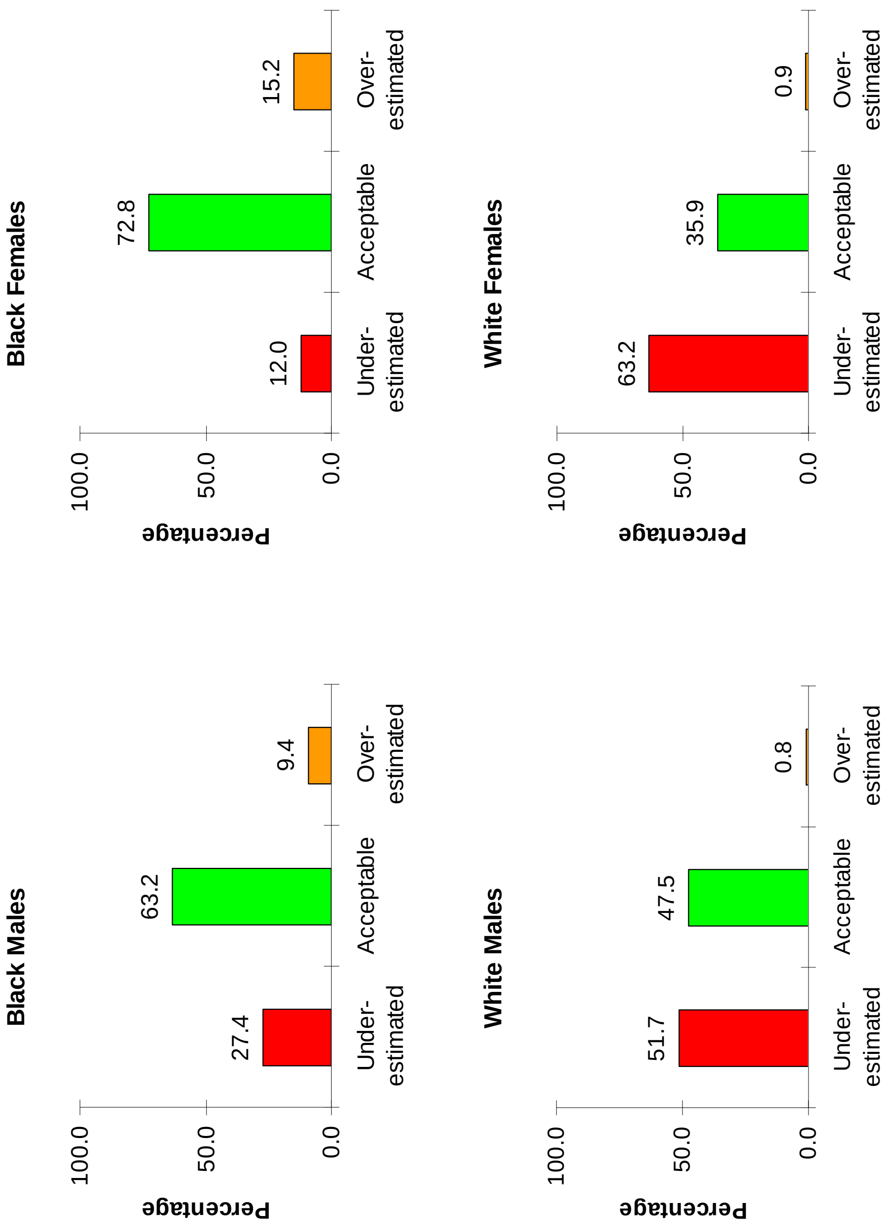


Figure 5.44. Percentage distribution of acceptable, under-estimated, and overestimated ages using the Meindl & Lovejoy (1985) method of the lateral anterior cranial sutures system on the right side.

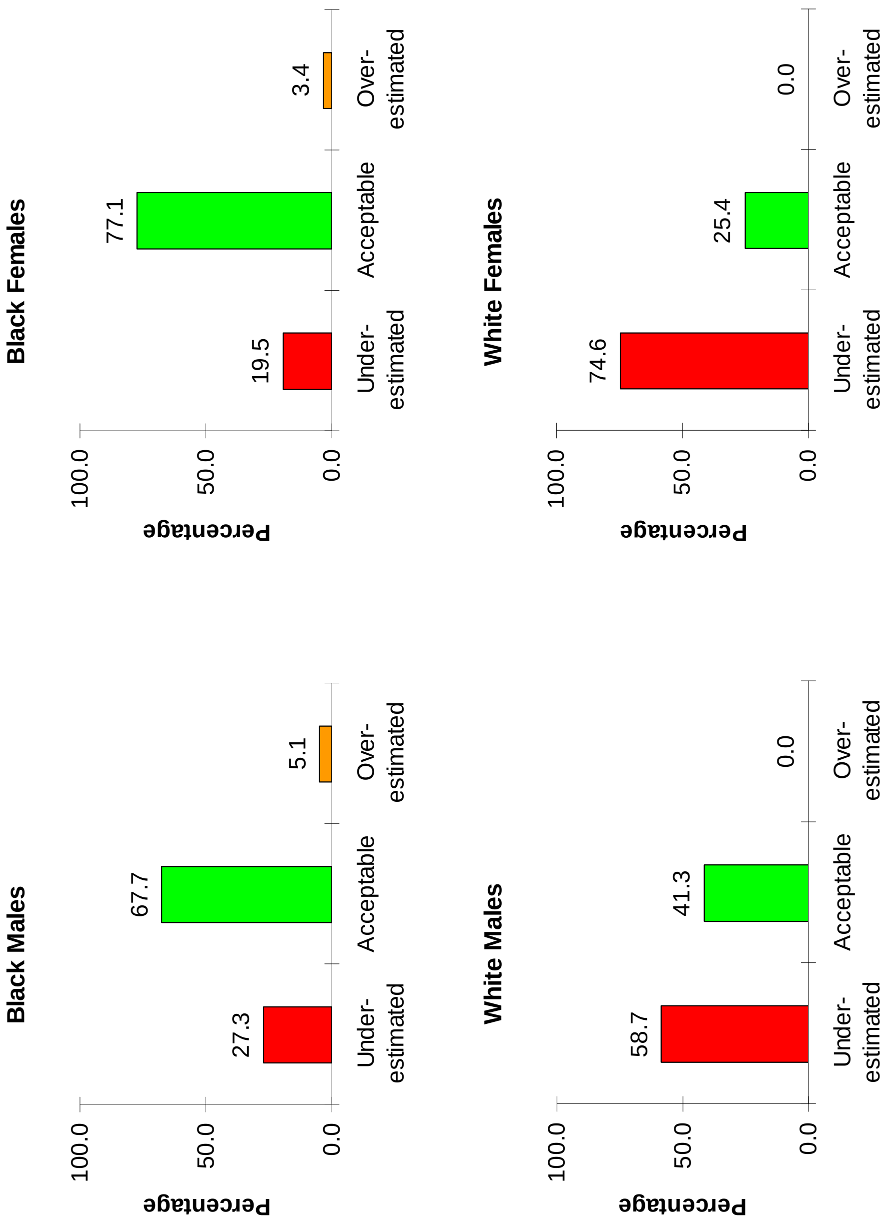


Figure 5.45. Percentage distribution of acceptable, under-estimated, and over-estimated ages using the Meindl & Lovejoy (1985) method of the vault cranial sutures system on the left side.

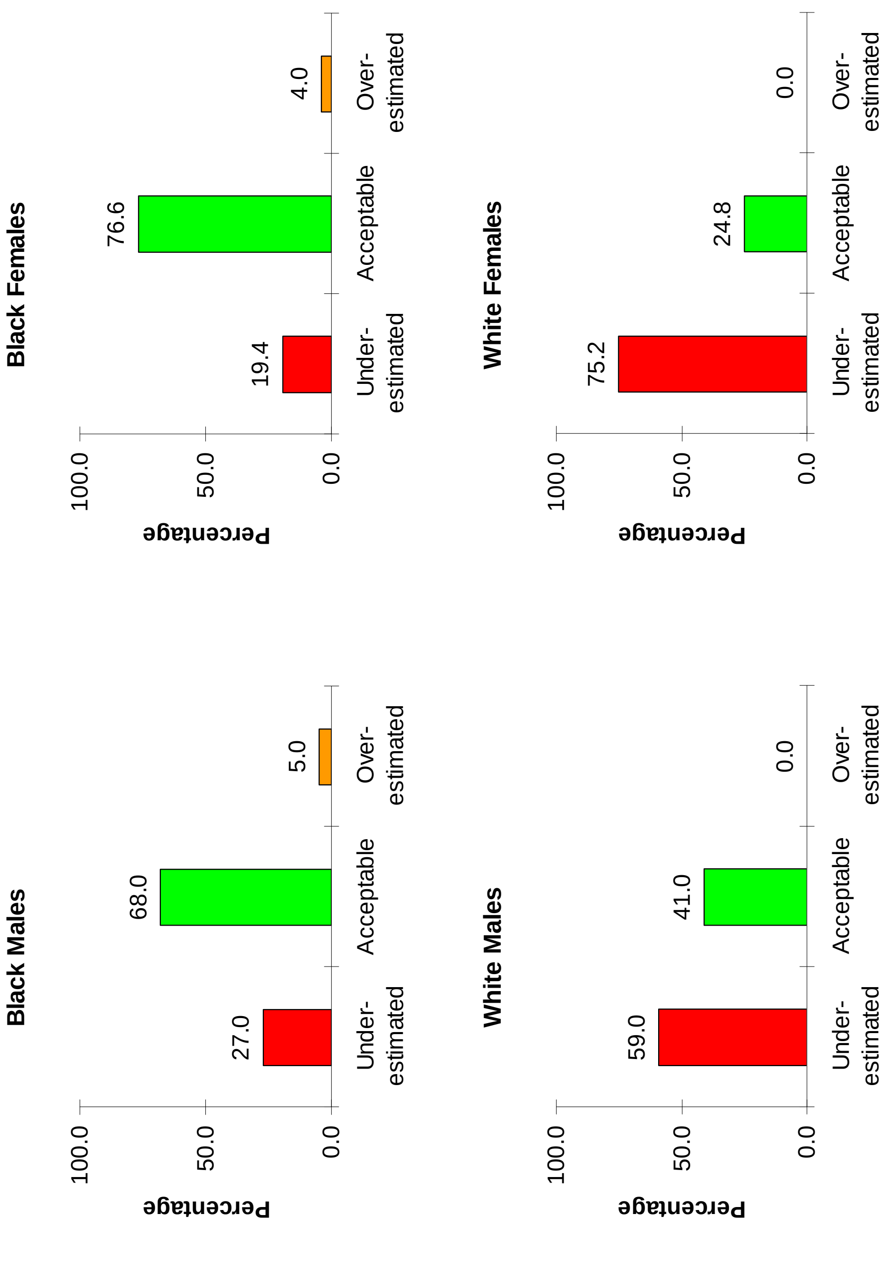


Figure 5.46. Percentage distribution of acceptable, under-estimated, and over-estimated ages using the Meindl & Lovejoy (1985) method of the <u>vault cranial sutures system</u> on the <u>right side.</u>

Figure 5.47. Percentage distribution of acceptable, under-estimated, and over-estimated ages using the Acsádi & Nemeskéri (1970) methods of ectocranial cranial sutures obliteration in age categories.

