A STUDY OF THE AGE RELATED CHANGES ON THE ENDOCRANIAL SURFACE OF THE SKULL

GERALDINE ANNE BARBER

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Abstract

The accurate estimation of age at death of human skeletal remains is an important aspect of many disciplines including archaeology, palaeopathology and medicine. There are many techniques in current use, but most of these have maximum cut-off points, leaving older individuals underaged. Current opinion suggests that a suite of techniques, rather than one specific method be used when estimating age at death.

The aim of this project was to investigate five aspects of the endocranial surface of the skull; mid-parietal thickness, hyperostosis frontalis interna (HFI), cranial suture fusion, vascular grooves and arachnoid granulations and to evaluate their relationship with age.

Four samples (total 697 skeletons) were used **1**.a modern post-mortem population; **2**.an early 20thC American anthropological collection; **3**.a 17th-19thC French/English archaeological sample **4**.an English 10th-19thC archaeological sample. Three of these samples were of known age at death. Direct measurement, recording and x-ray techniques were used to evaluate the relationship between specific bone changes and age.

A measurable, but weak relationship with age was observed in skull mid-parietal thickness, HFI, rate of endocranial and ectocranial suture fusion and the cross sectional profile of meningeal vessel grooves.

A new technique for the diagnosis of HFI was proposed, based on standard x-ray scores. Use of this method on the four samples showed that HFI is not increasing in prevalence with modernity, as previously thought.

A strong relationship was observed between arachnoid granulation pit counts and age. A new method for estimating age at death was proposed and tested on two populations of known age. This new method was as accurate in estimating age at death as two of the most popular techniques currently in use. The method had less bias in ageing, can be applied to both sexes with equal accuracy and has no maximum age cut-off point.

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Although there is only one name on the cover of this thesis, it is by no means a work carried out in isolation. I have been fortunate to have the help of very many friends and colleagues in the production of these volumes, whom I would like to thank below.

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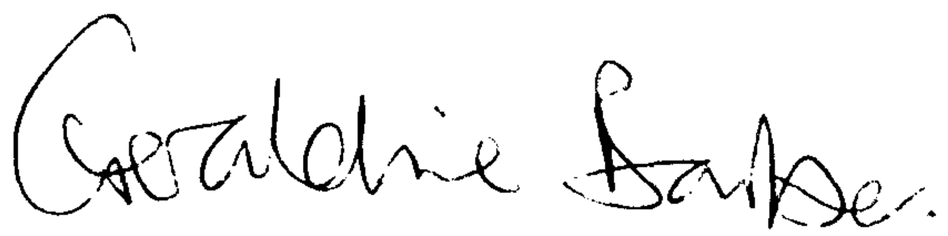
I declare that the work contained in this thesis, apart from that acknowledged, is my own work. The views expressed here are those of the author, and are not necessarily those of the University.



Geraldine Barber

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Chapter 1. Introduction to and aims of the study

At your age death has no meaning.... There's nothing left of the strong, vigorous, healthy young man that I was when I was thirty. Carefully, viciously, it has slowly, so slowly turned my dark hair into white, it's taken away my smooth skin, my muscles, my teeth, the body I used to have.
- translated from "Bel Ami" (Maupassant)

Introduction

The human species is unique in several ways; its large brain capacity relative to body size, the time it takes to mature (at 16 years it is twice as long as the great apes, Stringer and Gamble, 1993), that females live considerably beyond the age at which fertility stops (the menopause) and most relevant for this thesis, the fact that ageing is a commonplace feature of the population in its normal environment.

All of these features undoubtedly contribute to the fact that the human species has been so successful in its environment. A long lifespan gives humans the chance to pass on knowledge and acquired skills; in turn these lead to developments which benefit society as a whole. On a more philosophical note increasing age infers wisdom and maturity (the biblical Methuselah), the passing on of cultural ideas and spiritual beliefs.

It is important for a society to know the age of its individuals. Specific ages are used as landmarks - today one can marry at 16, vote at 18 and retire at 65. In past societies similar landmarks were used - before Hardwicke's marriage act of 1753 marriage was only allowed between those aged over seven years (Molleson and Cox, 1993).

There has been much debate as to whether life expectancy is increasing over time (Angel, 1947; Molleson, 1986; Armelagos and Chrisman, 1988) and if in fact it will continue to do so (Kirkwood and Holliday, 1986). To help answer these questions, which are of direct concern to us all, a knowledge of the lifespan of past populations is necessary. It is to that aim that this project has been undertaken. The use of anthropological techniques is the only way by which we can age most past populations and although there are many methods in current use (see chapter 3 for a synopsis of the most popular) they are of varying accuracy and there have been many calls for new ones to be devised (Molleson, 1986; Maat and Mastwijk, 1995).

What is ageing?

Ageing is a relentless process which cannot be halted whoever one is. Gerontologists make the distinction between ageing and senescence and it is appropriate to do so for the introduction of this thesis. Senescence refers to the deteriorative processes that constitute natural causes of death (Martin, 1984) whereas ageing is used to define the processes that occur when "accruing maturity with the passage of time" (Leopold, 1978). Comfort (1956) described ageing as "what is being measured is a decrease in viability and increase in vulnerability". Tonna (1985) attempts to distinguish between normal ageing and pathological change, which is often age related by suggesting the following definition for normal ageing: "for any skeletal change to be considered normal biological aging - every member of a given population under study, if it were to live long enough, would eventually have to exhibit the observed total spectrum of skeletal change". It is not ageing that causes death per se, but senescence (Benjamin, 1986). The relationship between age and pathology is a complex one. It is true that with increasing age comes increasing pathology (Kohn, 1985), but not every individual will suffer the same amount of disease (or disability) before death.

To complicate the problem of "what is ageing" one must realise that everyone has two ages - their chronological age (as marked by birthdays), and their biological age, which is effectively the rate at which their body is ageing. Everyone has heard of the individuals who are ninety and look sixty, or in contrast are thirty and look fifty. These are classic examples of people whose chronological and biological ages are unsynchronised, and several researchers have attempted to measure these differences (Comfort, 1969; Borkan 1986).

Borkan (1986) looked at cross-sectional data for 1086 males aged between 17 and 98 years from the Baltimore longitudinal study of ageing. He chose 24 variables by which to measure biological age (including reaction times, maximum breathing capacity, basal metabolic rate and amount of cortical bone). The sample was split into two by degree of education (the underlying hypothesis being that more educated individuals would be biologically younger as they had better health care, longer life expectancies and safer work environments). The results showed that the less educated group were biologically older in 17 of the 24 variables - 10 of which were statistically significant. In the study

groups were a large number of related individuals, and the relationship between pairs (father - son and brother - brother) was investigated. The results from this analysis appeared to indicate that there is a possible genetic aspect to biological age, but some of the similarities may be due to families sharing similar backgrounds and lifestyles.

Why do we age?

Although many studies have looked at the changes that occur as people age (Rodeheffer and Gerstenblith; Makinodan and Hirokawa; Keller et al. and Brizzee, all in Johnson, 1985), why an ageing process evolved in man is under debate. There are two current lines of thought which try to explain the evolution of ageing. The first suggests that ageing is beneficial to the species as a whole, if not to an individual, and is seen as an adaptive process. Weismann (1891) and later Wynne-Edwards (1962, both in Bittles and Collins, 1986) thought that ageing prevented a species from overcrowding its environment and exhausting the resources. Ageing increases turnover of a species and so can help it adapt to environmental change (Woolhouse, 1967). These theories are flawed in that they do not take into account that individuals of most species do not survive long enough in the wild to reach an old age in any number, and that although this approach may benefit the species as a whole, genetic influence is strongest when benefiting the individual.

The second, non-adaptive theory can be split into two sub-types. The first proposes that ageing is a by-product of selection for other advantageous traits, and the second is that individuals age because they have no way of stopping the process. Both of these ideas share the assumption formulated by Haldane (1941) that the effect of natural selection reduces with increasing age. Williams (1957) produced a theory that genes which had good effects early and bad effects later in life would be actively selected, for genes that act early in life will affect the greatest proportion of the population and will have the maximum reproductive time to be passed on (Kirkwood and Holliday, 1979; 1986). Even slight benefits would outweigh later disadvantages, as these would affect less of the population. These side effects, Williams argues, would accumulate and give rise to senescence.

The second of the non-adaptive theories is similar, but does not assume individual genes have both good and bad effects at different ages. Medawar (1952) suggested that any selection of genes that acted at age specific times would tend to defer the detrimental ones until later in life, when they would act on fewer members of the population. Once the gene(s) had been selected to act so late as to be expressed at an age when in the wild survivorship would be zero, no further selection could take place. If the species was then placed in a more protective environment (for example laboratory animals) the later acting genes might then be expressed. Medawar used the analogy of a test tube to demonstrate his theory; it has only one component - the glass tube, which if it breaks would render the whole tube as "dead". If the chance of breakage is constant, then there is no increase in mortality with age. In more complex organisms several or all components must break (or fail) before death occurs, but even if the chance of each part failing is constant, the cumulative effect will be increasing risk of death with senescence. From this idea came the work of Elandt-Johnson and Johnson (1980, discussed in detail by Wood et al. 1994) who devised the "multi-hit" model, which showed that organisms which needed failures of more than one component would cause an increased likelihood of death with increasing age.

Theories of ageing

There are several differing theories as to why cells age, which fall broadly into two categories: - programmed ageing and stochastic (from random processes) ageing. The theory of programmed ageing is based on the fact that fibroblasts have been shown to have a limited lifespan (Hayflick and Moorhead, 1961 and Hayflick 1965) which ends after a certain number of cell divisions. Further work supports this theory, including studies of those with childhood onset (Hutchison-Gilford syndrome) or adult onset (Werners syndrome) progeria. Both these disorders cause rapid premature ageing and are caused by autosomal dominant and recessive genes respectively, implying that the normal ageing process is under genetic control (Turner and Weiss, 1994). Certain hormonally regulated age changes such as the menopause are also thought to reflect genetic programming (Turner and Weiss, 1994).

Stochastic ageing is based on the idea that cells decline in function due to an accumulation of random errors time. Free radicals (Pryor, 1987), decreased efficiency of DNA repair (Saul et al., 1987) and random error in the transcription of amino-acid

sequences (Orgel, 1963) have all been implicated by this theory (Turner and Weiss, 1994).

Life Expectancy and Cause of Death

It is a widely held view that life expectancy was much lower in past populations (Brothwell, in Manchester, 1983; Molleson, 1986; Armelagos and Chrisman, 1988 and Anderson, 1994), and that most individuals died at a young age. Life expectancy appears to have increased dramatically over the past 100 years, a man born in America in 1900 had a life expectancy of 49, by 1970 this rose to 67. The oldest documented human in the world today is a French lady aged 121 (Guinness book of records, 1997). However, a cursory search through most ancient graveyards will uncover individuals who have experienced very long lives - it is not uncommon to see octogenarians named on 17th and 18th century gravestones (Dawson, 1979). In contrast, past literature and biographies of the lives of famous people show that life could be cut short by disease or childbirth, all but one of the six Brontës died before the age of thirty, and Maupassant, quoted at the beginning of this chapter, died of syphilis aged 42.

Specific causes of death are also changing with time. In 1900 the three most common causes of death in the U.S.A. were tuberculosis, pneumonia and diahorrea / enteritis, but by 1946 these had changed to heart disease, cancer and accidental death (Dublin et al., 1949 cited in Kohn, 1985). This change can be explained by advances in medicine, such as the use of antibiotics, and the fact that different diseases are more common in different age groups (Kohn, 1985). Palaeopathology is the study of ancient disease (Ruffer, 1913), usually through skeletal remains. Research in this field had provided medicine with much useful information, such as data on the date and origin of tuberculosis (Manchester, 1983) and rheumatoid arthritis (Rogers and Dieppe, 1990), as well as studies on age specific diseases and whether they have varied in the past (Rogers and Dieppe, 1994).

To investigate how life expectancy is changing over time, and how this affects (and is affected by) diseases, it is necessary to have accurate age specific data from as far back in the past as possible. Palaeodemography is the study of past population demographic profiles and has been used to estimate life expectancy and survival curves for ancient peoples (Ascádi and Nemeskéri, 1970). For palaeodemography to be of use, the ages of

the individuals used in the construction of these profiles should be as accurate as possible.

Palaeodemographic data is used by both archaeologists (Brothwell, cited in Manchester, 1983) and modern researchers (Bittles and Collins, 1986). The valuable addition which palaeodemography provides to medicine is supported by the fact that anthropologists are often invited to contribute to publications based on the gerontological problems faced by a modern ageing population (Loth and Isçan, 1994; Molleson, 1986).

The demographic profiles used to estimate life expectancy in past populations are produced using two main methods; the use of documentary evidence, and of ageing skeletal remains directly. Before one discusses the contribution of anthropology to gerontology it should also be remembered that when using documentary and skeletal material, only a sample of the entire population is being examined which is not necessarily representative of the complete group.

Documentary Evidence

From such documentary evidence as birth and death certificates or parish records, or the study of gravestones, the age at death of large numbers of individuals can be reconstructed, as at the Parish of Belleville, Ontario (Saunders et al. 1992). There are several problems with this method, however. Documentary evidence is available only for relatively modern populations, and these are unlikely to give a complete account of all individuals. Stillborn children were not registered (Molleson and Cox, 1993), marriages, immigration and emigration removed many people from their parish of origin, and so from the records. Even those records which are present may not be accurate, people lie or forget about their date of birth. Occasionally gravestones or coffin plates can be used to produce demographic profiles for graveyards, but even these ages must be used with caution as there is a tendency for people to add or subtract years to round off ages to those ending in a 5 or 0 (Ascádi and Nemeskéri 1976, Molleson and Cox 1993).

Ageing Skeletal Remains

The second, and more commonly used method of reconstructing the ages of past populations is by examining human skeletal remains. The use of excavated skeletons has the advantage that one is actually dealing directly with the population whose profile one

is trying to reconstruct. There are however several problems. Not all individuals are buried in graveyards or burial grounds - criminals, suicide victims, women and illegitimate children have all been excluded at some time in the past (Hamlin and Foley, 1983). Of those that were buried in a graveyard not all would survive to excavation, and there is evidence that certain bones survive differentially (Henderson, 1987).

In most cases only the skeleton is preserved. Isolated cases of bog bodies (Brothwell, 1986) and preserved ice people (Spindler, 1995) are found, but these represent individuals and are of little use in reconstructing past populations. The skeleton is limited in the fact that it has no soft tissue, so only bony age related changes can be noted, but the skeleton is believed to show more age associated change than most of the body. Delling (1973) noted that the "changes in skeleton structure and mass are more striking than in any other organ of the human body during life as a result... of the ageing process".

There are many anthropological ageing techniques currently in use around the world, of varying accuracy and popularity. The use of tooth attrition (Miles, 1962, 1963; Brothwell, 1981) and pubic symphysis changes (Katz and Suchey, 1986) are the two most commonly used in this country, although tooth attrition is not as popular in the US (Molleson, 1986). A detailed discussion of these and the other most common methods used in the UK is given in chapter 3.

The major problem with most ageing techniques is that they are based on degeneration or alteration of specific bone (or tooth) surfaces with increasing age. Degeneration, such as the wearing down of enamel of the surface of the tooth usually leads to a plateau beyond which further changes become hard to discern, such as Brothwell's 45+ years maximum category in his tooth attrition method (1981). Individuals older than this cannot be aged with any degree of accuracy. A hypothetical model for this type of change is drawn in figure 1.1 (see below). Some degenerative changes, however, once they reach a plateau, are further complicated by some degree of reparative change, such as the appearance of bony rims around the edges of the pubic symphysis (Katz and Suchey, 1986). Both these types of degeneration produce non-linear rates of change and this invariably leads to a bias in estimating ages between different age groups, and also to a maximum age limit of individuals for each method. This problem can be seen clearly

when populations of known age at death are studied, such as that at St. Thomas Church, Belleville, Ontario (Saunders et al. 1992) and at Christchurch, Spitalfields (Molleson and Cox, 1993). In these sites the use of the standard ageing techniques as outlined below have shown that "clearly...skeletons are under-aged by traditional methods" (Molleson and Cox, 1993). It may be that some of these methods involving degeneration that we use today are based not on age related changes, but senescent changes, which are not uniform, and might account for some of the inaccuracies in ageing.

Current opinions (Saunders et al. 1992, Meindl and Lovejoy, 1985, Ascádi and Nemeskéri 1970 and others) suggest that because of individual skeletal variation no one technique should be used in isolation. The "complex" or "multifactorial" approach, as it is termed was first used by Ascádi and Nemeskéri (1970) who combined results from several ageing techniques to get a composite score. This technique appears to be more accurate than any one individual method, whether it be simple averaging of scores (Saunders et al., 1992) or by more complicated principle components analysis (Lovejoy et al., 1985).

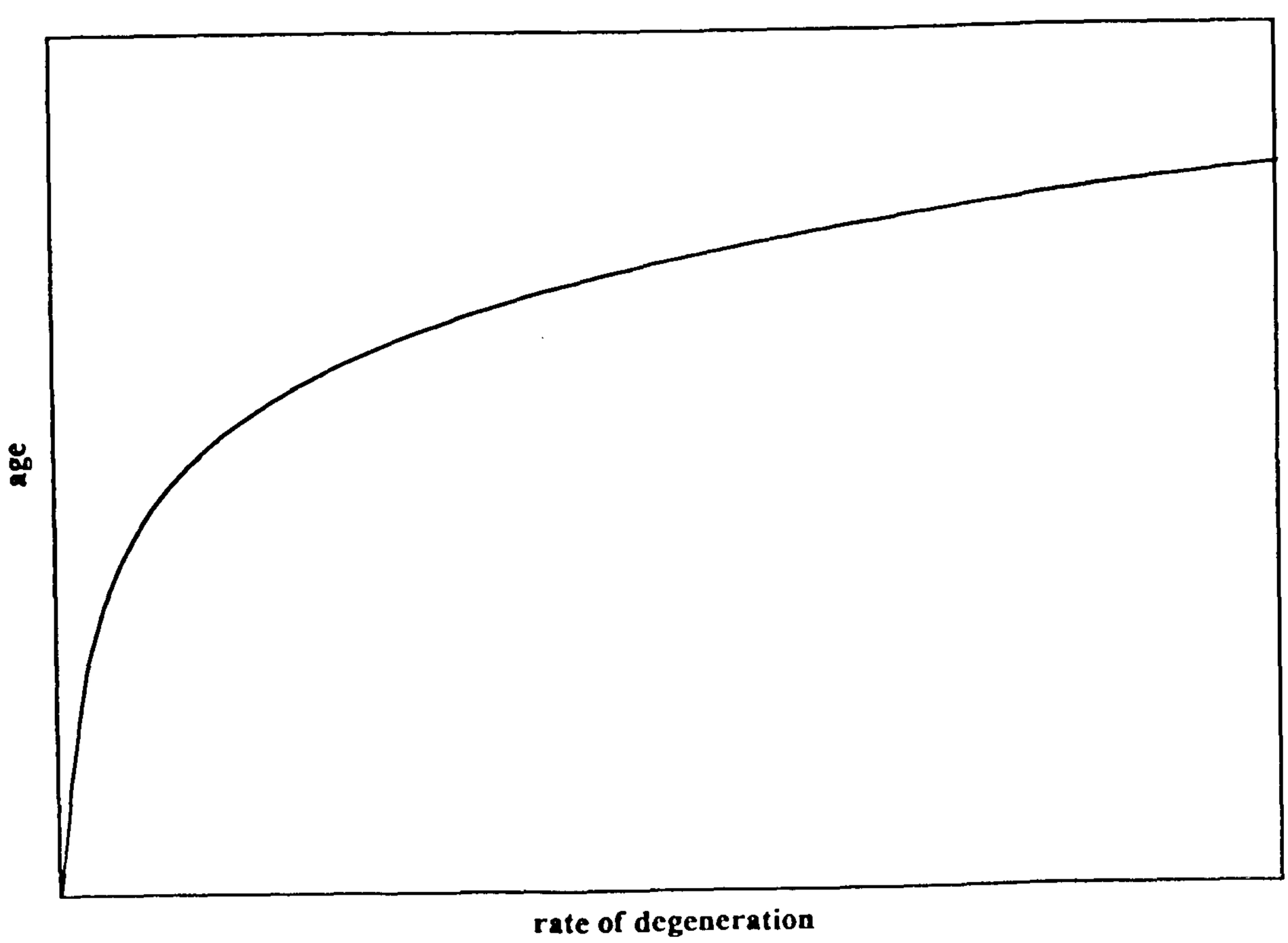


Figure 1.1 Hypothetical model of age related degeneration

Although there are a number of ageing techniques used by physical anthropologists (see chapter 3 for a full discussion), there are problems with the accurate estimation of age, especially in older individuals. If skeletal remains are to play a dominant role in the area of palaeodemography, and so advance the fields of gerontology and medicine, new techniques will need to developed in addition to those already in use. In especial need are techniques which are not based on degenerative or senescent processes, and those which have no maximum cut-off point.

To produce a new ageing technique based on an aspect of the skeleton (e.g. bone thickness) one must document how it changes with age, whether this is a constant change and also the range of normal variation at any specific age. It should be shown that any age specific change hypothesised is a normal change, and is not due to disease (which may or may not be age related, see earlier discussion). New techniques should be as accurate (or of greater accuracy) than those in use at present and should add to the subject (such as increasing the maximum age one can currently estimate, or the accuracy of age estimation). The method should take into account the fragmentary nature of archaeological skeletal material, and be applicable to as many individuals as possible.

The aim of the study

This study aims to investigate normal age change of five aspects of the endocranial (inside) surface of the skull for their potential to provide new simple field methods of estimating age at death. This study hopes to distinguish between normal age related change; pathological change and those pathological changes which are inherently age related.

Choice of the skull

The skull is arguably the most striking bone in the skeleton, and has the most attention paid to it by physical anthropologists. At the turn of the century in excavations where human remains were uncovered, often only the skulls were retained for observation (as at Glastonbury lake village, Barber et al. 1995). The relatively large numbers of skulls in anthropological collections makes them ideal for the investigation of age related changes, indeed, the skull is already the basis for several ageing techniques (e.g. jugular plate fusion, Maat and Mastwijk, 1995; tooth attrition - see chapter 3 and cranial suture closure- see chapter 6). However, these methods focus mainly on the outside (or

ectocranial) surface. Apart from cranial sutures (see chapter 6) little work has been carried out on the endocranial surface, or to differentiate endocranially between pathological and normal age related change. This is surprising as the area is unique in several ways, and has much potential for investigating age specific variation.

Firstly the table of the skull responds rapidly to changes in intracranial pressure (du Boulay, 1980) and may act in a similar manner to a shrinking, ageing brain (see chapter 4). Certain endocranial pathologies such as hyperostosis frontalis interna (see chapter 5) appear to be age related (Armelagos and Chrisman, 1988), but the relationship needs to be clarified before it can be used as an indicator of age. The bones of the calvarium articulate by means of sutures which do not fuse until late adulthood (Todd and Lyon, 1924, 1925), if at all, which is a unique feature of the skull and is supposed to be age related (see chapter 6).

The endocranial surface of the calvarium is the only part of the skeleton which regularly shows any trace of the vascular system that underlies it (Lindblom, 1936), and might provide information on the soft tissue which is so often lacking in archaeological material. The shape of the grooves formed by the vessels is thought to change with age (Coen, 1913; see chapter 7). Lastly, the presence of endocranial pits caused by arachnoid granulations have had little anthropological attention focused on them, despite evidence from radiologists which proposes a strong relationship with age (Grossman and Potts, 1974; see chapter 8).

This study is based on the calvarium only, as it would be impossible to cover every aspect of the skull in sufficient detail. As the main aim of the study is to investigate the potential for new ageing techniques which can be applied to the archaeological or forensic fields, the parts of the skull studied need to be commonly present and identifiable in archaeological and other excavated material. The top of the calvarium, namely the frontal, parietals and occipital bones are among the most common parts of the skull recovered from excavations (in Barton-on-Humber, see chapter 3 for details, at least one of these bones was present in approximately 95% of all skulls recovered).

A distinction must be made between normal ageing and the changes caused by an increased burden of pathology with age (effectively senescence). Palaeopathologists tend

to look at skeletons for indicators of pathology, with age being mentioned only in terms of age specific diseases, whereas physical anthropologists concentrate on estimating age at death, often without any comment on how disease can modify the skeleton, and the age related changes they are investigating. These investigations will attempt to connect palaeopathology and physical anthropology using the medical disciplines of radiology and histology (although this thesis does not claim to be written from the perspective of medicine) and the anthropological methods of observation, measurement and visual recording.

Outline of the thesis

Chapter 1 is an introduction to the study of ageing. It briefly outlines why ageing studies are necessary, some of the theories currently held on ageing and an introduction to the use of physical anthropology to gerontology. The site of study for this thesis is introduced, and reasons for the study are outlined.

Chapter 2 is a basic introduction to the growth and development of the skull, concentrating on the parts of the skull being specifically studied - namely the frontal, parietals and occipital bone.

Chapter 3 discusses in detail the four skeletal samples used in this study. The methodologies used to age the skeletal samples are outlined in detail, with the advantages and disadvantages of each being discussed in depth.

Chapters 4 to 8 cover a series of investigations on five aspects of the endocranial surface of the skull. They are all studies in their own right, but all have the same underlying theme and basic hypothesis - that the adult skull changes in a predictable way with increasing age, and that these changes have the potential to be used in the formation of new ageing techniques.

Chapter 4 investigates the relationship between skull thickness and age. The literature on skull thickness presents a range of opinions concerning how the table of the skull changes with age. The study is in two parts, firstly a comparative study of x-ray measurements, which are the most common form of medical investigation, to direct visual measurements of the skull, which is the method favoured by physical

anthropologists. The second part of the chapter looks at the relationship between directly measured skull thickness in samples of differing age and race.

Chapter 5 is a study of hyperostosis frontalis interna (HFI). HFI is both an age related and pathological condition and appears to be rare in archaeological samples. This apparent rarity is commonly quoted by anthropologists as being due to reduced life expectancies in the past. This chapter investigates the hypothesis that at least part of the apparent difference in frequency of the disease in archaeological samples is due to a different diagnostic criteria being applied to that of radiology. This chapter is in two parts - firstly the formation of a visual diagnostic criteria based on radiological appearance, and secondly a test of the new method on a selection of samples of different time periods and races to see if HFI is really a much rarer condition in the past.

Chapter 6 looks at both endocranial and ectocranial suture closure, which is used with varying confidence by physical anthropologists as an ageing technique. The methods that are currently in use are based on whole pristine skulls (which are rare findings in archaeological excavations) and are designed for use on non-pathological material only. This chapter is in two parts. Firstly a modified version of the cranial suture fusion method is devised for use on the calvarium only, which is the most commonly occurring part of the skull in archaeology. The second part concentrates on separating age-related changes from those caused by pathology in suture fusion.

Chapter 7 is a study of the vascular channels of the parietals. The calvarium is unique in the skeleton as it is the only part of the skeleton that normally shows any trace of vasculature. Hypervascularity is believed to be associated with disease (Lindblom, 1936) and the vessel grooves themselves are thought to change shape with age (Coen, 1913). This chapter investigates three aspects of vascularity in the skull. The first is a study of the shape and size of the main meningeal vessel groove in individuals of known age at death. The second is a comparison of the number of vessel branches in individuals of known cause and age at death. The third study surveys the types of hypervascularity present on the endocranial surface of the skull in individuals of known cause of death.

Chapter 8 is a study of arachnoid granulation pits, which are often present on the endocranial surface of the skull. These have rarely been studied, but the radiological

literature provides evidence for a change in the number and size of arachnoid granulations with increasing age (Grossman and Potts, 1974) This study is in four parts. Firstly, a morphological and histological study of arachnoid granulations using modern cadaveric specimens was undertaken. The second part of this investigation is a study of the number of arachnoid granulations in samples of known age at death, and the production of a model to estimate age at death. This model was then tested on other populations of known age at death. The third part of this chapter looks at racial variation in the expression of arachnoid granulation pits, and lastly the shape and size of the arachnoid granulation pits themselves was studied to see if this changed with increasing age.

Chapter 9 Is a general discussion of the results from the five study areas investigated in this thesis. It attempts to compare the findings from these chapters and evaluate at the potential use of each aspect in estimating age at death. This information is then discussed in the perspective of both anthropological and palaeopathological studies as well as modern research into ageing and forensic science.

Conclusions

From the literature reviewed above, it can be seen that a knowledge of ageing is an important part of life. It affects us all, and many studies have been undertaken to look at various aspects of the subject - why we as a species age, what causes the ageing process and what changes we can expect to experience as an ageing population. Interest has also focused on life expectancy, and it is in this area that anthropologists can provide an unparalleled view on the history of ageing. The study of palaeopathology has provided new information on the prevalence and age of onset of diseases in the past, and this too requires accurate data on age at death in past populations.

By using archaeological material we can both age individuals and reconstruct demographic profiles of past populations, and there are many methods which we can use to do this. However there are few methods which are successful at ageing older individuals, and they are based on degenerative processes, which lead to maximum cut-off points for ageing. The skull has been shown to be a potentially excellent area to investigate new age relationships as it has many unique features. The work presented in this thesis is a study of five features of the endocranial surface of the skull which are

believed to be age related. The aspects will be investigated to ascertain their potential use as new ageing techniques.

Chapter 2. Growth and Development of the Skull

Introduction

At birth the skull is the most completely formed part of the skeleton, at just over 60% of its final adult circumference, and comprising one quarter of the total body length (Bogin, 1988). It is made up of on average 45 bones (Williams, 1957) which grow and develop until the skull is fully formed in early adulthood (Bogin, 1988). As this thesis examines only the bones of the calvarium, namely the frontal, parietals, and occipital bones (excluding the ethmoid, sphenoid and most of the temporal bone), these are the bones whose formation and development are discussed in detail, although one could discuss at great length the changes involving the base and facial parts of the skull. Skull morphology is determined by a number of factors, and is believed to be combination of environmental influences such as temperature (Heath, 1984 cited in Herring 1993) dietary changes (Moore, 1965) and genetic determination (Herring, 1993). Herring summarizes the arguments for these three theories. The first is that the form of the skull is genetically determined, but after birth, epigenetic regulation (development of an organism from an undifferentiated cell, thought to be partly influenced by environmental factors) takes over. The second is that certain tissues are genetically determined e.g. cranial cartilages (Scott, 1954) whilst the bones are epigenetically controlled. The third theory is the one currently supported by most researchers which holds that cartilage and bony growth are secondary to the soft tissues in which they are found (Moss, 1968). This "functioning matrix" theory distinguishes between two types of tissue - periosteal, where the tissues act directly on the bone, and capsular, where the indirect action of what is termed a "functioning space" (such as the pharyngeal cavity) affects how bone is shaped.

Growth and development of the foetal skull

The bones of the calvarium / vault differ from the rest of the skeleton in the fact that most develop by membranous desmal (ligamentous) ossification whereas long bones develop endochondrally (Herring, 1993). Osteogenesis of bone is triggered by increased vascularity, oxygen tension and mechanical stress (Hall, 1970) and bone growth spreads through osseous trabeculae leading from an ossification centre (Fazekas and Kósa, 1978). Approximately 110 ossification centers develop in the skull to form bone (Scammon, 1925). A diagram of a lateral view of the foetal skull is shown in figure 2.1.

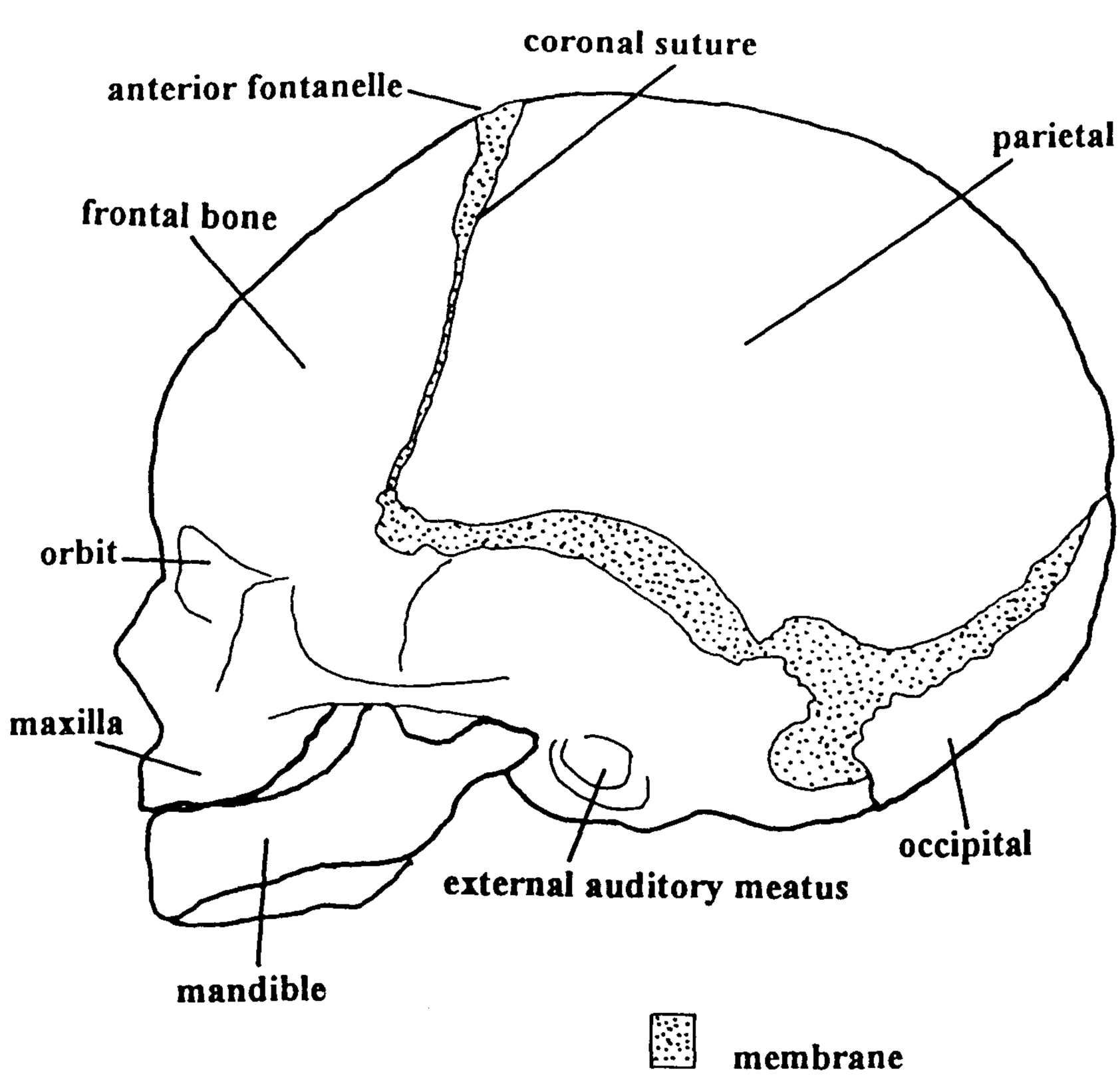


Figure 2.1 A lateral view of the foetal skull aged circa 9 lunar months

Frontal bone

Membranous ossification of the frontal bone (see figure 2.2) begins in the 7th to 8th week after conception (Toldt, 1882; Fischel, 1929 and Toro and Csaba, 1964 all in Fazekas and Kósa, 1978; de Beer, 1985) in the middle of the upper margin of the orbit. Two centres of ossification (which later become the left and right frontal eminence's in the older skull) divided by the metopic suture appear at the start of the third month, with the nasal spine of the frontal bone having a separate origin (de Beer, 1985). At this time only the contours of the bones can be identified, and the width of the bone is greater than the height. By the fourth month, however, the frontal bone has begun to take a more recognisable form, with the overall length being greater than the height. At birth the frontal bone measures approximately 60mm in length by 55mm wide (Fazekas and Kósa, 1978). An area of approximately 20mm^2 between the coronal suture and the midline of the frontal bone is covered only in membranous material - this is known as the anterior fontanelle (which is known as the anatomical landmark bregma). The function of the fontanelles (there is another at the junction of the parietals and occipital bones) is to allow greater flexibility of movement of the frontal and parietal bones during birth, and so lessen any possibility of trauma. The fontanelle closes at about 18 months of age (Mc

Minn, Hutchings and Logan, 1981). In neonates some trace of vascular grooves can be seen on x-ray in about 60% of individuals (Williams, 1957; Swischuk, 1972).

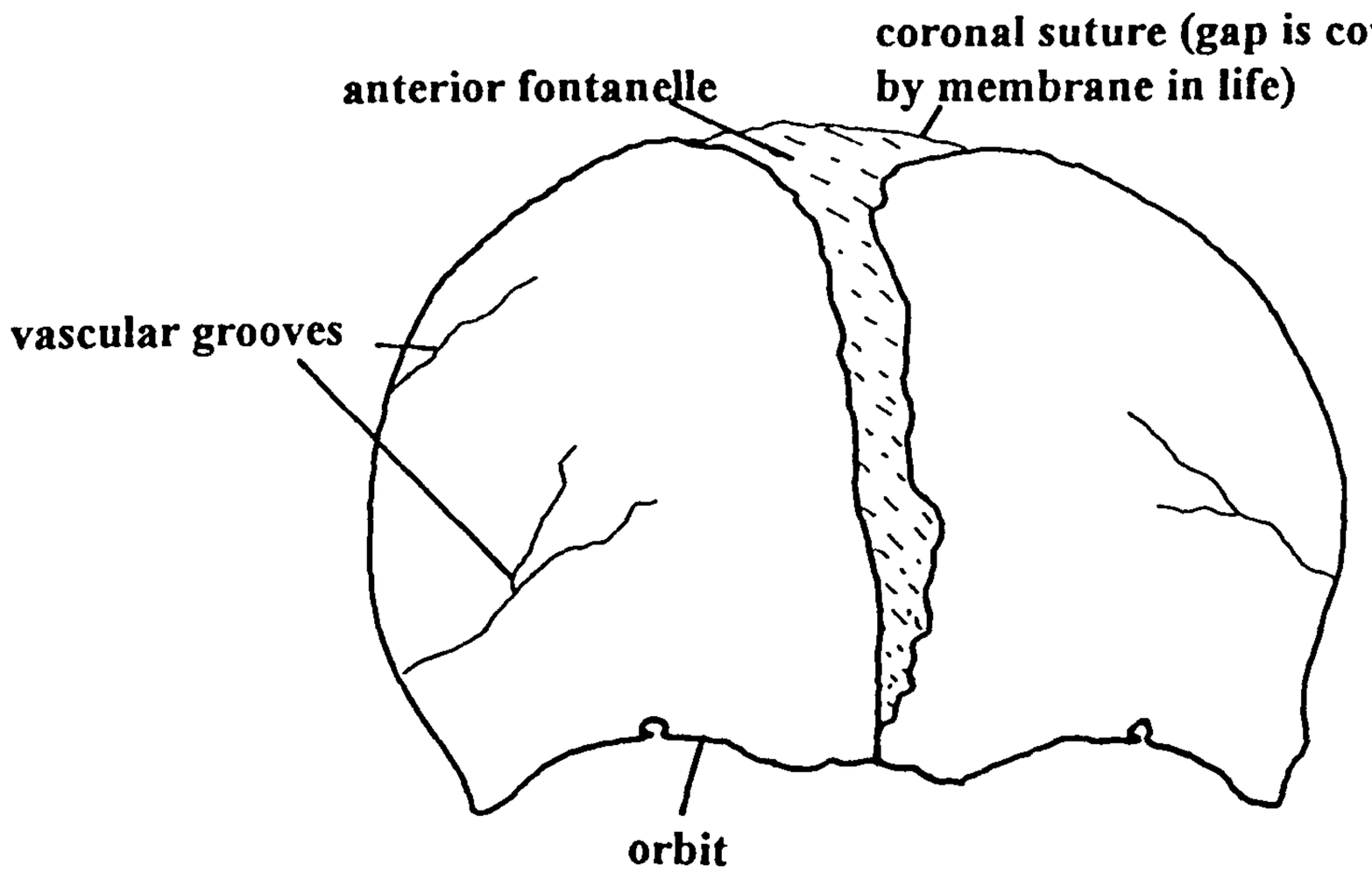


Figure 2.2 Foetal skull aged circa 9 lunar months - the endocranial surface of the frontal bone

Parietal Bone

Each parietal bone begins to form with two ossification centres at the end of the second month after conception. These centers fuse to form the left and right parietal eminence's around the fourth month. The parietal begins to take shape during the 6th month, with the edges of the bone gradually straightening at the coronal, sagittal and lamboid sutures to produce the classic angular appearance (see figure 2.3 below). At birth the parietal bone has a marked eminence (or boss) and is highly convex in shape. A normal parietal bone at full term measures about 85mm by 80mm (Fazekas and Kósa, 1978). There is no true diploë in the neonatal skull (Swischuk, 1974) and the parietal can often appear to be under ossified, especially on X-ray. The appearance of vascular grooves for the main and accessory meningeal vessels is rare (Swischuk, 1974). Moulded convolutional impressions on the endocranial surface can be visible occasionally, these appear as a response to brain growth. They are more common in older children, especially those aged 4 to 8 years (du Boulay 1956; 1980).