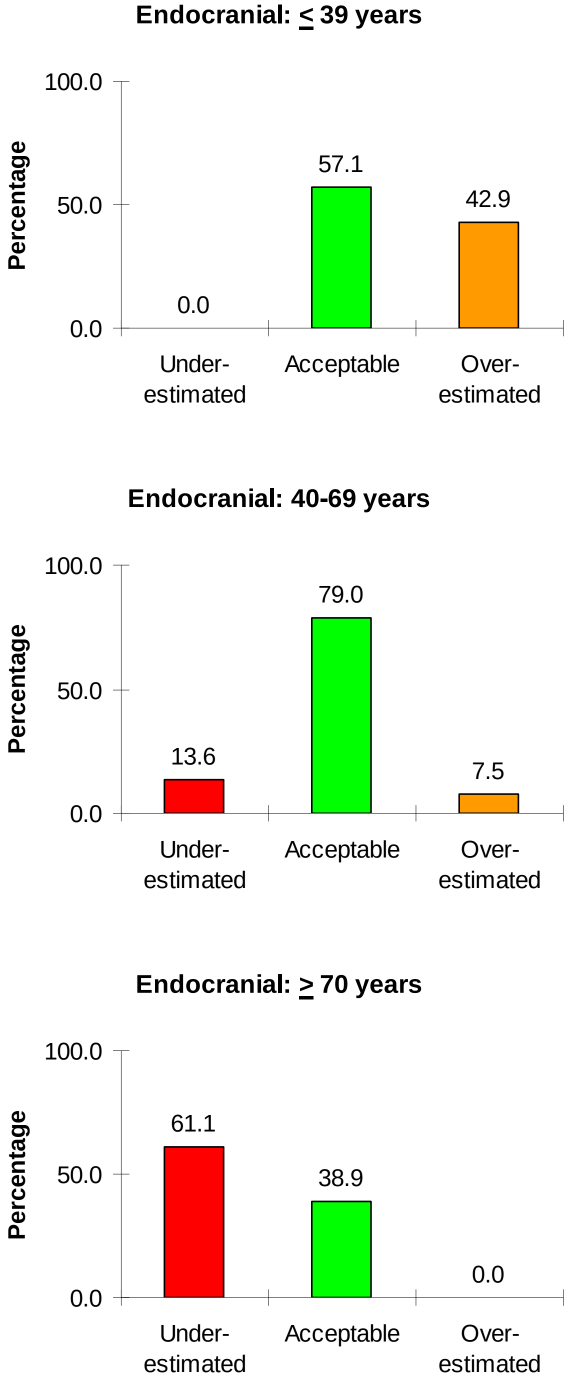


Figure 5.48. Percentage distribution of acceptable, under-estimated, and over-estimated ages using the Acsádi & Nemeskéri (1970) methods of endocranial cranial sutures obliteration in age categories.

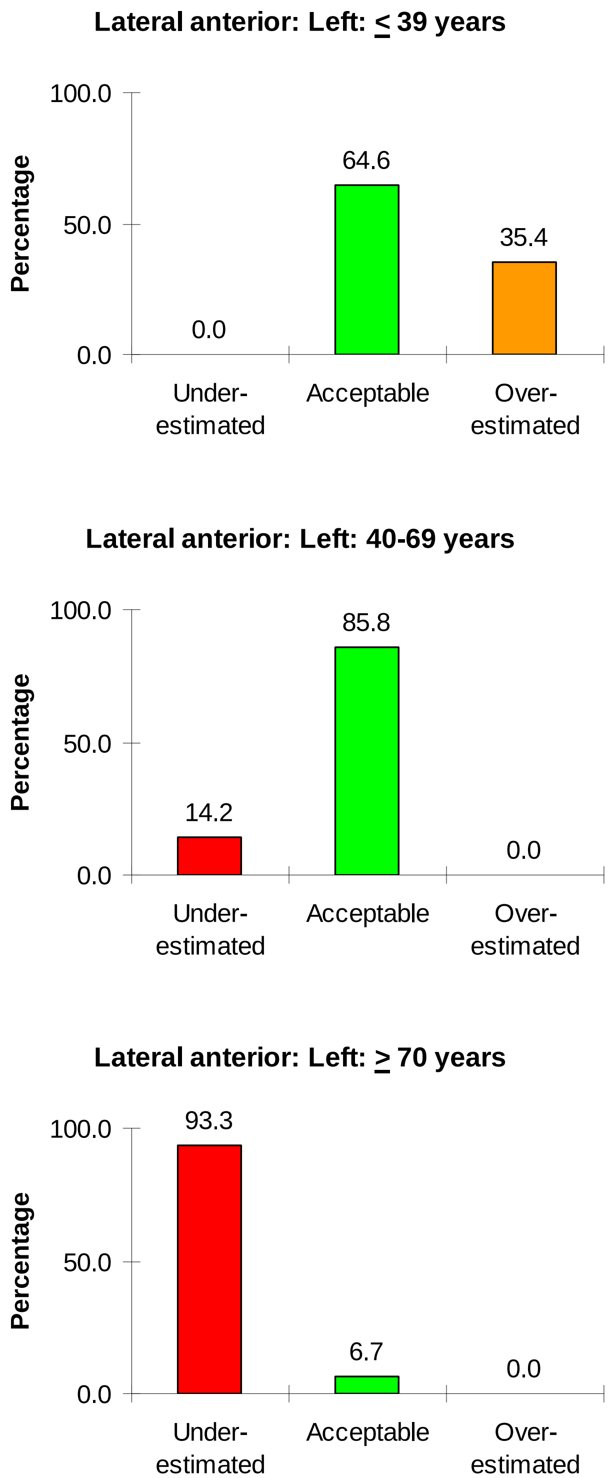


Figure 5.49. Percentage distribution of acceptable, under-estimated, and overestimated ages using the Meindl & Lovejoy (1985) method of the lateral anterior cranial sutures system on the left side in age categories.

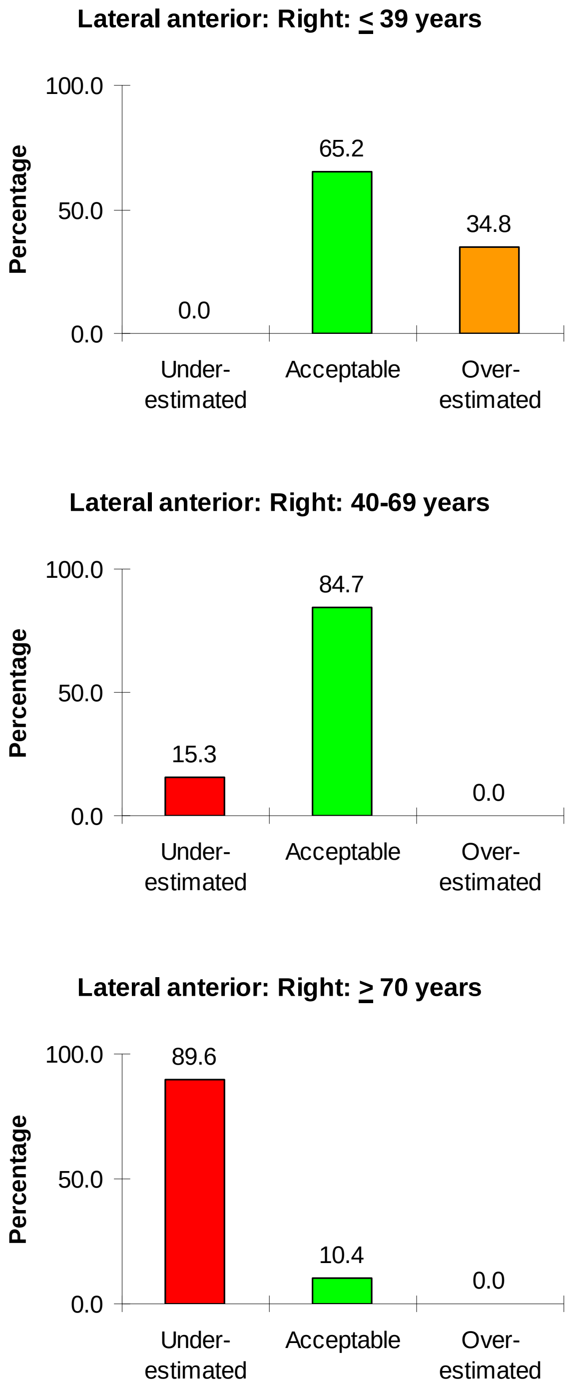


Figure 5.50. Percentage distribution of acceptable, under-estimated, and overestimated ages using the Meindl & Lovejoy (1985) method of the lateral anterior cranial sutures system on the right side in age categories.

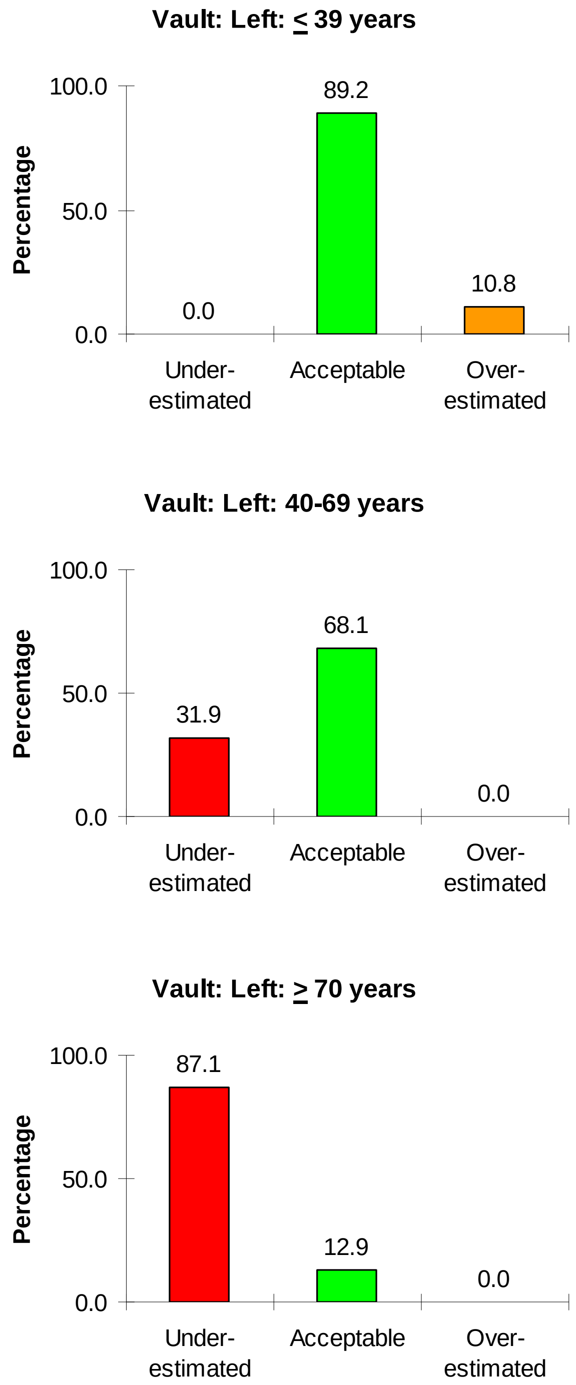


Figure 5.51. Percentage distribution of acceptable, under-estimated, and over-estimated ages using the Meindl & Lovejoy (1985) method of the vault cranial sutures system on the left side in age categories.

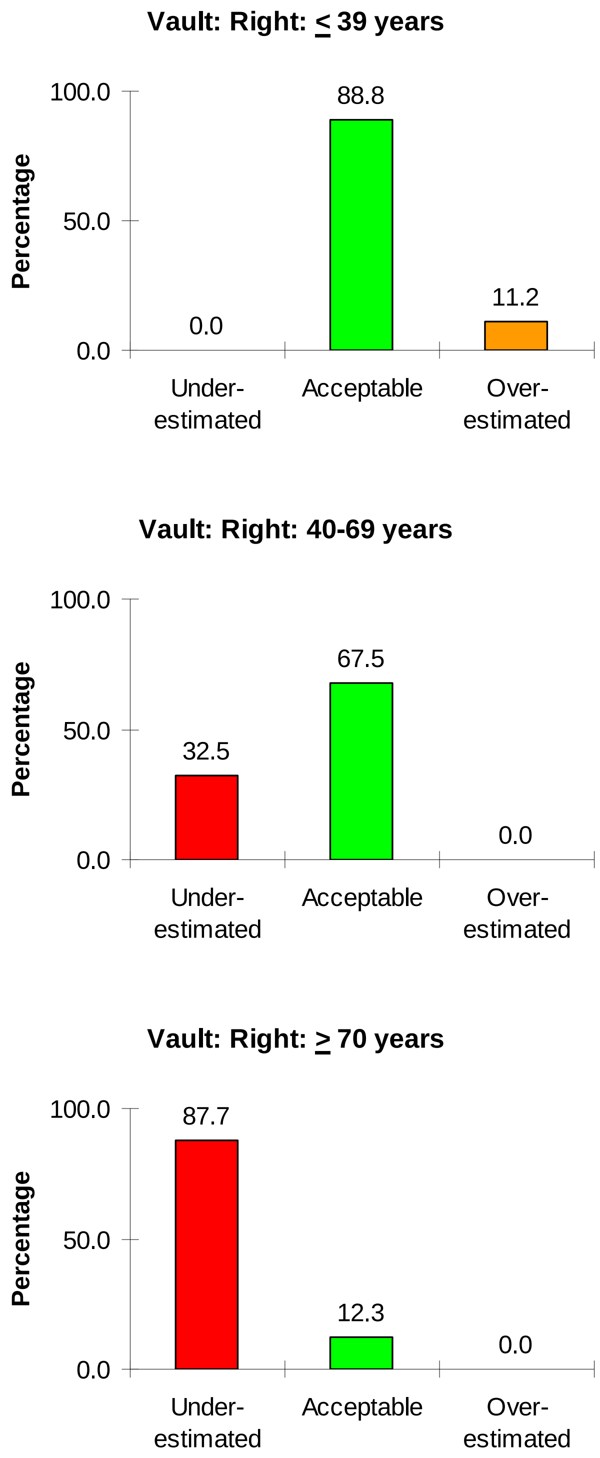


Figure 5.52. Percentage distribution of acceptable, under-estimated, and over-estimated ages using the Meindl & Lovejoy (1985) method of the <u>vault cranial sutures system</u> on the <u>right side</u> in age categories.

5.9 General Discussion

The results of the repeatability tables showed that both the methods used in the present study were repeatable. This was particularly true for the Acsádi and Nemeskéri (1970) method when assessing the endocranial aspect of the skull. These methods which had been used to investigate the obliteration of the cranial vault sutures are morphological methods. Unlike metric methods, morphological methods are based upon the qualitative judgement of the investigator. The reliability of morphological methods has been shown to increase with the experience of the investigator in certain areas of the skeleton (Bruzek, 2002; Duric et al., 2005).

Although the methods employed in this study were repeatable, there were a few considerations when initially collecting data. Firstly the uncertainty of the variable being scored played a major role in the actual scoring of the segment of the suture. This was evident from the number of cases that did not agree with the original score in the repeatability tests. This was probably the same reason that Saunders et al. (1992) did not achieve a high level of reliability when results from two observers were compared. However, the authors found that there was greater consistency in scores for the novice investigator than for the experienced observer (Saunders et al., 1992). This is in disagreement with other morphological methods which show that the experience of the investigator increases the reliability of the method (Bruzek, 2002; Duric et al., 2005).

The division of the sample into age groups between 18-39 years, between 40 and 69 years and greater than 70 years is justified as many of the age determination tables using other skeletal indicators consider the ageing process to be the same after the age of 70 years (İşcan et al., 1985). As many victims of crime are not always less than 70 years, in this study the obliteration status of the sutures was investigated in individuals older than 70 years as well. The individuals less than 70 years were further divided into an 18-39 year group and a 40-69 group to track any age changes that might occur in these groups. Dividing these groups as mentioned above have also, in the process, lessened the number of individuals for analysis of the data.

Table 5.1a shows the number of individuals that were found in each decade. This might have skewed the data as there were not too many whites in the younger groups and the numbers were low for the blacks in the older categories. The choice of individuals in this study was made by a random selection. Using an equal number from each group was thought to have biased the groups and data collection would not have been a blind process. Thus a total of 100 skulls for each of the groups were aimed at with the results presented.

The number of young white individuals in the Dart Collection is limited. Most of the white individuals are bodies donated by elderly individuals, thus the skewed age sample found in the collection. The best possible solution to this problem would probably be a living sample in a longitudinal study. The longitudinal investigation of the progress of the closure or non-closure of the cranial sutures would solve many of the problems that have been highlighted in this study.

Human skeletal collections have become a rich resource for many medically based projects involving skeletal adaptations and variations (Cardoso, 2006; Eliopoulos et al., 2007). The Dart Collection is one such collection which has been used for many different skeletal projects in physical anthropology (Aiello & Wood, 1994; Loth & Henneberg, 1998) and forensic anthropology studies (Steyn & İşcan, 1997; 1998; Bidmos & Dayal, 2004). The cadaver-derived skeletons of this collection allow it to be a well documented skeletal collection like other collections found at some medical schools (Meindl & Lovejoy, 1985; Galera et al., 1998). Other skeletal collections used for similar studies include excavated material from cemeteries and newly acquired forensic autopsy material (Sahni et al., 2005; Dorandeu et al., 2008). Some of these collections do not contain the relevant demographic information of the individuals, especially the age of the individual. Studies that used these collections and required the age of the individual, usually estimate the age from other indicators that are present on the skeleton (Powers, 1962; Perizonius, 1984).

Skeletal collections that were derived from cadavers used at medical schools (Todd and Lyon, 1924; 1925a; 1925b; 1925c; Brooks, 1955; Meindl & Lovejoy, 1985; Hershkovitz et al., 1997; Galera et al., 1998) were the preferred collections to use as the personal data of the individuals are well documented. These collections were also used by many investigators in the early 1900's where the Todd & Hamman Collection and the Terry Collection were started (Tobias, 1985). Many years later it was found that the skeletal collections might not represent the most modern individuals due to secular trends, thus more recent studies used forensic autopsied material (Sahni et al., 2005; Dorandeu et al., 2008). Other sources of information using skeletons include either archaeological material with well kept records (Powers, 1962; Key et al., 1994) or excavated material from ancient cemeteries.

The two methods used in this study have limitations as to the final obliteration status of the cranial vault sutures. The Acsádi and Nemeskéri (1970) method was based upon that of Todd and Lyon (1924) and on earlier studies of suture obliteration. The results of the present study showed that this method was limited in its potential to investigate the obliteration status of the cranial vault sutures. The limitations included the divisions of the cranial vault sutures into their component parts and the scoring of each of these sutures. Similar issues were identified in the Meindl and Lovejoy (1985) method but instead of the divisions of the sutures the sites that were scored caused difficulties in scoring.

The scoring of a part of the suture that is not of uniform obliteration status (Beresford, 1993) posed a problem as no guidance was given when there was a change in the complexity or the obliteration in a single part or site of the suture. It has been shown that a suture can change its configuration in terms of the number of inter-digitations (i.e. its complexity). If the suture is divided along lines where there is a change in the complexity, the score that is awarded to the suture is not representative of this part of the suture. This creates a problem as these scores are intended to be indicative of the obliteration status thus influencing a greater or maybe lesser score in some areas. If the hypothesis that an increase in age will increase the obliteration status is accepted, then averaging the suture scores along the entire suture, as well as averaging all the other sutures concerned, does not give a true reflection of the status of the suture obliteration. This is very important as these scores assigned to the sutures are then used to estimate the age of the individual. The greater the score, the older the individual, thus influencing the estimate suggested by these indicators.

When Meindl and Lovejoy's (1985) method was used, some sites were at the junction of two or more sutures. The same drawback was seen here where in some cases one of the sutures had already been obliterated and the other sutures were either patent or were only starting to close. Thus confusion arose as to the score that should be assigned. There was a dilemma: should the obliterated part of the site be ignored or should the obliterated part of the site only be scored? The evidence of this is best illustrated by the poor repeatability of the scores of some of the sutures.

The problem of complexity of the suture has previously been addressed by introducing the concept of fractal analysis of the suture (Saito et al., 2002; Lynnerup

& Jacobsen, 2003; Skrzat & Walocha, 2003; Yu et al., 2003; Górski & Skrzat, 2006). This new method is based upon calculation of the areas that are taken up by the suture and considers the entire suture instead of just a segment. This method is useful in categorising the complexity of the suture but does not work well if the parts of the suture have already been obliterated. This is important as it has been shown that with an increase in complexity of the suture there is less obliteration, meaning simpler sutures obliterate more than complex sutures (Parsons & Box, 1905). The fractal analysis method, however, did not resolve the issue of using the obliteration of cranial sutures for the determination of age. The results of these studies were similar to other age determination methods using the obliteration of cranial sutures. This method has also shown to be an unlikely predictor of age for individuals older than 40 years (Lynnerup & Jacobsen, 2003).

So the question arises: how should the sutures be divided to allow the representative scoring of the region? This can only be answered if one assumes that the rate of suture obliteration of all parts of the suture and the entire skull are equal. Since 1907, however, the sutures were described laboriously taking into account the different aspects of the suture like the complexity, the shape and the size of the suture (Oppenheim, 1907). A more recent study (Hauser et al., 1991) also included the extension of the pattern of the suture. These characteristics, however, were not considered when the obliteration of the sutures was used as an age indicator from skeletal remains (Todd & Lyon, 1924; 1925a; 1925b; 1925c; Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1985).

Most of these studies were based upon the mechanistic view of scoring a suture. The biological understanding of the development of the suture in terms of the formation of the vault should be taken into account before a method can be developed to score the cranial vault sutures. Future research should include the factors that contribute to the closure of sutures. These studies should include partially obliterated and fully obliterated sutures by methods other than the scoring with the naked eye. These should include studying sutures by micro-techniques, computed tomography, mineralisation levels and also general micro-architecture of the sutures.