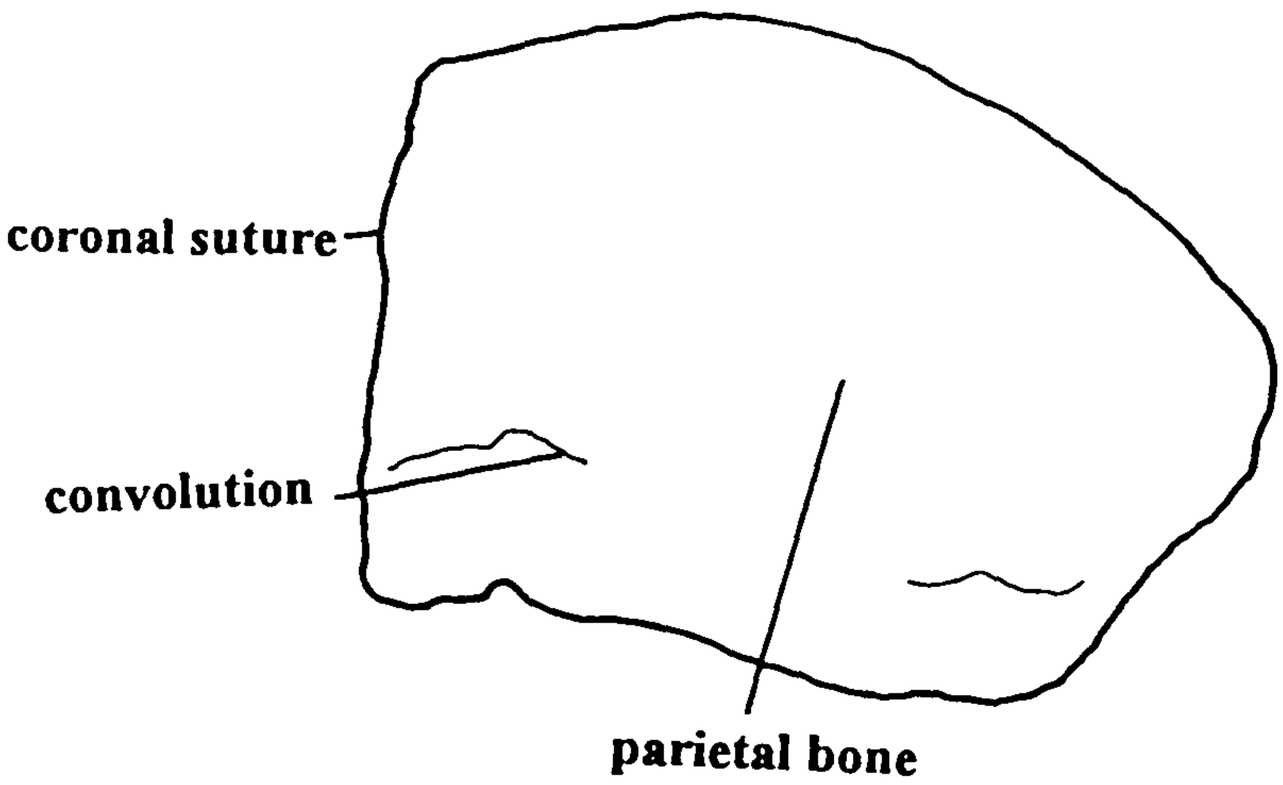


Figure 2.3 Foetal skull ages circa 9 lunar months - the endocranial surface of the parietal bone

Occipital bone

The occipital bone develops from four distinct parts (see figure 2.4) - the squama and the basilar part and between these the left and right condylar portions. The condyles and the basal part of the occipital develop from the chondrocranium, while the squama develops like the parietal and frontal bones, by desmal ossification (Fazekas and Kósa, 1978). The squamous part begins to ossify between the 8th and 9th weeks after conception in two areas. These fuse at around the 10-11th week and grow upwards and laterally. The superior part of the occipital bone grows faster than the median part, causing a two lobed shape to form. In the third month two new centres of ossification appear on each side, which grow and fuse in the 4th month (Fazekas and Kósa, 1978). Occasionally another extra ossification centre appears in the midline, which, if it does not later fuse with the surrounding bones, can become an interparietal (or Inca) bone (Brothwell, 1981; Aiello and Dean, 1990). On the left and right sides between the original lobed bone and the new ossification centres two fissures are formed, known as the mendosal sutures. These sutures do not fuse until around four years of age, and if they fuse only partially lamboid Wormian (or extra-sutural) bones form. Between the 5th and 9th months the occipital grows rapidly until at birth it is a smooth triangle in shape of

roughly equal length and width (approximately 66mm by 66mm). The basal and squamous parts of the occipital have fused completely by the age of six years (Aiello and Dean, 1990).

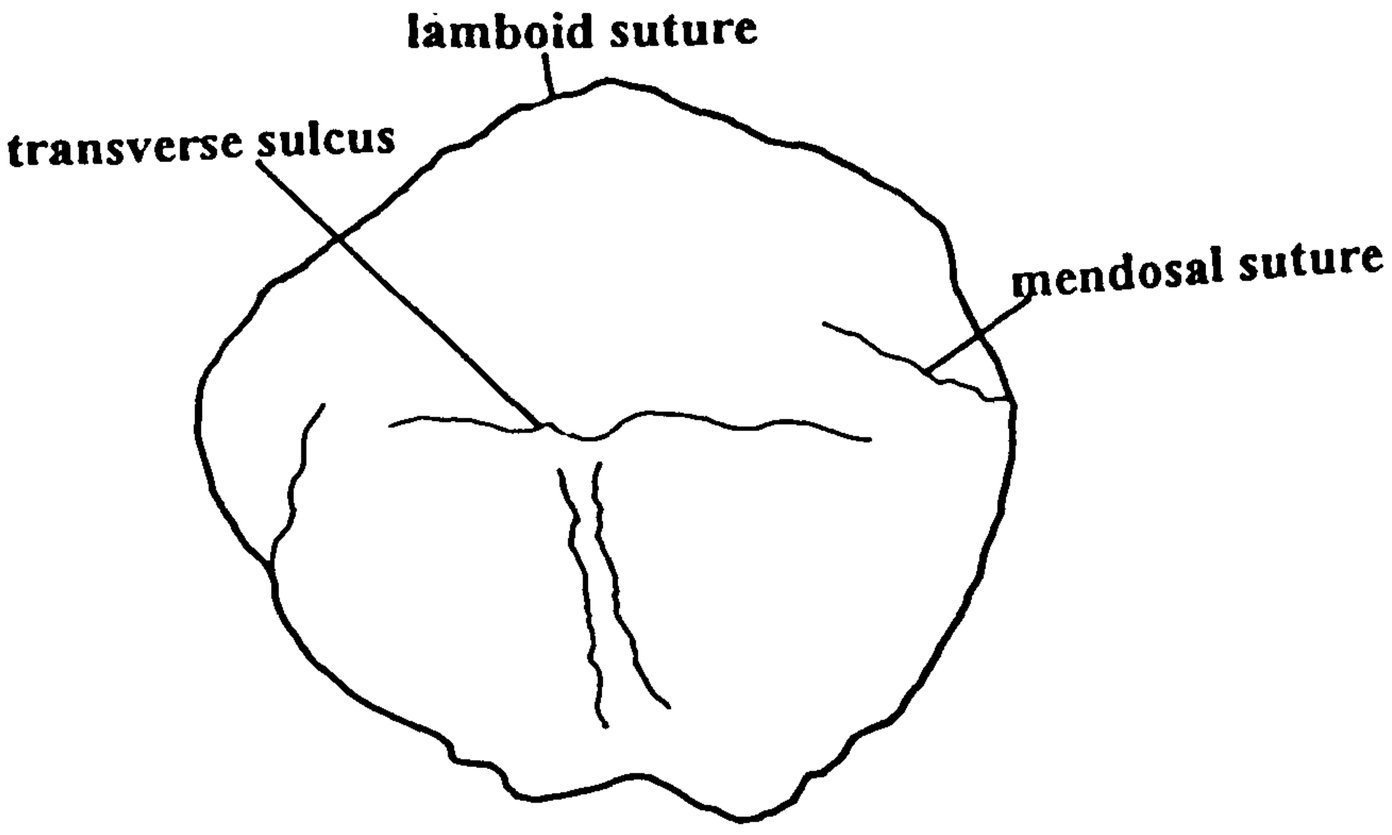


Figure 2.4 Foetal skull aged circa 9 lunar months - the endocranial surface of the occipital bone

Skull Growth and development during childhood

It is known that the skull continues to develop and grow throughout childhood and early adulthood (Young 1957, Hansman 1966, Knott 1969, 1971, Brown, Pinkerton and Lambert 1979). The brain grows at a faster rate than the rest of the body (Scammon, 1930) and head circumference changes from being 70% of total body length at birth through 42% at seven years to an adult ratio of 30% (Bogin, 1988).

Roche (1953) investigated cranial growth of children in a longitudinal study and found that during growth average cranial thickness is larger in males than females, and that the skull continues to grow throughout childhood and puberty (the study did not continue beyond age 21). He noted variations in the rate of growth both between males and females, and for different areas of the skull. The other studies mentioned look at different measurements within the skull or in different ethnic groups, and have similar findings.

The adult skull

A cross-section of the head is given in figure 2.5 below. The scalp covers the head, and is made up of five layers (Mc Minn, Hutchings and Logan 1981) the skin, a dense connective tissue layer, the epicranial aponeurosis and occipitofrontalis muscle, a loose connective tissue layer and a periosteal layer (the pericranium). Below these is the cranial vault. The bones that make up the adult calvarium (frontal, parietal and occipital bones) have developed inner and outer tables of compact bone divided by a centre of cancellous bone called diploë. These begin formation after the age of about 2 years (Oktsuki, 1977). The diploë is one of the most important sites of erythropoiesis in the skeleton, and causes the tables of the skull to be the most highly vascularised bones in the body (Aiello and Dean, 1990). Diploic veins are also present in the diploë, which drain the de-oxygenated blood to either the intracranial venous sinuses or to the exterior of the vault. A detailed description of the types of vessel which leave vascular grooves is outlined in chapter 7.

Below the inner table of the skull are the meninges, which consist of the dura mater, arachnoid mater and the pia mater, and below this is the brain. Between the dura mater and the skull are the vessels for meningeal arteries and veins. Pressure from these vessels causes grooves to be formed on the endocranial surface of the skull (see chapter 7 for further details). The dura mater covers both brain (cerebral) and spinal cord (spinal). The cerebral part consists of an outer endosteal layer and an inner meningeal layer. The venous sinuses (sagittal, transverse and sigmoid) lies between these two layers. Between the arachnoid and the pia mater is the sub-arachnoid space, which contains cerebrospinal fluid (Nolte, 1988). Along the dural layer the surface is occasionally broken by granular clusters of microscopic villi from the arachnoid mater, known as arachnoid granulations. The function of the villi is to drain the cerebrospinal fluid back in to the venous system.

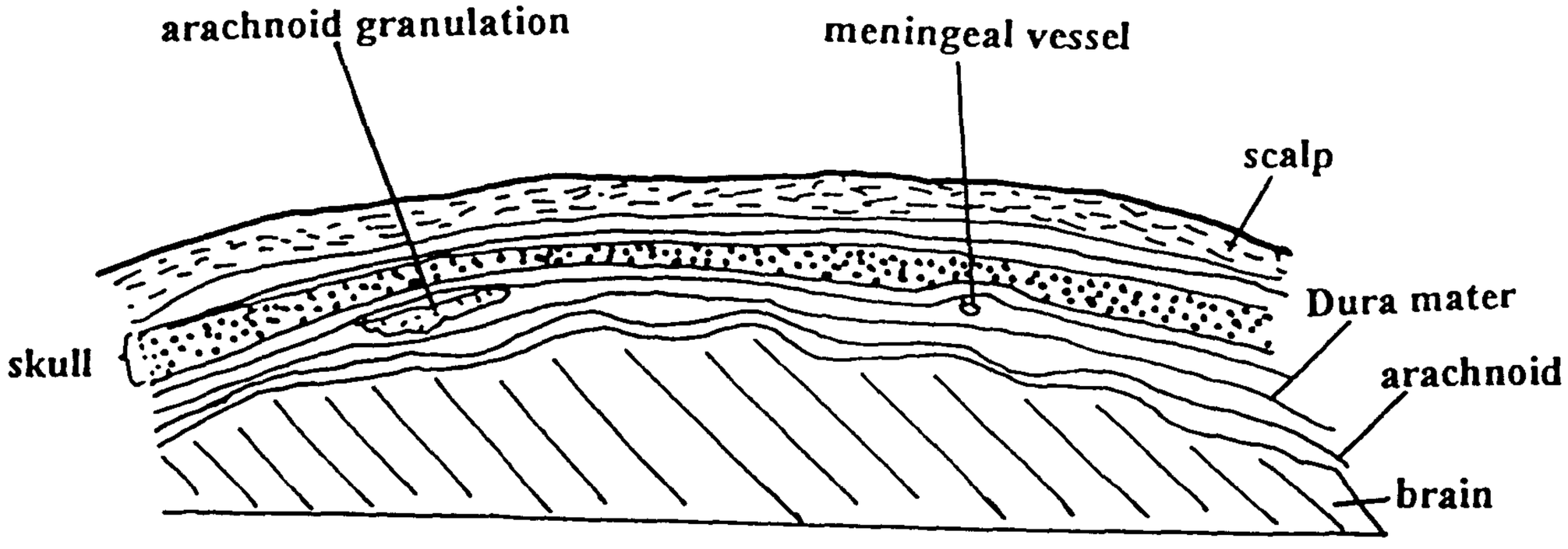


Figure 2.5 Cross-section through the scalp, skull and the meninges.

Frontal bone

The frontal bone articulates with the left and right parietals at the coronal suture. The endocranial surface of the frontal bone (see figure 2.6) is often marked by grooves for the anterior meningeal vessels (see chapter 7) and small scattered pits where the arachnoid granulations (see chapter 8) lie. The original frontal or metopic suture may still be present in the midline of the frontal bone (see chapter 6) but is usually obliterated by the age of two years.

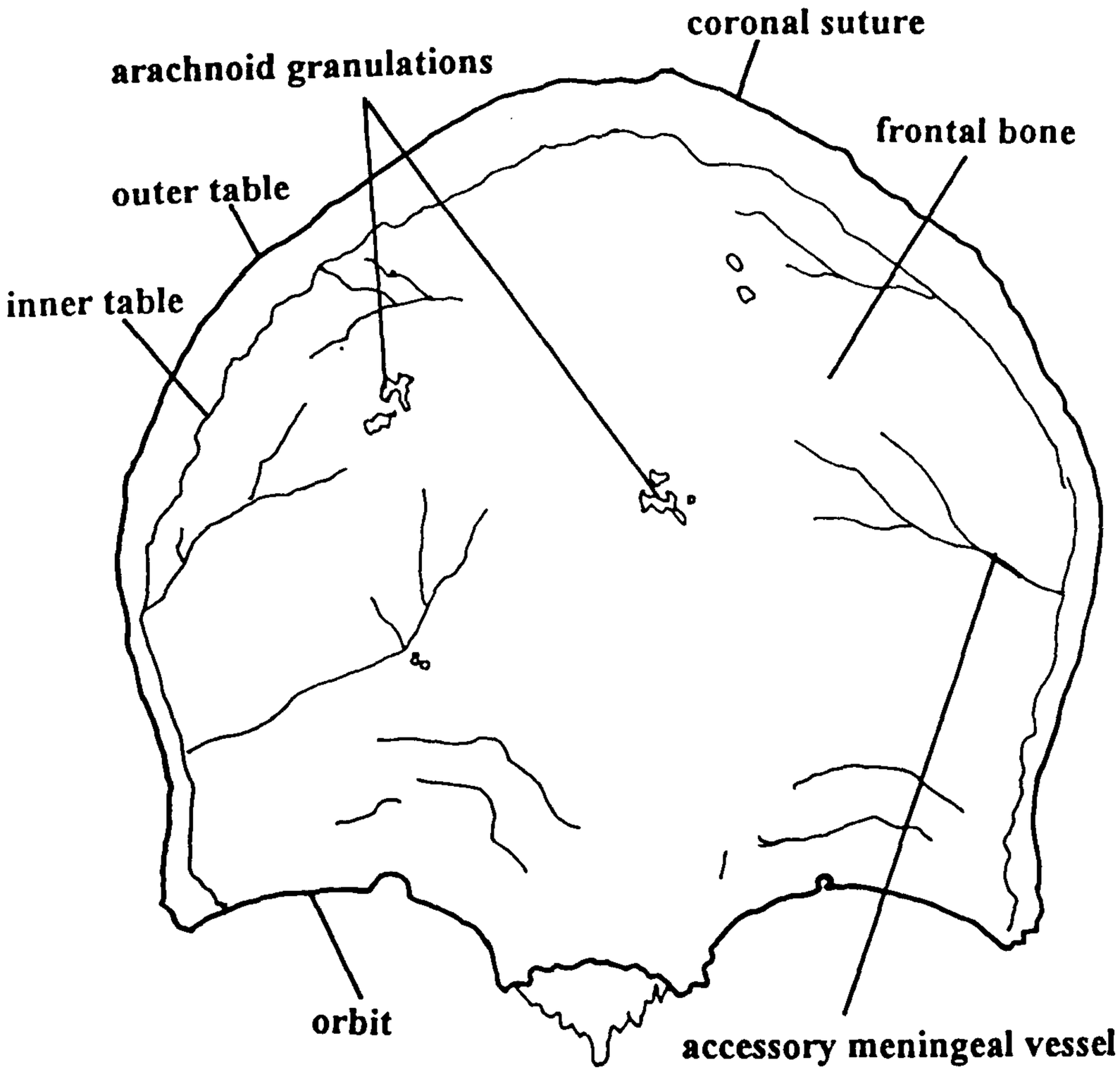
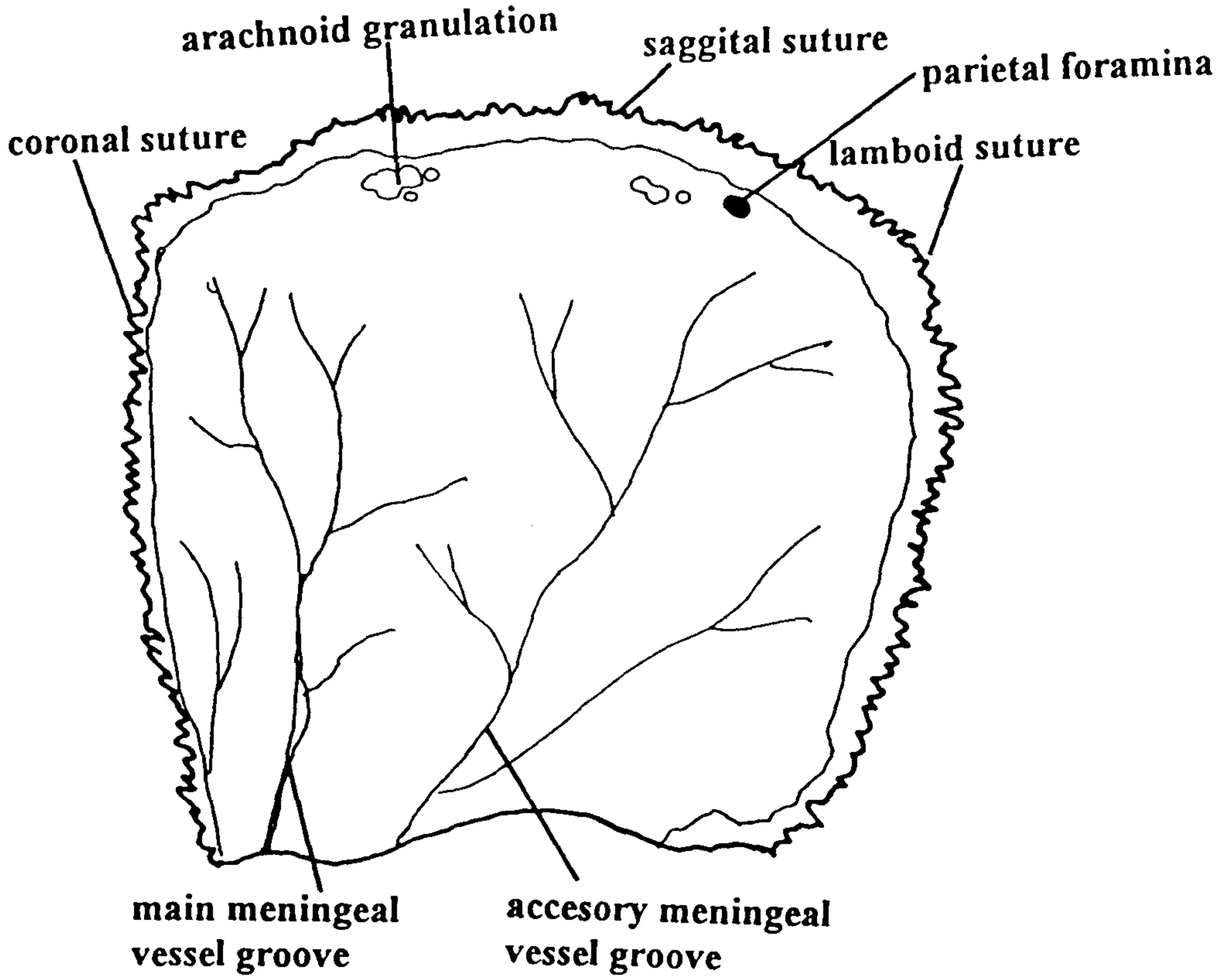


Figure 2.6 The adult frontal bone - endocranial surface

Parietal bone

The two adult parietal bones articulate with each other at the saggital suture. They form a t-shaped junction with the frontal bone anteriorly at bregma, and a y-shaped articulation at lambda, posteriorly. Each parietal is roughly square in shape, with rounded corners and is bevelled on three sides, the parieto-temporal junction being smooth and tapered. Endocranially, the parietals are covered with grooves for the main and accessory meningeal vessels (see figure 2.7 below, and chapter 7 for more details) and often with pits containing the arachnoid granulations (see chapter 8). Approximately 2/3rds of the way down the sagittal suture, and up to 10mm in from the suture line itself is the site of the parietal foramen. These two foramina carry emissary veins right through the table of the skull. Work by Berry and Berry (1967) show between 22 and 62% of the population have at least one of the foramina still open, and in 1% of individuals a double left or right foramina can be seen.



2.7 The adult parietal bone - endocranial surface

Occipital bone

In adulthood the endocranial surface of the occipital bone is roughly triangular in shape. It articulates with the posterior part of the left and right parietal bones along the lamboid suture. The ectocranial surface has two protuberances, the nuchal line and external occipital protuberance. At the base of the occipital is the foramen magnum, and on either side of this are the occipital condyles, which articulate with the first cervical vertebrae.

Endocranially, there are several grooves visible on the adult occipital bone. Figure 2.8 below shows the grooves for the superior sagittal sinus, the transverse and the sigmoid sinuses (see figure 2.8). These sinuses drain venous blood from the brain and play an important part in protecting the brain from changes in venous blood pressure (e.g. when lifting heavy objects, or standing up from a lying position) as well as helping maintain body temperature (Aiello and Dean, 1990). At the centre of the squamous part of the occipital is the internal occipital protuberance, around and below this are occasionally seen small pits caused by arachnoid granulations, although these are less frequently observed than those on the parietals (see chapter 8).

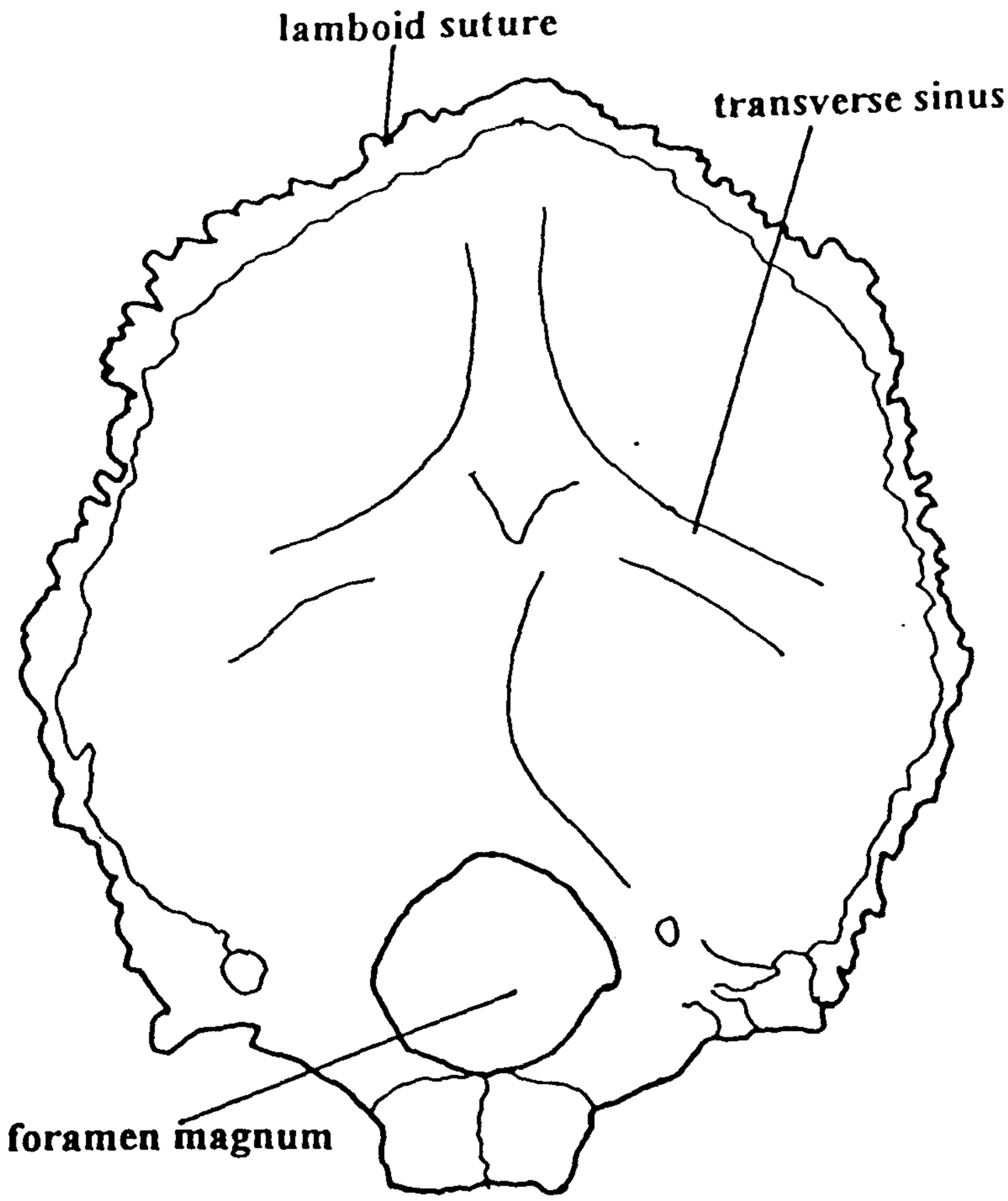


Figure 2.8 The adult occipital bone

Area for study

The area of study on which this thesis will concentrate is the area above a line bisecting the occipital bone at the transverse sinus, the parietals at just below the temporo-parietal margin and above the orbital part of the frontal bone. This area was chosen as it roughly corresponds to the line taken at a standard post-mortem (see chapter 3 for more detail) and for reasons outlined in chapter 1 of this thesis. Figures 2.9 and 2.10 below shows the approximate area of study drawn on a complete skull, and an endocranial view of the features to be investigated.

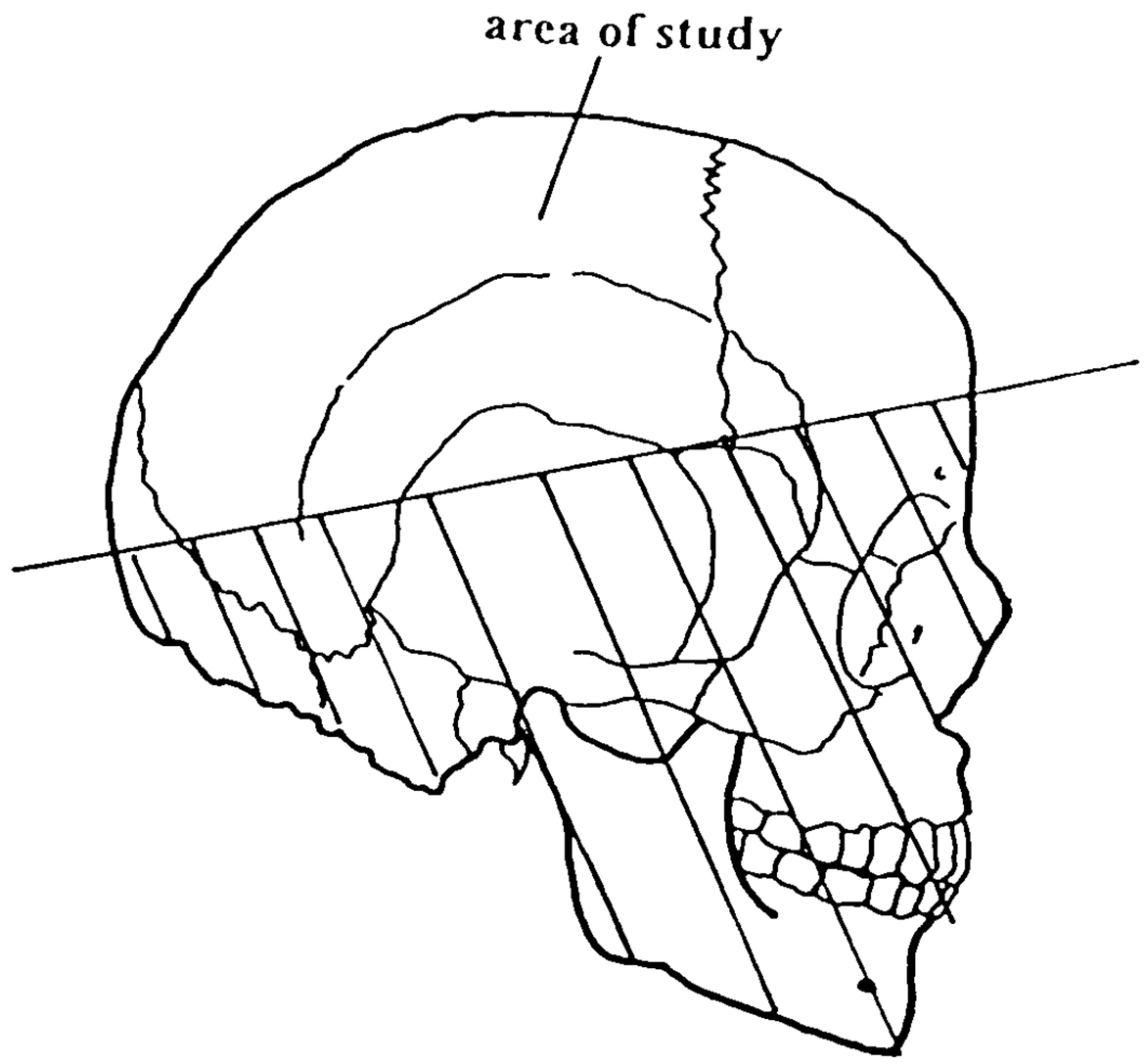


Figure 2.9 Lateral view of the skull showing the approximate area of study (above shaded area)

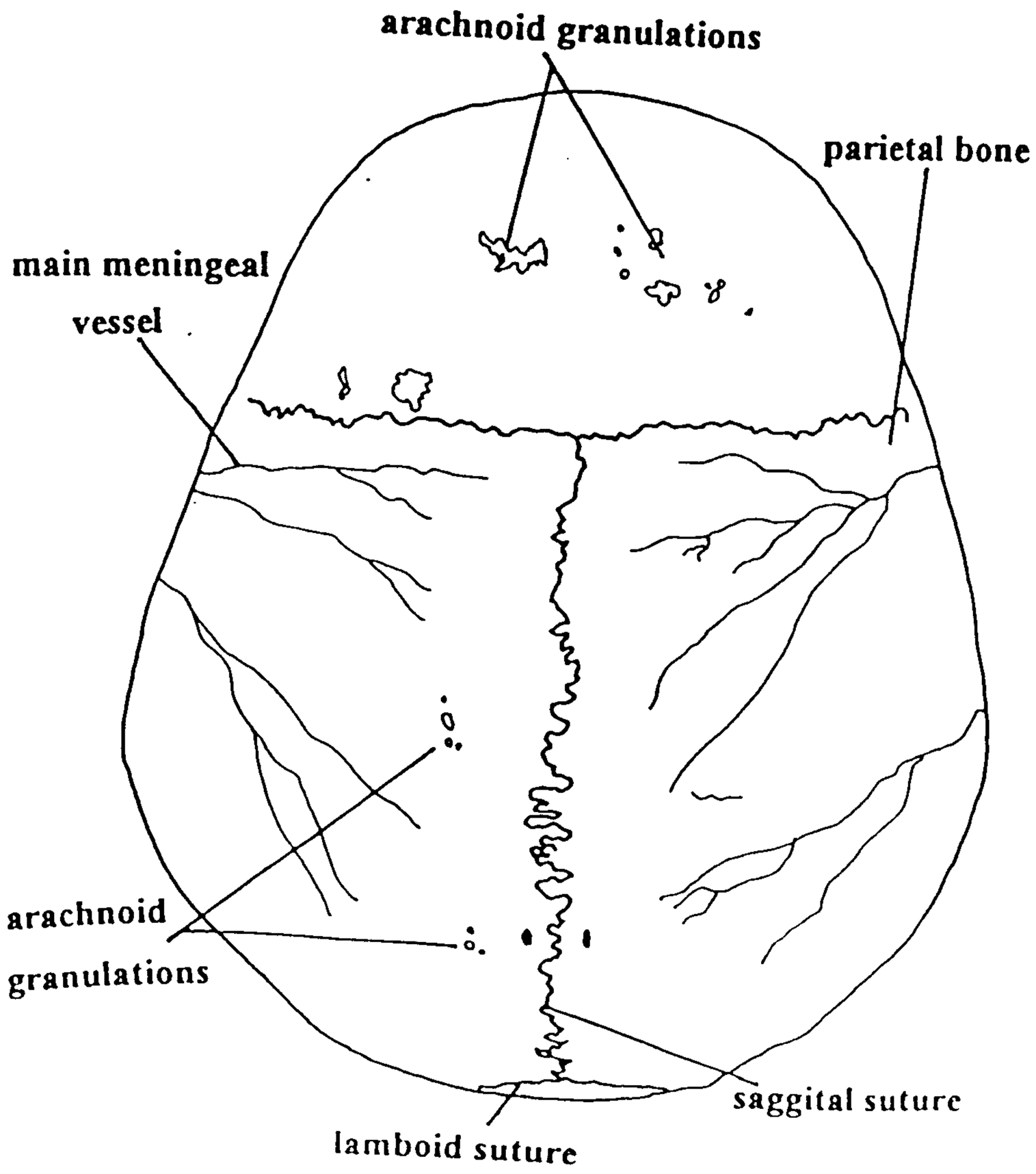


Figure 2.10 Endocranial surface of the skull - showing areas of interest to this thesis

Chapter 3. Materials and Methods

Introduction

One of the major drawbacks of investigating age related changes in archaeological material is that few skeletons are recovered of which the actual age at death is known. Occasionally gravestones or coffin plates are recovered in association with a skeleton, but even these ages must be used with caution as there is a tendency for people to add or subtract years to round off ages to those ending in a 5 or 0 (see chapter 1). Anthropological collections may contain some individuals of known age at death which can be checked using birth certificates and other documents, but again there are problems as these individuals usually date from the early 20th century, and being subject to much more invasive medical treatments (e.g. use of antibiotics and immunosupressant medications) there is an argument that they may not be completely representative of skeletal variation in more ancient populations.

Because of these difficulties, the samples used in this study were chosen with great care. No one archaeological or anthropological collection had enough individuals of known age at death to carry out the complete range of investigations required for this thesis. In fact, to use only one sample would limit the testing of any age related changes uncovered by this work, so four groups were chosen. These samples represent a variety of time periods, geographical locations and races. Some have a great deal of information recorded about them, such as cause of death (as determined by post-mortem), previous medical history, occupation and parity. Not every sample was appropriate for every investigation (e.g. it was impractical to x-ray the heads of the post-mortem individuals in this study), but by using four groups, there is enough overlap of methods to compare them statistically. Each sample used in this study is discussed individually below.

20th century European post-mortem sample n=50

Bristol Royal Infirmary and Department of Anatomy post-mortems

Fifty individuals were selected at random from those cases referred to the mortuary for autopsy at the Bristol Royal Infirmary between 1993-1995. To avoid sample bias due to seasonality of death (Bradley 1982) these were collected in three two week periods (every individual coming to post-mortem on the Monday and Tuesday) in the spring and

autumn, and thereafter on a once weekly basis for 6 weeks through the winter. Included with these were 15 individuals who had donated their corpses for medical research, and access to these was provided by the University Department of Anatomy. After this initial sample collection (n=45) it became apparent that most of the individuals were aged over 70 years, and that younger adults were vastly under-represented. Although this pattern mirrors the demography of a modern dead "population", it does not have a wide enough range of ages required for studying age related skeletal changes. This is a normal problem when using post-mortem material as a sample, and to offset this it was decided to selectively choose a further 5 cases with an age at death of below 60 years. These were chosen as the first five individuals to fit this criterion in a two week period following on from the main sample collection. The total sample collected consisted of 22 females and 28 males, with a mean age of death of 68.2 years (64.5 males, 72.7 females). Figure 3.1 shows the age profile of the complete sample.

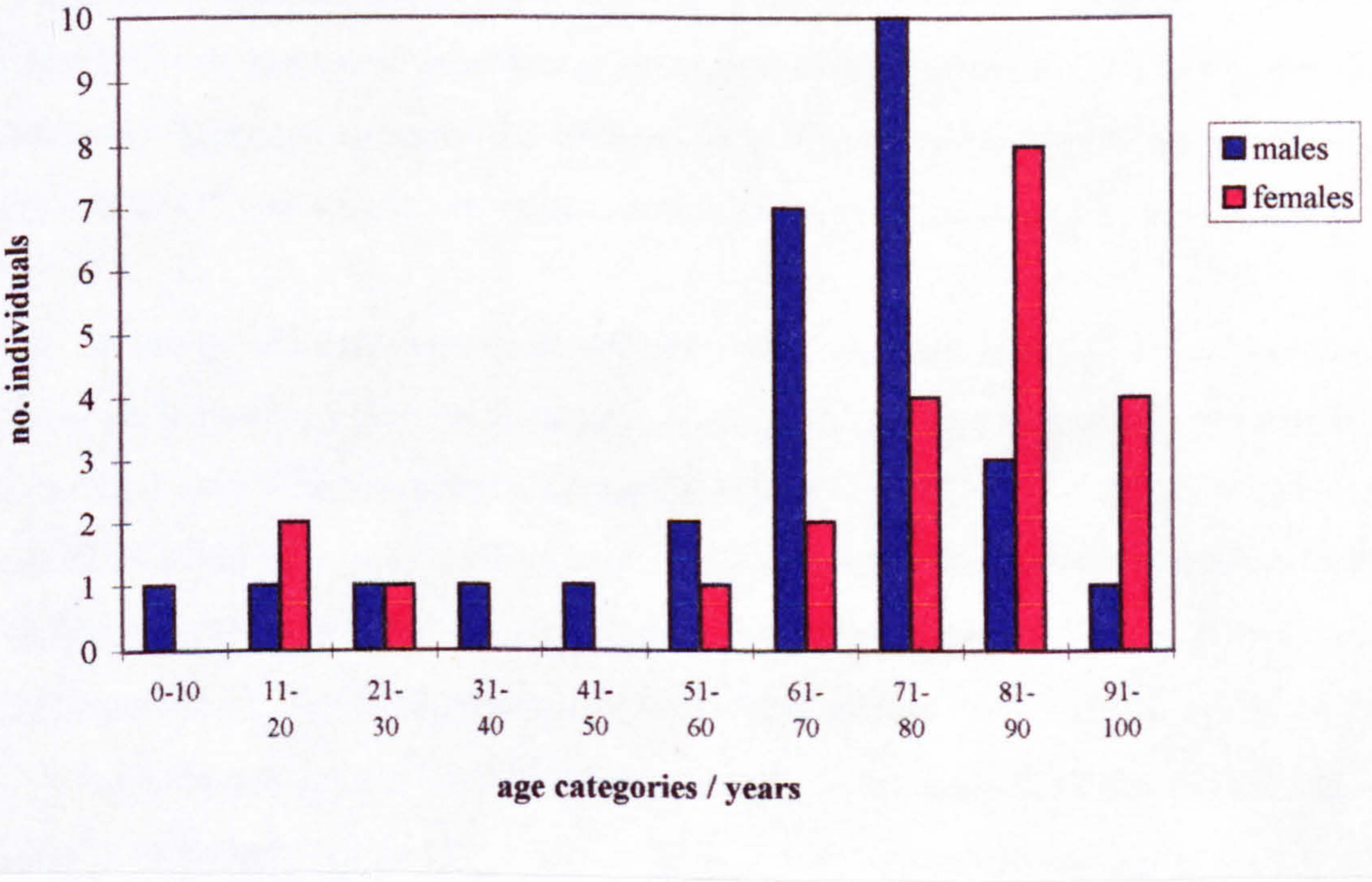


Figure 3.1 Age at death - male and female Bristol post-mortem sample

Each of the fifty individuals had a known cause of death. The post-mortem room sub-sample (as opposed to the anatomy department cadavers) also had further information on

past medical history, medication taken and previous operations. All of the individuals except two, a black African male and a white Australian male, were British citizens of white European origin.

All observations and measurements were fitted in with the routine of the post-mortem room, which did not then require any extra ethical approval, other than the original permission obtained from the next-of-kin for the post-mortem to take place. A standard post-mortem involves the removal of the top of the skull at the mid-parietal level to gain access to the brain, which is routinely weighed. This then gave a large section of the endocranial surface of the parietals, frontal and occipital bones available for study.

This sample was chosen as it had the most accurately recorded ages at death of all the groups, and also the most complete information on cause of death and underlying pathologies. This was the only one of the four samples studied which still had soft tissue available for observation. From the Anatomy Department cadavers histological sections were taken and dissections made in order to show that the bony phenomena noted (e.g. vessel grooves, arachnoid granulation pits) were actually associated with the soft tissue which was supposed to cause the changes (e.g. blood vessels, arachnoid granulations). The results of these investigations can be seen in the relevant chapters.

A disadvantage of using these cadaveric specimens was that none of the anthropological ageing techniques used on the other samples could be attempted (the observations of the molar wear and pubic symphysis changes), as this would mean medically un-necessary mutilation of the cadavers, and further permission would then have to be sought from the families of the deceased. An application for ethical approval to carry out these investigations was not thought necessary and the disadvantages of not being able to look at the pubic symphyses and tooth wear patterns (see section below for protocols) were thought to be minimal as these comparisons could be carried out easily on the other groups, and would avoid distress to the relatives of those in the post-mortem sample.

Early 20th century American (European and African) anthropological collection n=261

The Terry collection

The Terry collection is housed in the Natural History Museum in Washington DC in the USA It is composed of over 1700 adult human skeletons collected after post-mortem between 1930 and 1950. The individuals are mostly paupers or labourers and domestic servants, and were macerated for the collection after their bodies were either donated to the museum, or remained unclaimed by relatives (many of them were homeless people). For most of the skeletons there is information on age at death, although this may not be completely accurate. Figure 3.2 shows the frequency of specific second digits in the ages of the whole collection, and a bias towards ages ending in a 5 or 0 is clearly seen. This problem was offset by looking at the material as decadal groups (20-29, 30-39 etc.) which is a technique used in other studies where there is thought to be some rounding off of ages (Ascádi and Nemeskéri, 1970).

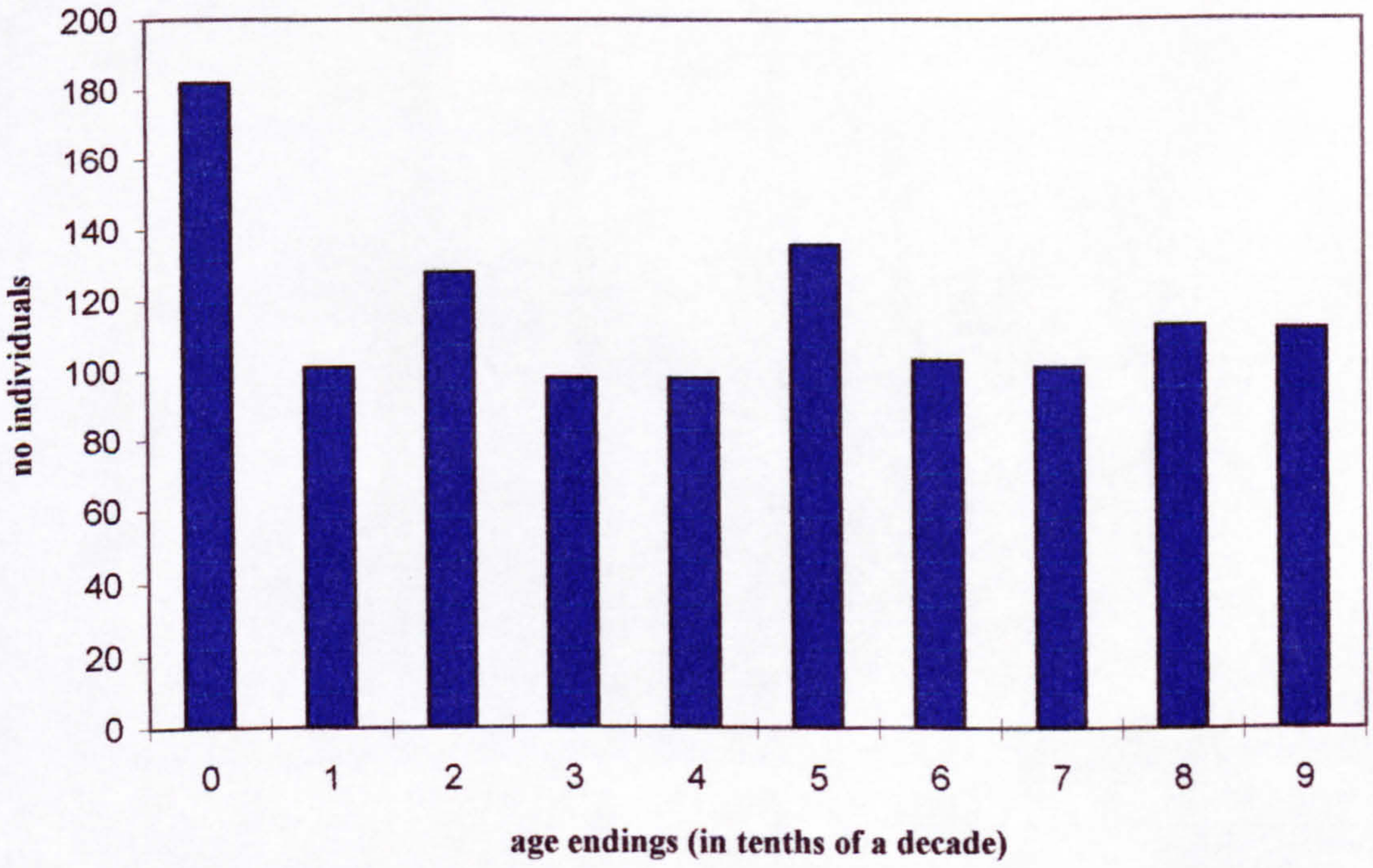


Figure 3.2 Frequency of ages ending in specific numbers - Terry collection

The author was only able to study this collection for a period of three weeks after obtaining a scholarship from the Natural History Museum. Given the short length of time

available for examination of the material, a sub-sample of the whole collection was chosen. Equal numbers of black and white males and females (125 of each race) were selected from the following age categories; up to 20, 21 to 30, 31 to 40 and so on to 91 to 100. It was not possible to acquire exactly the same number of individuals in each category as, as seen in the post-mortem sample above there were certain age groups which had few or no bodies to represent it. Only one white female aged under 30 years was present in the entire collection, and no white males over 85 had been collected at all. In addition to these eleven extra individuals were selected. This group contained all individuals in the Terry collection who had an accidental cause of death. These were chosen to provide a greater "control" group when looking at the effect of specific disease on age related change.

The complete sample selected had in total 69 and 60 black and white males, and 79 and 69 black and white females. Figure 3.3 below gives a breakdown of numbers of each age group selected.

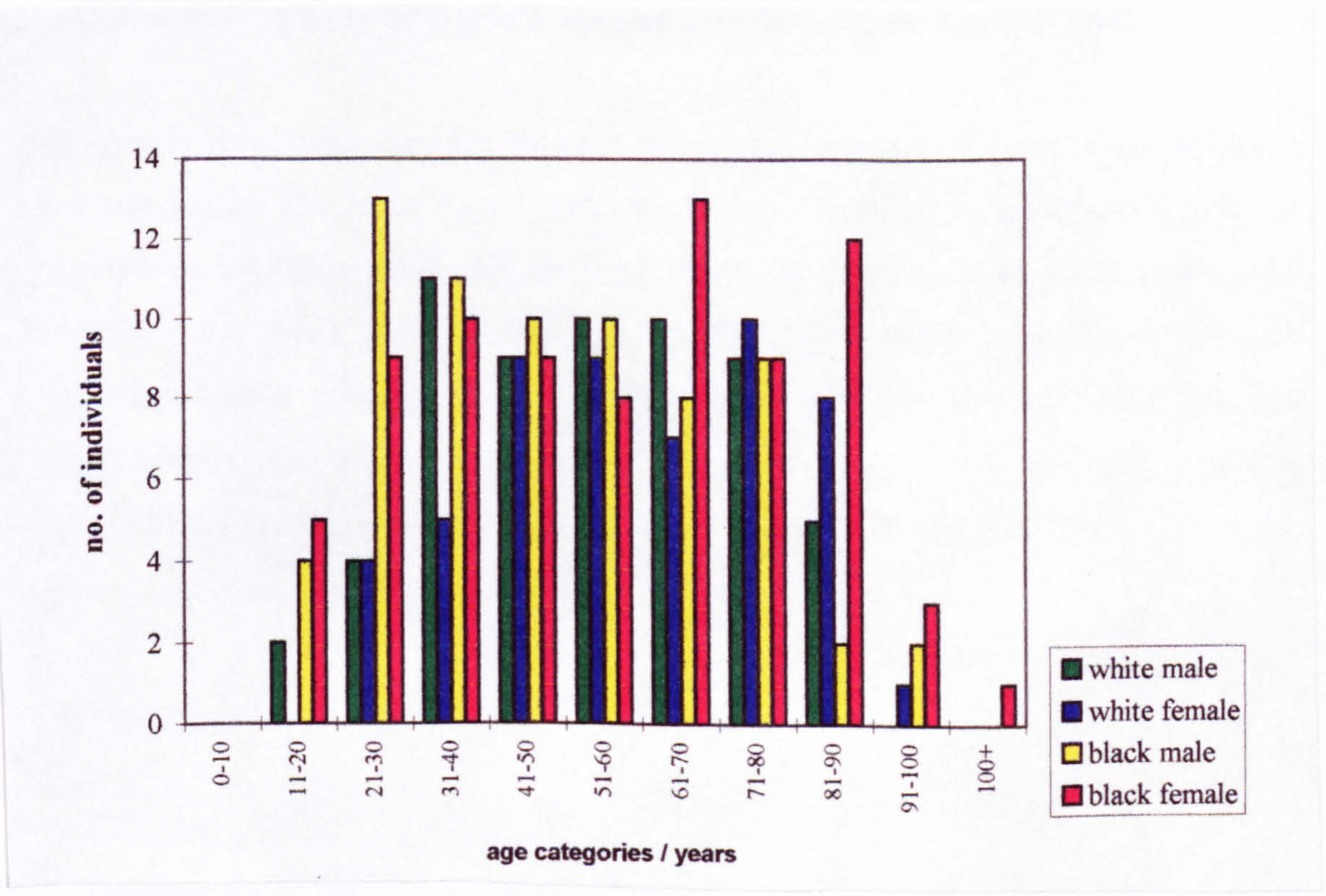


Figure 3.3 Numbers of individuals in each age category - Terry collection black and white males and females.

The amount of information recorded for each skeleton varies depending on which year it was entered into the collection. The best recorded have photographs, death masks, body weight and height noted, as well as a vast number of soft tissue measurements. Most skeletons have the cause of death recorded as obtained by post-mortem. It is difficult to compare these causes of death with those of the more modern Bristol post-mortem sample above as medicine has advanced so far in fifty years. Some of the names of diseases have changed, e.g. dementia praecox is now known as Schizophrenia, and other ailments given as the cause of death e.g. osteoarthritis would certainly not be used in modern practice. No information is given on how these diagnoses were reached (e.g. what examinations or tests were used), other than by post-mortem. Despite these drawbacks it is very useful to have some indication of the possible pathological conditions affecting the skeletons, especially those soft tissue lesions which are normally invisible to palaeopathologists. In the analysis of this sample the list of causes of death were read by a practicing clinician, who has advised that most of the diagnoses may be used as diseases affecting the individual at the time of death, but great caution should be used in interpreting some of these ailments as actually being the cause of death.

This sample was chosen specifically as it had a large number of reasonably accurately aged individuals. The inclusion of skeletons from different racial groups and different geographical locations made this an ideal sample to look at both racial and spatial variation of the ageing skull. In addition about half of the skeletons in this group were aged independently using up to six anthropological techniques by one of three physical anthropologists. This provided a useful check on the authors own accuracy in applying these methods to all the skeletal material studied and is discussed in detail later in this chapter.

17th - 19th century English / French archaeological collection n=106

The crypt sample of Christ Church Spitalfields, London

The mid to late 1980's archaeological excavation of the crypt of the church of Christ Church in Spitalfields recovered approximately 1,000 skeletons (Molleson and Cox, 1993). Of these 389 had in situ coffin plates which gave information on the names, ages and date of death of each individual. The majority of the population buried at Christ Church were of Huguenot descent, and were mostly middle class workers - weavers and merchants being common occupations among this sample.

The Spitalfields collection is unique in Britain as it has the largest number of individuals of known age at death at the time of this study. In addition there is a substantial amount of demographic information available on the individuals of any archaeological sample in this country. Birth and death certificates are available for some, and many of the skeletons were buried in family groups. As mentioned, the occupations of several individuals are known, which has helped to reconstruct their social backgrounds. There are even paintings of some of the more prominent citizens.

The collection is currently housed in the Natural History Museum, London and permission was given to study the skeletons (although several skulls had been removed by other researchers and were not available for observations at the time of this study). Of the skeletons available for study 106 adults and children, 63 males and 40 females, had observations taken. All broken, but complete (with frontal, parietals and occipital) skulls in the collection were studied. Christchurch crypt offered a greater level of protection than normal to the archaeological material, so many of the skulls were unbroken - these could only provide limited information, and though some observations were made, they are not included in the total given above. Figure 3.4 shows the distribution of ages and sexes of the broken skull sample.

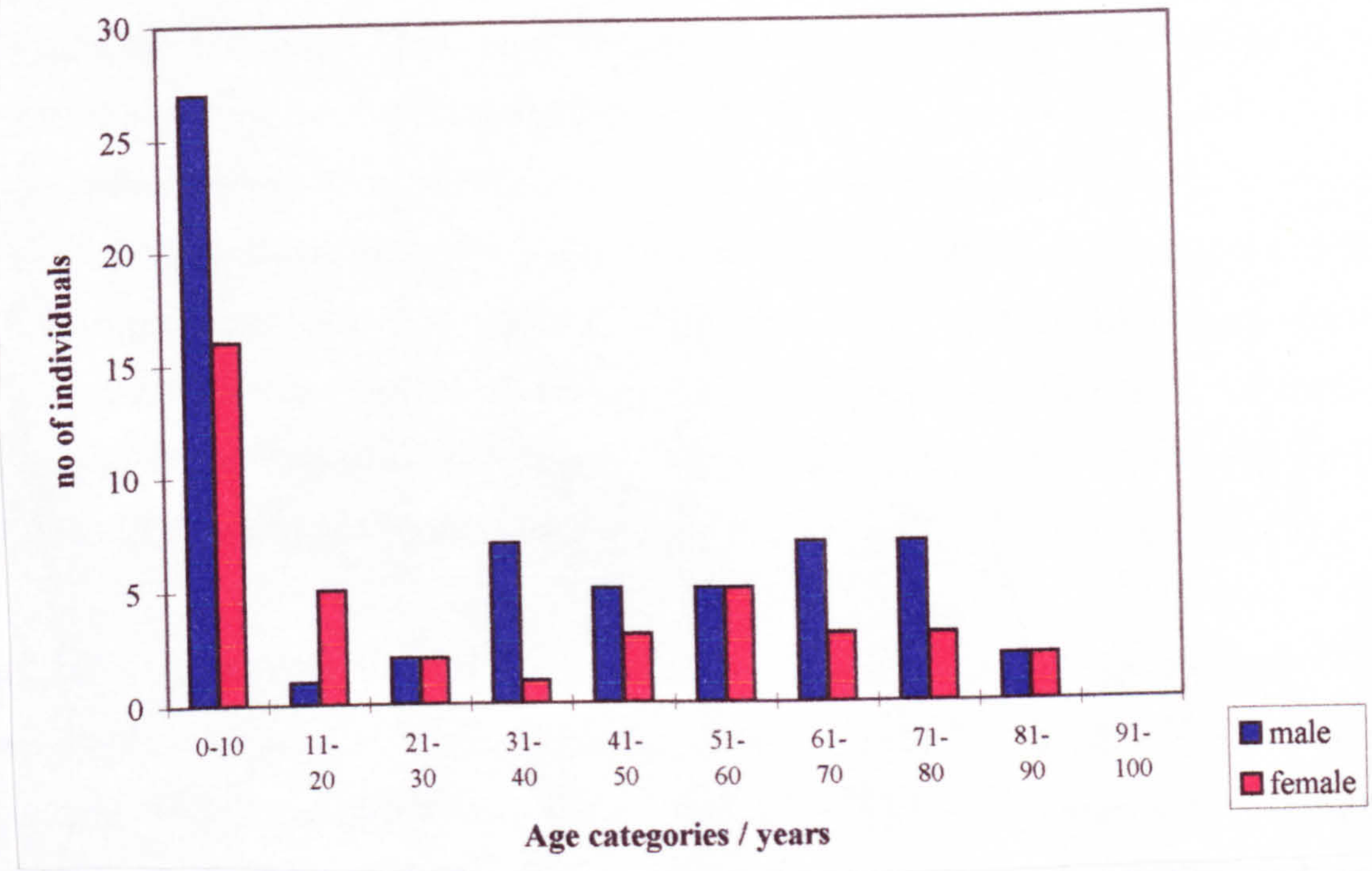


Figure 3.4 Age at death - Spitalfields sample

The Spitalfields sample provided a useful comparison between modern and ancient populations. This group of skeletons could also be used to investigate the currently held (but not fully tested) belief that it is unwise to study age related changes in the skull (or any part of the skeleton) with a view to looking at past populations using only modern material (see the beginning of this chapter). This sample, although relatively recent in archaeological terms, is early enough to begin to see if there is any temporal variation in the way the skull ages due to increased medical intervention.

One drawback of using this sample is that because of the unique nature of the material certain restrictions were placed on recording information - histology samples, x-rays and casts could not be taken for fear of damaging the skulls which were often very fragile.

10th - 19th century British archaeological collection n=280

St. Peter's Church, Barton-on-Humber

Almost three thousand skeletons were excavated from the cemetery and inside the church of St. Peter, Barton-on-Humber between 1979 and 1983. This sample constitutes the largest single collection of human skeletal remains ever uncovered in Britain, and so

it is a unique resource. The date of the material ranges from the 10th to the 19th century and the skeletons themselves range from excellent to very poor condition, and from 2 to 99% completeness. Strict criteria were applied to select an initial 200 skeletons from the 2,000 skulls available for study. The sample covers individuals of all age ranges and were randomly chosen from every period of occupation of the site. Only individuals who had complete, but broken skulls were selected for the main analysis. A further random sample of 80 skeletons with whole unbroken skulls were chosen as a check against any possible bias from choosing just broken (and possibly weaker) skulls.

For each skeleton the following information was available; sex and age as determined by standard anthropological methods (these will be explained in detail later in this chapter) and any evidence of pathologies which affect bone. Figure 3.5 shows the demographic profile of the Barton-on-Humber sample as aged using tooth attrition and pubic symphysis changes (including both the broken and whole skulls).

The Barton sample was essential for this study as it was the only group of individuals from which all the types of recordings could be taken (see table 3.1), and was used to connect and compare all the groups together. It is typical of the condition of an archaeological sample, and it was used to test the field viability of the age estimation techniques devised in this thesis.

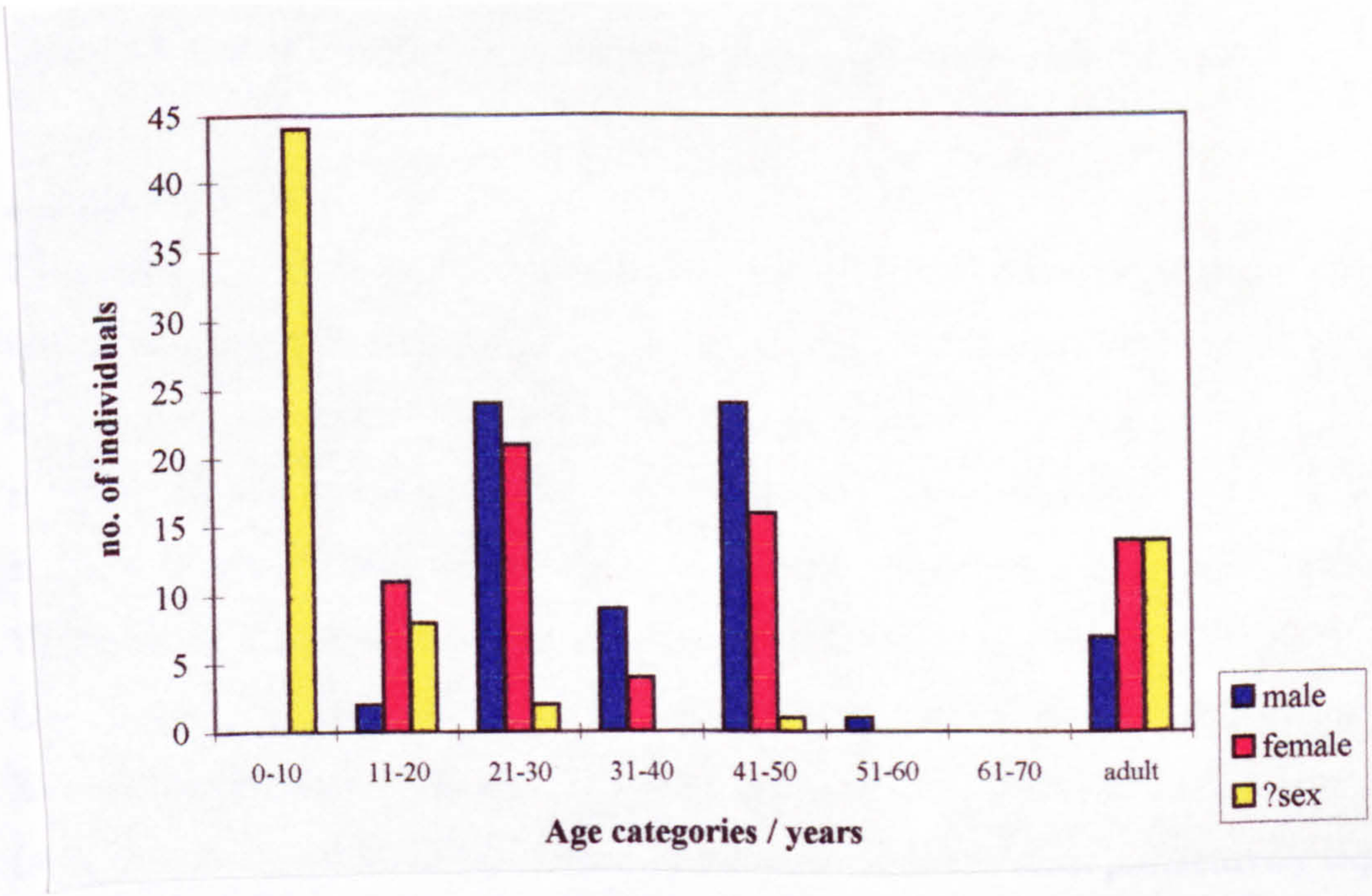


Figure 3.5 Age at death Barton-on-Humber adults and children

Methods

General methodologies are outlined here as they were used for each of the investigations. To avoid repetition, the basic methodologies used in several or all investigation are outlined here, and any further elaborations and additions used in the separate chapters will be discussed as they arise. A copy of each of the recording sheets used for the studies is given in appendix A.

Investigation	Post-mortems	Terry collection	Spitalfields	Barton-on-Humber
visual observations- endocranial	y	y	y	y
visual observations - ectocranial	y*	y	y	y
plaster cast taken	n	y	n	y
measurements	y*	y	y	y
x-ray	n	n	n	y
histology	y	n	n	y
pubic symphysis aging	n	y	y	y
tooth attrition aging	n	y	y	y

* in some cases the soft tissue could not be completely removed, so incomplete observations were made

Table 3.1 List of investigations carried out on each of the samples in this study

Ageing Techniques

Estimating age at death in archaeological and anthropological skeletal material is an important element in the specialists studies. There are many anthropological techniques currently in use around the world, of varying accuracy and popularity. The use of macroscopic and microscopic laboratory techniques can often provide the most accurate estimate of age at death, for example root dentine translucency (Bang and Ramm 1970, Whittaker et al., 1990, although this technique has been disputed by Sengupta, 1996), Osteon counts of thin sections of the femur (Kerley 1965, Bouvier and Ubelaker, 1977, Kerley and Ubelaker 1978) and the use of x-rays in determining cortical bone thickness (Ascádi and Nemeskéri 1970). However these methods are often prohibitively expensive to apply to large archaeological samples as a routine, require access to laboratories and

usually involve an element of destruction. As this thesis is concentrating on the construction of simple field methods, which arguably may be less accurate but are cheap and easy to use in the estimation of age at death, it was not thought an appropriate comparison to use the complex and expensive lab-based specialist techniques described above with those devised in this study.

As age related changes are central to this thesis the two most common methods used in anthropology are outlined in some detail below, and the advantages and disadvantages of each method are discussed in turn. A short discussion is given of some of the other less frequently used methods in this country, but space does not permit an exhaustive discussion of every ageing method ever devised. Only the pubic symphysis and tooth attrition methods were used to anthropologically estimate age in this study. The reasons for omitting some of the other methods are given in the section below.

Pubic symphysis

Morphological changes of the pubic symphysis in the pelvis is the most commonly used and is believed to be one of the most reliable methods of estimating age at death in skeletal material (Buikstra and Ubelaker, 1994). Todd (1920) first devised a method looking at changes of the face of the pubic symphysis in 306 males, and later 47 females (1921) of known age at death. From these he developed a ten phase system for ageing skeletons from 18 to 50+ years. An appraisal of this method by Brooks (1955) showed that there was a greater level of accuracy in ageing males than females, but that the method had a tendency to overage individuals. McKern and Stewart (1957) modified the system completely using a sample of 349 males of known age at death from the victims of the Korean war. They proposed a three component numerical scoring system, and later added females to the method (Gilbert and McKern 1973). Nemeskéri, Harsanyi and Ascádi (1960) produced the first method using European material. In all these studies there appeared to be greater variation among the pubic symphyses of women and that there was a tendency to overage females. This point has been discussed in detail by several researchers (Gilbert 1973, Suchey 1979). Putschar (1976) stated that the problems of inaccuracy with females were due to changes caused by the loosening of pelvic ligaments and cartilage in pregnancy, and that alterations of the pubic symphysis caused by parturition may "not always (be) clearly interpretable in terms of age, but generally will appear 'older' than in males of the same age".

A test of McKern and Stewarts' method by Suchey (1979) using a group of professional physical anthropologists produced disappointing results in terms of accuracy and she devised a further modification of the method based on a much larger sample (n=1225) of modern post-mortem material from Los Angeles (Brooks and Suchey, 1990, Suchey and Katz 1986). Their results showed that although this new method (known as the Suchey-Brooks method) could separate 6 different phases with a mean age of from 19.4 years (phase 1) to 60 years (phase 6) it was a poor technique for those aged from phase 4 onwards (with 95% confidence interval ranges of 26-70, 25-83 and 42-87 years for phases 4 to 6 in females). Although they suggest that there is no upper age limit to this technique, they advise that the "results for 'older' individuals will be poorer but can be somewhat improved by eliminating subjects with certain advanced patterns", and give a greatest mean age at death of 60 years for females and 61 for males. These mean ages at death should not be used without reference to at least the poor 95% confidence intervals (as listed above), but few researchers have followed this strict scientific approach when writing their reports (e.g. Molleson and Cox, 1993).

The large number of competing techniques of ageing the pubic symphysis and its apparent inaccuracy and bias with increasing age led to a number of papers testing the accuracy of these various methods on individuals of known age at death (Meindl et al., 1985; Klepinger et al., 1992). In these studies they support the use of pubic symphysis age determination, but advise it is not to be used in isolation. In practice the use of this technique shows a poor level of reproducibility between observers (Suchey, 1979) and archaeologically this method can only be applied to a low proportion of skeletons in an assemblage as the bone is fragile and prone to breakage or destruction (Henderson, 1987).

Although the results of these tests show the potential for serious inaccuracies using this method on older individuals, the Suchey-Brooks technique is still the most favoured by researchers today. As such it is the method chosen for this study to compare with the age related changes suggested by the results in this thesis, but given the additional problems outlined above when ageing females, age estimation was only attempted only on the males in this study.

Dental Attrition

The use of tooth attrition as an indicator of age in archaeological material was first used by Zurht (1955, in Brothwell, 1981) on German material. The method is based on the hypothesis that continued chewing through life wears down the enamel surface of the tooth to expose the softer dentine below it. Zurht noted how much wear had taken place on the first molar at the time the second molar erupted (usually at around age 12), and then how much wear had taken place when the third molar erupted. By this method he could work out how much attrition had taken place over a fixed period of time, and was able to extrapolate this information to age the adults in the population. Miles (1962) was the first to attempt this type of technique on British material, but it is the chart formulated by Brothwell (1981) that is used most commonly today (see figure 3.6). Brothwell produced a visual attrition score based on the appearance of dentine with age on the molars.

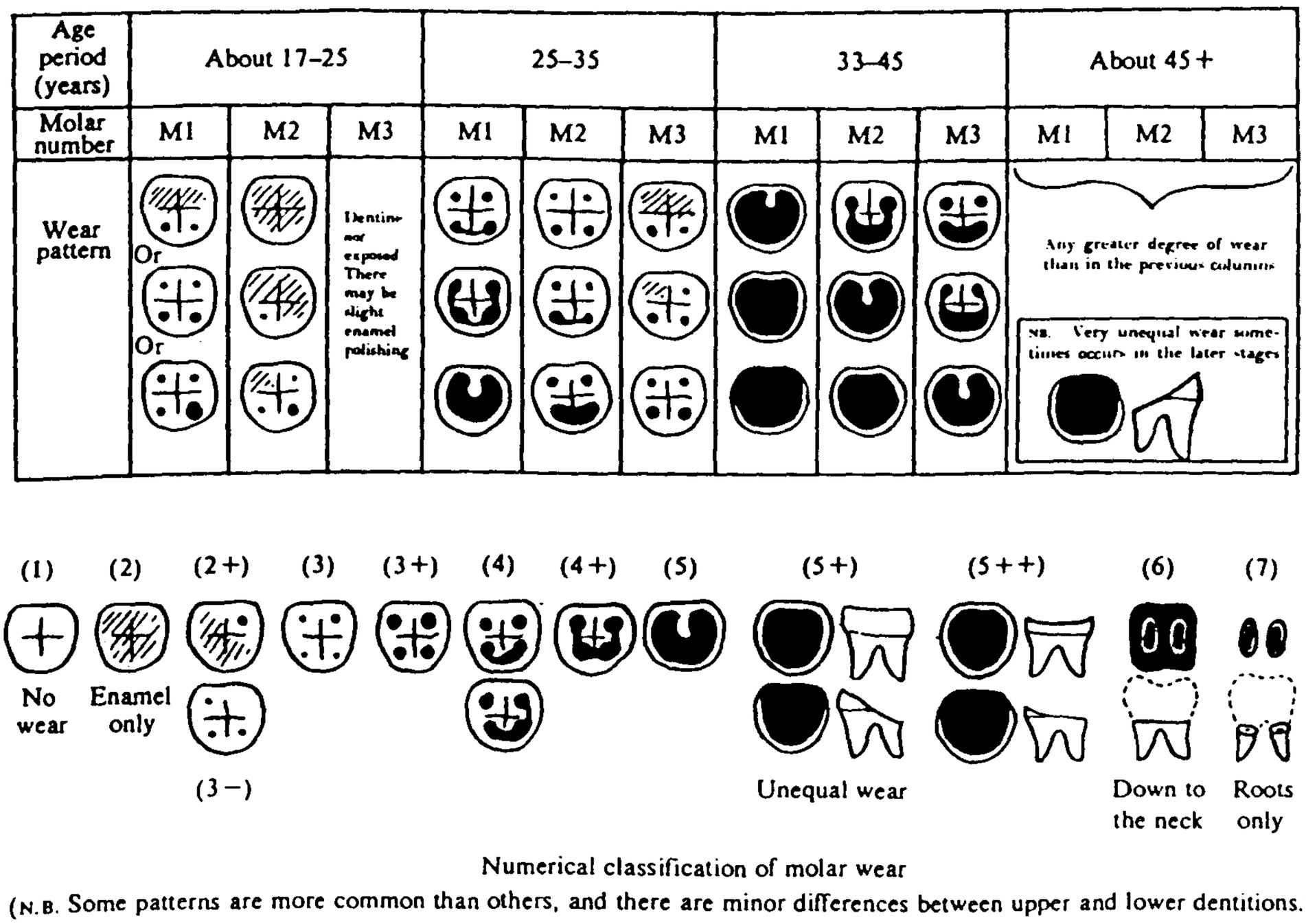


Figure 3.6 Brothwells tooth attrition classification "A tentative classification of age in Neolithic to Medieval British skulls, based on molar wear". Reproduced from D.R.Brothwell 1981 "Digging Up Bones" (O.U.P./B.M.N.H publication)

This method is simple and easy to use, and has good reproducibility, but there are a few problems associated with this method. The underlying assumption is that a populations' diet is similar across social classes and that it is constant over time. Enamel thickness can vary between individuals (Macho and Berner, 1993) and perhaps most importantly not every individual studied has a complete dental arcade (at least all the molars on one side, palate and maxilla) of correctly occluding teeth. Brothwell suggests his method is best applied on Neolithic to Medieval material, as the marked increase in tooth decay and tooth loss following the post-Medieval introduction of sugar in the diet means many skeletons are edentulous or have few molars to age (Hardwick, 1960). This method is rarely used on American skeletons (Molleson, 1986) as the material is mostly post-medieval in date, but as this is the second most popular method (after pubic symphysis ageing) in the U.K. all the skeletal material in this study (excluding the post-mortem material as it was impossible to obtain observations) was aged by Brothwells criteria.

Other ageing techniques - osteophytes and vertebral lipping, auricular surface changes and sternal rib end morphology

These three methods, auricular surface changes, osteophyte formation and sternal rib end changes are quite commonly used to estimate age at death in archaeological material. As such it could be a criticism of this thesis that these methods have not been used in addition to the two chosen for study. However, each of these methods is based on changes that may be due to pathology (senescence), and not just degeneration (see chapter 1 for a discussion on this subject). Using ageing techniques which are inherently pathologically based can become a serious problem if one then attempts to look at age specific pathological changes, which is usually discussed in every substantial human bone report. It is true to say that the prevalence of skeletal pathology rises with age (see chapter 1), but not everyone over a particular age will uniformly show these pathological changes and it should be considered bad practice to use ageing techniques which can lead to this circular *increasing age = increasing pathology = increasing age* argument. This is borne out by the observations of Saunders et al. (1992) who found that using the auricular surface method to age the sample of known age at death from Belleville, Ontario, the level of inaccuracy and bias increases with age.

It has been argued that the presence of osteophytes and osteophytic lipping on the rim of vertebral bodies is purely age related "degenerative" change (Stewart, 1958, Ascádi and

Nemeskéri, 1970) and not pathological at all, especially if there is no evidence for true osteoarthritis (such as eburnation). Work by Rogers, Shepstone and Dieppe (1997) however, has shown that certain individuals may have an inclination to form new bone more easily, and may produce vertebral osteophytes and enthesophyte formation, whereas others of the same age show no changes at all.