In the present study the parts of the suture which lie next to each other presented completely different states of obliteration showing the polymorphism of the obliteration of these sutures. It has also been shown that in a single section of the suture the obliteration status was not consistent. This finding is consistent with that of the palatal suture as well, where the suture pattern was shown to vary in a single individual, while there was great variation in the closure of this suture among individuals of the same age (Wehrbein & Yildizhan, 2001).

A possible solution to the problem would be to divide the sutures into equal parts and then score a number of factors that contribute to the status of obliteration. Firstly the complexity of the suture should be taken into account. Secondly the obliteration status of these areas of the sutures should be scored. The scoring system should also probably incorporate fewer options or should be more descriptive to clear any confusion as to the aspect of the suture being scored.

Irrespective of which scoring system was used, confusion as to the score to be given in any case seemed likely, especially between investigators. This same observation was noted by Saunders and colleagues (1992). The classic definition of the scoring system of the cranial vault sutures is an ordinal scale, assuming that there is a progression with obliteration status. This is evident as the score of zero represents an open suture, and a score of four represents a completely obliterated suture. Through the research of the present study, some sutures were open with a visible distance between the two surfaces of the sutural edges. Sometimes the distance was not visible but the suture was still considered open as there was no visible connection between the two sutural edges. The intermediate scores were also a bit confusing as one had to judge the percentage of obliteration that had taken place without internal views of the suture structure between the ectocranial and endocranial aspects.

Some factors that have been attributed to the closure of sutures include mechanical loads of the skull, genetics, suture structure, hormones, suture function and muscle function (Hershkovitz et al., 1997; Sabini & Elkowitz, 2006; Dorandeu et al., 2008). The lambdoid suture is found to be more often patent than it is obliterated (Sabini & Elkowitz, 2006). The results of the present study are in agreement with Sabini and Elkowitz (2006). The muscles that attach to the occipital bone contribute to the mechanical loads in the skull. These muscles include the trapezius, semispinalis capitis, longissimus capitis, rectus capitis posterior minor, rectus capitis posterior major, obliquus capitis superior, occipito-frontalis, splenius capitis, sternocleidomastoid, rectus capitis lateralis, rectus capitis anterior and longus capitis. The ligamentum nuchae also attaches to the external occipital protuberance and plays a role in the mechanical load of the skull (Sabini & Elkowitz, 2006).

The lambdoid suture is more complex in its appearance than the other vault sutures. If the lambdoid suture is affected by the mechanical forces produced by these muscles and ligaments then a simple suture would not allow the skull to be a unit (Byron et al., 2004). Thus the sutures in the lambdoid area are of a more complex nature to maintain some rigidity so that the occipital bones do not separate from the parietal bones during mechanical loading of the skull (Jaslow, 1990).

The concept that explains this phenomenon is called myofascial continuity (Sabini & Elkowitz, 2006). The definition states that muscle origins that attach to an area and then cross joints to attach to another area can exert a force onto the first area (Sabini & Elkowitz, 2006). This reason, however, does not hold true for the lateral aspects of the coronal suture. The coronal suture has often been divided into four parts instead of three to investigate the effect of the temporalis muscle on this part of the suture (Singer, 1953; Eränkö & Kihlberg, 1955; McKern & Stewart, 1957). The results of these studies show that the lateral aspects of the coronal suture are more often obliterated than other parts of the coronal suture and other sutures of the vault. If the same concept as that of the lambdoid suture is applied to this area then the lateral aspects of the coronal suture should remain patent throughout life, however, these sections of the skull are more often obliterated than the rest of the suture.

This should occur as the temporalis muscle exerts a force on the frontal and the parietal bones. This force will be exerted in a supero-inferior manner. If the lateral aspects of the coronal suture obliterate to allow the bones of this region to act as a unit, then the obliteration of sutures might be caused by the functioning of the suture or as a part of the functioning of the skull as a unit.

Another suture that shows the same characteristics is the squamosal suture. This suture is covered almost completely by the temporalis muscle. It has often been shown that this overlapping suture is also more complex than other sutures of the cranial vault (Standring et al., 2005). Patency of this suture is maintained throughout life (Mitchell & Patterson, 1967) thus not adhering to the theory that if the bones need to act as a unit, then the sutures will close early as the temporalis is a muscle of mastication which is used throughout life. Some studies, however, have found that patent sutures in mammals allow for more flexibility than a fused suture might (Herring & Teng, 2000). Further investigation on the biomechanics of these sutures, which are found connected to muscles of mastication, are needed.

Another suture that has been recently isolated and investigated is the fronto-sphenoidal suture (Dorandeu et al., 2008). This suture had been previously investigated by Meindl and Lovejoy (1985) but was considered part of a number of other sutures in the lateral anterior system. This system was shown by Meindl and Lovejoy (1985) to be more favoured than the vault sutures to predict age, which was also shown in the present study. This is in disagreement with the results of Saunders et al. (1992) who found that the vault system fared better on their sample than the lateral anterior system. These authors (Saunders et al., 1992) thus reinforced the idea that methods developed on a certain reference sample should not be extrapolated to other samples.

The variation in the obliteration of sutures in a single skull and across sexes and populations has still not deterred investigators from using the concept that cranial sutures obliterate with age. There are many more studies that have been recently published that still regard this as probably an important indicator of age if the correct method is proposed (Key et al., 1994; Dorandeu et al., 2008). These were the notions that Meindl and Lovejoy (1985) asserted to in the conclusion of their study: "Future work may allow refinement of these systems, and data from populations with markedly regular wear patterns may prove valuable in functional studies......." (Meindl & Lovejoy, 1985; p56).

Since the early 19th century there has been a warning against using the closure of cranial sutures as an indicator of age (Dwight, 1890). Yet more and more work is produced to try to find a relationship of some sort. This is probably due to the fact that the cranium is often the best preserved bone of the skeleton as is evident in paleoanthropology. Other reasons could also include the fact that many other methods of age determination need sophisticated statistics or a set of comparable examples like those of the ribs or the pubic symphysis. The cranial sutures technique is a morphological method and is considered simple and easy to use. However, on closer inspection, many factors need to be considered when using this method. Finally, other methods of age determination also seem to be as unsatisfactory as that of the cranial suture closure, thus the persistence of research in this area (Key et al., 1994; Sahni et al., 2005; Dorandeu et al., 2008).

As most of these studies (Todd & Lyon, 1924; 1925a; Acsádi & Nemeskéri, 1970; Meindl & Lovejoy, 1985) worked with the preconception that there is a progressive closure of the sutures with age, all data represented in these studies are based upon the age categories in which they belong. The scores for the different parts of the suture are not kept separate but are averaged. This is either done for the entire suture or for the left and right sides of the skull. Thus no new concept can be derived as age has always been associated with cranial vault sutures.

A study by Gowlett (1995) explains that the same thinking is found when trying to investigate human evolution. There is a general misconception that all things need to fit into categories and thus humans have made a habit of doing this when it comes to cranial suture closure. Just the mere mention of cranial suture closure brings to mind the concept of age determination, thus trying to find a relationship, albeit one that might not exist, between age and suture closure is a natural process.

The sample sizes in the studies have also been chosen to match up with age categories (Acsádi & Nemeskéri, 1970). While many other studies also tried to achieve a large sample size, some studies tried to achieve an equal number of skulls in each given age group. If the skulls are assessed according to age groups, systematic bias might occur, during the data collection process, due to the knowledge of the age of the specimens. Although one might not know the ages of the skulls, one does know that all the skulls are from a certain age group. Thus there is systematic bias just by collecting the data. The sample sizes have also been increased in many of these studies but it has been noted before that no matter how many more skulls are used to collect data the result will not change (Eränkö & Kihlberg, 1955). Thus a blind study is favoured as there is minimal bias when collecting data, especially if the outcome concerns age.

In some studies the sample size was restricted to include only normal individuals and reject skulls with abnormalities (Todd & Lyon, 1924; Acsádi & Nemeskéri, 1970). Todd and Lyon (1924) had culled their sample by removing all specimens that showed complete patency in all sutures and also excluded specimens that showed a growth deviation in the pubic symphysis. Acsádi and Nemeskéri (1970) employed the same technique and discarded all specimens from their sample that showed complete patency in all sutures. These authors, however, have included all other specimens that have completely obliterated sutures (Acsádi & Nemeskéri, 1970).

Another concept of suture closure which was introduced by Todd and Lyon (1924) was the concept of "lapsed union." This was when the suture had failed to close but had showed signs of closure by heaping up bone at the sutural edges. This concept has been picked up by some investigators (Sahni et al., 2005) but in the present study was not observed across any specimens in the samples examined.

Fluctuating asymmetry of the closure of the cranial sutures in the present study was assessed by using Van Valen's formula ($1- r^2$) (Gawlikowska et al., 2007). 'r' is the correlation coefficient that was calculated between the scores of the left and right sides. This fluctuating asymmetry index thus gives an indication of the random difference that would be seen in these bilateral sites of the skull (Hutchinson &

Cheverud, 1995; Gawlikowska et al., 2007). These random differences would be caused by external factors that are not controlled by the genetic pattern of the closure of these sutures. This random difference is sometimes referred to as the 'epigenetic noise' (Hutchinson & Cheverud, 1995). In the present study this 'epigenetic noise' probably refers to the environment that these sutures normally develop and grow in. A change in the environment would allow the closure of these sutures to be varied. This variation of suture closure thus lends evidence towards the possible epigenetic nature of cranial suture obliteration.

There has been a large volume of research that shows the uncertainty of the closure of cranial sutures in the determination of age (Dwight, 1890; Singer, 1953). Some studies have shown an increase in suture closure till the age of 30 years while others have shown a relationship with individuals of 50 years (Perizonius, 1994). Some studies have shown sexual dimorphism (Galera et al., 1998) present in the study while others have pooled the samples of males and females as there were no statistically significant differences (Perizonius, 1994).

Thus there seems to be a large variation in the pattern of obliteration across populations and even across sexes (Reichs, 1989). Females tend to have sutures which close at a later stage or remain open all their lives (Parsons & Box, 1905; Frédéric, 1906; Brooks, 1955; Sahni et al., 2005). It has already been noted that the individual variation of cranial sutures is so great that this trait cannot be used as an indicator of age (Eränkö & Kihlberg, 1955). Further evidence that there is no relationship between the cranial suture closure and age is illustrated by investigating the obliteration status of each of the suture sites with recorded age (Fig 5.53-5.56). It is clearly evident that there is a variation of the suture closure even in single sutures.