In addition to this general problem, each of these methods has been heavily crititcised by researchers who have tested them on populations of known age at death. The auricular surface method (Lovejoy et al., 1985 and Bedford et al., 1989) and sternal rib end morphological changes were two of the methods applied to the Belleville population mentioned above (Saunders et al. 1992). The auricular surface method was difficult for the investigators to apply, as it is based on comparison of pictures, which do not represent the whole range of changes which can been seen on the joint surface. The technique was shown to be poor on individuals aged over 35 years, with a tendency to under-age. The test of sternal rib end changes (Iscan et al. 1984) fared little better - the fourth rib, which is the site of choice to carry out this method, is hard to identify, and the researchers found the rib end was often damaged beyond use. The method was also found to under-age older individuals, and worked best on those aged under 29 years. Further tests of this method on the sample from Spitalfields using only the second rib (Molleson and Cox, 1993) gave worse results, leading them to conclude that "..the sternal end of the second rib is clearly not a good indicator of age".

Test of Intra-observer error

Many studies have used samples of known age at death to look at the general rate of inter-observer error for all of the ageing methodologies outlined above. In addition it is vital for the observer, before starting any study where accurate use of the methods is needed to know that a) they are internally consistent at using the above techniques, and b) that the level of accuracy of applying the techniques is of a professional standard. If an individuals' personal attempts at ageing skeletons are not compared with their colleagues in the field, then criticism can arise, especially if unexpected results occur. The use of only one observer when ageing the material from Spitalfields (Molleson and Cox, 1993) led to such an argument. Cox denounced most of the methods currently in use as inaccurate, but it was suggested that it was she, not the methods used, that was inaccurate (Rose, 1995). To avoid this problem two approaches were taken. Firstly the

author tested her accuracy compared to that of two colleagues (one of which had been trained in another institution) within the department using the pubic symphysis and tooth attrition methods. They showed 91% and 86% agreement between all colleagues for the tooth attrition and pubic symphysis changes respectively (and 100% for both methods within one grade / score, see appendix B). In addition the data from some of the skeletons in the Terry collection had been independently aged by one of three physical anthropologists, and it was initially proposed to compare these results with those independently obtained by the author. Although the level of agreement was quite high this approach had several problems. The three anthropologists looked at the skeletons between 1930 and 1950, and none of them were available to question personally about which version of the methodologies (e.g. Todd's pubic symphysis method) they used, which differ from the modified ones used today. Some of the results they obtained were remarkably accurate - much greater than any researcher would claim today, and it is not known how much they were influenced by knowing (if they did) the actual age of the person. In one instance the real age of one person was changed after a mistype, from 32 to 60 years, but the anthropologist who aged the person before the mistake had been noticed had aged the skeleton at exactly 32 years! Because of these problems, and the fact that the level of agreement was so high between the author and her colleagues, it was decided not to compare the results of the three anthropologists to those obtained by the author as an indicator of reproducibility.

Sexing

The sex of the individuals in the post-mortem room was recorded as on the certification available (e.g. hospital notes). The Barton-on-Humber sample was sexed only using the standard anthropological criteria which records morphological variations on the pelvis, skull and the femoral and humeral head size (Brothwell, 1981, Bass 1981, Buikstra and Ubelaker 1994). The Spitalfields and Terry collections were sexed blind by the author using the anthropological standards above, and were then checked using the certification available (coffin plates and post-mortem notes). A level of 94.5% accuracy was achieved by the author using these anthropological methods (see appendix B), which is consistent with standards achieved by many researchers (Saunders et al, 1992), and of the maximum level of accuracy obtainable as suggested by the authors of this method (Krogman, 1946, Washburn, 1948, Genoves, 1959 and Phenice, 1967).

Pathology

The use of the post mortem notes in the modern Bristol sample and the Terry collection have been discussed in the previous sections, along with their limitations. For the archaeological samples, bony pathology was recorded by an experienced palaeopathologist (Juliet Rogers for the Barton sample, and Tony Waldron for the Spitalfields sample). For the purposes of this thesis the diagnoses given by these individuals, following the standard diagnostic criterion for each disease category, is taken without question as being the most likely.

Visual observations

All observations were made in the presence of artificial light. Where the skulls were whole a pen torch was used. For each sample between 2.5 and 10% were randomly re-examined at a later date (usually at least a week later). It was not possible to re-examine the post-mortem skulls at a later date as they were only out in the mortuary for one morning, so only the Anatomy Department skulls from that sample were re-studied. For reproducibility results for individual observations, see the relevant chapters.

Casting

For a number of observations it was necessary to make casts of features on the endocranial surface of the skull (e.g. vessel grooves and arachnoid granulation pits). All casts were made with dental alginate of the type used for making prosthetic appliances. Permanent positives of the alginate cast were then made up with dental stone. The method had to be simple and portable enough to use in a standard lab as well as the post-mortem room, and had to be easy to transport (e.g. to the U.S.A.). The following protocol was devised and used on every skull:

1. The skull was first washed in cold running tap water to remove any soil / blood present. This also primed the surface as alginate is designed to work in a damp environment.

2. Three parts alginate to 8 parts tap water at room temperature were mixed together in a plastic bowl. The mixture was stirred for approximately twenty seconds to remove any air bubbles.

3. The mixture was then poured onto the bone starting at one edge, easing it over the surface to avoid trapping any air between the bone and the alginate. This was then left for approximately 3 minutes to set.

4. When set the alginate cast was carefully peeled from the bone. If a positive was not made within 15 minutes the alginate cast started to dry out and began to shrink.
5. One level measuring pot of dental stone was then mixed with 70ml of tap water at room temperature. It was then stirred for a minute to remove any air bubbles.
6. A thin film of this mixture was then poured on to the alginate cast and was carefully rubbed onto the surface to avoid air bubbles. A thicker layer of between 10 to 15mm thick was then poured on top of the cast.
7. The stone positive was left to harden overnight before removing the alginate cast, which was discarded. After further two days the cast had dried out completely and was ready to use (see figure 7.5 in chapter 7, page 126 for an example of a stone cast).

Measurements

Macroscopic

All the macroscopic measurements for every sample in this study were taken using the same pair of Mitutoyo electronic calipers, which are accurate to 0.001mm. Given the level of reproducibility achieved by the observer (see specific chapters for details) it was decided that measurements should only be recorded to the nearest 0.1mm.

Microscopic

All microscopic measurements were taken using a reflex microscope (Speculand et al., 1988). This is a three dimensional bifocal light microscope with an inbuilt point of light which can be lowered or raised to sit on the surface of the object being measured, without touching it. The machine is linked directly to a computer, and by pressing a mouse sends landmark/point data to the computer in three planes, from which measurements can be calculated. The instrument is designed to measure irregular objects of up to 100mm in any dimension. It has been shown to be reproducible, with an operator error of less than 0.2mm (Speculand et al., 1988a,b). As the average inter-observer has been measured, it was only necessary to test the intra-observer error. Two experiments were undertaken. The first was to test how consistent the operator was in observing exactly where the level of the surface was. A pencil mark was made on the surface of a cast, and the point of light was placed on its surface, pressing the mouse to take a measurement. The z (height) plane was then moved by turning the focus without looking down the eyepiece. The operator then focused on to the same spot and repeated the measurement. This procedure was repeated 10 times at the start and finish of every

session. The error of focusing on a single point on the surface was on average 0.006mm (see appendix C for further details).

The second test was to calculate how few observations would be needed to accurately measure a straight line of uneven height and fixed length, which would cut down on the time needed to use the microscope. Five casts were chosen to represent the range of complexity. Each cast was measured in random order using 4, 8, 12 and 16 points across a 4 mm long pencil drawn line. A week later the measurements were repeated. The spline (angle of the slope) was calculated for each cross-section. For every pair of observations (week 1 and 2) the two curves were plotted on computer. As the reflex microscope has no fixed internal grid the two plots were laid over each other by transformation to get the best fit. The difference between the two curves was calculated, and it was decided that for a line of between 2 and 4mm eight points gave the best value in terms of time taken for good reproducibility.

X-ray

A sub-sample of the Barton-on-Humber group were given standard lateral and anterio-posterior (AP) x-rays. There were no facilities to x-ray material from any of the other samples, and it was not possible to bring any of the collections back to Bristol to have them x-rayed. All x-rays were taken in the Department of Radiology, Bristol Royal Infirmary. The radiographs were standardised using a film focal length of 90cm and a focus spot size of 0.5cm. Figure 3.7 shows a diagram of the apparatus used. The skulls were held in position using foam pieces and a cardboard tray of similar shape to the skull.

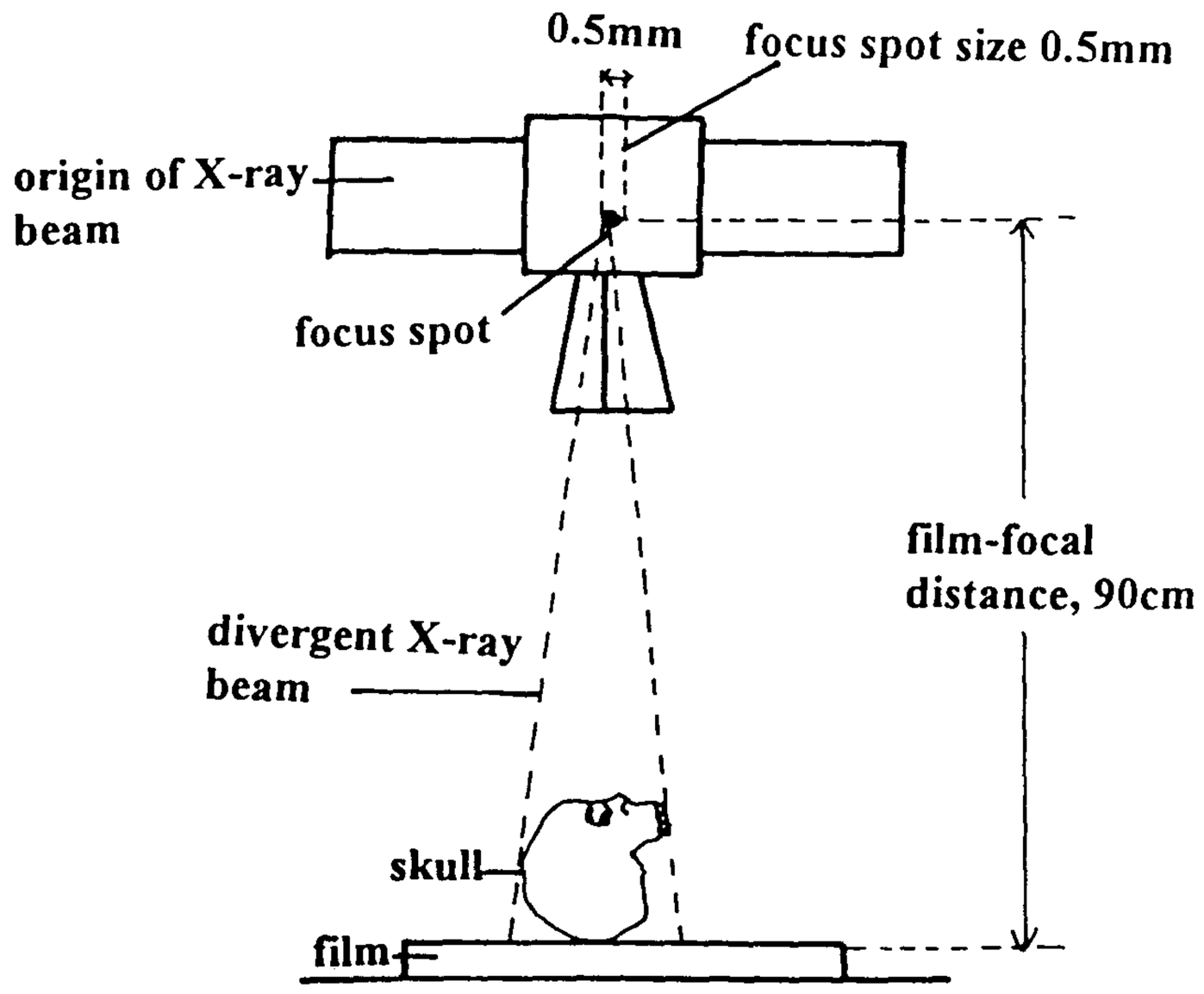


Figure 3.7 Diagram showing position of the skull and x-ray equipment.

Based on a diagram from "A Survey of Human Remains for Evidence of Pituitary Adenoma" R.J.Crossley Unpublished B.Sc thesis 1995

Histology

Owing to factors beyond the control of the author, the original proposed contribution of histological samples to this project is much reduced. In addition half of the samples that were taken produced only poor sections which were not of a quality to be presented as part of this thesis.

The samples selected for histological analysis were processed by two technicians. The samples were mounted in wax, and were then cut with a bandsaw. Thin sections were produced by slicing with a microtome. These sections were then washed in alcohol and decalcified on a slide.

Statistical Methods

The advice of two statisticians was taken when drawing up the methodologies for each of the studies and the analyses presented in this thesis were carried out by the author. The main statistical tool used was regression analysis, which measures the degree of correlation between two (or more) variables. The method produces an equation, and

standard deviations, which can then be applied to other samples to test its accuracy, including confidence intervals. A significance level of 5% ($p<0.05$) was used throughout. This method assumes a linear relationship between the variables, which may not always be so (see chapter 9, and comments in relevant chapters for further discussion on this problem).

Non-parametric tests (Mann-Whitney) were carried out when comparing data sets, as the populations used in this study were not normally distributed in terms of age. Individuals were selected to produce roughly evenly sized age groups in the Terry and post mortem samples and the population profiles of both the Barton and Spitalfields samples were not normally distributed (see figures 3.1,3.3,3.4 and 3.5).

The reproducibility of each method was assessed by calculating an intra class correlation coefficient (I.C.C.) which gives an estimate of accuracy based on the number and range of observations made.

The results of each study was analysed using Microsoft excel spreadsheets and the Minitab statistical analysis package. It was decided to use only this basic analysis for the production of this thesis, but more complicated statistical analysis was carried out by Lee Shepstone to produce the models shown in the papers that have been published/submitted based on the work in this thesis (see appendix F).

Chapter 4. Skull Thickness

Introduction

In both anthropological and medical literature the link between age and skull thickness in adults has been sporadically studied, but the relationship is a rather complex one. There are two avenues of thought, with anthropologists looking mainly at increasing skull thickness as a phenomenon of ageing, whilst clinical research has been concentrated on studying the causes of abnormal skull thickness and thinness, which may be age related. For both of these lines of investigation some normative data for skull thickness is needed, for both males and females. In addition some indication of variation between races is also necessary.

Normal Adult Skull Thickness

Anderson (1882) was the one first people to produce data on adult cranial thickness (see chapter 2 for details on skull growth and formation). He looked at 154 Irish cadavers of known age at death, but it has been difficult for later researchers to compare results as the points used to take the measurements were not clearly defined, and not all of the skulls measured were of known age at death. Todd's work in 1924(a) looked at 448 male white skulls and was able to give an average skull thickness in four areas. He concluded that "cranial thickness increases slightly with age up to about 60 years, but thereafter there is no real evidence of any normal change" and that skull thickness "..is so variable that one may not expect to predict it with a real degree of accuracy for any particular cranium". Todd (and later Wiedriech in 1941) believed that increased brain weight caused thinner skulls and he cited the examples of increased skull thickness in cerebral hemiatrophy and thinness in hydrocephalus. One major criticism of Todds study is that some of the skulls he used were not of known age at death, but were determined anthropologically. This then gives rise to a circular argument when one is trying to examine age related changes using anthropological methods instead of known age at death, one cannot be certain they have been aged accurately. In his methodology he states that "..448 male white crania of known age or of age determined to within a year or two by methods which I have previously outlined". He does not state how many he actually knows the exact age of and how many he himself has determined. It can only be assumed that the methods he has used are the anthropological techniques he devised for

ageing using the pubic symphysis (as discussed in chapter 3) although he does not reference these methods in this paper.

In 1927 Hellman studied a series of American Indian crania and concluded that the face, at least continues to grow to what he termed "old age", but later shrank in size during "senescence". A drawback of his study is one which was similar to Todds in 1924. He aged the skeletons himself using a tooth attrition method which he devised, and the actual age of death of the individuals in the sample studied was not known.

After this initial work on skeletal remains further work on live populations was undertaken. The anthropologist Hrdliçka (1936) concluded that the length and breadth of the head and face continue to grow until at least 60 years of age using the populations he studied of adult French, Alsatians, Russians, American whites and American Indians. Buchi's longitudinal study (1950) of Swiss males and females also supported this conclusion, as did work by Hooton and Dupertuis (1951) on 10,000 Irish males, although their results were based only on ages 30 to 39 years.

A conflicting opinion was produced by Lasker in 1953. He looked at Mexican adults and found little change in skull thickness with increasing age in males. Baer challenged these findings directly in his 1956 paper which studied data from the 1946 Army Anthropometric Study (5,688 male white Americans) and a survey of white American female Army workers (7,420). He only included those individuals in their third decade and found a good comparison with earlier researchers who found an increase in face height, but not with head length, breadth or circumference.

The studies based on direct measurements of these live individuals either cross-sectionally or longitudinally present several problems in interpretation of skull changes. The degree of change involved in all studies is very slight, and to what extent the change may be due solely to soft tissue factors, as it is well known that in most individuals the relative proportion of body fat increases with age (Behrents, 1985) is unclear. Baer commented on this problem briefly and suggested that with increasing emphasis on x-rays, not only would the degree of skull and soft tissue involvement be resolved, but would also indicate which specific bones in the skull were growing or shrinking.

Despite these problems further data were still being collected. Stramrud (1959) produced cross-sectional data from Danish males. Adeloye et al. (1975) studied North American blacks (n=300) and whites (n=200) using only true lateral x-rays. They studied four different sites on the skull and found differences between both males and females, as well as a statistically significant difference between blacks and whites.

Israel (1968, 1973a,b) re-examined skull thickness as he believed a different process of age-related alteration was occurring from that of the post-cranial skeleton. This had also been seen by other workers (Campbell, 1966, Moore 1955 and Todd 1923, 1924a), and may account for continuance of skull growth during adulthood. He chose the x-rays of 43 male and 53 healthy females from an longitudinal study sample at the Fels Research Institute and measured five locations on the skull. Although he noted an increase in skull thickness, diameter and intersutural distance over time, it was not possible to statistically prove that greater increase in the skull was associated with the older age of the subject. He suggests this may be because in this technique the measuring error was similar in size to the mean cranial gain, and that it might have obscured the expected observation.

One problem when comparing all these studies is that most modern medical researchers use live individuals, and take measurements from x-rays, whereas anthropologists use direct recordings from the dry skulls of the dead. These must also be compared to earlier anthropological work using direct measurements of living subjects. Although there are standard calculations to correct for any magnification caused by x-rays (e.g. Chapman and Nakielny, 1986), there have been few studies which have tried to correlate measurements from x-rays to actual size (Grossman and Zuckermann, 1955) but none have been carried out on the parietal.

Parietal Thinness

As this chapter is concentrating on non-pathological causes of skull thickening and thinning, it is not necessary to discuss in detail the extensive literature on parietal thinning. However, the condition needs to be described as it is a possible differential diagnosis for thin skulls, and will need to be excluded.

Parietal thinness appears to be a relatively rare occurrence, but this may be due to its apparent lack of clinical relevance. Sandifort (1783) was among the first to notice the

unusually thin bones of the parietal, describing them as "as thin as paper" (in Greig, 1926). Virchow (1854) believed that the thinness was caused by senility and atrophy. Greig (1926) presented nine cases of symmetrical thinness of the parietal bones, suggesting it was caused by a dysplasia of the diploë. There was no evidence for injury or inflammation in any of the skulls. Camp and Nash (1944) undertook a survey of the x-ray changes in 119 cases of what they termed "developmental thinness", and found four types - flat or grooved depressions with either uni- or bi-lateral presentations, and noted that the endocranial surface was unaffected. They did not find any overall association between any of the symptoms suffered by the patients (such as headache, vertigo or tinnitus) with the thinness and concluded that the phenomenon was "clinically not very important". Wilson (1944, 1947) also noted a case of unilateral parietal thinness of no clinical significance; however work by Epstein (1953) showed a possible correlation between parietal thinness and osteoporosis. Moore (1929) believed that the presence of enlarged parietal foramina was an incomplete case of thinning, but this view is not widely held.

Archaeological examples of biparietal thinning

As with modern populations, there appear to be few cases of biparietal thinning in archaeological collections. Elliot-Smith and Wood-Jones (1910) noted seven cases in over 10,000 skeletons from Nubia, which are also discussed by Lodge (1967). Brothwell (1967) described three cases, all female, two of which were Saxon and one Roman in date.

Pathological Skull Thickness

There are many diseases which can affect the thickness of the skull, and these should be excluded before any correlation with age at death can be undertaken, but it is necessary only to discuss the most common (see appendix D for a more complete list), hyperostosis frontalis interna (HFI) and Pagets disease. Hyperostosis frontalis interna (see chapter 5 for main discussion on this subject) affects the endocranial surface of the skull of the frontal and occasionally the parietal bones with endosteal deposition of billowing symmetrical new bone, which in turn increases the thickness of the table dramatically.

Paget's disease, which is an infective disorder, can also cause increased thickness of the skull. In Paget's disease (also known as osteitis deformans) bone turnover is affected,

eventually causing the trabecular structure to appear disorganised and structurally inadequate (Cotran, Kumar and Robbins, 1989) leaving it prone to fracture. It has two forms; monostotic (a single bone involved) or polyostotic (several bones) and in both types the skull is the fourth most common site to be affected (Meunier, 1987). Pagetic skull thickening begins in the frontal and occipital regions, but can spread to affect the parietals. Platybasia (flattening of the base of the skull) can also occur, which may lead to medullary compression.

A third cause of cranial thickening is anaemia. Anaemia is defined as a reduction in either red blood cell volume, or in the concentration of haemoglobin (Wyngaarden and Smith 1985). There are over a hundred different types of anaemia, and these can be either inherited or acquired (Cotran et al. 1089). The subsequent lack of oxygen can cause expansion of the diploë, and so thickening of the skull. Thalassemia is an example of a type of anaemia which produces classic new bone formation on the outer table of the skull, producing a "hair on end" appearance on X-ray. It is not known, however, whether transient conditions, such as childhood anaemia cause permanent changes, or whether the table of the skull can return to a normal thickness with time.

The diagnostic changes of these diseases can all be seen on a standard X-ray, but is not known how much the presence of any age related pathologies may be causing at least some of the apparent skull thickening phenomena. Not all the skulls measured in the studies discussed were X-rayed and diseases such as Pagets may be hard to identify skeletally without the aid of an X-ray (Rogers 1996). Finby and Kraft (1972) excluded Pagetic skulls from their cross-sectional study of adults aged between 25 and 34 years but most commonly no mention of pathology is included in these studies. Adeloye et al (1975) discuss the possibility of haemoglobinopathies causing increased skull thickness in blacks, but does not consider HFI as a possible reason for some of the increased frontal bone thickness in their discussion.

Archaeological Aspects of Skull thickness

Studies of skull thickness have concentrated mainly on the differences between early man and modern across time (e.g. Ivanhoe 1979, Webb 1990), but the study of fossil human bone is beyond the scope of this thesis.

Where studies have been carried out on anatomically modern man, any differences seen are often interpreted as being due to population replacement (Hrdliçka, 1938; Arensberg, 1973 and Ferembach 1973) or due to differing "interaction of humans with their environment" (Smith et al. 1984, 1985) with time. The population replacement theory ties in well with the evidence from the medical literature for racial differences in skull thickness, but proving that occupational change over time produces bone changes (Brace 1973 and Frayer, 1980 both hypothesise causal relationships between reduction in stature and change in hunting strategies) can be problematic. Although one can predict a number of possible activities in a past population (such as corn grinding or spear throwing) specific occupations cannot be allocated to individual skeletons. It is unrealistic to assume a corn grinder would grind corn all day every day for his/her whole lifetime, and we do not know how repetitive an activity needs to be before skeletal change occurs. The few objective studies which have been carried out on people of known occupation (Waldron, 1993) show no correlation between bone change and specific activity. In addition there is new evidence to suggest that the skeletons of different individuals will react to the same stress in different ways (Rogers et al 1997).

Choice of recording site

Most previous studies have focused largely on measurement of anatomical landmarks which involve the cranial sutures, and not on the table of the skull itself. A section through the normal table of the skull from outside to in will contain two periosteal covered surfaces, two compact layers of bone and both endosteii interspersed between diploic bone (Israel, 1968). The cross section through suturally based landmarks lacks cancellous bone, and can be more variable than that of the adjacent table (Law, 1993) and so they may not be the best sites to give an indication of general skull thickness.

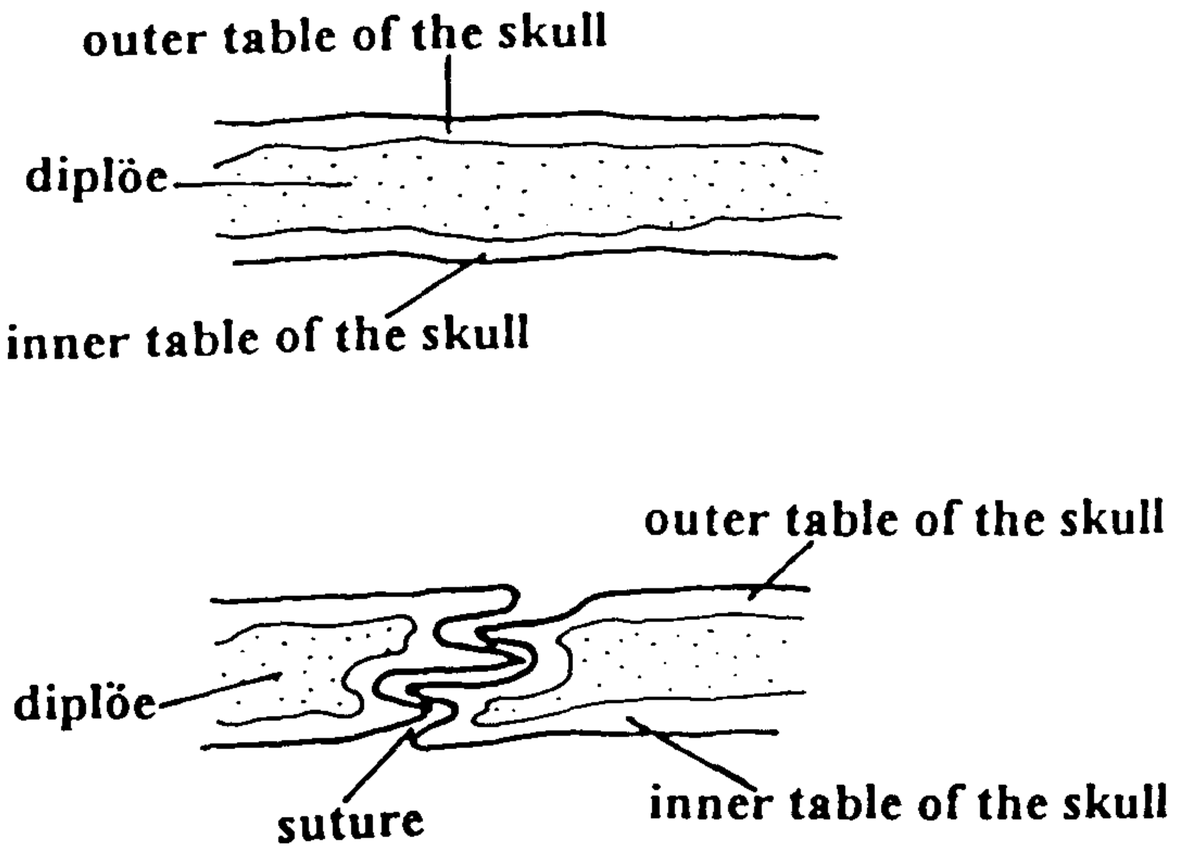


Figure 4.1 Simplified diagram of a cross section of the table of the skull, and at a sutural junction

Several researchers have tried to correct for this using fixed measurements from anatomical landmarks. Adeloye et al (1975) used a method which took measurements from points 3cm anterior and posterior to the coronal and lamboid sutures. Most of these recorded points were still on the sutural junctions, but those that were not did not take into account any variation in parietal length. Not every parietal has the same dimensions, and so a measurement of 3cm from bregma on a long skull, may not be in a directly comparative place as 3cm away from bregma in a shorter skull. Although this could be overcome by using percentages, e.g. a recording taken 10% along the suture from bregma, this would still not cover the basic problem of measuring at sutural landmarks.

The literature review above gives a long history of investigation of skull thickness in adults. It would appear that there is some degree of increasing cranial thickness with age, as well as evidence for sex and race variations. However, all studies have concentrated on either X-ray or direct measurement (of either living people or dry skulls) with no attempt to correlate the two methods. Often earlier work on live samples has not taken into account the added complications of scalp and hair thickness when discussing skull growth with age. Studies which have looked at the skull on its own have concentrated on anatomical landmarks which may not be the most informative places to look at changes in diploic thickening. In addition much work on dry skulls has not been tested on adults

of known age at death, rather those aged anthropologically. The effect of disease on skull thickness was not always considered when discussing the results of the studies.

Aims of the Study

This investigation of cranial thickness has two aims; firstly to see if one can accurately calculate the difference between skull X-rays and direct observation in skull measurements, and so be able to compare the results of the different types of study. The second is to correlate normal table thickness (not on a sutural junction) in a population of known age at death, looking for evidence to support the earlier conclusions that there are sex and race differences. Three studies were proposed:

1. To compare skull mid-parietal thickness on X-ray with actual measurement of the skull itself using standardised X-rays (see chapter 3 for protocol).
2. To examine whether there is any correlation between mid-parietal thickness and age at death in four non-pathological sub-samples of known age: white males and females, and black males and females. Those females with hyperostosis frontalis interna (HFI) were compared to those without to see if its presence affected the correlation.
3. To determine the maximum limit of skull thickness which is normal, and to investigate cases beyond this range in an attempt to provide guidelines for further investigation of pathological change.

1. Direct versus X-ray measurements of skull thickness

Sample

Eight skulls from the sample of Barton-on-Humber were chosen for this pilot study. The numbers involved in this study were necessarily small as part of the methodology involved slicing open the skulls after X-ray. Given the importance of the site, and the desire not to render useless (in terms of measurement) too many skulls the choice was restricted to those whole skulls which were either from disarticulated skeletons, or from areas of the site which could not be phased. It was thought that these skulls could be sacrificed as they would provide only minimum information in terms of the whole site analysis. As a precaution, however, all standard measurements and recordings were taken before cutting. It was decided that ten skulls would be a minimum number to observe if there is a possible correlation would between the x-ray and direct measurements. As most of the skulls were disarticulated they provided only limited demographic information.

Methodology

A standard anterior-posterior skull X-ray was taken of each skull (see chapter 3 for protocol). The point of maximum width of the skull at the parietal avoiding the temporal bone (see figure 4.2) was chosen on each X-ray, and the parietal thickness was measured at this point using calipers. This point was chosen as it was the easiest measurement to reproduce (see appendix E) on X-ray.

All of the skulls had repeat measurements taken at a later date (before slicing) to check reproducibility. Each skull was then sliced approximately along the line of maximum skull width and a recording was taken of skull thickness at the same point as on the X-ray, using the same pair of calipers. The results were repeated in random order on the same eight skulls as above to check reproducibility. The length of each skull was measured and the film - object magnification was calculated for each skull using the standard equation (Chapman and Nakielny, 1986)

$$\text{Magnification} = \frac{\text{image size}}{\text{object size}} = \frac{\text{focus-film distance}}{\text{focus-object distance}}$$

The results from the x-ray measurements were compared to the direct measurements.

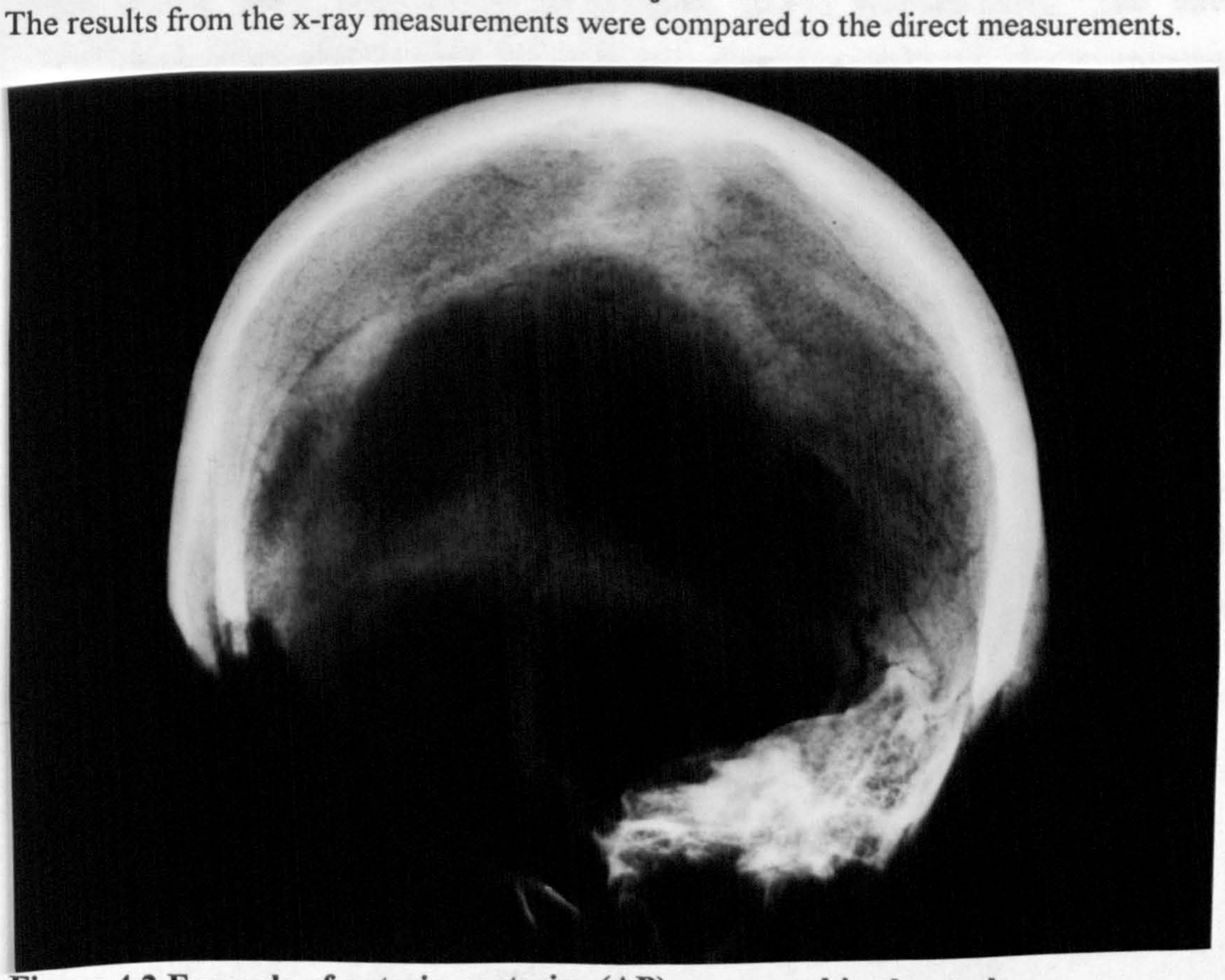


Figure 4.2 Example of anterio-posterior (AP) x-ray used in the study

Reproducibility

An intra-class correlation coefficient was calculated to check the reproducibility. Table 4.1 below shows the results for both left and right scores for the x-ray and the skull measurements.

Site	I.C.C.
Left x-ray measurement	0.87
Right x-ray measurement	0.62
Left skull measurement	0.64
Right skull measurement	0.28

Table 4.1 Results of the reproducibility study

These results show poor (0.28) to excellent (0.87) reproducibility. The direct measurement of the skull is much harder to reproduce accurately than the measurement taken from the x-ray.

Results

Comparison of measurements.

Figure 4.3 shows a plot of x-ray versus real measurement. The systematic variation between the two groups was calculated to see if there were any differences between the x-ray and visual scores. This gave an average difference between x-ray scores and direct measurement of -0.653 (St Dev 2.17; S.E. mean 0.544).

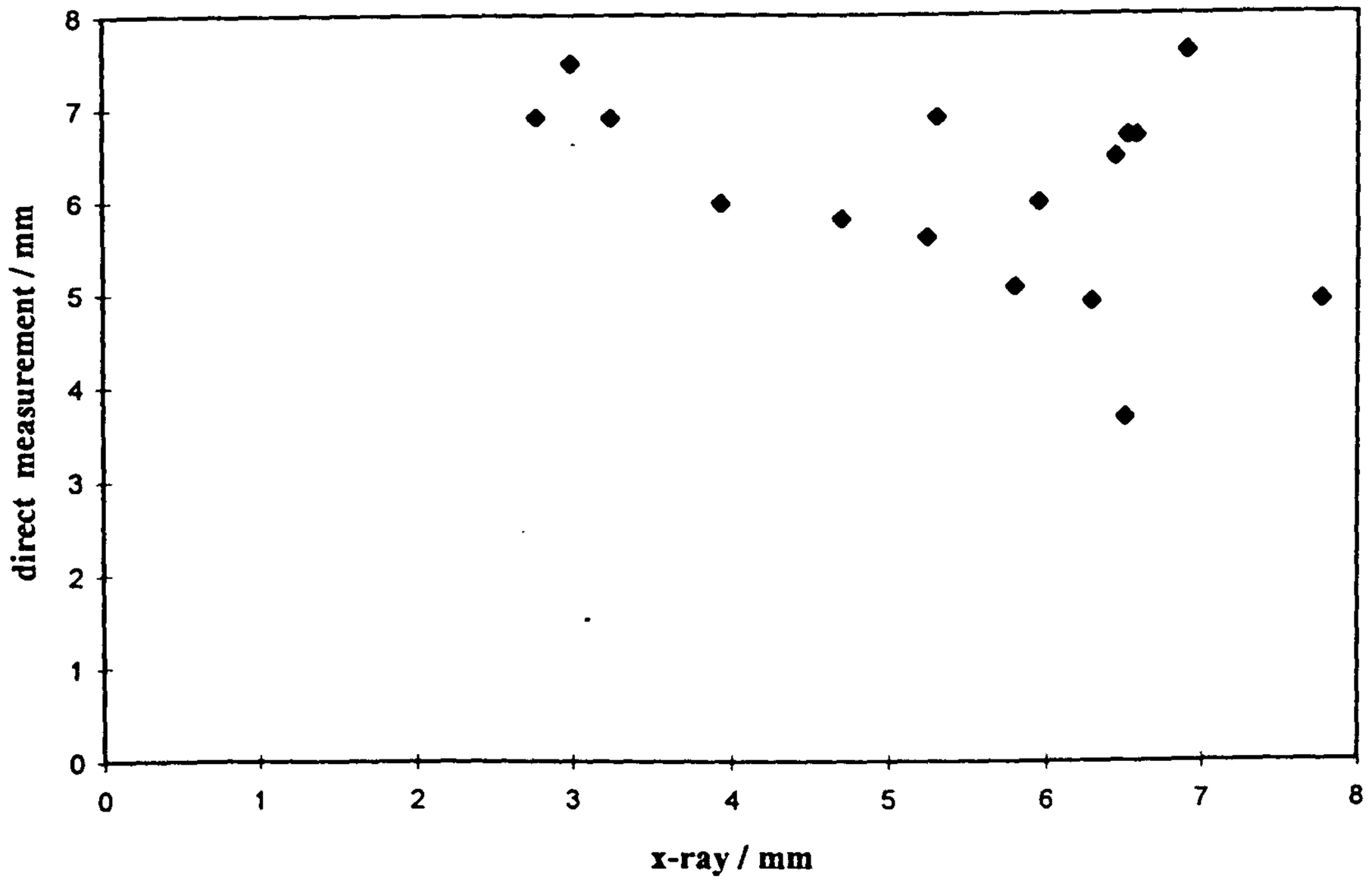


Figure 4.3 Difference between x-ray observation and direct measurement (after calibration)

Discussion

It can be seen from the results above that, even when the calibration is taken into account, it is difficult to even rank skulls in the correct order of thickness from their x-rays. There are several reasons why this may happen. Firstly, although the calvaria were whole the skull bases and maxilla were incomplete, which made it difficult to place them exactly in the same position every time. Although the calibration equation makes up for skulls of different lengths, if they are missing all or part of their base, they have a tendency to lean, and the margins become difficult to define. Some of the skulls had more curved parietals than others, and this also tended to distort the lines on the x-ray. It may be difficult to rank the skulls as the differences between them are relatively small. This is in concordance with the results of Israel (1968) which is discussed in the introduction to this chapter.

The difference in reproducibility between the x-ray scores and the direct measurements is probably due in part to the small size of the sample. The main source of error is probably

due to a poor choice of the measuring site on the skull, which although easy to define on a 2- dimensional x-ray, is much more difficult to pinpoint on a 3-dimensional skull which gives more room for error when trying to repeat the recording. It was decided from this study to define the point of measurement on the skull using a different approach in the subsequent work.

From this study the main conclusions drawn are that one cannot directly compare x-ray and direct visual measurements of the skull, even if the magnification percentage of the x-ray is known. When using x-rays one can accurately reproduce measurements using the point of maximum width of the parietal, but this method does not work as well using the skulls themselves.

2. Skull thickness and age at death

This study used a new approach to measuring direct skull thickness, in an attempt to investigate any relationship between thickness and age at death.

Sample

To test the second hypothesis 252 of the 261 skulls from the Terry collection (see chapter 3) were selected (table 4.2). Those individuals which were not used were discarded from this analysis because they did not have their skull caps removed in the standard post-mortem way (laterally - see chapter 3), but had been sliced to remove a 'v' shaped section of the frontal and some of the parietal bones, which made it difficult to take comparative measurements.

Sample	n=	mean age	min age	max age
Black males	69	55.01	17	98
Black females	75	49.39	16	102
White males	60	56.46	18	85
White females	48	61.54	30	91
All samples	252	55.01	16	102

Table 4.2 Numbers of individuals examined from the Terry collection

Methods

Two measurements were taken from each skull, one on each of the left and right parietals, two thirds of the way down from the sagittal suture and midway from the coronal and lamboidal sutures (see figure 4.4). This area was chosen after several measurements were taken and repeated from a sample of skulls (see appendix E), and any two measurements taken within this box (see figure 4.4) are within 0.5 mm and the results are highly reproducible (see appendix E).

In the Terry collection the measurements were taken in the same boxed area (see figure 4.4) avoiding any obvious anomalies which have been seen (Law, 1993) in other studies (such as extra large convolutions, vascular channels or areas of localised parietal thinness), and laterally along the line of the cut made during post-mortem to remove the brain. It was decided that a measurement should be taken in this general area, rather than a specific landmark or point along the parietal for several reasons, most of which have been discussed in detail above:

1. It was not thought that a recording taken at a sutural landmark would necessarily give a true indication of the general thickness of the table, including the diploe.
2. Not every parietal is the same length, and so a measurement of 3cm from bregma on a long skull, may not be in a directly comparative place as 3cm away from bregma in a short skull.
3. In addition to the variation in bone length, the degree of curvature of the parietal bone can also vary greatly between individuals (as discussed in the first study of this chapter). This can make the recording of measurements more difficult, and so give greater chance of error. An attempt at using a pair of spreading calipers to overcome this problem was tried, but gave poor results.
4. In those skeletons where the calvarium has been removed for a post-mortem, there can be a several centimeters of variation as to where the lateral cut is made (e.g. this can be dependent on many factors, such as position of the ears or hairline, to personal preference of the mortician) as it is harder to standardise on a curved surface.
5. In archaeological skeletons, many individuals have broken and fragmented skulls. It is not generally advised to re-glue skulls to take measurements (Rogers, pers. comm.), and so this can limit the number of records that can be taken appreciably. The choice of a

"general area" rather than a fixed point makes it possible to use more broken skulls, and so lends itself well to archaeological samples.

6. In giving the observer some leeway in being able to avoid obvious anomalies (as mentioned above) the results obtained should give a truer picture of the skull thickness. If for example a site was chosen (as in Adeloye's study, 1975) where the measurement was taken 3cm midparietally on every skull, this is an area where vascular channels often cross (see chapter 7 for more details), thus affecting the thickness by several millimeters, and masking the true result (a phenomena seen by Law, 1993).

7. As mentioned above, and shown in appendix E, any measurements taken within the marked box area (figure 4.4) which avoids the anomalies mentioned above will be within 0.5mm, and will have an excellent level of reproducibility.

The level of reproducibility was measured (see below, and appendix E for more details), and when this was considered satisfactory, the age at death of each individual was correlated with both the left and right measurements of skull thickness. In addition, the systematic variation was calculated to check for any differences in skull thickness between the left and right sides of the parietal.

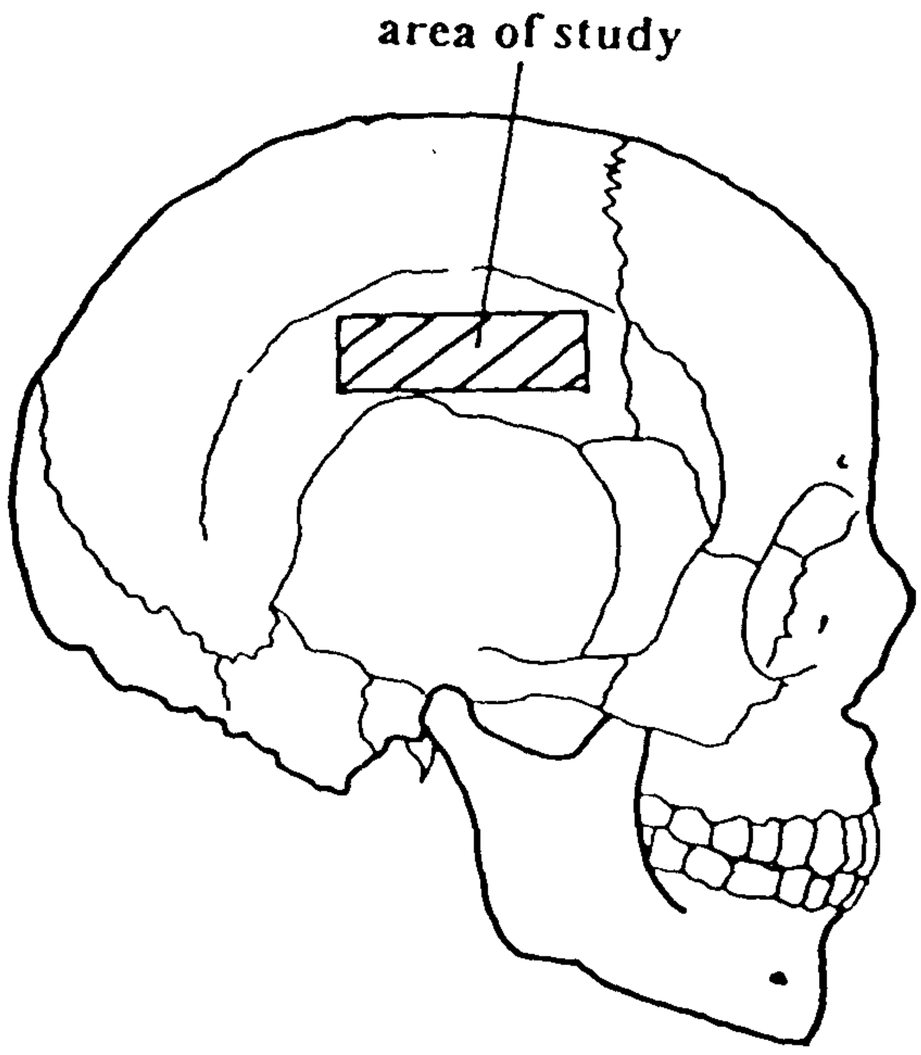


Figure 4.4 Diagram of skull showing area where measurements were taken (within the area marked by the box).

Reproducibility

Five skulls were randomly chosen and measured at the start of the study, and were re-measured at the end . An intra-class correlation coefficient was calculated for the results. This was 0.92 for the right side, and 0.89 for the left, indicating excellent reproducibility.

Results

Investigation of left side thickness compared to right

	N=	median thickness left	median thickness right	mean difference	S.E. mean
black males	69	4.8	4.8	-0.25	0.126
black females	75	5.9	5.8	0.189	0.075
white males	60	4.8	4.65	-0.017	0.099
white female	48	5.65	5.55	-0.014	0.112
all sample	252	5.3	5.2	-0.04	0.0528

Table 4.3 Results of the comparison of left and right thickness

The results in table 4.3 show that there is no evidence for a difference between the left and right sides in terms of thickness. Figure 4.5 below shows a plot of left versus right side thickness to show any asymmetries. This graph shows that there are a few anomalies in comparing the left and right sides, and although they are not statistically significant, it was decided that in addition to individual correlations of left and right sides mean skull thickness would also be correlated with age, which might help to smooth out these outliers, and increase the strength of the correlation.

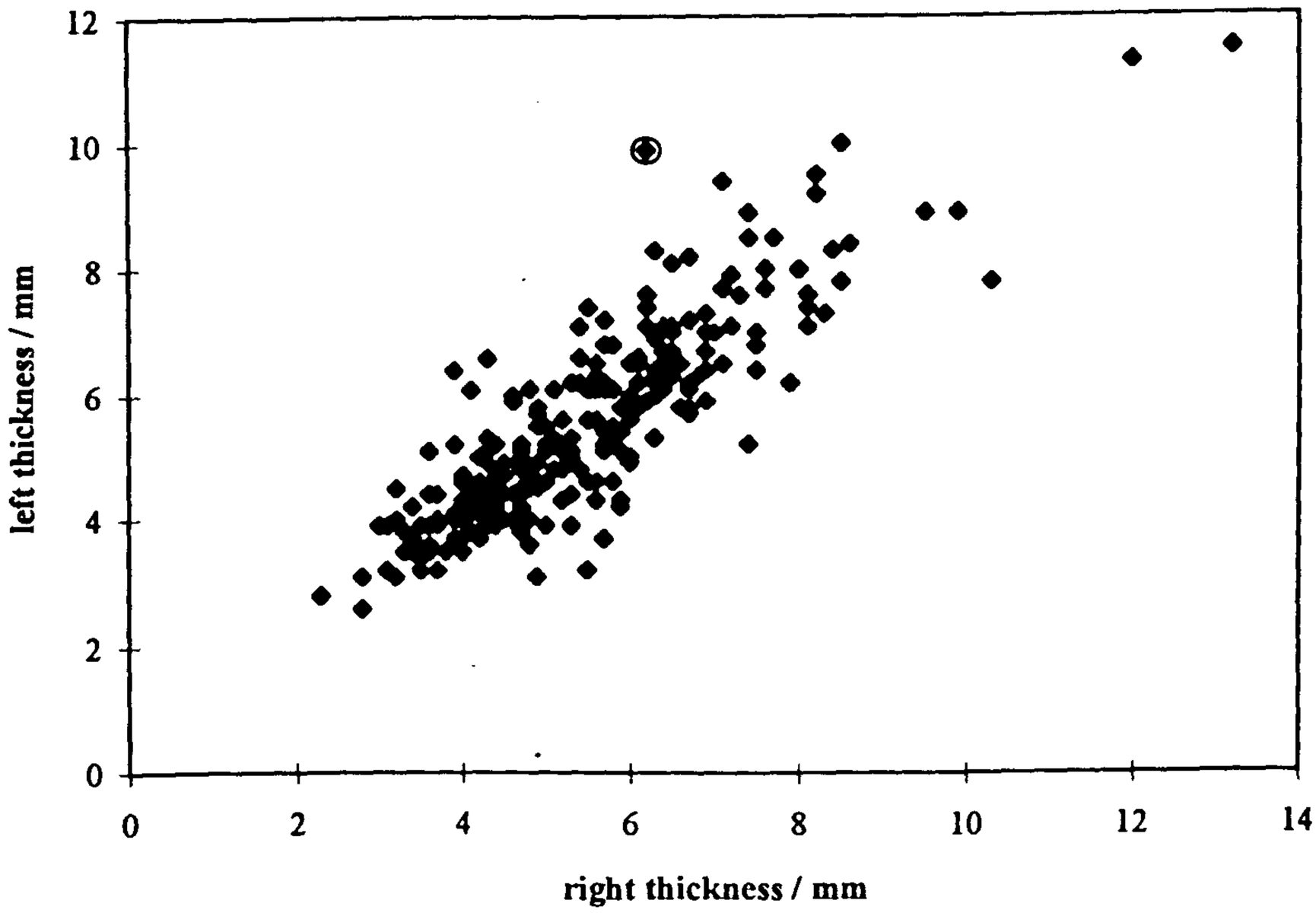


Figure 4.5. Left versus right sided skull thickness (the most anomalous result is circled).

The most asymmetrical skull in this sample is circled, which had a 3.7mm difference between the left and right sides. The skull was that of a black female aged 36. When the post mortem notes were read, the cause of death was given as epilepsy and hemiplegia (stroke). Only one other case in the sample was given as hemiplegia (which did not show any sign of asymmetry, although it did show some parietal erosion and pitting), and no other individual in the sample had a diagnosis of epilepsy.

The diagnosis of hemiplegia may be a cause of the asymmetry, as a stroke can cause asymmetrical shrinkage of the brain, and if this is long term it may produce a localised thickening of one parietal (Wyngaarden and Smith, 1985). The post mortem notes did not say how long the stroke occurred before death. There are also other possible causes of this asymmetry which should be considered. A tumour or meningioma may give the same symptoms as a stroke, especially in the pre-scanning 1930's. The thickening may also be due to localised Pagets disease (see appendix D). Pagets disease can occur in young people, but this is very rare and is an unlikely diagnosis in this case given the age of the patient. It was not possible to obtain an x-ray of this skull or any histological data

(see chapter 3). Without these, or further information on the patient, it was not possible to come to a definite diagnosis.

The relationship between age and skull thickness

As there is no statistical difference between left and right median skull thickness in an individual, the results from the mean skull thickness were used in the analysis. Age at death and skull thickness were treated as continuous variables, and the correlation between age and skull thickness was assessed using a linear regression, and a plot of age against mean mid-parietal thickness was drawn. Table 4.4 and figure 4.6 below give the results of the correlation calculation, and a plot of mean mid-parietal skull thickness against age.

Parameter	**Coef**	**St Dev**	**t-ratio**	**p<**
Intercept	37.553	4.831	7.77	0.0001
Mean thickness /mm	3.1817	0.8496	3.74	0.0001

s=20.16 R-sq (adj) = 4.9%

Regression equation age = 37.6 + 3.18 (mean mid-parietal thickness)

Table 4.4 Summary of results from correlation of age against mean mid-parietal skull thickness

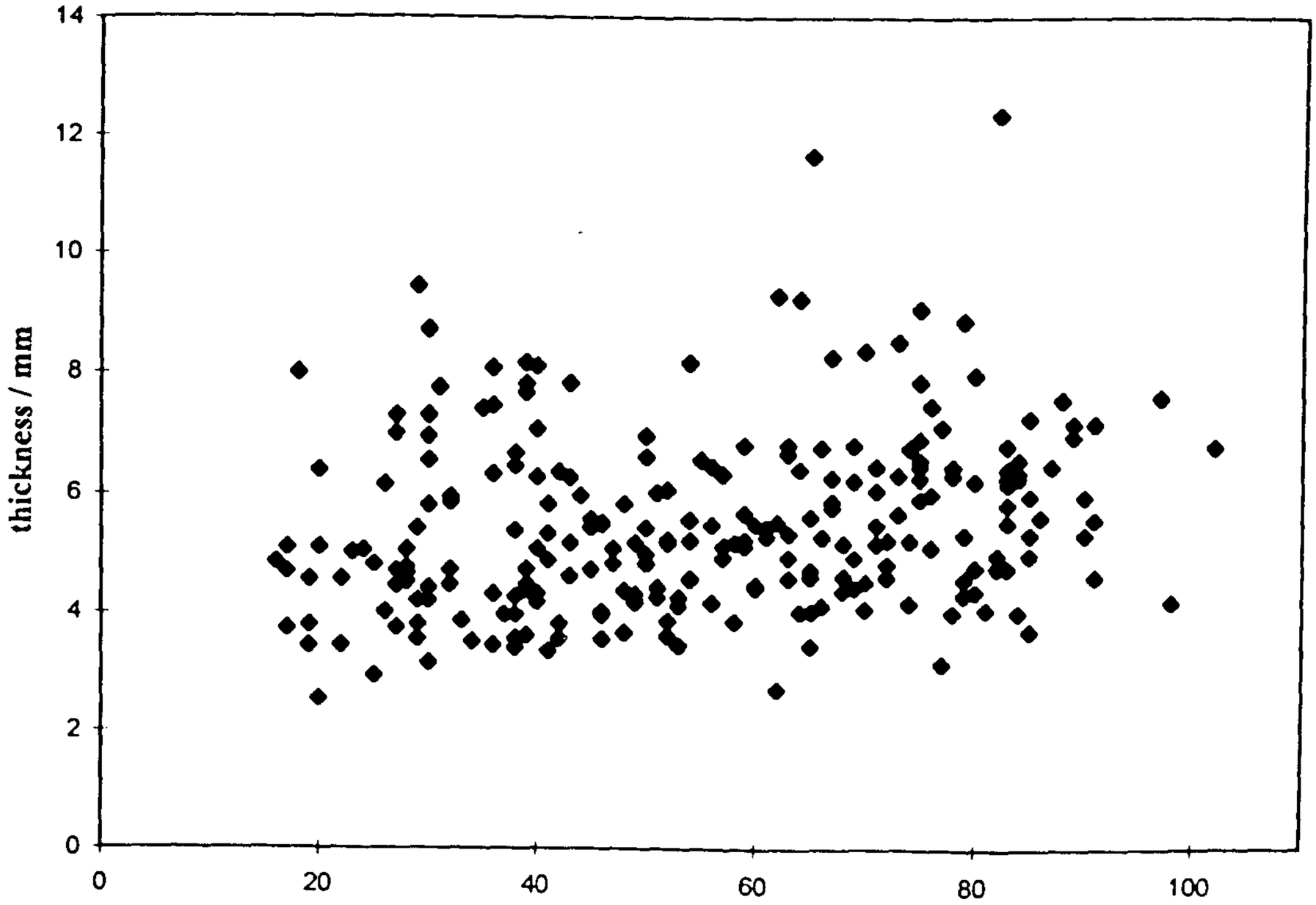


Figure 4.6 Plot of mean mid-parietal thickness against age - all sample

All individuals

The highest correlation between age and skull thickness occurred when the sample was looked at as a whole. Both the right and left sides, and the mean all gave a high degree of positive correlation with increasing age.

Discussion

The regression calculation marked four skeletons from the Terry collection as having either unusually high or low skull thickness for their real age. These individuals were investigated further. Two, a black male and black female (aged 98 and 102 respectively) had unusually thin skulls for their advanced age. The thicknesses recorded (means of 4.8 and 6.8mm) from these skulls are by no means as thin as the cases suggested in the literature (Sandifort, 1783; Greig, 1926; Wilson 1944). In view of this it was decided that these skulls were not pathologically thin, and so it was decided not to investigate these individuals further (e.g. by using x-rays, which would be the appropriate procedure to diagnose the pathology correctly). It is interesting, but anecdotal, to note that these were two of the few skulls which had been aged by all the other methods as being biologically "young" for their chronological age. This apparent phenomenon, which is also outlined in chapter 1, has implications which are discussed further in the final chapter of this thesis.

In addition two individuals, both white males had unusually thick skulls for their age. When the notes taken during examination were checked it was found that both of these individuals had pathological skulls. The first, an eighteen year old, had plaques of periosteal new bone, with pitting and marked hypervascularity of the endocranial surface of both parietals (see chapter 7 for a description of what constitutes unusual vascularity in the skull). The cause of death given from the post-mortem was broncho-pneumonia (this is common cause of death attributed to 13% of the Terry sample - 33 cases). This degree of periosteal change was also seen in 48 out of the 261 skulls in the whole sample (see chapter 7), but as none of the other similar cases identified showed marked skull thickening this may indicate that this unusual result in such a young individual may not have been directly caused by the pathological changes observed. The person was unlikely, given his age, to have been affected by Pagets disease, so this was also discounted from differential diagnoses.

The second case was of a male aged twenty-nine years who had also died of broncho-pneumonia. On visual inspection of the parietals there was evidence for some substantial skull trauma affecting both parietals. A large hole with smooth healing edges was present along the left parietal, with evidence for a possible fracture extending across the right parietal. The outer surface of the table had been extensively re-modeled with new bone growth. The diploë on both parietals also appeared to be enlarged. There was no evidence of infection. Healing trauma causes new bone growth and so it is not surprising that this skull had thicker parietals than normal. Three other skulls from the Terry sample showed evidence of skull trauma but none of these had unusually thick bones. This may be due to the fact that none of the other trauma cases had the endocranial table of the parietals affected.

It was then decided to look at the sub-samples of the group (by age and race) separately, to see if there was any marked differences between them. Tables 4.5 to 4.8 are the results of the correlations.

Black males only

Parameter	Coef	St Dev	t-ratio	p<
intercept	22.806	8.753	2.61	0.011
mean thickness/mm	5.274	1.676	3.15	0.002

R-sq (adj) = 11.6%

Regression equation is age = 22.8 + 5.27 (mean thickness/mm)

Table 4.5 Results of the correlation between skull thickness and age - black males

Black females only

Parameter	Coef	St Dev	t-ratio	p<
intercept	25.693	9.202	2.79	0.007
mean thickness/mm	5.113	1.447	3.46	0.001

R-sq (adj) = 12.9%

Regression equation is age = 25.7 + 5.11 (mean thickness)

Table 4.6 Results of the correlation between skull thickness and age - black females

White males only

Parameter	Coef	St Dev	t-ratio	p<
intercept	69.797	9.147	7.63	0.0001
mean thickness/mm	-2.968	1.723	-1.72	0.09

R-sq (adj) = 3.2%

No significant correlation

Table 4.7 Results of the correlation between skull thickness and age - white males

White females only

Parameter	Coef	St Dev	t-ratio	p<
intercept	59.35	13.19	4.5	0.0001
mean thickness/mm	0.38	2.239	0.17	0.866

R-sq (adj) = 0%

No significant correlation

Table 4.8 Results of the correlation between skull thickness and age - white females

There is a strong correlation between age at death and skull thickness in both the black males and females. It appears that there is a slightly stronger relationship for females than males. There is, however, no correlation at all between age at death and skull thickness in either white males or females. These results provide an interesting race variation and similar to some of the results produced by Adeloye et al. (1975). Work by Trotter et al. (1960) suggested that racial factors might influence bone weight and bone thickness but later work (Trotter and Peterson, 1962) found no difference between ash weight of the skull in blacks and whites. One explanation for racial variation suggests that different muscle sizes can cause different skull thicknesses (Washburn 1947). This is supported by further work on the difference in muscle insertions (entheses) which has also shown race differences (Rogers, pers. comm.). Diseases such as malaria or sickle cell disease which can cause diploic expansion have also been implicated in skull thickening (Adeloye et al. 1975). Sickle cell disease is especially common in black Africans (Wyngaarden and Smith, 1985) but no cases of this were present in the Terry sample.

Another reason for the positive correlation is that HFI (mentioned earlier, but see chapter 5 for details) which increases in prevalence with age and causes increased

thickness in the skull, may be causing this apparent relationship. It may also be clouding the results of the white male and female samples.

2b Does the degree of HFI affect the mid-parietal skull thickness?

In order to see if the presence of HFI affects skull thickness the black and white females affected were plotted against those who did not have the condition. The criteria for HFI used in this study are outlined in chapter 5, and only those of grade 2 or above were counted as having HFI. The mean skull thickness was plotted against age for black and white females both with HFI and those without (termed "normal" for this study). The mean skull thickness was also correlated against age for the whole sample, and also each sub-group. Figure 4.7 and Table 4.9 below show the results of this analysis.

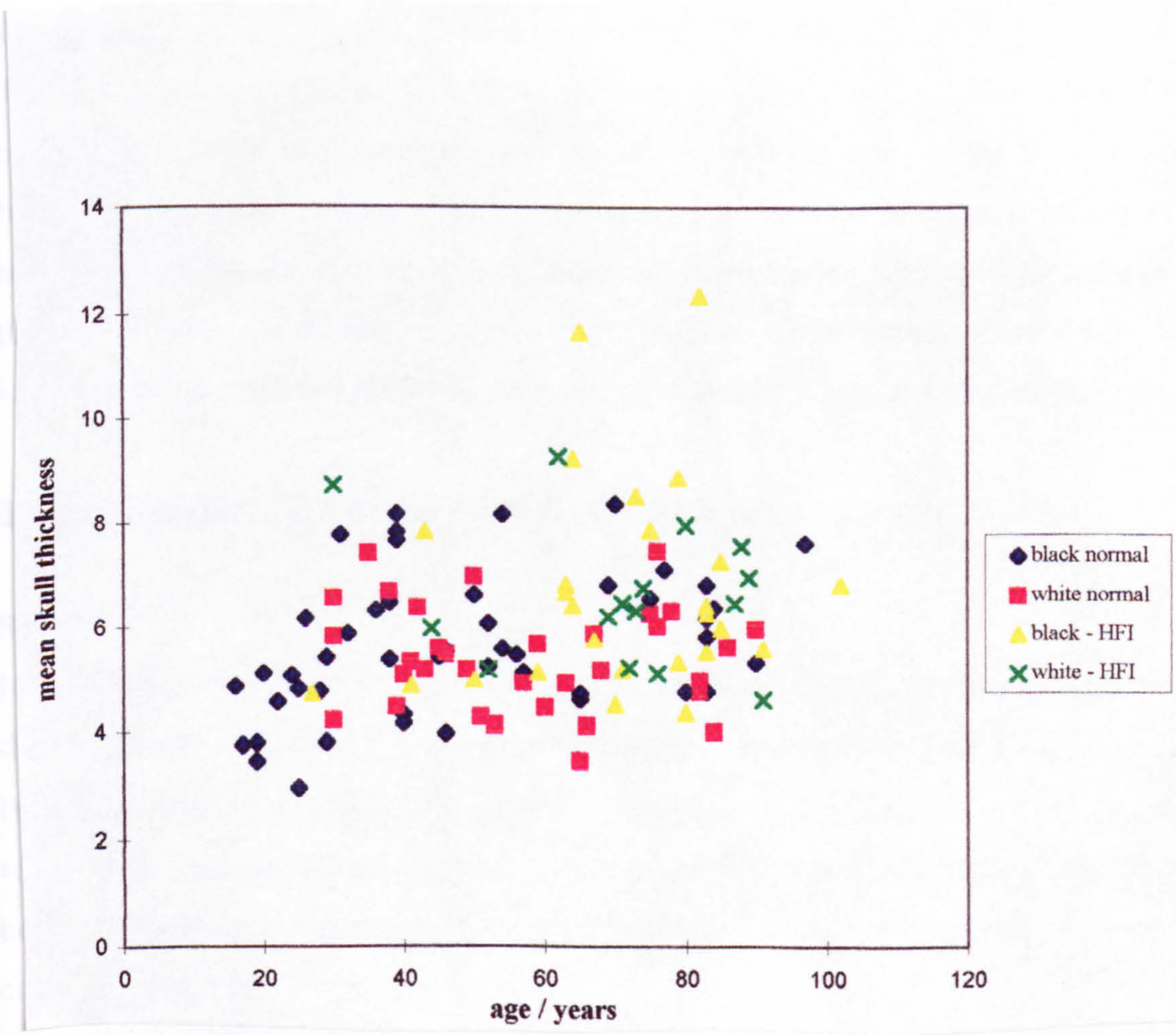


Figure 4.7 Plot of mean skull thickness in normal black and white women compared to those with HFI.

Sample	n=	mean age	min age	max age	p value	R-sq
all	122	58.5	16	102	0.003	6.2%
white - HFI	15	70.5	30	91	0.374	ns
white - normal	33	57.5	30	90	0.635	ns
black - HFI	27	70	27	102	0.418	ns
black - normal	47	48.5	16	97	0.009	12.4%

ns = not significant at 5% level

Table 4.9 Summary of correlation calculations between normal black and white females and those with HFI.

Discussion

The results of this analysis provide some very interesting results. There is still no correlation between skull thickness and age in the white sample. In the black sample however, one would perhaps expect there to be a correlation between a greater HFI score and age, but the opposite is true. There is no correlation between HFI and age in the black females either, which is perhaps not what one would expect, given that HFI is known to cause increased skull thickness, and increases with age (see chapter 5).

3. Determination of the level of normal skull thickness

Sample

Ninety-five of the skulls from Barton-on-Humber were chosen for this study. Those discarded were individuals for whom a mid-parietal measurement could not be taken on both sides because of either missing bone or abrasion of the bone surface which made recording impossible. Barton was chosen as the best site to look at pathologically related bone thickness as it was the only sample from which X-rays and histological samples could be obtained.

Methodology

Left and right mid-parietal thickness was measured directly from the skull using the method outlined in study 2 of this chapter. The left and right skull thickness were plotted for each individual to see if there is any asymmetry. A histogram of the frequency of the

numbers of individuals with mean skull thickness between 4.0mm and 18.5 (minimum and maximum measurements recorded in the study) were plotted. From the graphs a maximum level of normality was calculated using 2 standard deviations. All individuals beyond this measurement were studied further using X-rays and histological techniques to determine what, if any pathology was present.

Reproducibility

A series of 5 skulls were randomly chosen and re-measured at the end of the study. Intra-class correlation coefficients were calculated for both sides. This was 0.58 for the right and 0.56 for the left sides indicating fair within observer reproducibility.

Results

Asymmetry

Figure 4.8 below is a plot of the left and right thickness of each skull. The mean difference between the left and right sides of the skull was -0.127, with a standard error of the mean (S.E.) of 0.11. These results shows that there is no real difference in the left and right sides in this sample. In view of this, for the further analysis the mean of the two sides was taken.

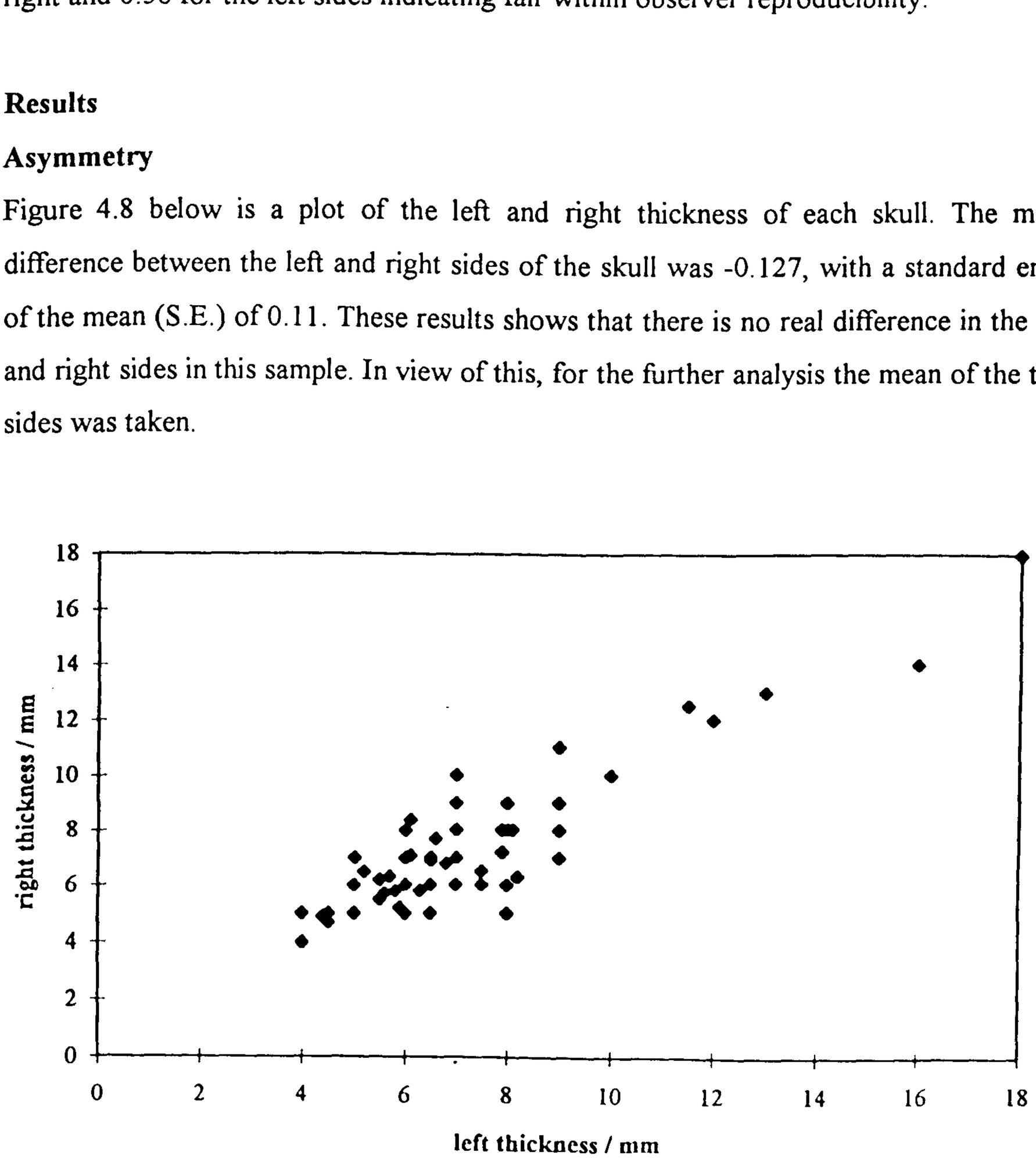


Figure 4.8 Left mid-parietal thickness against right - Barton-on-Humber

Normal Skull thickness

The Figure 4.9 below shows a histogram of numbers of individuals in each category of mean (left and right) skull thickness.

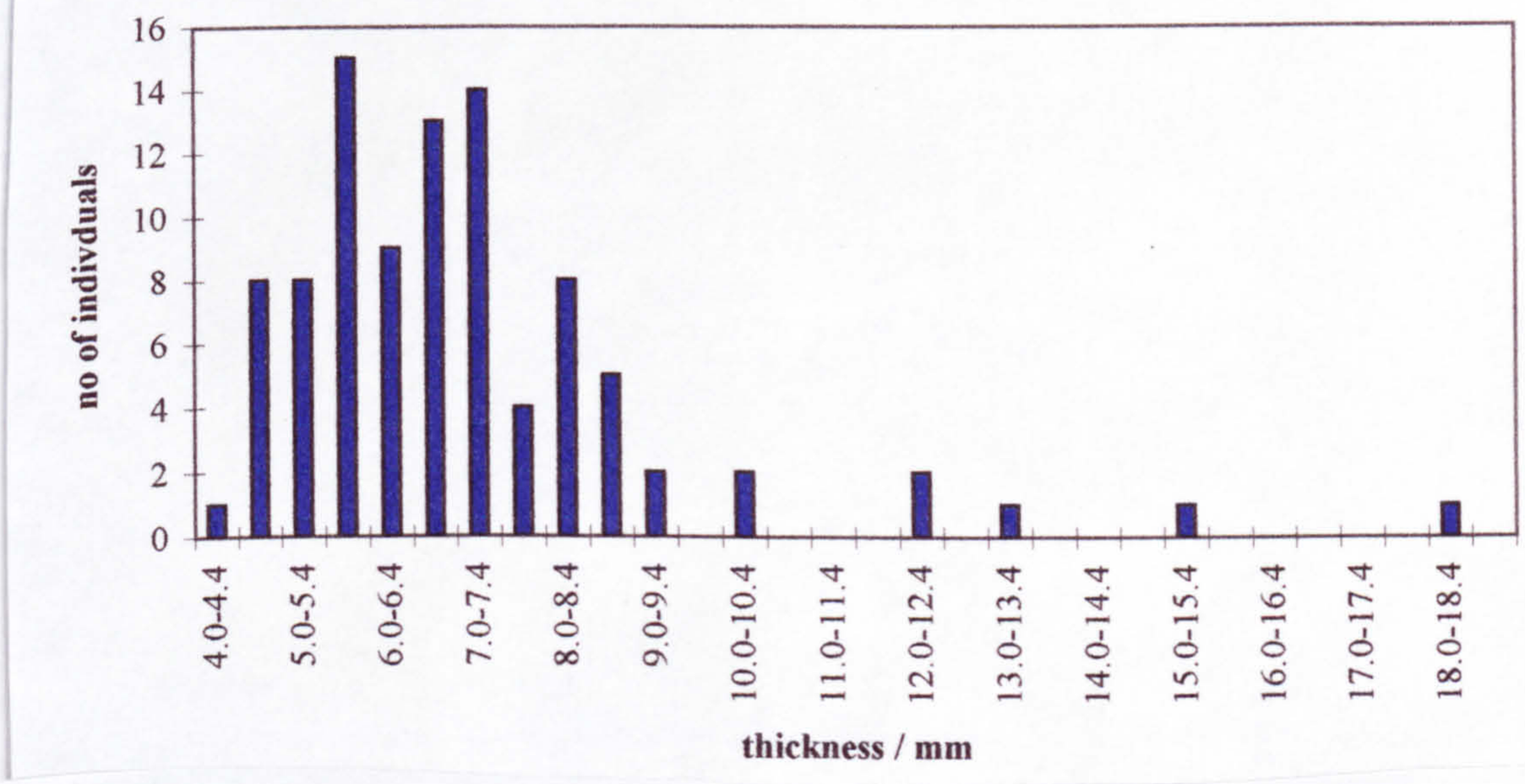


Figure 4.9 Histogram of frequencies of mean skull thickness

The results show that the most common skull measurement is between 5.5 and 6.0 mm, but normal skull thickness can vary between 4 and 10mm. It can be seen from the graph that there are five outliers beyond two standard deviations, all of which are thicker than normal. Each one is discussed separately.

Sk 742 male aged 19-22 years

The thickness of this skull averaged 12mm in the mid parietal. There were no other abnormalities in the skull except for a slight increase in the vascular markings of both left and right parietals (see chapter 7). The skull appeared normal on x-ray. There was no evidence for any post-cranial skeletal abnormality.

Sk 2730 male aged 35-45 years

As above this skull averaged a 12mm thick mid-parietal measurement. There were no other abnormalities except, again a slight increase in the vascular markings on the endocranial surface of the parietals, and a slightly mottled appearance of the diploë.

There was no evidence for any other cranial or post-cranial abnormality. The skull appeared normal on x-ray (see figure 4.10 below).