The discrepancy in complexity seen between the ectocranial and endocranial sutures also plays a role in the scoring of the sutures. Initially both the ectocranial and endocranial aspects of the skull were used but eventually some noted that the ectocranial suture closure was too erratic and thus only assessed the endocranial aspect (Acsádi & Nemeskéri, 1970). The closure of the endocranial aspects in this study, however, have shown a correlation with age that is extremely weak (Table 5.7). This correlation is regarded as acceptable to some investigators because correlations of other skeletal age markers to age are also similar to this. This includes changes with age of the pubic symphysis (Brooks, 1955). This forms the basis for an argument that the closure of endocranial sutures should be accepted as a skeletal trait for estimating age. Clearly this argument is illogical because any trait showing poor correlation with age cannot be considered a reliable age indicator, especially for forensic purposes. Since the changes on the pubic symphysis and cranial sutures obliteration are the only, besides the ossification of sternal rib ends (İşcan et al., 1984), purported indicators of age in skeletal remains, the only reliable way to establish age of adult skeletal remains should be examination of the state of dentition.

From the present study, however, it is evident that the closure of cranial sutures is a one-off occurrence. If the individual possesses the gene responsible for the closure of the suture and the environment allows for the closure to take place, then in such skulls only the closure will be seen. The skulls that are between 60 and 90 years and still have open sutures are the incontrovertible evidence of this phenomenon. Thus the estimation of age from the closure of cranial sutures is erroneous and should not be performed.

The current paradigm, which is a hypothesis accepted as a correct approximation of truth, is that the closure of cranial sutures is a mono-morphic character like some three quarters of all human biological characters (Torgersen, 1950; 1951a,b) . To falsify this one has to show polymorphism of this character. To test polymorphism the following needs to be adhered to: in individuals of the same age, same origin and living in the same environment there should be a different pattern of closure. The nature of this polymorphism can either be: genetic or environmental or both. If persons from the same environment at the same age have differently obliterated sutures, then the polymorphism is genetic (Bodmer & Cavalli-Sforza, 1976).

The present study is based on individuals from the same geographical region, with similar ages. The patterns of suture closure are polymorphic as is clearly evident from the results of the present study (Fig 5.57- 5.59). These figures are an example of the polymorphic nature of the patterns of cranial suture closure in a specific age category (the over 70 year olds) on both the ectocranial and endocranial aspect of the skull. The scores of each of the individuals were plotted against each of the suture sites. Different coloured lines represent the different groups to illustrate the polymorphic nature of closure of cranial sutures. This illustrates the probability that these traits are epigenetic in nature. This is shown by the bands of similar colour displayed on the graphs.

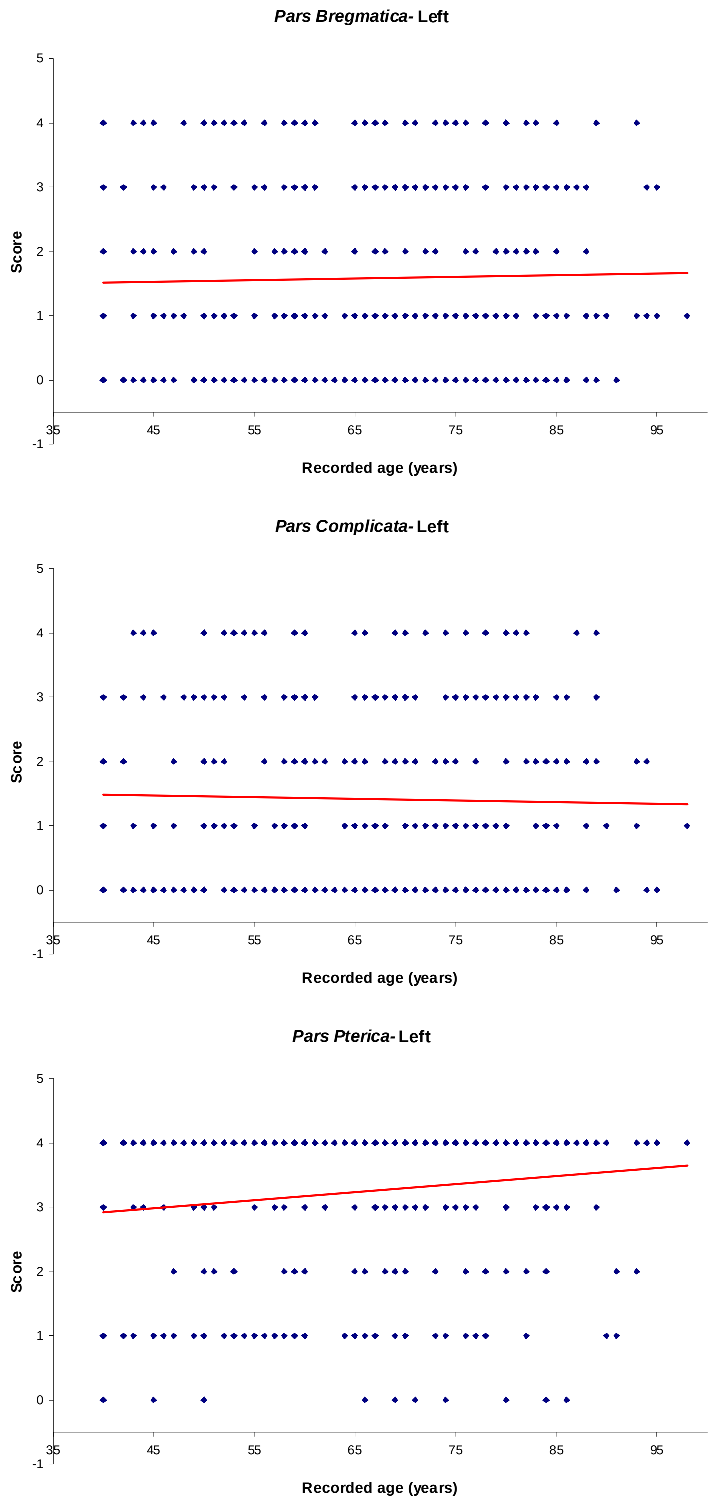


Figure 5.53. Scattergrams of the recorded age vs the coronal suture scores, on the ectocranial aspect, using the Acsádi & Nemeskéri (1970) method. The red line represents the regression line.

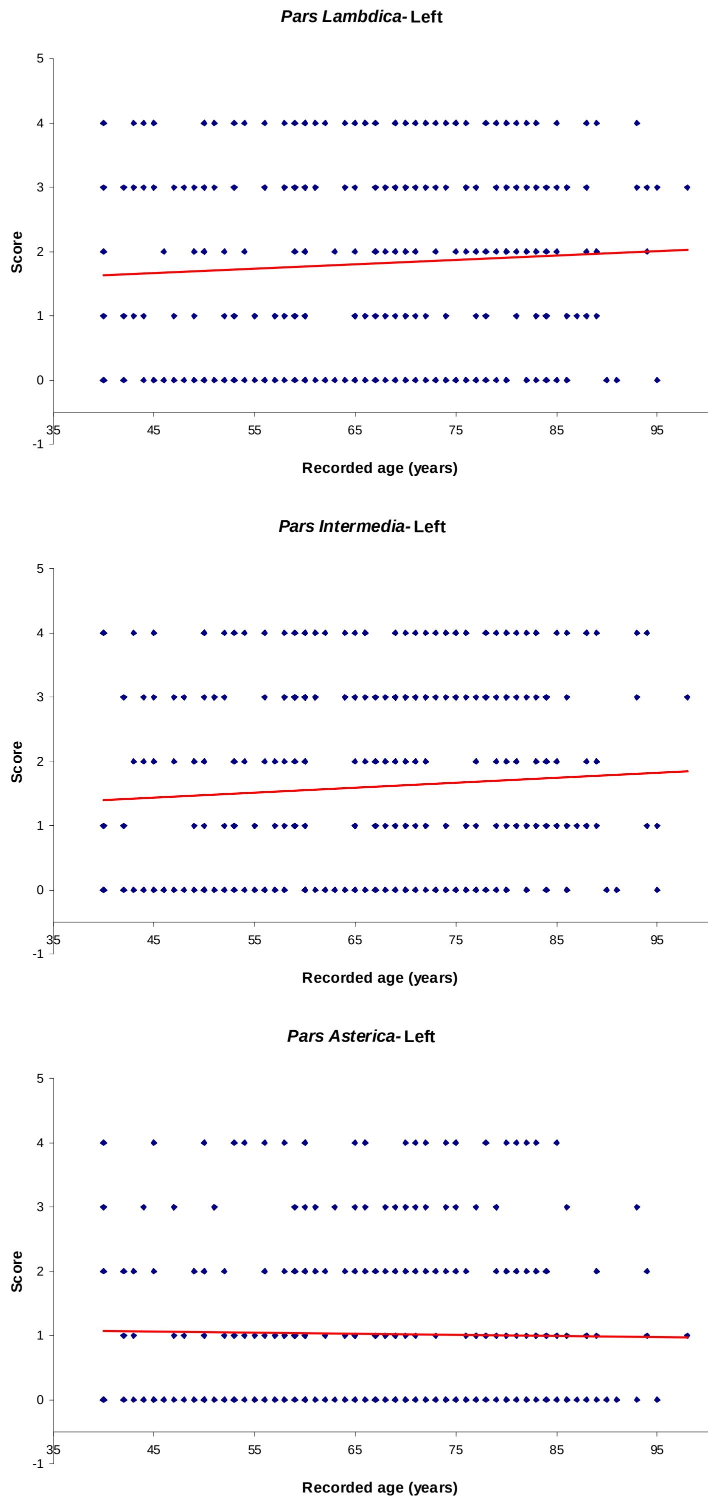


Figure 5.54. Scattergrams of the recorded age vs the lambdoid suture scores, on the ectocranial aspect, using the Acsádi & Nemeskéri (1970) method. The red line represents the regression line.

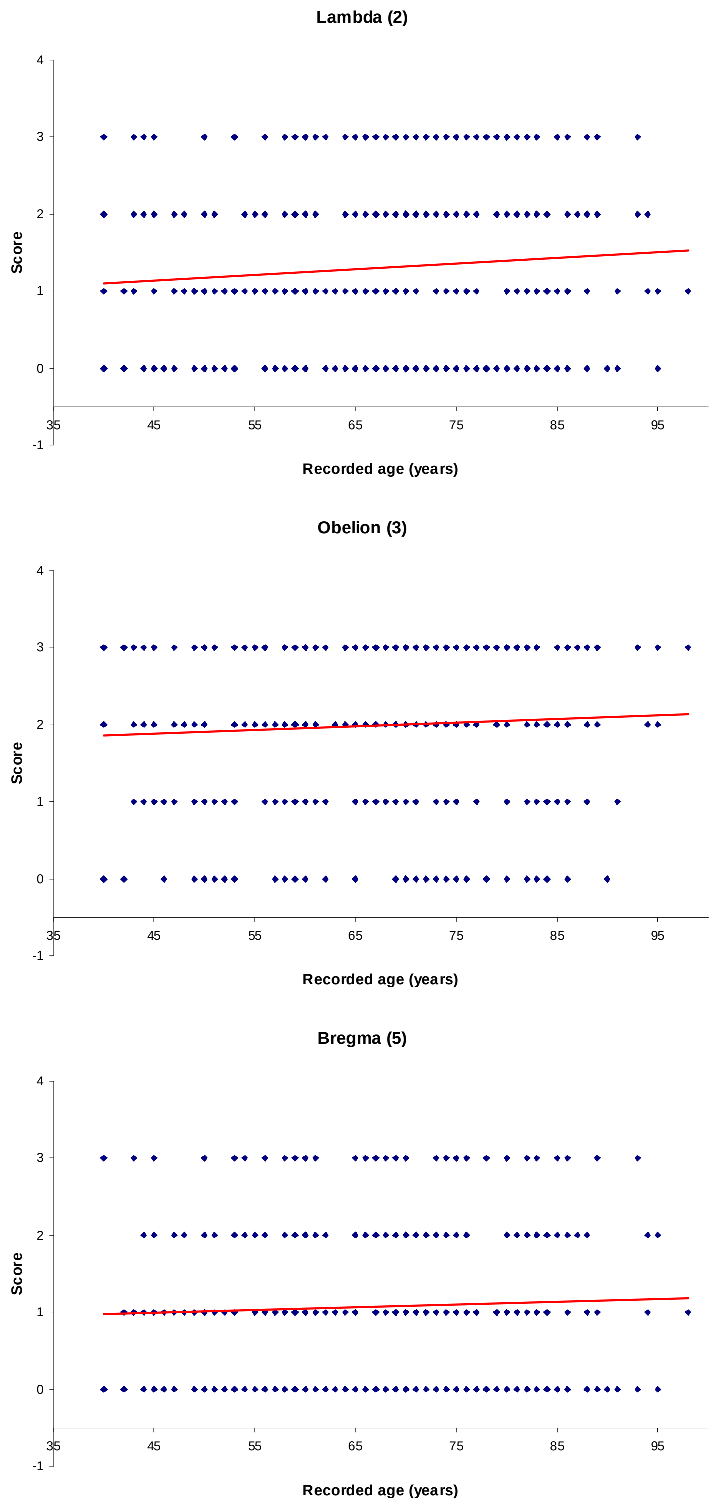


Figure 5.55. Scattergrams of the recorded age vs the midline suture site scores, on the ectocranial aspect, using the Meindl & Lovejoy (1985) method. The red line represents the regression line.

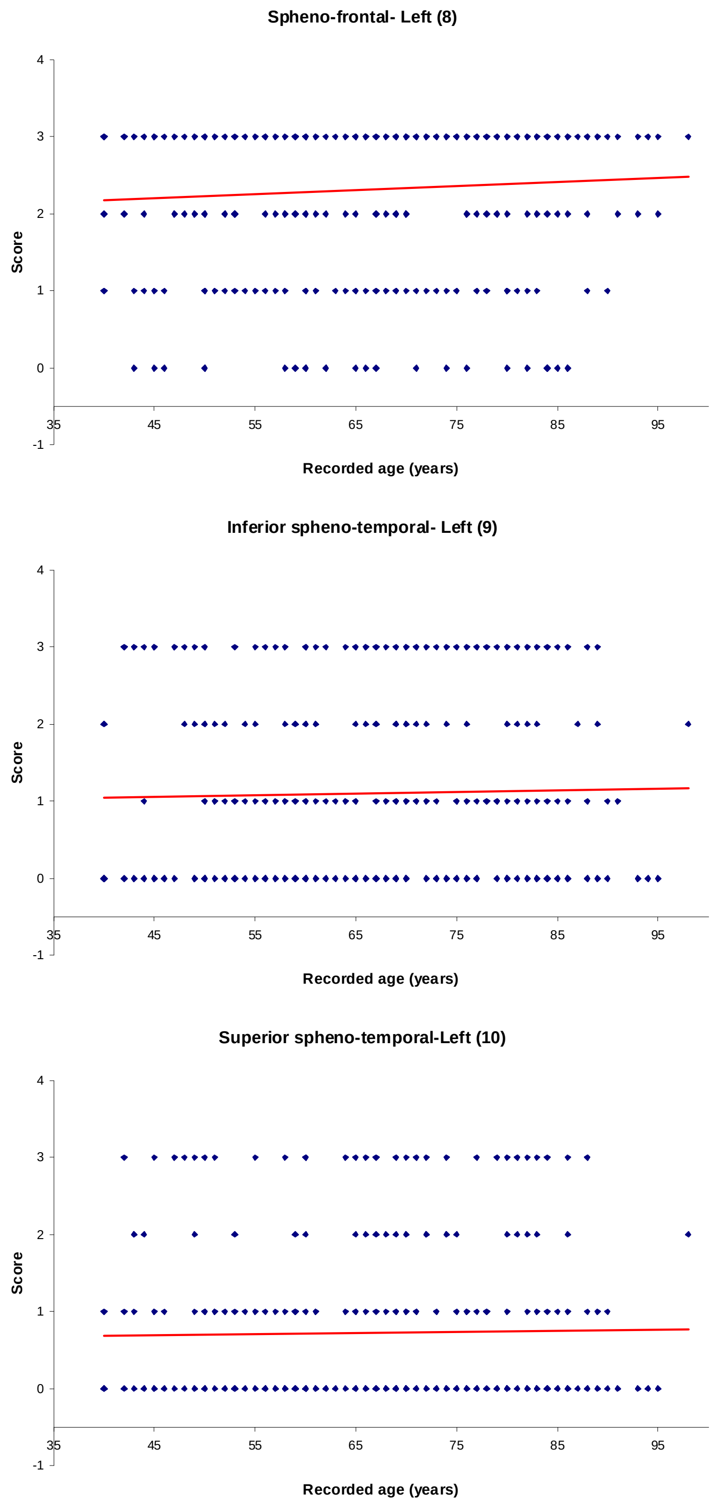


Figure 5.56. Scattergrams of the recorded age vs the accessory suture scores, on the ectocranial aspect, using the Meindl & Lovejoy (1985) method. Red line represents the regression line.

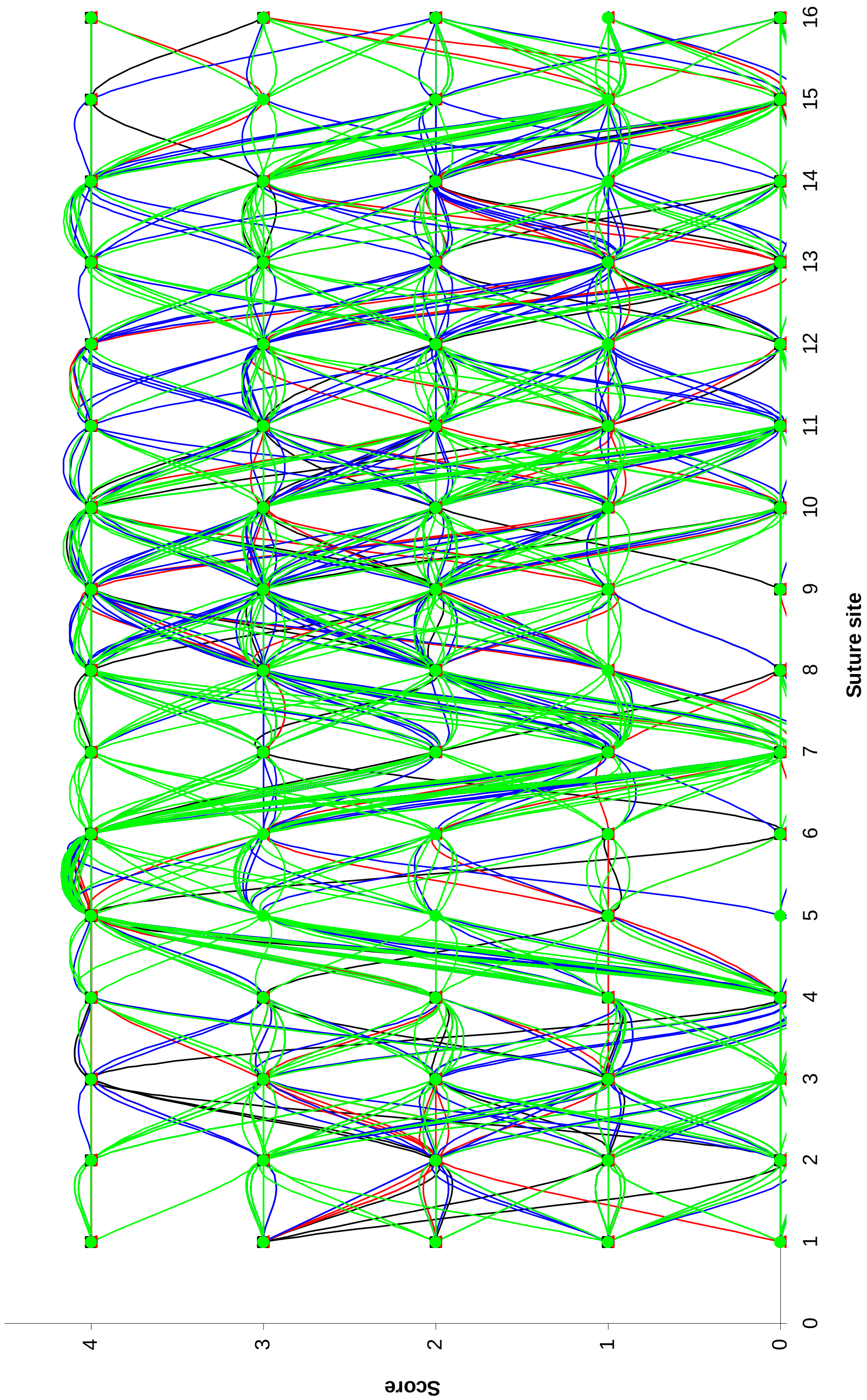


Figure 5.57. Polymorphic patterns of the obliteration scores of the ectocranial aspect of all individuals in the greater than 70 years group using the Acsádi & Nemeskéri (1970) method. Red = black males, black =black females, blue = white males & Green = white females.