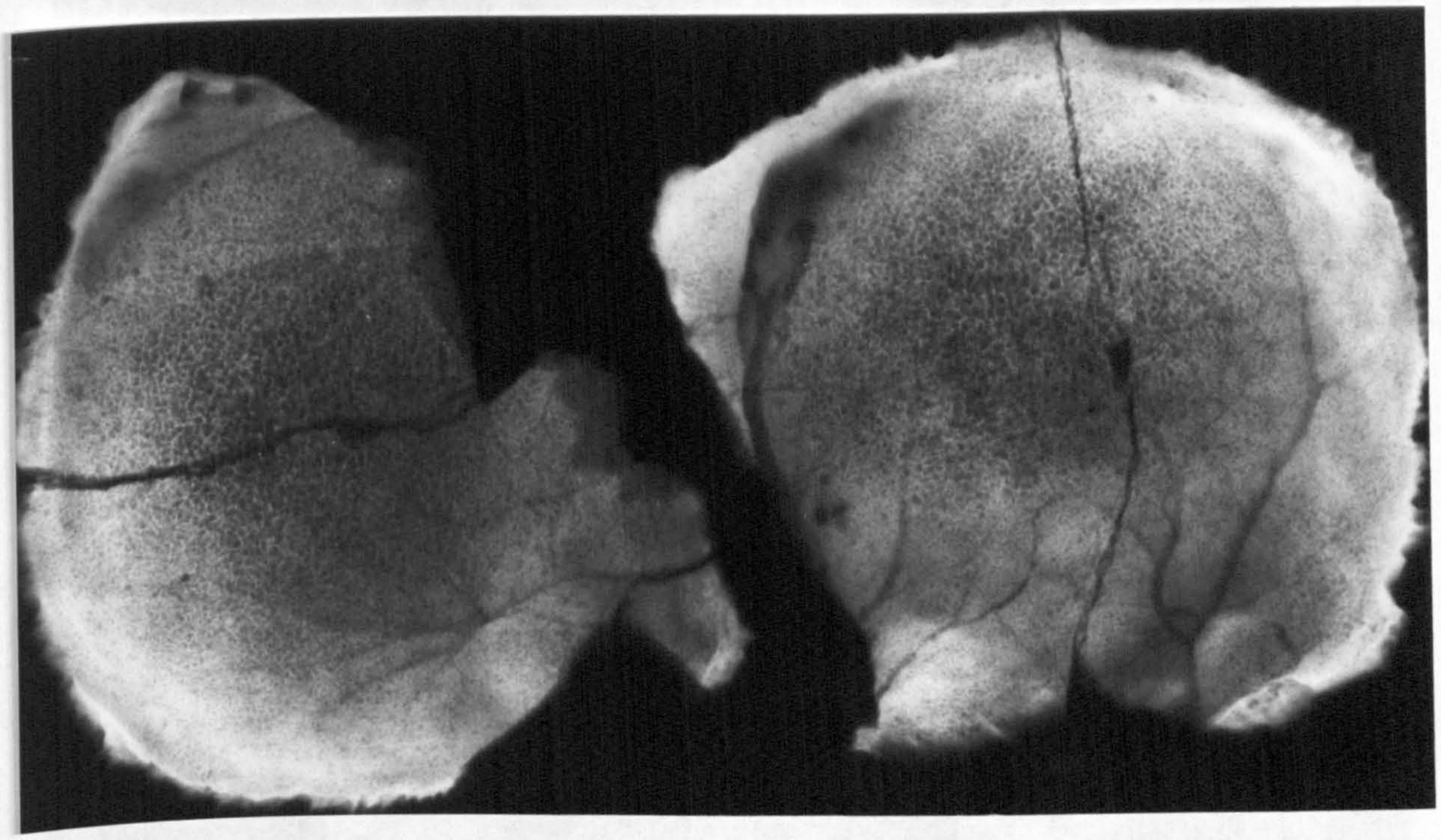


Figure 4.10 x-ray appearance of sk 2730

Sk 862 female aged 45+

The skull of this individual was 13mm thick. The cranial and post cranial bones all appeared normal except for grade 1 (slight) hyperostosis frontalis interna (see chapter 5 for a detailed explanation of the grading system used). Apart from the HFI, no change was seen on the x-ray.

Sk 1299 male aged 45+ years

This skull had a mean thickness of 15mm. On x-ray the skull was noted as being abnormally thick. No other abnormality was noted. There was no evidence for any post-cranial skeletal abnormality.

Sk 547 female aged 35-45 years

The endocranial surface of this skull had moderate HFI which had begun to spread into the parietal area, which may account for the skull thickness of 18mm. On X-ray a grade 2 HFI score (see chapter 5) was given (see figure 4.11 below). On a lateral X-ray some

abnormality of the sella could be seen (unusually large volume). No other cranial or post-cranial abnormality could be seen.

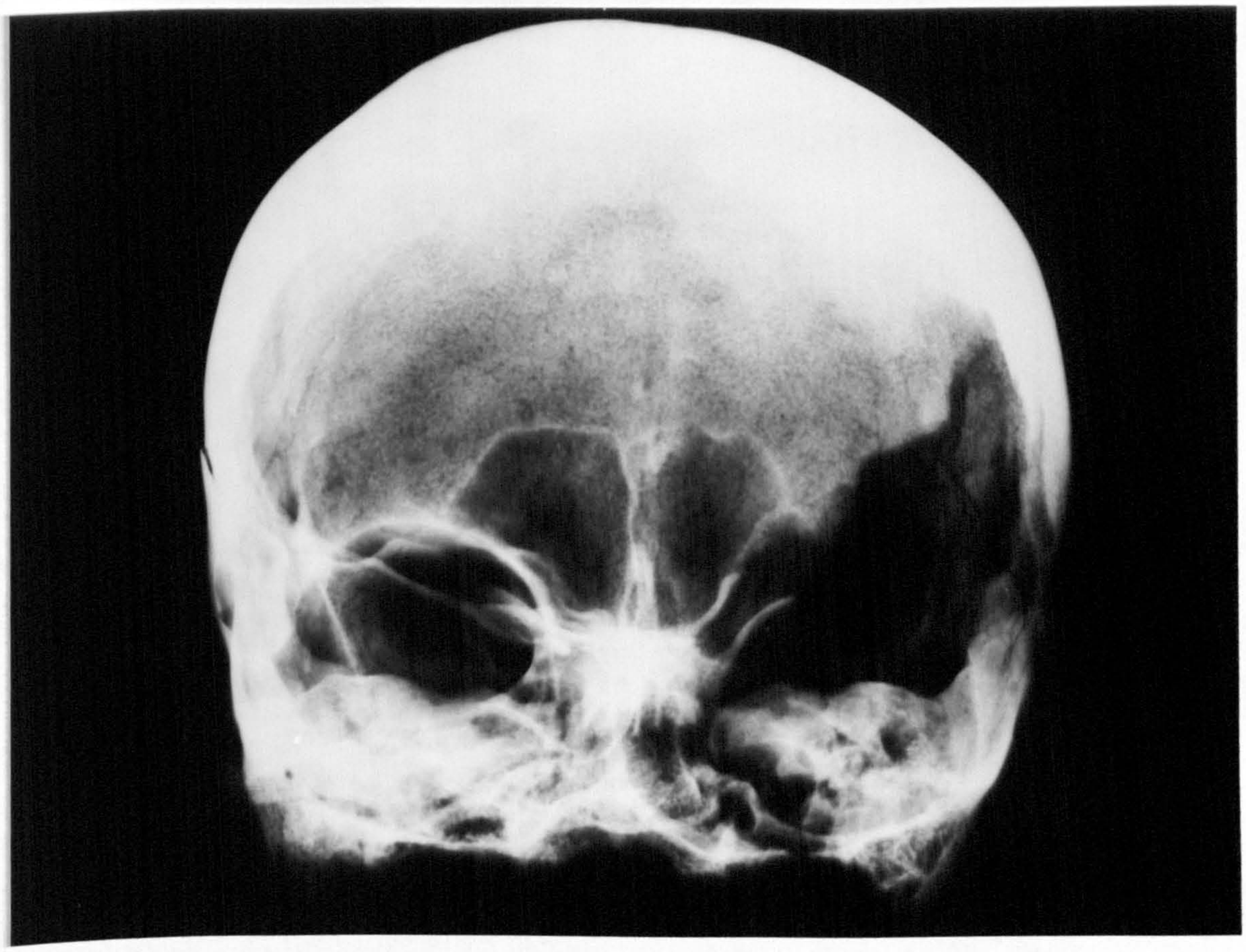


Figure 4.11 X-ray appearance of sk 547

General Discussion and Conclusions

These three studies provide some useful data, although they produce more questions than they answer. The results of the first study, the comparison of X-ray and direct skull measurements produced disappointing results, but a better designed study using a larger sample of more uniform (complete) skulls may produce more accurate calibrations.

The second study produced some very interesting results. Tests of asymmetry have produced an abnormal case, although more information is needed to come to a firmer conclusion. There appears to be a good correlation between skull mid-parietal thickness and age in only the black samples studied. The results do not appear to have been biased by the presence of HFI or any other pathology.

The third study has provided some level of normative data which could be used by other workers to determine if a skull is abnormally thick. The absence of any abnormally thin skull in any of the samples means that no comment could be made on the phenomena,

other than these results appear to support the belief that it is a very rare occurrence in both past and modern populations.

From this work it can be seen that although there appears to be a relationship between age and skull thickness, (in the black samples at least) it is not strong enough to be used with any accuracy as the basis of a new ageing technique.

Further work

These investigations have shown the potential for further work. An X-ray study of the skulls in the Terry collection would provide useful information and could help to explain some of the unanswered questions left in this study (such as the diagnosis of the asymmetrical skull in study 2 and the overall prevalence of Pagets and other causes of skull thickening in the Terry sample).

This study has not been able to look in any detail at which part of the table of the skull is changing. Garn et al. (1967) and Israel (1968) suggest that the bone change is due to continuing periosteal apposition over endosteal resorption. Epstein (1953) believed that parietal thinning could be caused by osteoporosis. Further work on this subject should include a chance to take a large number of histological sections. These would be useful to determine what normal variations of the skull table look like and also whether it is the whole table or just the diploë that changes.

These studies have not investigated the mechanism by which skulls thicken with age. Although there are many theories (including those by Todd, 1924 and Wiedriech, 1941) as discussed in the introduction to this chapter the reason for changes in the skull are still unknown. Recent studies by Rogers et al (1997) suggesting that some people can form new bone more easily than others (see chapter 3) could be tested using skull thickness. It could be hypothesised that an increased bone forming capacity (which may be caused in part at least by a genetic predisposition) will result in thicker skulls. If this argument is true, this may go some way to explaining the racial differences uncovered by the studies in this chapter.

Chapter 5. Hyperostosis Frontalis Interna

Introduction

HFI is a common x-ray finding in modern clinical practice, appearing visually on a plain x-ray as billowing symmetrical new bone on the inner table of the frontal (and occasionally the parietal) bone (see figure 5.1). The remodelling process involves all three layers of the skull vault (Dihlmann, 1981) often with diploic thickening and either or both tables thinning (Resnick and Niwayama, 1988) and can be distinguished from other disorders of skull thickening such as Pagets by x-ray (Pagetic changes in the skull also affect the basicranium - see chapter 4 for a fuller description of Pagets disease). It can also be identified on a bone scan by the typical "bulls eye"(McGinty and Charron 1992) or "bony bullets" (Dihlmann, 1981) appearance.

It was first described by Morgagni in 1779, who noticed that the thickening of the frontal bone was often accompanied by two other changes of obesity and virilism in women. Indeed, HFI is much more common in females than males, with an estimated male : female ratio of 1:9 (Salmi et al 1962). It has a strong positive correlation with age and has a peak incidence in modern patients in the 40 - 60 year age group (Eldridge and Holm 1940; Salmi et al, 1962).

This phenomenon can vary in prevalence between populations, with figures of anything from 22 to over 60% (Gershon-Cohen et al., 1953) of the population being affected (see table 5.1). There has been much research into the frequency of HFI in white European populations, and those of European extraction (such as white Americans and Canadians), but few studies have directly compared the prevalence between different races.

Modern Prevalence		**Archaeological Prevalence**	
Home for the Aged, U.S. (Gershon-Cohen et al.,1953)	62%	St Andrew Fishergate, York (Stroud, 1993)	1%
Elderly U.S. citizens. (Henschen et al., 1949)	40%	Poundbury, England (Molleson, 1993)	4%
Normal citizens aged 15-70+ years, Finland (Salmi et al, 1962)	22%	Pompeii, Italy (Lazer, 1994)	10%

Table 5.1 Comparison of Modern and Archaeological Prevalences of HFI

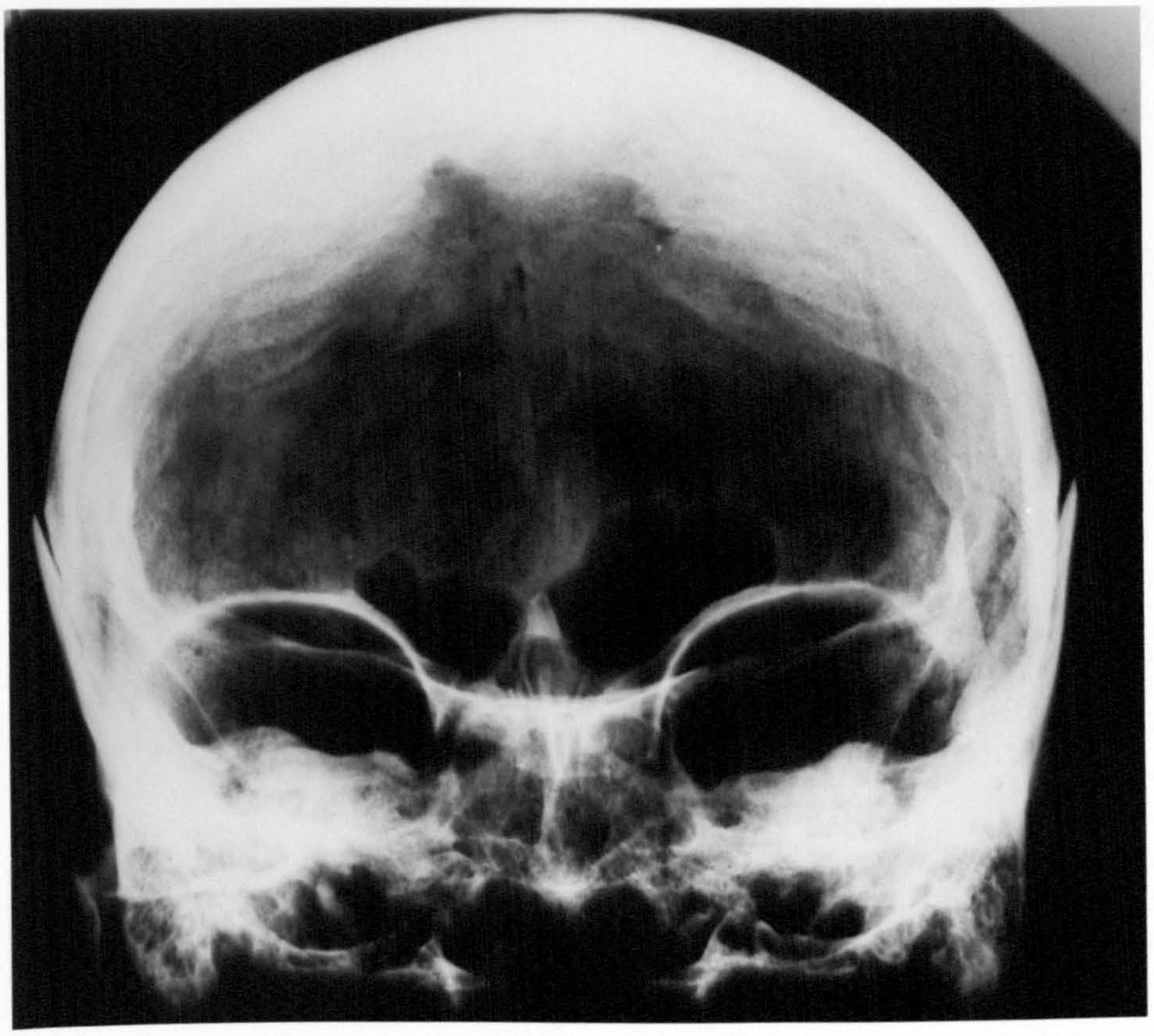


Figure 5.1 Typical appearance of hyperostosis frontalis interna (HFI) in a modern x-ray

The etiology of HFI

The exact etiology of HFI is unknown, but it is thought to be associated with an hormonal imbalance. In 1844 Ducrest, and later Dreyfuss (1922) showed that intracranial osteophytes could be reversed in pregnant women after birth. Greig (1928) first noticed HFI in acromegalics and suggested it was caused by a calcium disorder, causing excess bone deposition on the frontalis. In the same year Stewart presented five cases of HFI in patients termed "insane" (3 females and 2 males). All were obese adults with histories of dementia and the women were markedly facially hirsute. Moore (1935) also found an association between mental problems and HFI, and later (1955) produced a detailed study on HFI based on skeletal material, patients and normal volunteers. Eldridge and Holm (1940) studied 200 female patients in a mental hospital and found HFI in 25% of women, with a peak incidence in the fifth decade. They found no difference in occurrence between black and white patients, and only 15% of individuals could be classified as obese. Somogyi and Bak (1937) and Scotto (1961) observed that many

patients with HFI also had hyperadrenocorticism (an abnormally active adrenal gland associated with Cushing syndrome) and Henschen (1936, 1944) used the term "Cushingoid state" for 40% of his patients with HFI. In 1949 Henschen then proposed the title of Morgagni's syndrome, (also later known as MSM - Morgagni-Stewart-Morel syndrome), to cover the symptoms of obesity, hirsutism and mental retardation seen in patients with HFI. Further work by Peremans and Goemare (1958) noted the association between HFI and gigantism.

In 1968 Rudali experimentally produced HFI in normal and thymectomised rats in three experiments using **1.** implanted estrogen pellets, **2.** an oral contraceptive of 98.5% norethyndrel and 1.5% mestranol and **3.** gold thioglucose with or without estradiol. He found that all the experiments produced high frequencies (up to 83%) of lesions histologically identical to HFI (as described by Erdheim in 1935 and Calame in 1951). In addition, the third experiment changed the personalities of the normally docile species to aggressive and later epileptic animals. The frequency of HFI also varied between different strains of mice, leading the researchers to support the theory that HFI may be "strongly influenced by genetic factors", as proposed by Jequier (1950) and Dressler (1967).

Ortner and Putschar (1985) mention "pregnancy osteophyte" in their survey of pathological conditions in the human skeleton, as forming a "thin chalky layer of surface parallel periosteal bone" especially on the endocranial surface of frontal bone which they attribute to altered pituitary hormone secretion. Littlejohn et al (1986) looked at the frequency of HFI and DISH (diffuse idiopathic skeletal hyperostosis - a disorder of entheseal new bone formation of unknown etiology) in acromegalics, and found much higher than normal frequencies of both phenomena. They postulate that some sort of metabolic abnormality, possibly hyperinsulinaemia, is the cause of both DISH and HFI. Kollin and Feher (1986) showed that people with asymptomatic HFI had significantly higher bone mineral content than those with normal skulls. They suggest this may be caused by adrenal androgen over-production. The dearth of hirsutism in those individuals with HFI was explained by a lack of free testosterone (as opposed to protein bound testosterone) in the cases studied. Fulton et al (1990) studied 36 acromegalic patients and found a higher percentage of HFI than in their control group (72% compared to 25%). They concluded that the presence of HFI may have symptomatic significance and

should be actively screened for in cases of acromegaly and hyperprolactinaemia (increased levels of prolactin in the blood which may cause amenorrhea in women and hypogonadism in men).

It can be seen from the literature that HFI is a complex phenomenon of metabolic disturbance, with both oestrogens and androgens being variously implicated. Although past work showed much evidence that HFI was sometimes associated with Morgagni's syndrome and other hormonal disorders, these studies were based on mainly on hospital populations, and not on a normal healthy sample. When normal populations were studied it soon became apparent that HFI was very common indeed, with figures of between 2 (Scotto, 1961) and 22% (Salmi et al. 1962) of cases observed in healthy postmenopausal women, and that most cases of HFI were asymptomatic (Moore 1935, Salmi et al 1962, Resnick and Nimayama 1988, Prescher and Adler 1993).

The Classification of HFI

There have been several attempts to classify HFI into different types, as it can be seen from the literature that HFI can be both associated with a range of symptoms, or be completely asymptomatic. Moore (1935) was the first to attempt a classification based on x-ray appearance, and identified four types: a) nebula frontalis b) hyperostosis frontalis interna c) hyperostosis fronto-parietalis and d) hyperostosis calvariae diffusa. These concentrated on the site of the new bone as well as the shape of the bone formation. Dihlmann (1981) used computed tomography of patients with HFI to clarify some of these criteria. This classification did not attempt to grade the degree of new bone formation, and so in 1986 Littlejohn and co-workers looking at the association between DISH and HFI devised a scale of 0 to 3 for use on x-rays:

0 - no new bone formation

1 - early endosteal new bone on the inner table

2 - more advanced endosteal bone with a bosselated appearance

3 - severe change with much irregularity and increased thickness

Historical Evidence for HFI

In archaeological material the prevalence of HFI appears to be much rarer (see table 5.1). Cases are diagnosed by direct visual observation, and there are no standard diagnostic criteria. Those site reports which mention cases of HFI usually have a few individuals

affected, and give prevalences of between 1-4% of the population. Both Moore (1955) and Henschen (1949) looked for HFI in ancient populations. Moore could not find any cases in the 162 Ohio mound builders, but discusses a dubious case in a Neanderthal cast. Henschen wrote a case report on a skull from an older female from a 10th century Viking ship burial in Oseberg. The difference between ancient and modern population is striking, and has been commented upon by several researchers (Armelagos and Chrisman, 1988 and Anderson, 1994). Armelagos and Chrisman (1988) suggests "this high frequency in contemporary populations may reflect an increase in longevity". Others agree with this logical argument, but some go much further. Lazer is quoted by Dayton in the New Scientist (September 1994) as interpreting the slightly higher prevalence of 10% for the population of Pompeii as evidence that " a substantial minority.... were obese, a bit on the hairy side and would have suffered from headaches and a form of diabetes". Clearly this sort of statement (which may of course have been misquoted) has been produced without looking at the vast literature outlined above which shows that most people with HFI suffer from no symptoms at all. Anderson (1994) replied to this article in a letter where he suggests that the "paucity of archaeological cases is rather surprising". He attributes this again to a lower life expectancy in the past, but he also points to the fact that outwardly normal crania may not be subject to x-ray examination. A recent study by Phillips (1996) of skeletons from a 19th century American hospital population from Oneida County produced prevalences (35% males and over 50% of females) closer to those of modern samples, but he attributes this high rate to the population studied having a higher proportion of MSM sufferers, the hospital in question having functioned partly as an asylum.

It would seem therefore that there is a difference between the prevalence of HFI in past populations to modern ones. However as no standard method is used, nor one which has been compared to the radiological criteria currently in use, it may be that some percentage of the difference may be accounted for in this way. It was proposed therefore to undertake a study to score an archaeological sample of crania for HFI using exact radiological grading, and to compare the prevalence with that of modern populations. In addition the direct visual appearance of the endocranial surface of the graded frontal bones was used to provide a standard for palaeopathological use. This new methodology could then be applied to samples from past centuries to see if there is any change in the frequency of HFI over time.

Aims

1. To devise a new visual diagnostic methodology using standard x-ray criteria currently in use based on the Barton sample.

2. To apply this new method to the samples from the modern post-mortem sample, the Terry collection, Spitalfields and Barton-on-Humber to see if there are any changes in the prevalence of HFI in:

a) temporal spread

b) geographically / racially differing populations

1. Comparison of x-ray and visual grades of HFI

The Sample

To devise the new methodology a random sample of 87 complete adult skulls from St. Peter's church, Barton-on-Humber were chosen for this study, consisting of 37 males, 43 females and 7 of unknown sex (shown hereafter as ?). The dates of the individuals ranged from the 12th to the 18th centuries. All the skeletons were aged using standard anthropological methods (as outlined in chapter 3), the mean ages being 40 years for males and 35 years for females respectively (see figure 5.2)

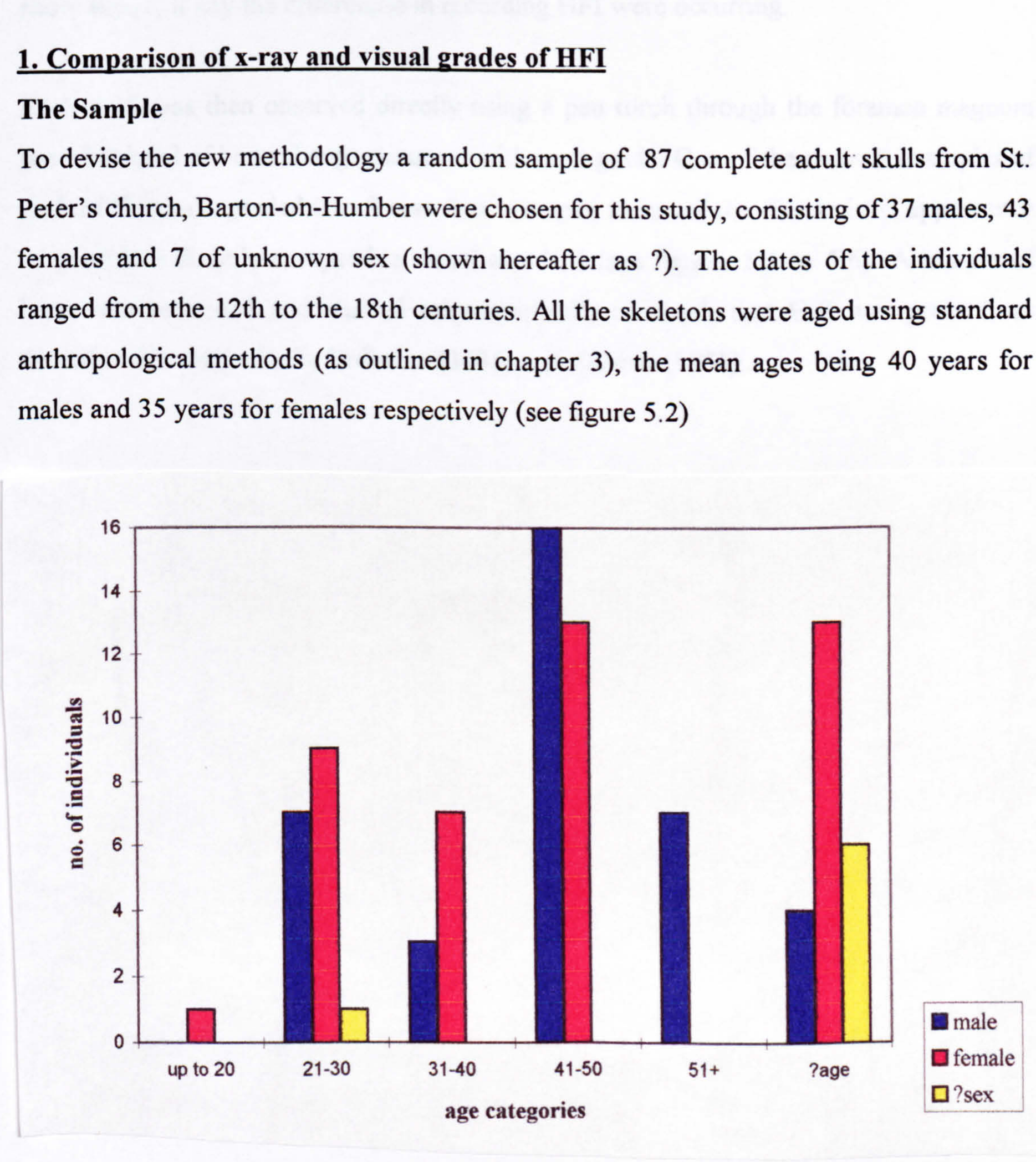


Figure 5.2 Demographic profile of the Barton-on-Humber sample

Methods

Each skull was radiographed using standard anterio-posterio (AP) and lateral x-rays. These were then graded (blind to the age and sex of each individual) for the presence of HFI using the radiological criteria of Littlejohn et al. (1986) as outlined above by a radiologist experienced in palaeopathology and "dry" bone radiology. This method was chosen as it is one of the most common methods quoted in other studies of HFI (e.g. Fulton et al 1990). As the study is investigating whether or not palaeopathologists and radiologists are scoring the same changes in the same way, this system was best placed to show where, if any the differences in recording HFI were occurring.

Each skull was then observed directly using a pen torch through the foramen magnum see what level of bone change occurred with each grade. One of the clearest examples of each of the skulls graded 0 to 3 was then cut open to reveal the direct visual appearance to provide a directly comparable visual standard (see figures 5.3 to 5.6). A sample of bone was sectioned and studied microscopically to check that HFI was present, as described histologically by Erdheim (1935) and Calame (1951).

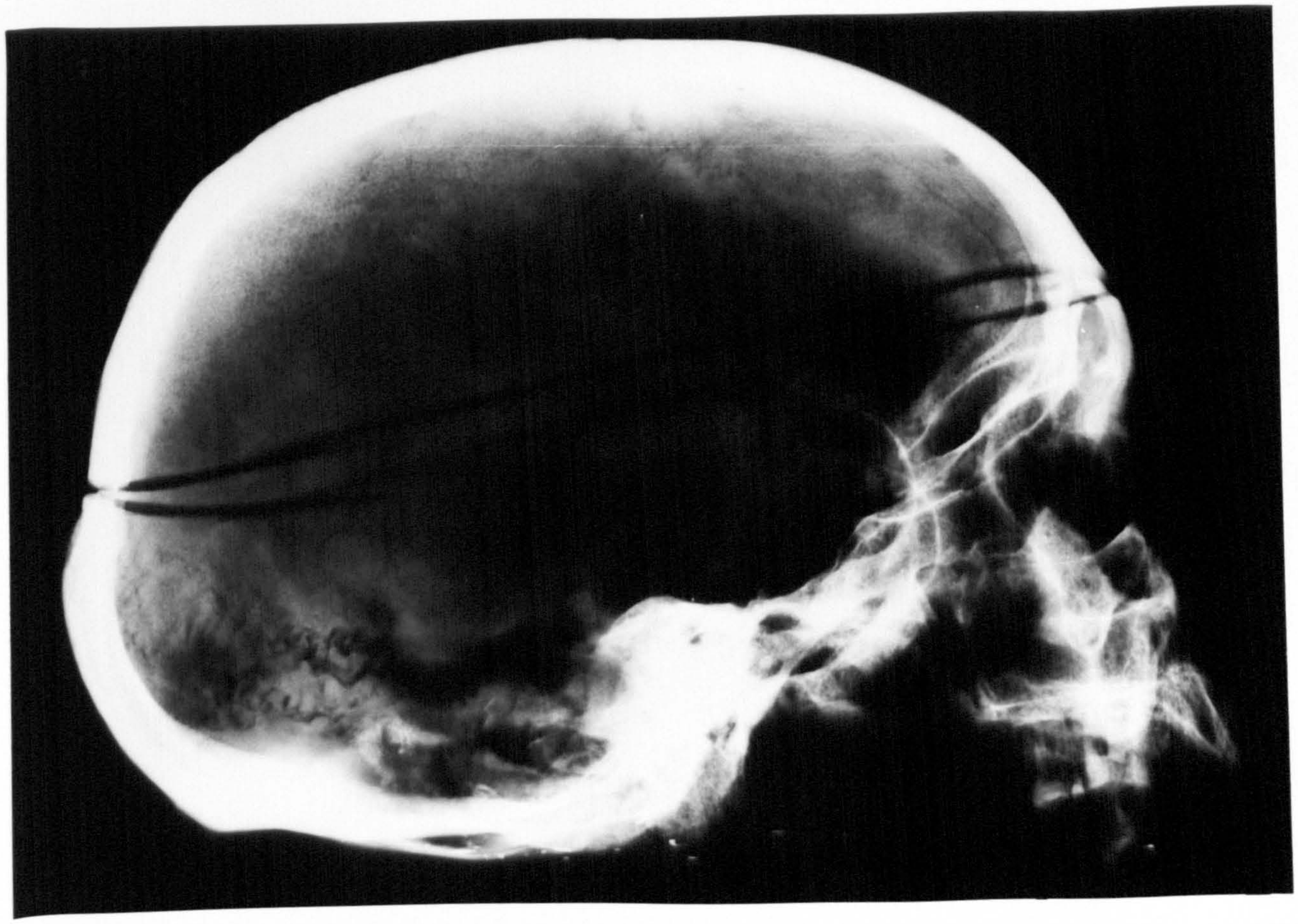
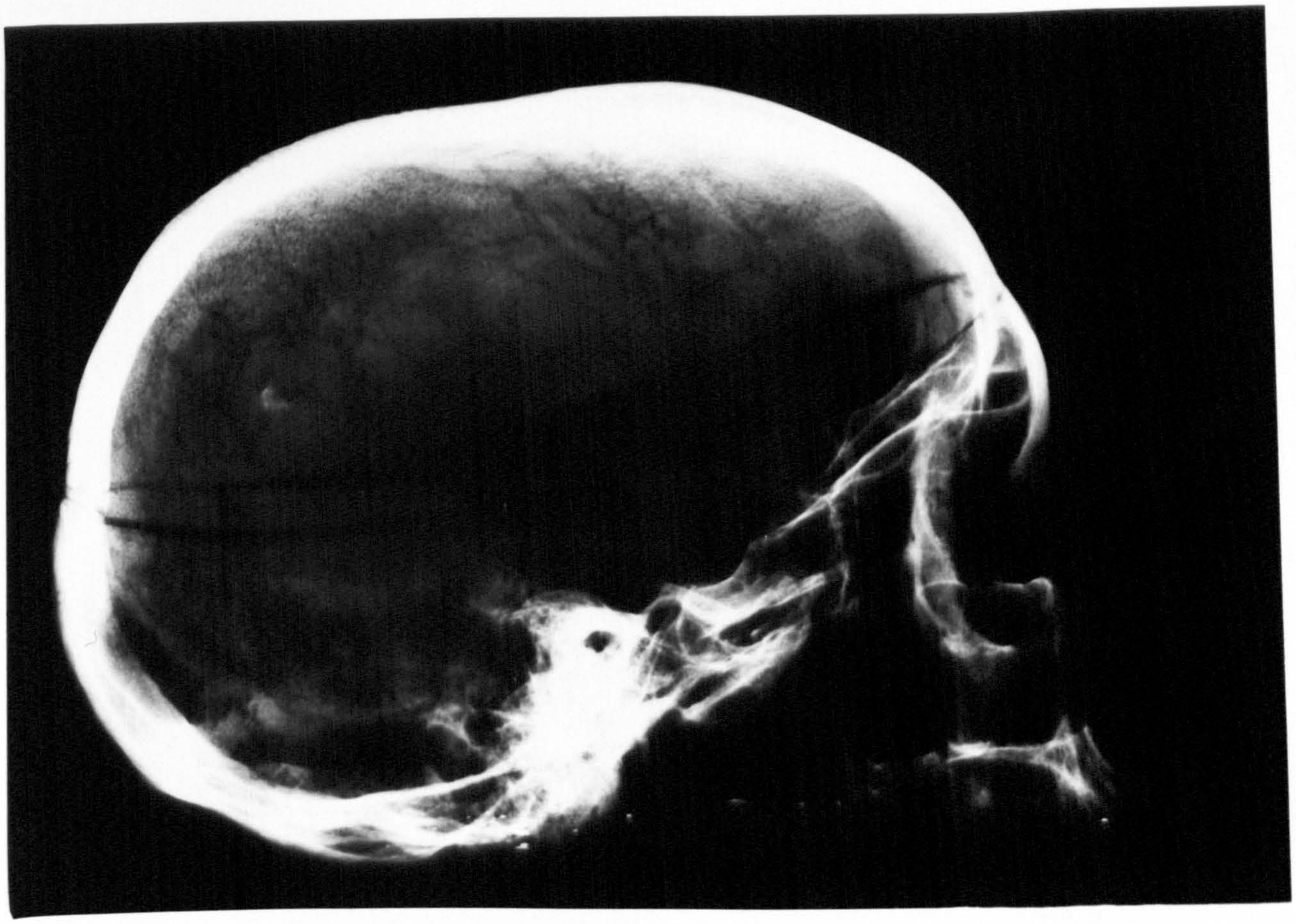


Figure 5.3 X-ray appearance and visual appearance of grade 0 HFI



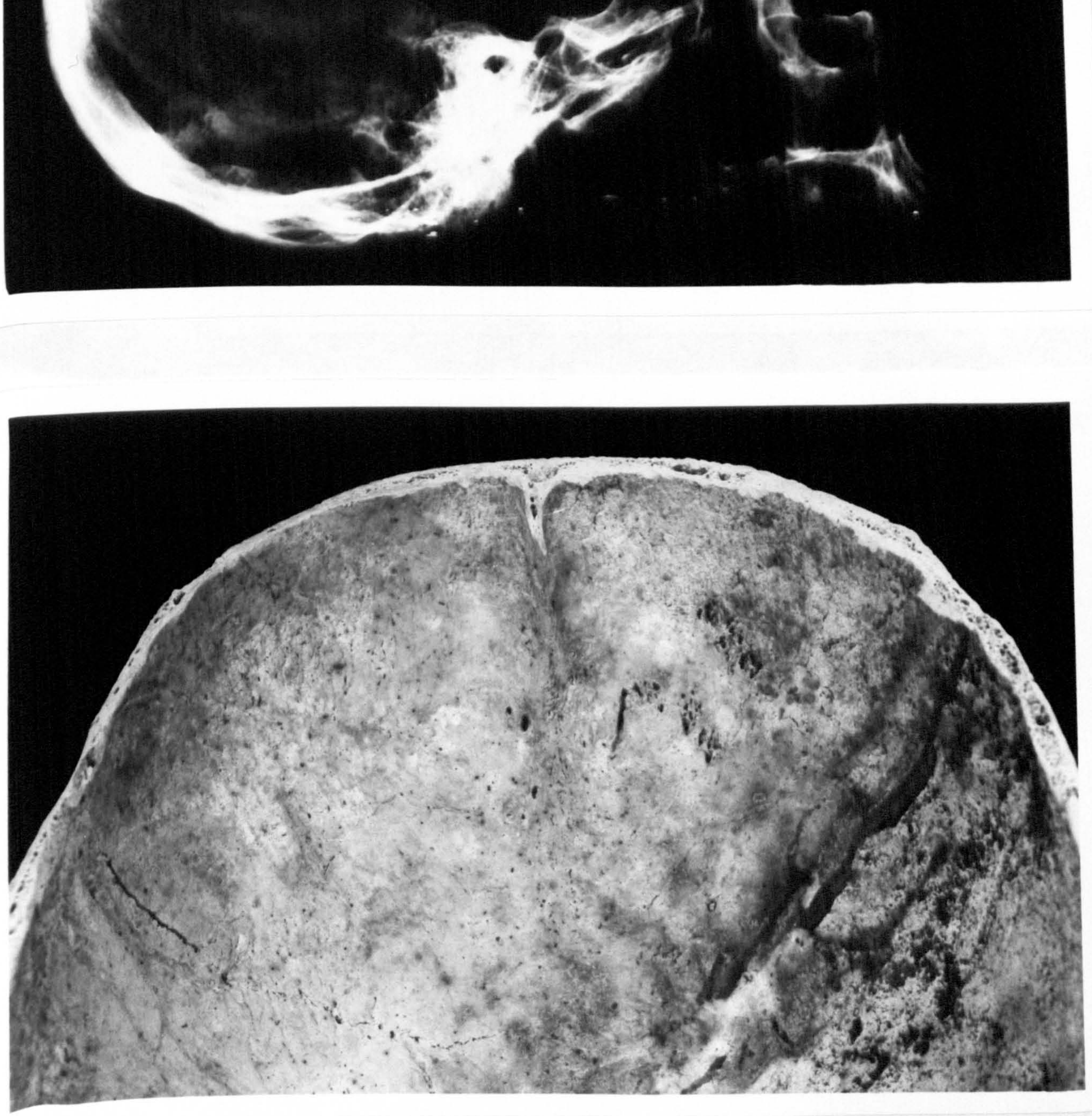
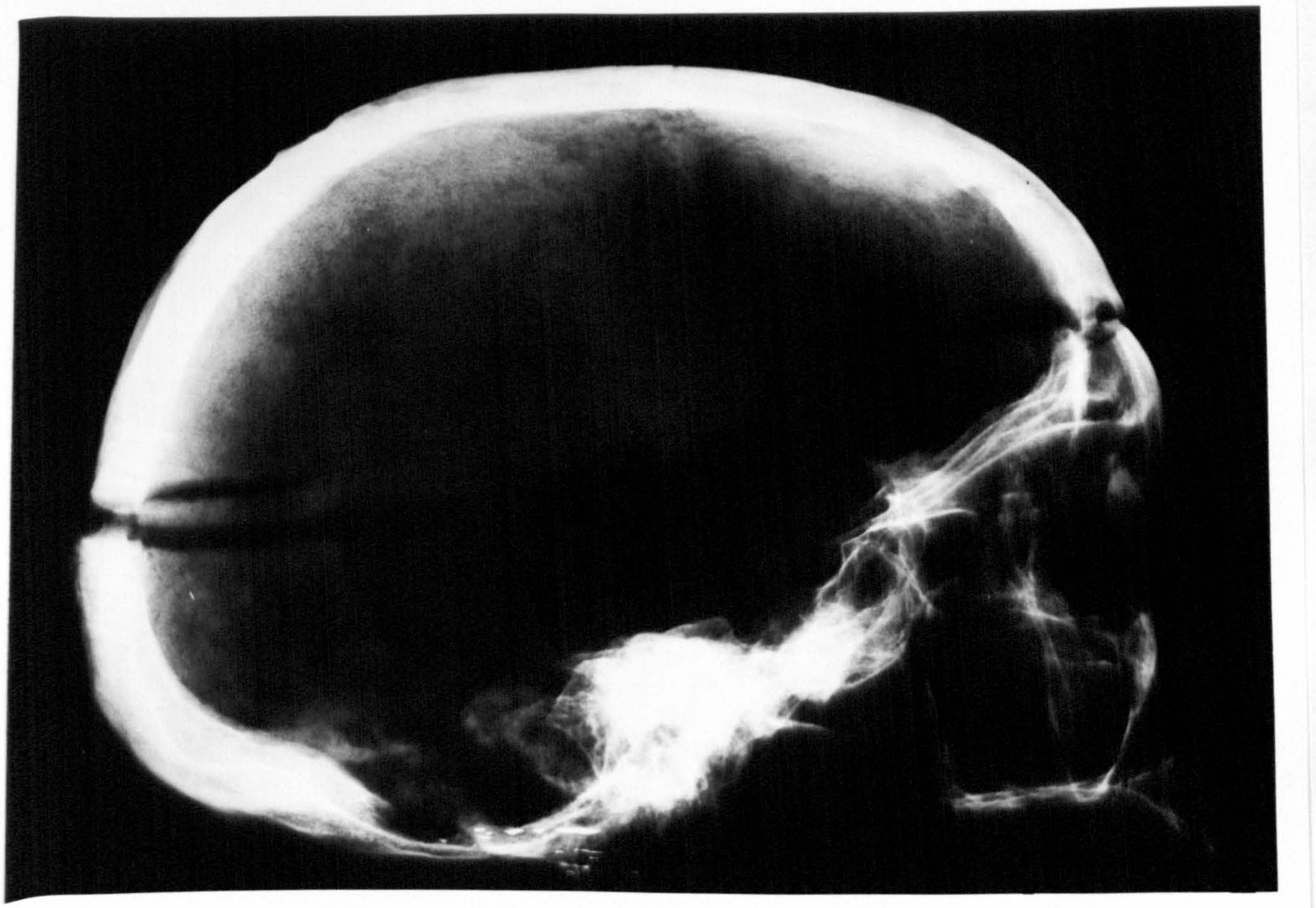


Figure 5.4 X-ray appearance and visual appearance of grade 1 HFI



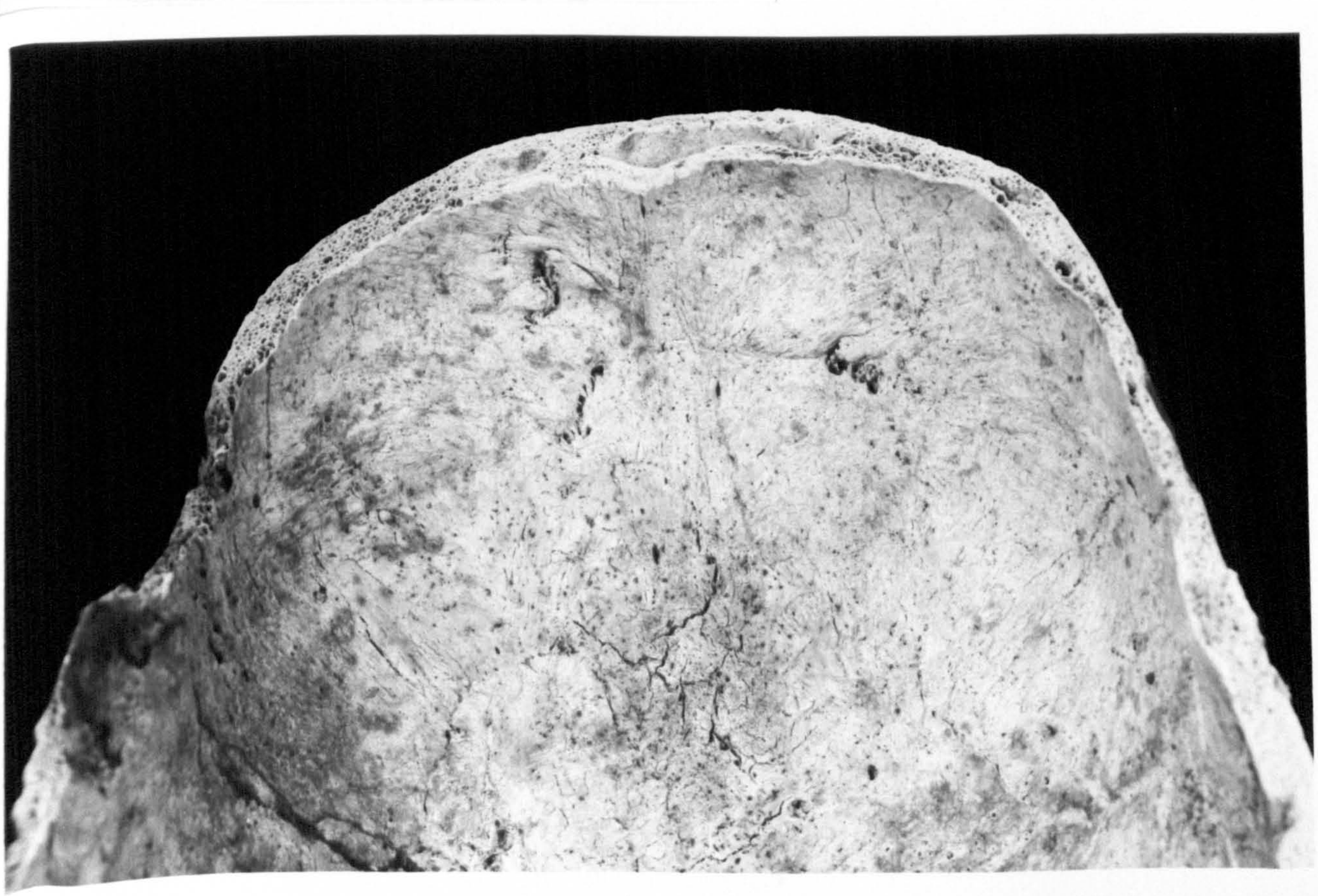
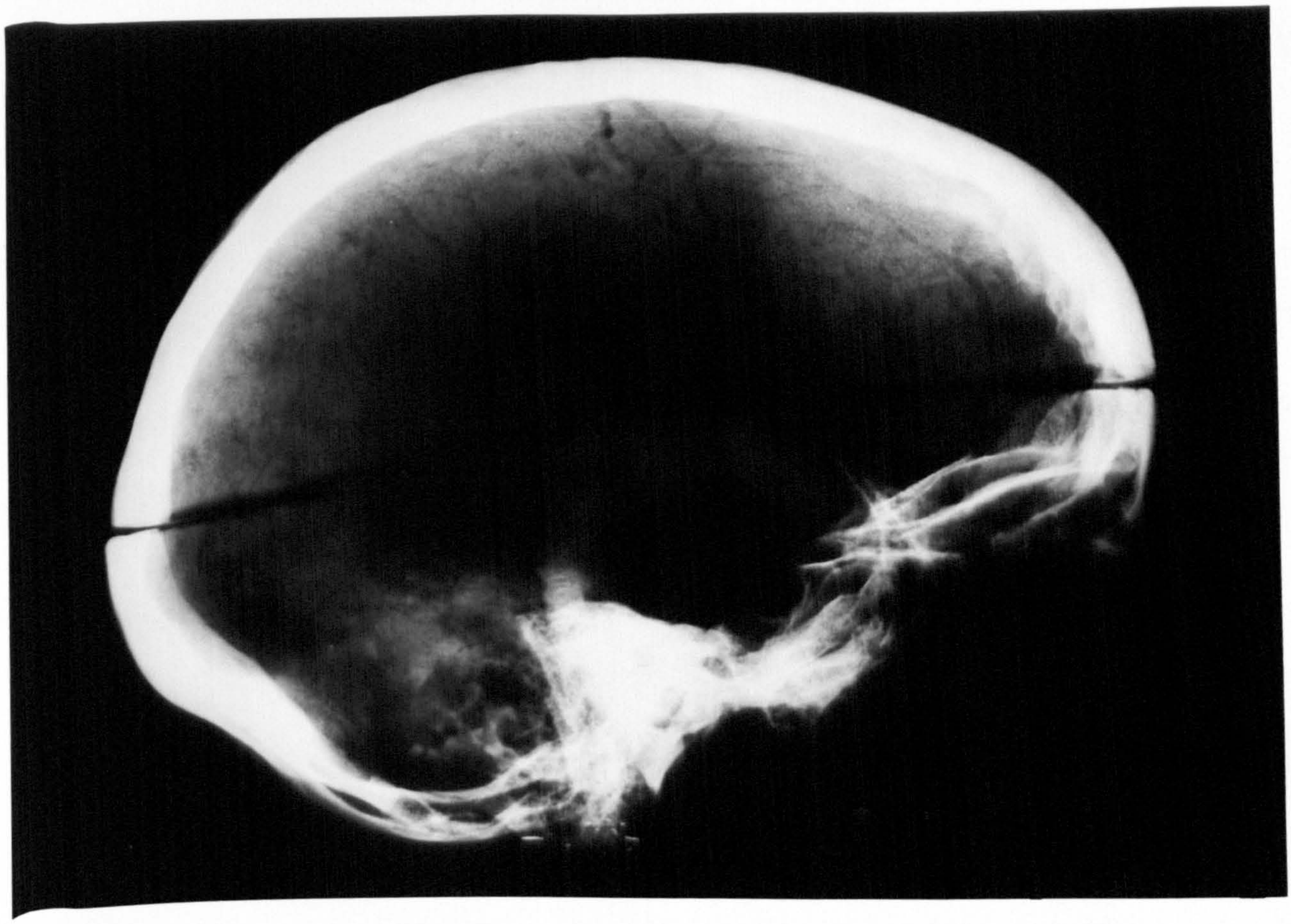


Figure 5.5 X-ray appearance and visual appearance of grade 2 HFI



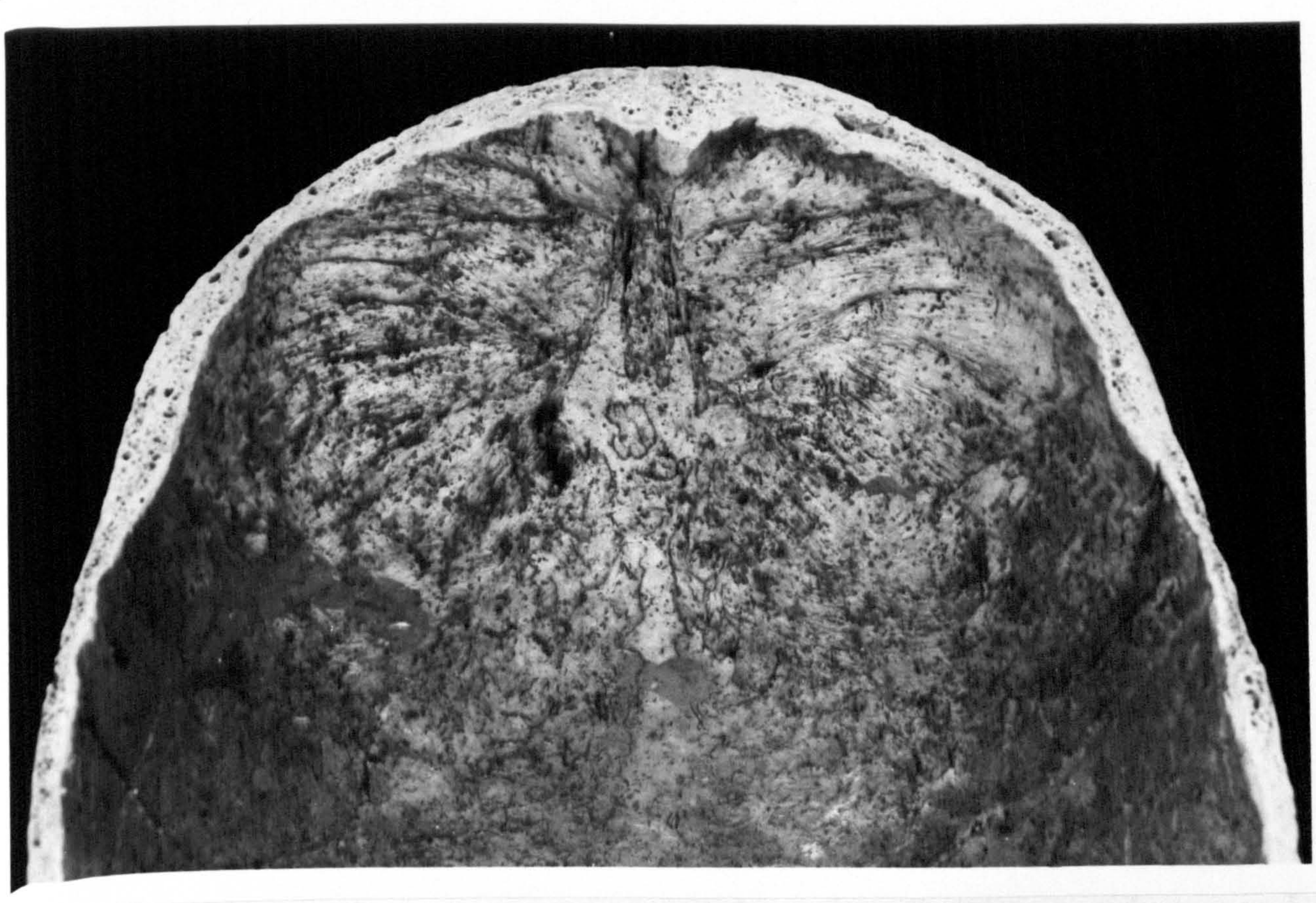


Figure 5.6 X-ray appearance and visual appearance of grade 3 HFI

Results

Observer error

A random sub-sample of eight of the radiographs were re-examined a week later by the same observer, blind to the original score, to check internal error. An intra-class correlation coefficient was calculated. All the x-rays were given the same score on both occasions giving an I.C.C. of 1.

Histology

Attempts to obtain decent histological sections for the ancient material used in this thesis failed, as the material was so friable. It was possible to produce only a poor histological section (see figure 5.7 below) from only one of the HFI types - grade 2 (see chapter 3 for methodological details). The section shows disorganised, expanded trabeculae in the diploë, but no interpretation was made from this picture, as it is so poor. Further work to look at the microscopic structure of this type of ancient bone should concentrate on using the technique of scanning electron microscopy, or macroradiograph analysis.

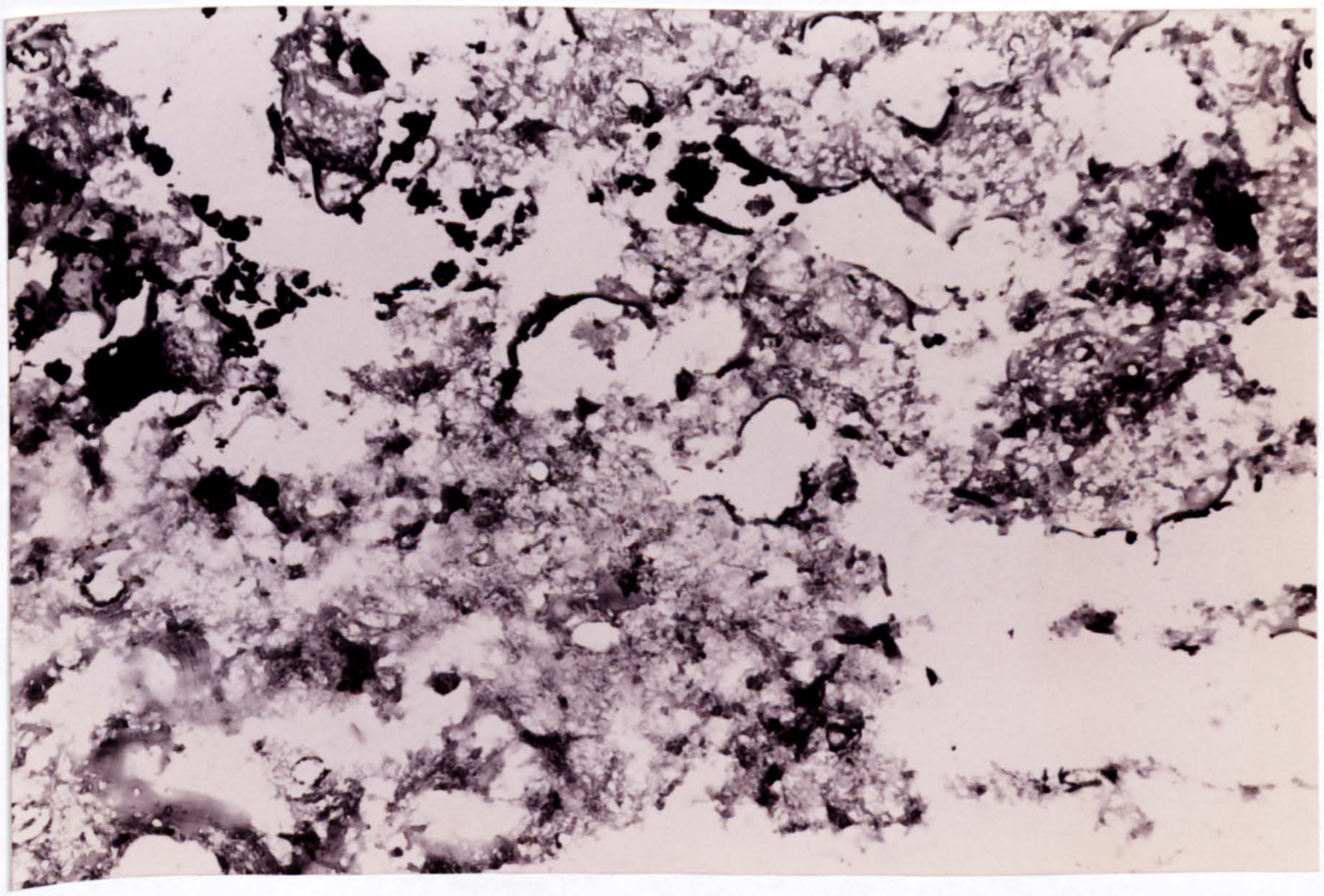


Figure 5.7 Illustration to show the failure of the histological section to produce any results.

HFI grades observed

The HFI scores given by the radiologist to all of the individuals in the sample are given in table 5.2 below

HFI grade	0	1	2	3
male	27 (73%)	10 (27%)	0	0
female	22 (51%)	13 (30%)	6 (14%)	2 (5%)
? sex	6 (86%)	0	1 (14%)	0

Table 5.2 Percentages of individuals with each grade of HFI by sex - all the sample

From table 5.2 it can be seen that no male obtained a score of over grade 1, but 19% of females had a score of 2 or above. The results of those aged over 45 are also shown separately in table 5.3 below.

HFI grade	0	1	2	3
male (n=23)	20 (83%)	3 (17%)	0	0
female (n=13)	6 (46%)	3 (23%)	3 (23%)	1 (8%)

Table 5.3 Percentages of individuals with each grade of HFI by sex - those over 45 years only

These results show a higher percentage of women over 45 (31%) are affected compared to those under (4 out of 30 - 13%).

Discussion and Conclusions

Even if a conservative grade of "2" is taken as definite evidence for the presence of HFI, then at least 31% of females anthropologically aged over 45 from the Barton-on-Humber population sampled have HFI. This is considerably higher than any archaeological prevalence previously quoted. It confirms the suspicion that workers reporting cases in archaeological material are not using the same criteria as the medical profession. These results show that no male in this sample had a HFI grade of over 1,

confirming the modern literature stating that males are less commonly affected. More older female individuals are affected than younger, which again concurs with the modern data.

It would seem that, comparing the direct appearance of the sectioned skulls in figures 5.3 and 5.4 (Littlejohns' grades 1 and 2) the appearance of the HFI is much less florid than the usual pictures of the cases that appear in the archaeological literature (e.g. Molleson, 1993). If only cases that are grade 3 are counted, the prevalence becomes much closer to the archaeological norm, and it may be that only those most extreme cases are recorded in palaeopathological reports. Given these results the current assumptions that the lack of HFI cases in the archaeological literature are due solely to lower life expectancy surely must be challenged. If researchers wish to use the presence of this phenomenon as an indication of the age at death of a population the results of this study suggests two actions. Firstly, when giving information on the percentage of the population affected, the number of skulls actually examined internally / x-rayed should be stated. Secondly, the grading method used on the sample should be stated (such as the direct visual method outlined in this text); if only those most florid cases (grade 3) are noted, this should be clearly mentioned, and no further comparisons with percentages in modern populations should be made.

2. Test of the new visual diagnostic criteria for HFI on other populations

Samples

Modern post-mortem sample

Forty-five individuals were selected from the post mortem sample (see chapter 3 for details). Those cases not used in this study were excluded as it was not possible to make an observation because of tissue adhering to the frontal bone, which was impossible to remove.

Terry collection

A total of 237 black and white individuals were selected from the sample of the Terry collection (see chapter 3). Those that were discarded from this study were skulls which

had partial or missing frontal bones, or had been sliced open in a 'v' shape (laterally) so that the frontal bone could not be seen properly.

Spitalfields sample

Fifty-one individuals were selected from the sample from the crypt at Spitalfields. Only adults aged over 16 years were studied (there are no reported cases of HFI in children), and those which had abraded or missing frontal bones were discarded.

Method

For each skull the direct visual degree of HFI was recorded, blind to age and sex of the individual, according to the method devised above.

Reproducibility

A random selection of 10 frontal bones were re-examined at the end of each study, and were compared to the original scores. All results before and after were identical, indicating excellent reproducibility.

Results

Post-mortem

Tables 5.4 and 5.5 below show the numbers and percentages of skulls graded 0 to 3 in the modern post-mortem sample.

HFI grade	all	3	2	1	0
female (% in brackets)	22	1 (4.6)	2 (9)	8 (36.4)	11 (50)
mean age	72.7	70	65.5	82.6	67

Table 5.4 HFI scores for the modern post-mortem sample - females only

HFI grade	all	3	2	1	0
male (% in brackets)	23	0	1 (4.3)	2 (8.7)	20 (87)
mean age	64.3	0	77	80	62.1

Table 5.5 HFI scores for the modern post-mortem sample - males only

The result from these analyses show a similar pattern to that of Barton-on-Humber above in terms of male : female affected ratios. There appears to be a lower prevalence of grade 2 and above (13.6% compared to 31%) but this may be due to the smaller numbers studied. The medical histories of each individual graded 2 or over were investigated and no-one showed all three symptoms required for a diagnosis of Morgagni's syndrome (see above).

Terry collection

Tables 5.6 to 5.9 below show the results of the analysis of HFI grades.

HFI grade	all	3	2	1	0
female (% in brackets)	51	5 (9.8)	10 (19.6)	23 (45.1)	13 (25.5)
mean age	60.8	78.6	66.9	59.9	50.6

Table 5.6 HFI scores for the Terry collection - white females only

HFI grade	all	3	2	1	0
male (% in brackets)	51	0	3 (5.9)	14 (27.4)	34 (66.7)
mean age	55.1	0	68	55.8	53.6

Table 5.7 HFI scores for the Terry collection - white males only

HFI grade	all	3	2	1	0
female (% in brackets)	73	10 (13.7)	16 (21.9)	25 (34.2)	22 (30.2)
mean age	56.4	71.5	67.6	61.4	35.8

Table 5.8 HFI scores for the Terry collection - black females only

HFI grade	all	3	2	1	0
male (% in brackets)	62	1 (1.6)	2 (3.2)	14 (22.6)	45 (72.6)
mean age	50.3	75	75	48.7	49.1

Table 5.9 HFI scores for the Terry collection - black males only

In both the white and black sub-samples, there is a marked increase in the prevalence of HFI in females. There appears to be a difference between black and white female

prevalences, with black females having a greater number of cases, even though the mean age of the sample is slightly lower than that of the white females.

Spitalfields

Table 5.10 and 5.11 below show the results of the analysis of the Spitalfields sample.

HFI grade	all	3	2	1	0
female (% in brackets)	21	1 (4.8)	1 (4.8)	6 (28.5)	13 (61.9)
mean age	51.3	56	73	66.1	42.5

Table 5.10 HFI scores for the Spitalfields sample - females

HFI grade	all	3	2	1	0
male (% in brackets)	30	0	2 (6.7)	3 (10)	25 (83.3)
mean age	52.6	0	53.5	44.3	53.6

Table 5.11 HFI scores for the Spitalfields sample - males

From these results Spitalfields has one of the lowest percentages of females affected. This may be due to the lower mean age of the sample - many of the women studied were in their early 20's or 30's. Although isolated cases of HFI have been noted in young people (Eldridge and Holm, 1940) they are rare. One interesting observation is that the mean age of the grade 3 group is considerably lower than that of grade 2, which might indicate that HFI can increase as well as decrease with age (as seen with pregnancy osteophytes, Ortner and Putschar, 1985) although none of the other groups show this, and the sample is quite a small one. This finding, if real, supports the results obtained by Moore (1955) which showed an increased prevalence of HFI in the 50-60 age group.

Barton-on-Humber

From the results above there appeared to be a trend towards increasing frequency of HFI over time. To help make these results clearer it was decided to separate the original Barton-on-Humber sample x-rayed into two phases, pre- and post- 1500 AD, and to plot these results separately. Tables 5.12 and 5.13 below show these results.

HFI grade		3	2	1	0
male (% in brackets) n=	9	0	0	3 (33)	6 (67)
mean age (n aged in brackets)	37.8 (7)	0	0	22 (1)	40.4 (6)
females (% in brackets) n=	15	0	0	4 (27)	11 (73)
mean age (n aged in brackets)	38.5 (10)	0	0	37.7 (6)	39 (4)

Table 5.12 HFI scores for the Barton-on-Humber - Pre 1500 sample

HFI grade		3	2	1	0
male (% in brackets) n=	26	0	0	6 (23)	20 (23)
mean age (n aged in brackets)	39.4 (23)	0	0	38.4 (5)	42.1 (17)
female (% in brackets) n=	23	2 (9)	6 (26)	6 (26)	9 (39)
mean age (n aged in brackets)	30.3 (14)	45 (1)	38.4 (5)	22 (2)	23.8 (6)

Table 5.13 HFI score for the Barton-on-Humber - Post 1500 sample

There is a marked difference between the pre and post 1500 AD samples, with no cases of HFI found in the former group. This may be due to the small sample in the pre 1500 AD category. It is difficult to tie these results into age specific prevalences, as not all the skeletons could be aged, and those that were are subject to the standard problems of ageing outlined in chapter 3 of this thesis. To get the best idea of the change of prevalence of HFI over time from these samples it was decided to compare the frequencies of HFI in the women from each of the four samples all together.

All samples compared

Figure 5.8 below gives a summary of percentages of women affected by HFI over time in all the samples studied.

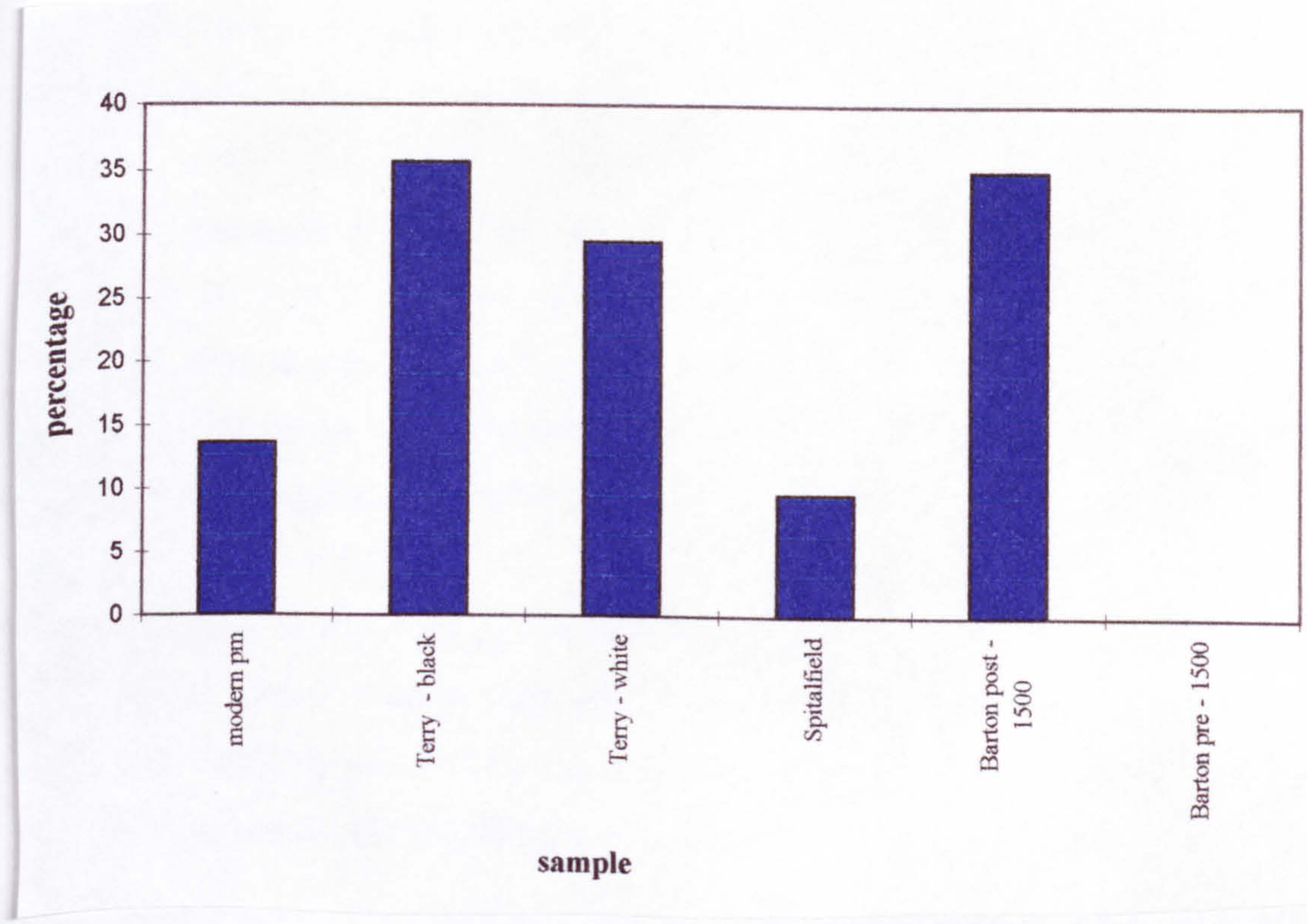


Figure 5.8 A comparison of HFI grades (percentages of the population studied) of grade 2 and above in females across all samples

Discussion and Conclusions

The most positive result of this study is the production of a reproducible methodology for anthropologists and palaeopathologists to diagnose HFI which for the first time is directly comparable to radiological criteria.

When this method was applied to the skulls in each of the samples, the results presented a rather confusing picture of the frequency of HFI over time. There appears to be a trend to greater relative numbers of cases with increasing modernity, as well as a difference between races. There is however, one exception. The most modern population (the Bristol post-mortems) seems to have one of the lowest frequencies of HFI. This may be because of the relatively small numbers of individuals in this sample, but they are the sample with the highest mean age at death, and the evidence from the literature states increasing prevalence with age (Resnick and Nimayama, 1988). It may be that if one does not get HFI around or before the menopause when the hormones implicated in the etiology of the disease are changing in activity then increasing age will not necessarily

heighten ones chances of being affected. This hypothesis is supported by the results obtained by Moore (1955), and in this study, by the lower mean age of the grade 3 HFI than the grade 2 in the Spitalfields sample.

Work by Littlejohn et al. (1986) has shown a relationship between HFI and DISH. Rogers et al.. (1997, discussed in chapters 3 and 4) suggests that DISH requires a genetic predisposition, which would imply that there is a similar element in HFI. This theory would tie in with the belief by some researchers that HFI has a genetic predisposition (Jequier, 1950; Dressler, 1967 and Rudali, 1968).

It is interesting to hypothesise why, if it is true, that the rate of HFI is increasing over time, albeit slower than archaeologists would have one believe (Armelagos and Chrisman, 1988). It may well be due to increasing life expectancy, but if this is so, then the most modern sample should have the highest frequency of HFI.

The age specific results are hard to analyse from this study; it is true that generally the older individuals get more HFI, but as mentioned above, the very oldest (and most modern) sample does not have the highest frequency. It is safe to say that HFI is more common in older people, but it would be dangerous to use the phenomenon as an indicator of age at death and to then use it as an indicator of life expectancy when it is so obviously a disease process. Any apparent age relationship may happen as a by product of the phenomenon - this is suggested by the fact that there are many cases in this study of HFI appearing in young adults - 13% of the under 45 year old females of Barton had grade 2 or above. In addition given the reports in the literature about HFI appearing in younger individuals (Eldridge and Holm, 1940 quote 28% of their cases as being under 39 years) and the evidence that a HFI - like appearance can occur in pregnancy (Ortner and Putschar, 1985) age may be somewhat of a red herring. A problem of using skeletal material is that one is looking at cross-sectional data at the point of death and cannot say whether someone with HFI has had it for five or fifty years. It is not known whether someone with grade 2 HFI will continue on to grade three, or reverse back to grade one, but data from Moore (1955) and from this study suggest that this may be happening - it would be useful to see more work on age of onset of HFI in modern populations, and longitudinal studies of individuals to see what happens to HFI with time.

One of the reasons why the results are inconclusive may be that some of the samples are rather small. The majority of the Barton sample fell into the post 1500AD group (49 compared to 24). The phasing of the skeletons was not available until the analysis had been completed. All the other samples were more recent, so this analysis was not comparing like with like in terms of numbers.

Further Work

Further work in this area should target a much larger sample of pre 1500 AD individuals so as to get a clearer picture of the prevalence of HFI in the past. As the results show that there may be a difference between races in the frequency of HFI this area could also be investigated further. If HFI is a menopausal phenomena it might have a use as an indicator of age of onset of menopause, which cannot be currently inferred from skeletal material (Molleson and Cox, 1993). Any study attempting to investigate this must be designed with care, though, because of the cross-sectional nature of the data as mentioned above.

Chapter 6. Cranial Suture Closure

Introduction

Cranial sutures and the extra-sutural bones (Wormians) found at suture junctions are two of the most frequently studied parts of the skull in anthropology. Both endocranial and ectocranial rates of suture closure have been found to correlate with age at death in many studies (Todd and Lyon, 1924b; Ascádi and Nemeskéri, 1970 and Meindl et al., 1985) although the validity of the method has been disputed (Brooks, 1952; Cobb, 1952 and Singer 1953).

Structure and Function of Sutures

A suture develops when two adjacent bones in the skull come into close contact (Herring, 1972). In childhood the gap is often wide (see chapter 2 for more details on how the skull develops), and narrows in adulthood. The bone edges are connected by the sutural ligament made of tissue (Retzlaff et al. 1985) which is thought to be a remnant of the membrane of the capsule of the brain connecting the outer and inner periosteum (Singer, 1953). Fusion is believed to occur as a result of a reduction in the vascular supply to the brain and diploë in senility (Torgersen, 1950).

The individuality of sutures is thought to be genetically controlled by a low penetrating dominant gene (Gregory, 1934). Todd and Lyons' work in 1924 noted a phenomenon they termed "vicious union". This is characterised by 'piling up of bone along the edges of the endocranial part of the suture', and is particularly common around the saggital, lamboid and supraglabellar sutures (Torgersen, 1950).

Other researchers (Ingraham et al., 1948 and Kemp, 1945) noted that cranial suture abnormalities such as craniosynostosis (premature fusion of the sutures) and acrocephalosyndactly (craniostenosis with shape changes of the head and webbing of the fingers) appeared more frequently in certain family lines. Torgersen (1951) undertook an x-ray study of suture closure in families and twins (n= 400). He found that individuals who had retained their metopic suture of the frontal bone (which obliterates at around 18 months in 92 - 98% of the population - Brothwell, 1981) also had a tendency to fuse their other sutures later than those of the same age. The 'vicious union' seen by Todd

and Lyon (1924) was found to be highly inheritable and also appeared to be related to the presence of HFI (see chapter 5 for details of this phenomena) in older women.

Although the appearance and fusion of sutures is genetically controlled, function also plays a large part in their appearance. Washburn (1947) demonstrated how muscles can affect the form and complexity of suture patterns. By removing the temporal muscle in rats he noted a decrease in the growth of the occipitoparietal suture. Conversely, in those rats where the muscle was not cut, he saw an increase in the complexity of the suture pattern.

There are two distinct types of suture which Moss (1957) categorised as being overlapping (beveled) or end to end. Figure 6.1 is a representation of each type.

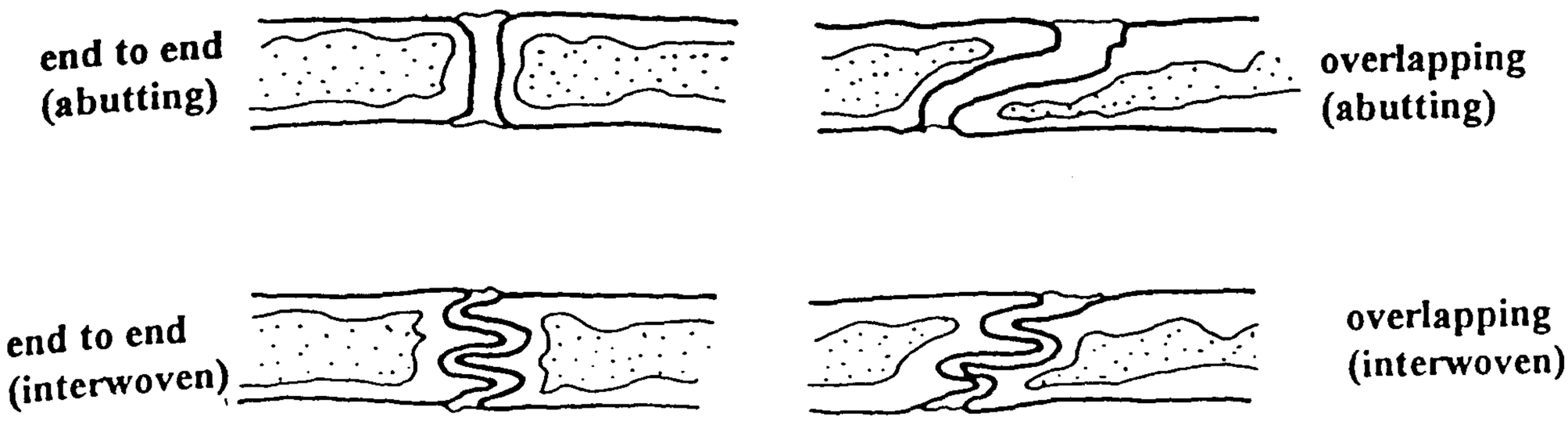


Figure 6.1 Types of cranial suture after Moss 1957.