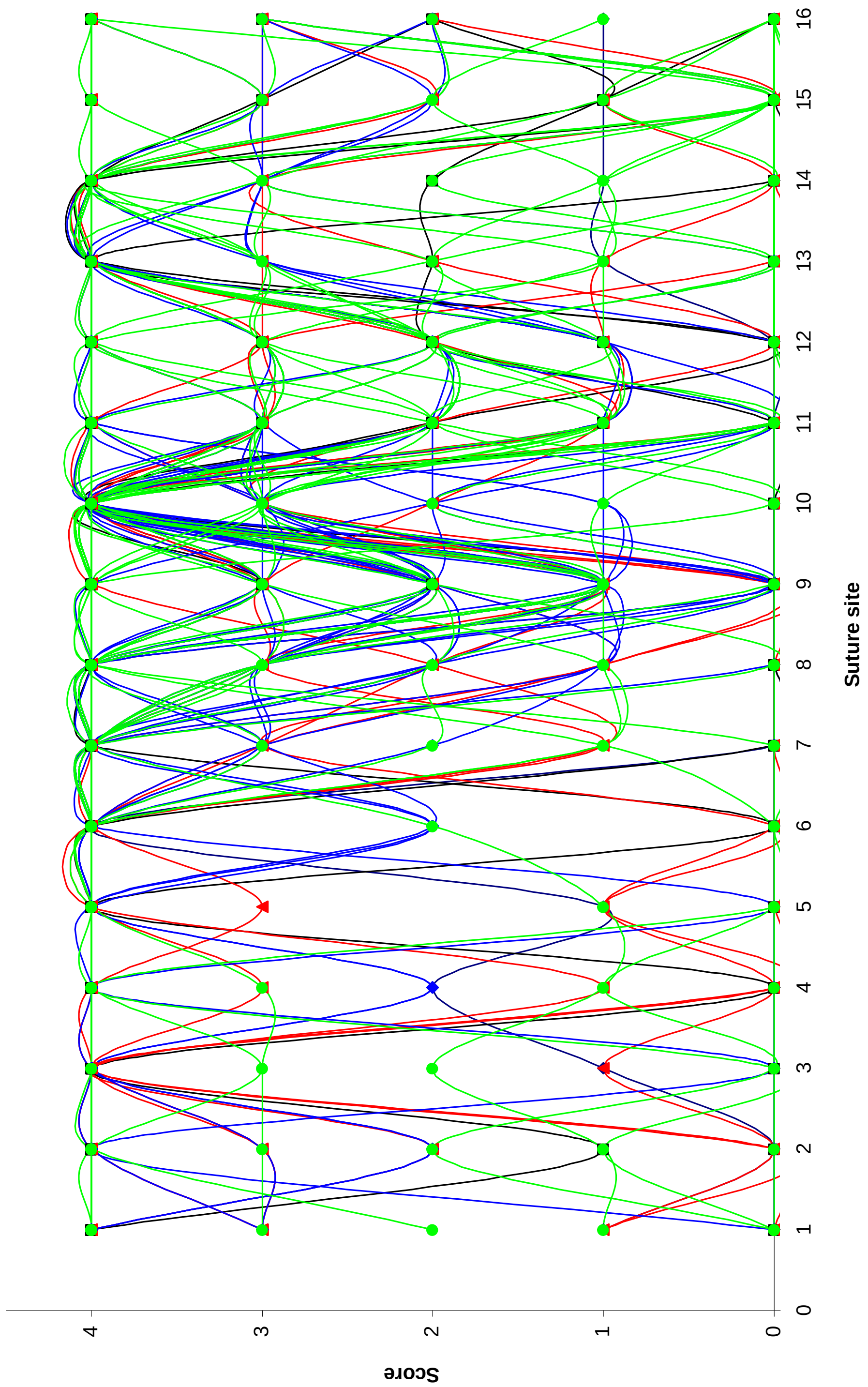


Figure 5.58. Polymorphic patterns of the obliteration scores of the endocranial aspect of all individuals in the greater than 70 years group using the Acsádi & Nemeskéri (1970) method. Red = black males, black =black females, blue = white males & Green = white females.

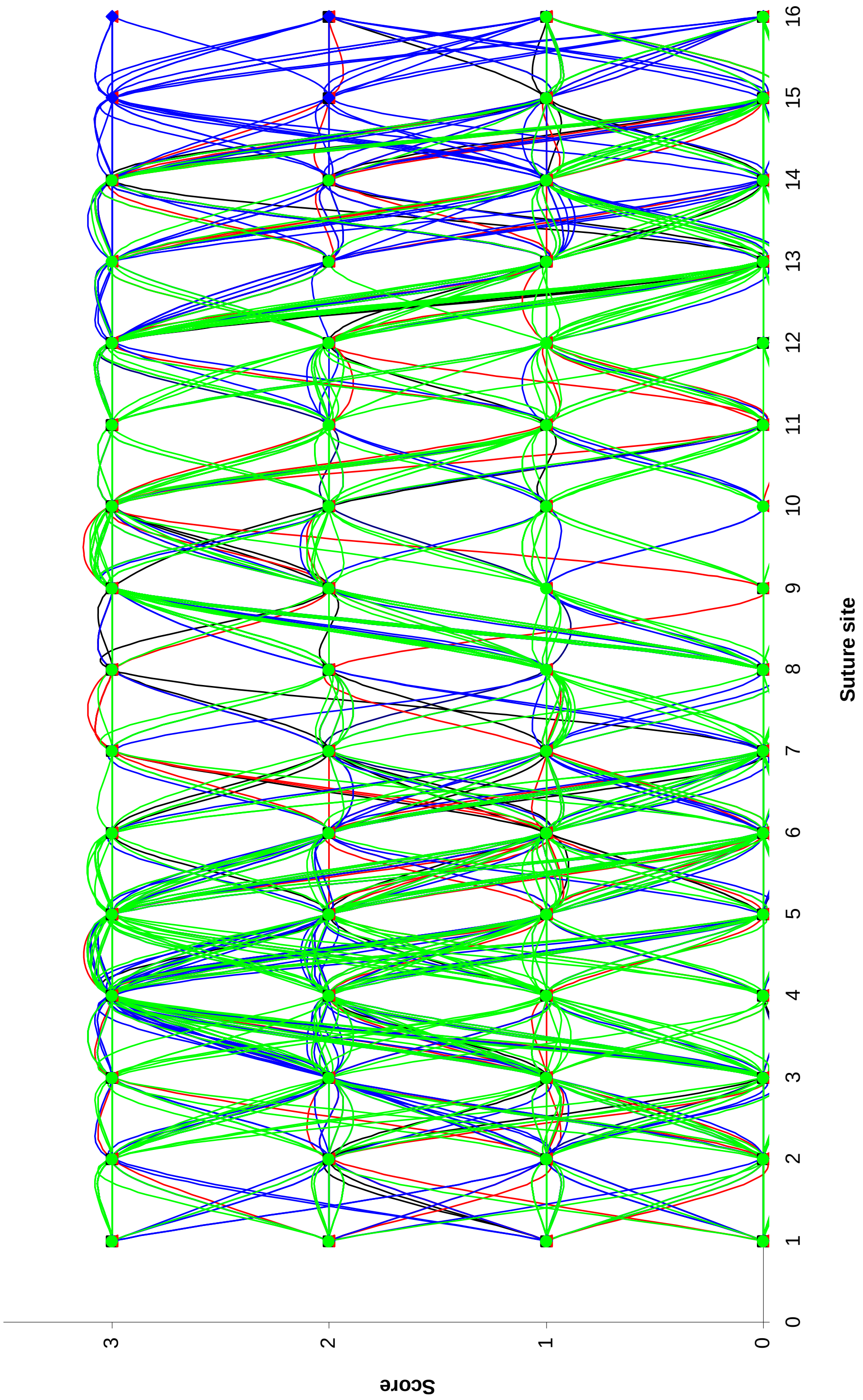


Figure 5.59. Polymorphic patterns of the obliteration scores of the ectocranial aspect of all individuals in the greater than 70 years group using the Meindl & Lovejoy (1985) method. Red = black males, black =black females, blue = white males & Green = white females.

The fluctuating asymmetry found in the closure of the sutures in the present study also illustrates that the pattern of closure is genetically controlled but there is random variation. Thus the polymorphism of this trait is probably best explained by genetics as it has been shown that sutural tissue is probably genetically controlled (van Doorenmaalen, 1984). This concept has already been touched on by many investigators who cautioned against the use of these traits as an indicator of age e.g. Hershkovitz et al., (1997). Recently it has also been shown that more research needs to be carried out to understand the genetics involved in the closure of cranial vault sutures (Key et al., 1994; Wilkie, 1997; Dorandeu et al., 2008).

The closure of cranial sutures in the molecular biology field has been extensively investigated. The factors that determine the premature closure of cranial sutures and also the normal factors, like regional dura mater and growth factors that contribute to the closure were identified (Opperman et al., 1993; Bradley et al., 1997; Opperman et al., 2000; Mathy et al., 2003; Nacamuli et al., 2004; Lin et al., 2007). Many experimental studies had removed a part of the dura mater and/or the calvarial bone and placed it in a different section of the skull. These studies have shown that even if the suture is moved it will still maintain the characteristics of the original suture. Dura mater has also been shown to be one of the factors that stimulate fusion of cranial suture closure (Bradley et al., 1997). Thus more research is needed at the microscopic and molecular level to understand the normal process of cranial suture fusion.

Cranial sutures in Rhesus monkey skulls have, however, shown that the sutural patterns found at the pterion show a variation that is consistent amongst families (Wang et al., 2006). It was thus suggested that these sutures were probably controlled by genes (Wang et al., 2006).

The present study shows evidence for the obliteration of cranial vault sutures to be included as an epigenetic character and not be used as an indicator of age. These can be considered discontinuous traits that are probably highly inherited. The limitation of the present study does not allow one to find individuals from the same family to compare the results. However, future research should be directed towards finding patterns of closure of cranial vault sutures in individuals that are related.

Chapter Six: *Conclusion*

The obliteration status of cranial sutures in skeletal material has often been used as an indicator of age of skeletal remains. This skeletal trait, despite repeatedly being labelled as a poor indicator of age, has been used in conjunction with skeletal age indicators as part of the multi-factorial method. This concept was based upon the preconception that suture closure progresses with age. The results of the current study have shown that there is no relationship between age and suture closure. The findings of the present study imply that cranial suture closure should not be used as an indicator of age as these sutures have a polymorphic nature of epigenetic traits in their closure. There was no consistent closure pattern that was evident in any of the groups. The endocranial sutures were better correlated with the recorded age of the skull than ectocranial sutures, but the correlation was very low.

The present study strongly suggests that the closure of cranial sutures is an epigenetic trait as it is seen in so many other aspects of the skull. These include the metopic suture and sutural bones. The present study was limited in its investigation of the suture closure as no individuals biologically related to each other were studied. Thus future research into the closure of cranial sutures should include samples of members from the same families.

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Appendices

Appendix A. An example of the data collection sheet.

Serial No.:	____________	Age:	____________________
A_No.:	____________	Pop Affinity:	____________________
Sex:	____________	Date of birth:	____________________
Stature:	____________	Date of death:	____________________

Cranial Sutures

Ascadi & Nemeskeri (1970)		
Site	**Ectocranial**	**Endocranial**
CL1		
CL2		
CL3		
CR1		
CR2		
CR3		
S1		
S2		
S3		
S4		
LL1		
LL2		
LL3		
LR1		
LR2		
LR3		

Meindl & Lovejoy (1985)		
Site	**Left**	**Right**
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Appendix B. P values for paired t-tests of ectocranial sectional scores using the Acsádi & Nemeskéri (1970) method.

Variable	*Black Males*	*Black Females*	*White Males*	*White Females*
Pars Bregmatica-Left & Right	0.51	**0.01**	0.32	0.76
Pars Complicata-Left & Right	0.48	0.80	**0.02**	0.47
Pars Pterica-Left & Right	0.09	0.29	0.52	0.45
Pars Bregmatica & Pars Vertices	**0.00**	**0.02**	**0.00**	**0.00**
Pars Bregmatica & Pars Obelica	**0.00**	**0.00**	**0.00**	**0.00**
Pars Bregmatica & Pars Lambdica	**0.00**	**0.00**	**0.00**	**0.01**
Pars Vertices & Pars Obelica	**0.02**	**0.00**	**0.00**	0.55
Pars Vertices & Pars Lambdica	0.68	**0.03**	0.52	0.25
Pars Obelica & Pars Lambdica	**0.01**	0.44	**0.00**	**0.04**
Pars Lambdica-Left & Right	0.59	1.00	0.21	0.88
Pars Intermedia-Left & Right	0.16	0.87	0.43	0.15
Pars Asterica-Left & Right	0.39	0.47	0.25	**0.00**

Numbers in bold indicate statistical significance

Appendix C. P values for paired t-tests of endocranial sectional scores using the Acsádi & Nemeskéri (1970) method.

Variable	*Black Males*	*Black Females*	*White Males*	*White Females*
Pars Bregmatica-Left & Right	**0.01**	0.89	0.51	0.07
Pars Complicata-Left & Right	0.58	0.48	0.58	0.25
Pars Pterica-Left & Right	0.72	0.91	0.85	0.57
Pars Bregmatica & Pars Vertices	**0.00**	0.69	**0.00**	**0.02**
Pars Bregmatica & Pars Obelica	**0.00**	0.47	**0.00**	**0.00**
Pars Bregmatica & Pars Lambdica	0.38	0.12	**0.00**	**0.03**
Pars Vertices & Pars Obelica	**0.00**	0.60	**0.00**	**0.00**
Pars Vertices & Pars Lambdica	**0.00**	0.06	**0.00**	0.81
Pars Obelica & Pars Lambdica	**0.00**	**0.01**	**0.00**	**0.01**
Pars Lambdica-Left & Right	0.26	0.55	0.89	**0.04**
Pars Intermedia-Left & Right	0.17	0.63	0.35	0.14
Pars Asterica-Left & Right	0.69	0.90	**0.04**	0.08

Numbers in bold indicate statistical significance

Appendix D. P values for paired t-tests of ectocranial sectional scores using the Meindl & Lovejoy (1985) method.

Variable	*Black Males*	*Black Females*	*White Males*	*White Females*
Midlambdoid-Left & Right (1)	0.88	0.29	0.68	0.72
Mid-coronal-Left & Right (6)	0.26	0.18	0.29	0.32
Pterion-Left & Right (7)	0.72	**0.00**	0.30	0.64
Bregma (5) & Anterior Sagittal (4)	**0.00**	0.46	**0.00**	**0.00**
Bregma (5) & Obelion (3)	**0.00**	**0.00**	**0.00**	**0.00**
Bregma (5) & Lambda (2)	0.32	0.58	**0.00**	0.13
Anterior Sagittal (4) & Obelion (3)	**0.00**	**0.00**	**0.00**	0.34
Anterior Sagittal (4) & Lambda (2)	**0.00**	0.19	**0.02**	**0.00**
Obelion (3) & Lambda (2)	**0.00**	**0.00**	**0.00**	**0.00**
Spheno-frontal-Left & Right (8)	0.69	0.30	1.00	0.57
Inf. Spheno-temporal-Left & Right (9)	0.10	0.82	**0.03**	0.55
Sup. Spheno-temporal-Left & Right (10)	0.37	0.44	**0.00**	0.42

Numbers in bold indicate statistical significance

Appendix E. Frequency distribution of scores for coronal, sagittal and lambdoid sutures using the Acsádi & Nemeskéri (1970) method for all individuals on the ectocranial aspect.

Section	Score 0	1	2	3	4	Total	x^2 value	p value
Pars Bregmatica-Left	165	127	54	83	57	486	94.33	**0.00**
Pars Bregmatica-Right	165	139	53	76	53	486	110.09	**0.00**
Pars Complicata-Left	193	97	62	94	40	486	140.93	**0.00**
Pars Complicata-Right	199	85	77	81	44	486	144.17	**0.00**
Pars Pterica-Left	26	76	31	57	296	486	525.09	**0.00**
Pars Pterica-Right	26	65	39	58	298	486	528.30	**0.00**
Pars Bregmatica	158	107	53	86	82	486	62.79	**0.00**
Pars Vertices	109	84	79	102	112	486	9.12	0.06
Pars Obelica	84	72	80	125	125	486	27.27	**0.00**
Pars Lambdica	107	86	69	112	112	486	14.97	**0.01**
Pars Lambdica-Left	174	78	59	98	77	486	83.69	**0.00**
Pars Lambdica-Right	161	81	71	102	71	486	58.94	**0.00**
Pars Intermedia-Left	198	79	59	81	69	486	133.84	**0.00**
Pars Intermedia-Right	193	79	64	84	66	486	120.98	**0.00**
Pars Asterica-Left	255	96	70	33	32	486	349.95	**0.00**
Pars Asterica-Right	252	89	76	36	33	486	332.79	**0.00**

Numbers in bold indicate statistical significance

Appendix F. Frequency distribution of scores for coronal, sagittal and lambdoid sutures using the Acsádi & Nemeskéri (1970) method for all individuals on the endocranial aspect.

Section	Score 0	1	2	3	4	Total	x^2 value	p value
Pars Bregmatica-Left	60	30	14	26	356	486	873.14	**0.00**
Pars Bregmatica-Right	64	28	15	17	362	486	917.68	**0.00**
Pars Complicata-Left	52	15	6	18	395	486	1153.03	**0.00**
Pars Complicata-Right	53	16	6	19	392	486	1130.52	**0.00**
Pars Pterica-Left	60	21	2	15	388	486	1106.74	**0.00**
Pars Pterica-Right	62	15	6	14	389	486	1115.05	**0.00**
Pars Bregmatica	73	36	12	23	342	486	792.42	**0.00**
Pars Vertices	83	36	50	50	267	486	383.07	**0.00**
Pars Obelica	101	57	64	44	220	486	212.37	**0.00**
Pars Lambdica	70	27	34	40	315	486	621.10	**0.00**
Pars Lambdica-Left	108	67	64	60	187	486	119.12	**0.00**
Pars Lambdica-Right	104	65	75	49	193	486	134.54	**0.00**
Pars Intermedia-Left	95	40	12	21	318	486	669.70	**0.00**
Pars Intermedia-Right	92	40	9	22	323	486	696.70	**0.00**
Pars Asterica-Left	120	45	11	23	287	486	537.09	**0.00**
Pars Asterica-Right	116	38	18	19	295	486	569.66	**0.00**

Numbers in bold indicate statistical significance

Appendix G. Frequency distribution of scores for all ten sites on the left and right sides of the skull using the Meindl & Lovejoy (1985) method for all individuals on the ectocranial aspect.

	Score						
Section	***0***	***1***	***2***	***3***	***Total***	**x^2 value**	**p value**
Mid-coronal-Left	250	105	73	58	486	190.69	**0.00**
Mid-coronal-Right	257	102	68	59	486	209.95	**0.00**
Pterion-Left	39	78	78	291	486	323.63	**0.00**
Pterion-Right	29	80	76	301	486	366.82	**0.00**
Bregma	196	151	85	54	486	101.31	**0.00**
Ant. Sagittal	147	102	105	132	486	11.63	**0.01**
Obelion	91	94	108	193	486	57.46	**0.00**
Lambda	173	135	93	85	486	40.98	**0.00**
Midlambdoid-Left	205	101	80	100	486	78.82	**0.00**
Midlambdoid-Right	201	111	78	96	486	73.85	**0.00**
Spheno-frontal-Left	44	92	77	273	486	261.80	**0.00**
Spheno-frontal-Right	37	93	78	278	486	282.61	**0.00**
Inf. Spheno-temporal-Left	231	111	48	96	486	149.41	**0.00**
Inf. Spheno-temporal-Right	216	119	40	111	486	129.13	**0.00**
Sup. Spheno-temporal-Left	291	106	34	55	486	337.85	**0.00**
Sup. Spheno-temporal-Right	282	101	32	71	486	302.40	**0.00**

Numbers in bold indicate statistical significance

Appendix H. Actual distribution (in numbers) of under-estimated, acceptable and over-estimated ages for all individuals.

	Under-estimated	Acceptable	Over-estimated	Total
Ectocranial-Acsadi & Nemeskeri	252	168	21	441
Endocranial-Acsadi & Nemeskeri	131	270	43	444
Lateral Anterior (Left) Meindl & Lovejoy	182	245	29	456
Lateral Anterior (Right) Meindl & Lovejoy	180	257	31	468
Vault (Left) Meindl & Lovejoy	209	238	9	456
Vault (Right) Meindl & Lovejoy	211	242	10	463

Appendix I. Actual distribution (in numbers) of under-estimated, acceptable and over-estimated ages for black males, black females, white males and white females.

	Under-estimated	*Acceptable*	*Over-estimated*	*Total*
Ectocranial-Acsadi & Nemeskeri	**252**	**168**	**21**	**441**
Black Males	45	53	7	105
Black Females	31	63	10	104
White Males	86	29	3	118
White Females	90	23	1	114
Endocranial-Acsadi & Nemeskeri	**131**	**270**	**43**	**444**
Black Males	20	74	11	105
Black Females	19	60	20	99
White Males	40	73	9	122
White Females	52	63	3	118
Lateral Anterior (Left) Meindl & Lovejoy	**182**	**245**	**29**	**456**
Black Males	30	66	8	104
Black Females	14	85	19	118
White Males	62	55	1	118
White Females	76	39	1	116
Lateral Anterior (Right) Meindl & Lovejoy	**180**	**257**	**31**	**468**
Black Males	29	67	10	106
Black Females	15	91	19	125
White Males	62	57	1	120
White Females	74	42	1	117
Vault (Left) Meindl & Lovejoy	**209**	**238**	**9**	**456**
Black Males	27	67	5	99
Black Females	23	91	4	118
White Males	71	50	0	121
White Females	88	30	0	118
Vault (Right) Meindl & Lovejoy	**211**	**242**	**10**	**463**
Black Males	27	68	5	100
Black Females	24	95	5	124
White Males	72	50	0	122
White Females	88	29	0	117

Appendix J. *Actual distribution (in numbers) of under-estimated, acceptable and over-estimated ages for black males, black females, white males and white females in the respective age groups.*

	Under-estimated	Acceptable	Over-estimated	Total
Ectocranial-Acsadi & Nemeskeri	**252**	**168**	**21**	**441**
≤ 39 years	0	58	15	73
40-69 years	107	94	6	207
≥ 70 years	145	16	0	161
Endocranial-Acsadi & Nemeskeri	**131**	**270**	**43**	**444**
≤ 39 years	0	36	27	63
40-69 years	29	169	16	214
≥ 70 years	102	65	0	167
Lateral Anterior (Left) Meindl & Lovejoy	**182**	**245**	**29**	**456**
≤ 39 years	0	53	29	82
40-69 years	30	181	0	211
≥ 70 years	152	11	0	163
Lateral Anterior (Right) Meindl & Lovejoy	**180**	**257**	**31**	**468**
≤ 39 years	0	58	31	89
40-69 years	33	182	0	215
≥ 70 years	147	17	0	164
Vault (Left) Meindl & Lovejoy	**209**	**238**	**9**	**456**
≤ 39 years	0	74	9	83
40-69 years	67	143	0	210
≥ 70 years	142	21	0	163
Vault (Right) Meindl & Lovejoy	**211**	**242**	**10**	**463**
≤ 39 years	0	79	10	89
40-69 years	69	143	0	212
≥ 70 years	142	20	0	162