Wormian bones

Wormian, or extra-sutural bones are found in varying frequency between most of the sutures in the skull (see figure 6.2). They are named after the Danish anatomist Wormius, who first noticed them in 1643 (cited in Cremin, 1982). They are detached primary ossification centres, which do not fuse to any other bone, and are of questionable etiology. The most probable cause is that they are a genetic partially dominant trait. Torgensen (1951) looked for the presence of wormian bones in his study of families and

twins. He noticed similar numbers and sites of wormian bones in twins, and he concluded that the metopism and the presence of extra-sutural bones shared the same genetic control. Berry and Berry (1967, 1968) and later Berry (1975) noticed a variation in the presence of different wormians in racially distinct populations. Berry (1974) then went on to use these variants to determine population movements in Scandinavia from 2,000 BC. Molleson and Cox (1993) also noted an association between the presence of rare ossicles at Bregma in two of the families from the crypt site of Spitalfields.

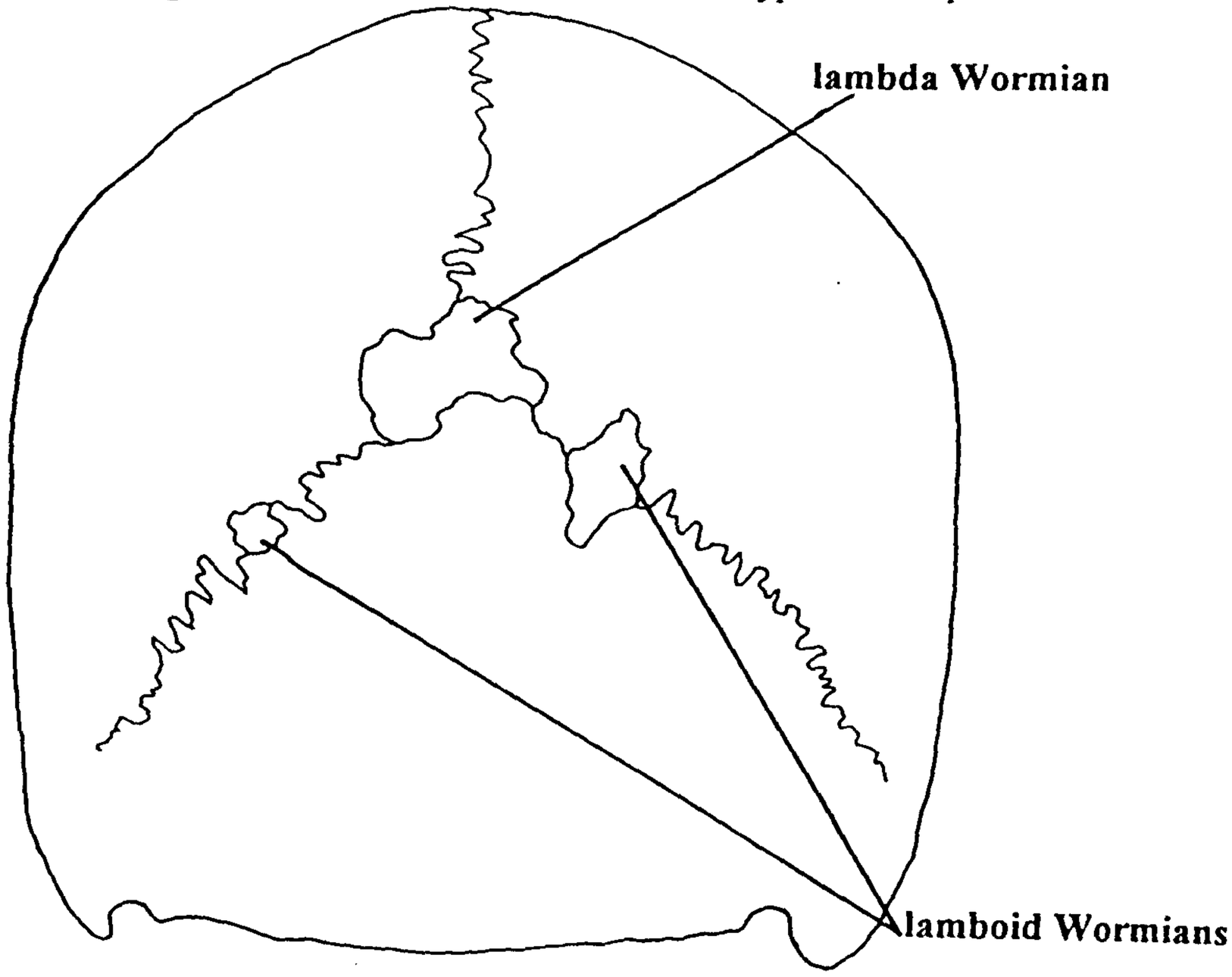


Figure 6.2 A lamboid wormian bone

Despite this evidence, not everyone agrees with a genetic etiology. Bennett (1965) looked at basi-occiput length and wormian bones in crania from Black, white and American Indian anthropological collections. He found there was a statistically significant difference in length between those who did and did not possess wormians. His conclusions did not support the genetic theory, instead he suggested that environmental stress (although he is vague about what exact mechanism controls the formation of the ossicles) causes wormian bones. Moss (1957) suggests that they may be caused by birth trauma, El-Najjar and Dawson (1977) note that they can be caused by deliberate cranial deformation.

The presence of multiple wormian bones can also be found in certain pathological conditions. Pryles (1979) saw wormian bones as a marker of underlying epilepsy or mental retardation. Cremin (1982) noted the association with osteogenesis imperfecta (O.I., Bromer, 1933), in his study of 500 normal children and 81 cases of O.I. He suggested that the pattern of the bones is necessary to distinguish between normal and pathological causes, with a "mosaic" of 10 or more bones present in almost 90% of those with O.I.

The use of sutures to estimate age at death

Vesalius and his pupil Fallopius were the first to show that cranial sutures fuse and become obliterated with age (in Ashley-Montagu, 1938), and the principle has been used to estimate age at death since the sixteenth century. However, there have been conflicting opinions on how accurately one can age an individual. Even early researchers had their doubts. Topinard (1885) , Dwight (1890) Frédéric (1906) and Zanolli (1908) all expressed concern about the accuracy of the method. Hrdliçka (1920), however considered the fusion of the basi-sphenoid suture (see chapter 2) to be "the most handy and reliable" of methods which could be used to age adult skulls. Brothwell (1967) points out that the basi-sphenoid suture is actually a synchondrosis, not a proper suture.

Between 1924 and 1925 Todd and Lyon produced four papers outlining a methodology for both endocranial and ectocranial sutures in white and black males. They concluded that endocranial closure was more reliable than ectocranial patterns. Their results are still used as the basis for many currently used techniques, although one of the main criticisms of their work is the way they selected skulls to provide their sample. Skulls that were removed from the study included "all skulls belonging to the anthropoid strain of pubic symphysis" (relating to Todd's work in 1920 - see chapter 3) "skeletons which exhibit a marked anomaly of skeletal age relationship" and "all skulls we felt perfectly certain belonged to Bolk's (1915) precocious group and also those of his antithetic class" .

Other workers also produced methodologies, (e.g. Martin, 1928) but these were often based on skulls of unknown age at death. The ages of these skulls was then estimated using anthropological methods, which can produce misleading results (see chapter 3). Singer (1953) applied Todd and Lyons criteria to a sample of skulls of known age from

the Smithsonian and University of Witwatersrand anthropological collections. He found that the method was unreliable, with a great deal of both under- and over-ageing in adults of the same age. He does not, however mention how many skulls he studied to find the unreliable cases described in his paper.

Krogman (1949) found no difference between sex or race in his study, but Brooks (1955) noticed a lag in females of between 5 to 25 years in comparison with the pubic symphysis age and a deviation of "not more than plus or minus 5 to 8 years" in men. Brooks, however, dismissed the method as "unreliable, regardless of sex and race" despite achieving high correlations in her study. Cobb (1955) also denounced suture closure as an accurate method of determining age at death and McKern and Stewart (1957) looked at a series of skulls and concluded that "..as a guide for age determination...of little use".

For a while the idea of using sutures fell out of favour in anthropology. Ascádi and Nemeskéri (1970) then used suture closure as part of their "complex" ageing method. They scored 16 sites on the endocranial surface with grades of 1-5 which was then used as a standard ageing method by the Workshop of European Anthropologists (1980). Perezonius (1984) wrote of the obligation he felt to "investigate possible age estimators in every unique reference collection" and did so in his study of 256 Dutch crania. He used both endocranial and ectocranial suture closure, and devised two systems, one for older individuals (over 50) and one for younger (under 50) which between them gave 16 stages. The method is quite complex and difficult to follow, and his results showed that using this method cranial suture closure correlated with age only in those under 50 years of age. In addition this method is problematic as it assumes that one can firstly put a skull into the "older" or "younger" category. This is not so hard to apply to the very young adult who may still be fusing other parts of the skeleton (i.e. iliac crest) but it can be hard to distinguish between a 40 and 60 year old skeleton, especially if no other ageing technique is available.

In 1985 Meindl and Lovejoy produced a revised methodology based on, for the first time, 'observed' closure using a grading system. They looked at how accurate different sites were in predicting age and produced two systems - the 'vault' and the 'lateral-anterior'. Mean scores of suture closure were used from specific sites and were found to

produce fair correlations (r scores of between .41 and .58). They found that unlike the Todd and Lyons method, their ectocranial results were the most accurate. They suggested that there was little, if any difference between sex and race (although they did not specifically test for this) using this method. Despite criticizing Todd and Lyons study for the way they selected their samples, they also removed 117 skulls from their collection of 402. Fifty of these were pathological (no cause given), which can be argued as a good reason to exclude them, but the other 67 were removed because they were "asymmetrically ossified". This accounts for 17% of the total sample and should have been considered. The application of this method relies on the material being whole pristine skulls, which are rare in archaeology. Lovejoy et al (1985) used Meindl and Lovejoy's new method on 118 individuals of known age from the Hamman-Todd collection. They found that the method had a tendency to underage individuals. Maat (1987), though supports the use of the Meindl -Lovejoy method over that suggested by Nemeskéri et al. (1960). He criticizes the Nemeskeri method as it uses both left and right sides of the coronal and lamboid sutures, which Maat believes is essentially counting the same site twice. However this assumes that all skulls fuse symmetrically, which given the above information from Meindl and Lovejoy's study (1985), some do not.

Masset (1989) reviewed the use of cranial sutures and suggested several statistical ways to help remove the systematic errors that the method produced. He concludes by saying that "it will long be unrealistic to expect to base fine comparisons on the basis of cranial sutures or any other indicator" .

In their study of known age individuals from Spitalfields Molleson and Cox (1993) noted that five members of one of the families all had premature fusion of cranial sutures, especially the sphenoid. Key et al (1994) then used the same Spitalfields sample to produce a comparative study of three of the most commonly used suture fusion techniques, using the methods of Ascádi and Nemeskéri, Meindl and Lovejoy and Perezonius (all discussed above). They did not find any statistical difference between most of the grades 1-5 in Ascádi and Nemeskéri's method, but they did conclude it was a useful method, although the age ranges obtained were very broad. The Meindl and Lovejoy technique fared worse, with a marked difference in accuracy between sexes and a tendency of the method overall to underage individuals. The Perezonius system was found to be of least use in the Spitalfields sample, with a basic problem in identifying the

"younger" from the "older" skulls to begin with. They then created a new method based on the Spitalfields sample using a simpler system of 0,1,3 scores representing open, fusing or closed. The method they use is based on individual suture closure rather than composite scores. Although they criticize other methods saying that a method devised on one sample does not necessarily work on a different one, when they attempt to use their new method on a different race population of known age they discard all skulls (11% of the total sample) who had "different" patterns of suture closure to Spitalfields.

Pathological fusion of sutures

Apart from the obvious changes caused by craniostenosis which has already been mentioned (El-Najjar and Mc Williams, 1978), there has been little work on how other diseases affect suture fusion. Moss (1957) lists multiple causes that can affect the rate of suture fusion - including meningeal inflammation, microcephaly, genetic mutation, rickets, birth trauma and syphilis.

Summary

From the literature review discussed here it can be seen that many studies have been undertaken using degrees of suture fusion and the presence or absence of Wormian bones, producing a variety of results. It would appear that there is some relationship between suture fusion and ageing, with genetic predisposition as one of the most important factors. In studying the various methodologies no account is made of the fragmentary nature of archaeological material, which might affect the accuracy of the final estimation if the skull is incomplete. A revised method is needed to address this problem. Little work has been carried out looking at whether pathology plays any part in either delaying or causing premature fusion (except in those diseases classified by suture fusion such as craniosynostosis). All studies which devised a methodology removed the pathological skulls before analysis.

It would be useful to investigate whether cranial suture fusion is a normal function of age, or to what extent pathological processes occurring in other parts of the skeleton affect the rate of fusion. If suture fusion is determined by vascular supply, or lack of it (Torgersen, 1951) then diseases which may alter the vascular supply to the skull (such as meningiomas, haemoglobinopathies or trauma) may also affect the rate of suture fusion.

Aims of the study

The study is in two parts:

1. To test a revised method of ectocranial and endocranial suture closure on a population of known age at death.

2. To attempt to determine whether specific cranial pathologies or the presence of hyperostosis frontalis interna can affect suture fusion.

1. Test of a revised cranial suture closure method on individuals of known age at death

A revised method was devised to study age related changes of the cranial sutures. The method attempted to combine factors of the Meindl and Lovejoy (1985) and Key, Aiello and Molleson (1994) methods, with an allowance to be made for the fragmentary nature of archaeological skulls.

The sample

All 261 individuals from the Terry sample were used in this study (see chapter 3 for the demographic profile of this sample).

Fusion scores

For each of the three methods outlined below the state of fusion of the frontal, sagittal and lamboidal sutures were scored using one of three grades. These were based on the scores of Key et al. (1994) who showed that more complex scoring systems could not statistically distinguish between grades.

0 - suture unfused

1- suture fusing

2- suture fused

Figures 6.3 to 6.5 below show an example of each grade of fusion.

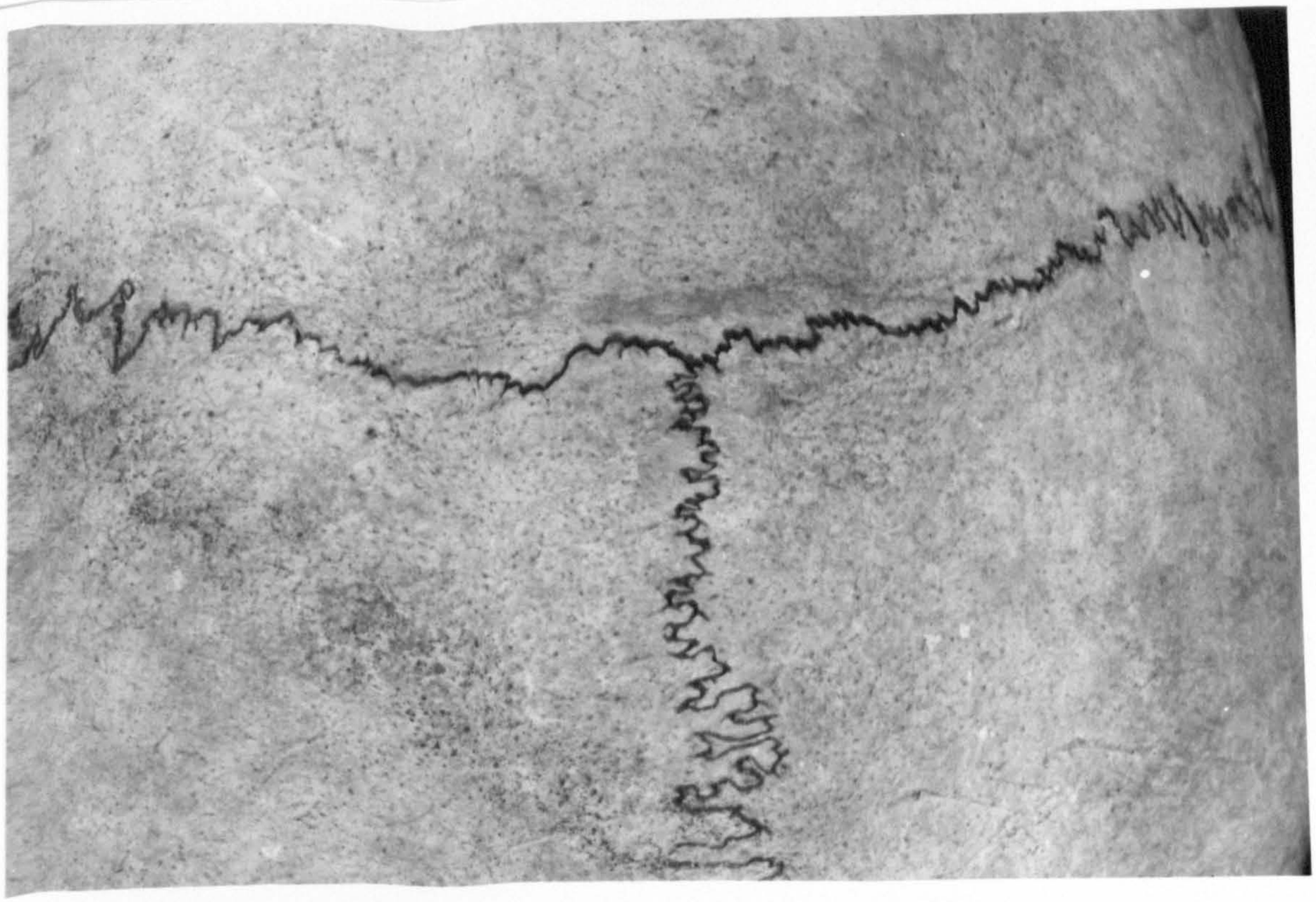


Figure 6.3 Suture closure grade 0 - unfused

Figure 6.4 Suture closure grade 1 - fusing

Figure 6.5 Suture closure grade 2 - coronal suture fused (sagittal suture is fusing - grade 1)

Skulls have a tendency to break, often leaving only the calvarium available for observation. It is estimated that from the site of Barton-on-Humber in 95% of individuals only the parietals, frontal and occipital were all that represented the skull (see chapter 1). Both the endocranial and ectocranial methods used here are based only on those parts of the skull.

Endocranial method

Fourteen sites were chosen on the endocranial surface of the coronal, saggital and occipital sutures (see figure 6.6 below), which are based on the sites as described by Meindl and Lovejoy (1985). For each site the fusion score was graded from 0 to 2. The total score (maximum 28) was then correlated with known age at death for each individual in the Terry sample.

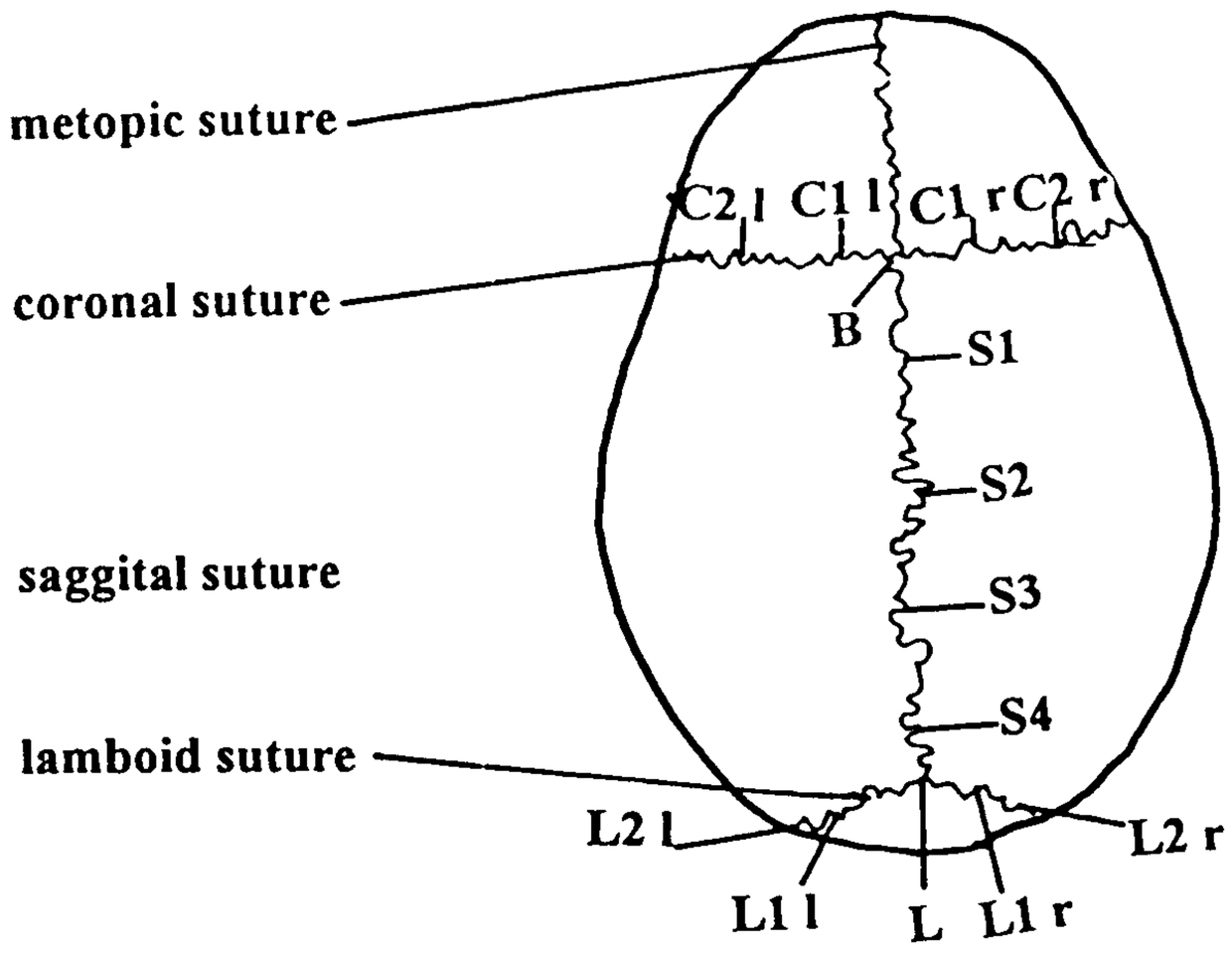


Figure 6.6 Sites scored for suture fusion on the endocranial and ectocranial surfaces of the skull (after Meindl and Lovejoy)

Ectocranial Method

The corresponding fourteen sites on the ectocranial surface of the skull were chosen for the second method (see figure 6.6 above). As with the endocranial method, the state of fusion of each site was scored as 0,1 or 2. Again the maximum score achievable was 28. This was correlated against age at death for each individual in the Terry sample.

Reproducibility

Five skulls were re-scored at the end of the study. Intra-class correlation coefficients were calculated for both the endocranial and ectocranial scores. The results were 0.98 and 0.99 respectively, indicating excellent reproducibility.

Results

Tables 6.1 and 6.2 and figures 6.7 and 6.8 below show the results of the correlation between total score and age.

sample	p<	R-sq (adj)	Equation	St Dev
all	0.0001	26.2%	age= 32.1 + 1.15(total score)	2.616
black male	0.0001	27.1%	age= 37.3 + 0.949(total score)	4.006
black female	0.0001	22.4%	age= 37.4 + 1.22(total score)	5.792
white male	0.0001	22.2%	age= 27.1 + 0.79(total score)	3.574
white female	0.002	16.4%	age= 29.2 + 1.24(total score)	8.89

Table 6.1 Results of the endocranial suture score against age - Terry sample

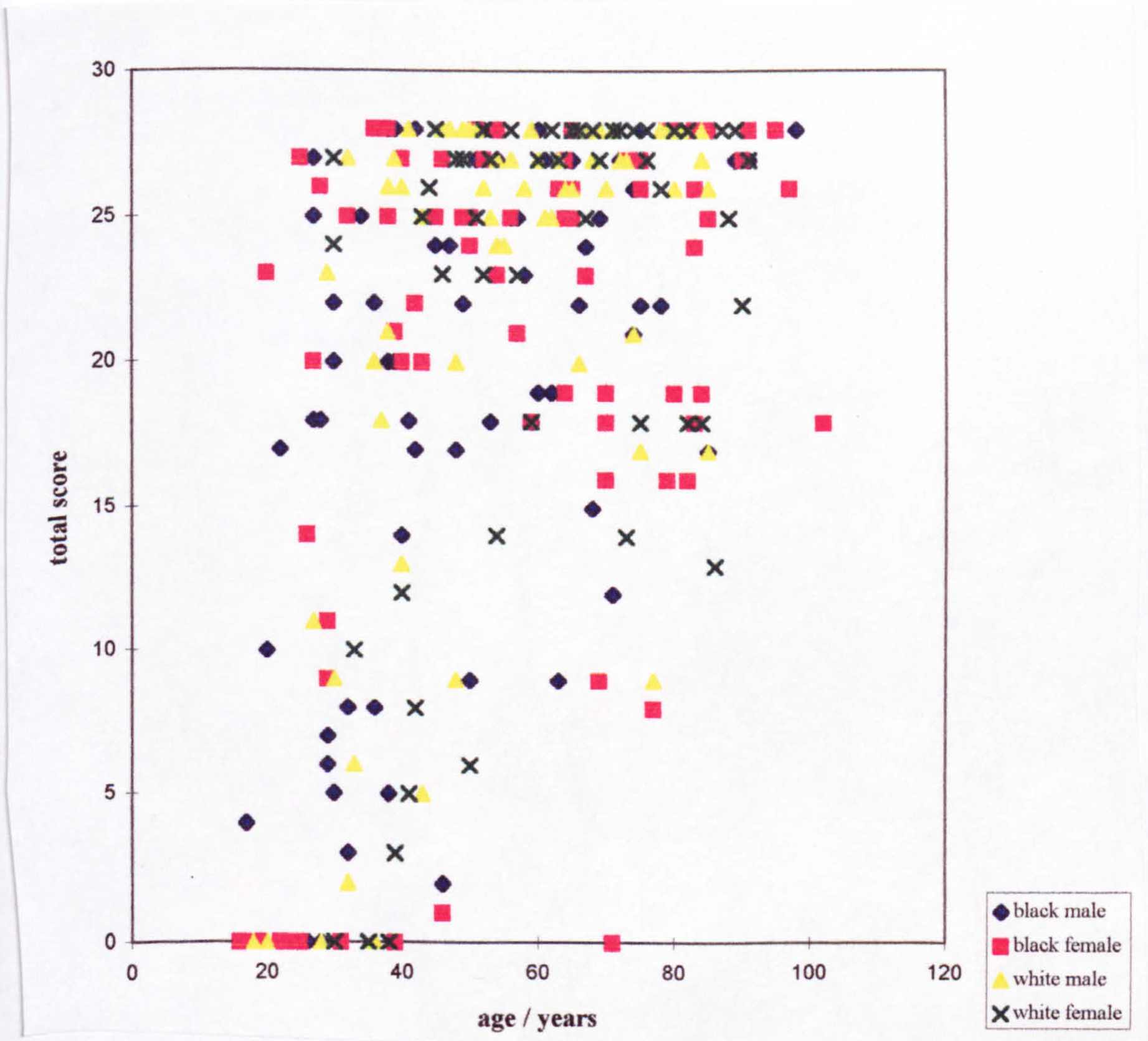


Figure 6.7 Plot of total score against age - endocranial sutures

sample	p<	R-sq (adj)	Equation	St Dev
all	0.0001	14.2%	age= 43.2 + 0.821(total score)	2.139
black male	0.001	13%	age= 46.3 + 0.665(total score)	3.428
black female	0.006	8.3%	age= 53.5 + 0.637(total score)	4.217
white male	0.002	14.2%	age= 31.1 + 0.749(total score)	3.508
white female	0.002	16.2%	age= 44.1 + 0.943(total score)	4.78

Table 6.2 Results of the ectocranial suture score against age - Terry sample

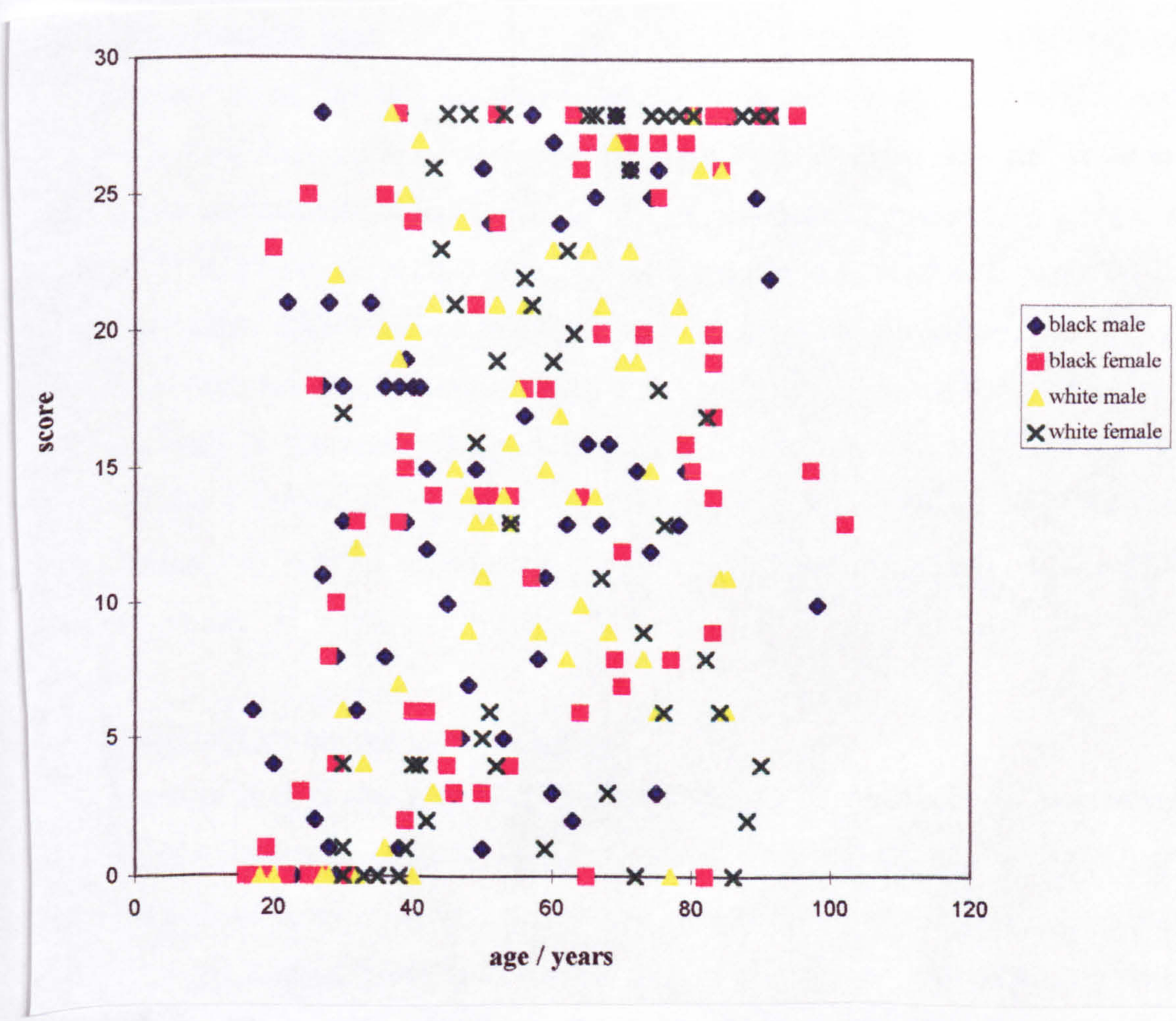


Figure 6.8 Plot of total score against age - ectocranial sutures

Discussion

These results show a strong correlation between both endocranial and ectocranial suture scores and age at death in all four of the sub-samples, although the graphs show that there is a great deal of variation of score in individuals of the same age - the oldest person in the sample (102 years) had score of 14 endocranially and 18 ectocranially, but there are several young cases of 20 years and younger who scored between 20 and 25. Using this statistic (linear regression) it is possible to have high correlations, but still have wide confidence intervals if many observations are made. The level of variation when taking into account the confidence intervals would lead to problems if one was to attempt to construct a model for estimating age at death. Both methods have a maximum score of 28, and from the graphs it can be seen that many individuals of all ages have both the maximum and the minimum scores. If one was to use this method it would have a maximum cut-off point of between 65 - 70 years (depending on which regression equation one used) but this compares well to the maximum age ranges obtained by anthropological methods in current use (see chapter 3). There is little difference in the endocranial and ectocranial regression results. The endocranial method has a lower base point of 27 to 37 years, whilst the ectocranial method starts to age at between 31 to 53 years. The slight difference in the results may well be due to the different demographic profiles of each sub-sample (this has been discussed in previous chapters). These results compare well to the results produced on whole skulls (Meindl and Lovejoy 1985), although the R values are slightly lower. This suggests that a pristine complete skull is not necessary to achieve an estimate of age comparable in accuracy to the methods currently in use.

2. Do different pathologies affect sutures?

The results of study 1 above showed that there was a strong correlation between suture fusion score and age at death. However, the results show a great deal of variation and it was decided to investigate the relationship (if any) between different pathological conditions and disease. Three classes of disease were selected - pneumonia, syphilis and tuberculosis. These were chosen as they were both among the disease categories mentioned by Moss (1959) as affecting suture closure, and were the largest disease groups identified in the Terry collection. In addition those individuals with hyperostosis frontalis interna (HFI, grade 2 or above, see chapter 5) were also selected, as HFI is also

thought to affect the rate of suture fusion (Todd and Lyon, 1924, discussed at the start of this chapter).

As a control a sample of those whose cause of death was listed as accidental - including train crash, suicide and murder victims were also investigated (see chapter 3). These individuals could be described as those who skeletally should not be dead, and if suture fusion is mainly age related, then this sample should show one of the strongest correlations. It was not possible, however, to match this control group by age and sex for each pathological group as the sample of accidental deaths was so small (n= 11).

Materials and methods

From the original sample of 261 individuals from the Terry collection used in study 1 of this chapter all cases with the cause of death diagnosed as pneumonia, syphilis, tuberculosis, and accidental death. All individuals in the sample which had been given a grade 2 or above score for HFI were also selected. Table 6.3 below shows the number and mean age of death of the sample chosen.

	N =	Mean age	Max age	Min age	St.D	S.E. mean
Pneumonia	33	52.3	85	18	20.49	3.57
Syphilis	10	37.7	71	17	16.92	5.32
Tuberculosis	46	38.8	68	16	13.91	2.05
Accidental death	11	35.4	67	29	12.22	3.68
HFI	48	69.2	102	27	16.67	2.41

Table 6.3 Demographic profile of the samples studied

For each of the samples, the endocranial and ectocranial suture scores as outlined in study one of this chapter were correlated with age at death. Figures 6.9 to 6.18 below are plots of the endocranial and ectocranial scores against age for each sample. Table 6.4 below is a summary of the regression analyses.

Results

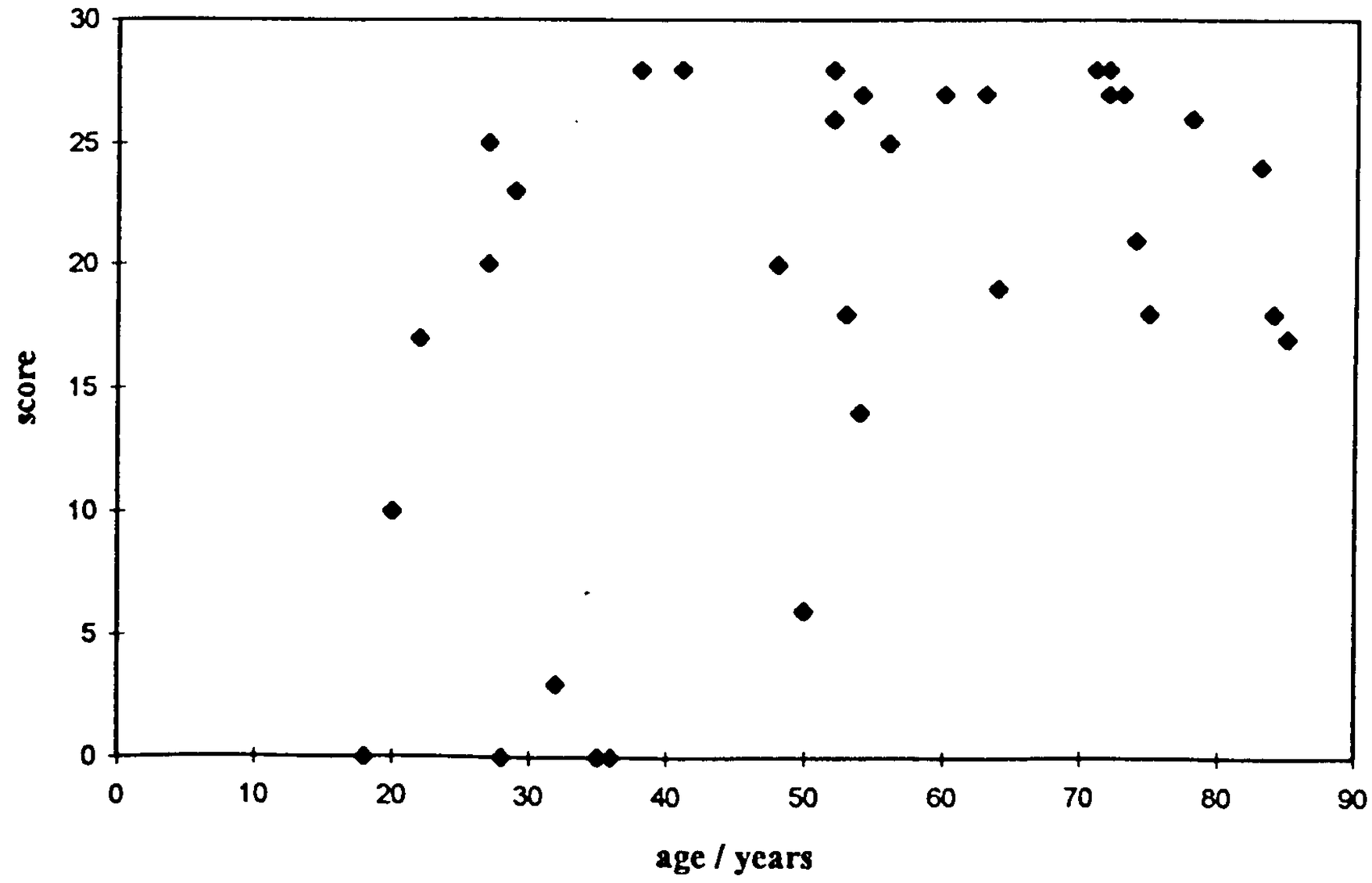


Figure 6.9 Endocranial suture score against age - pneumonia

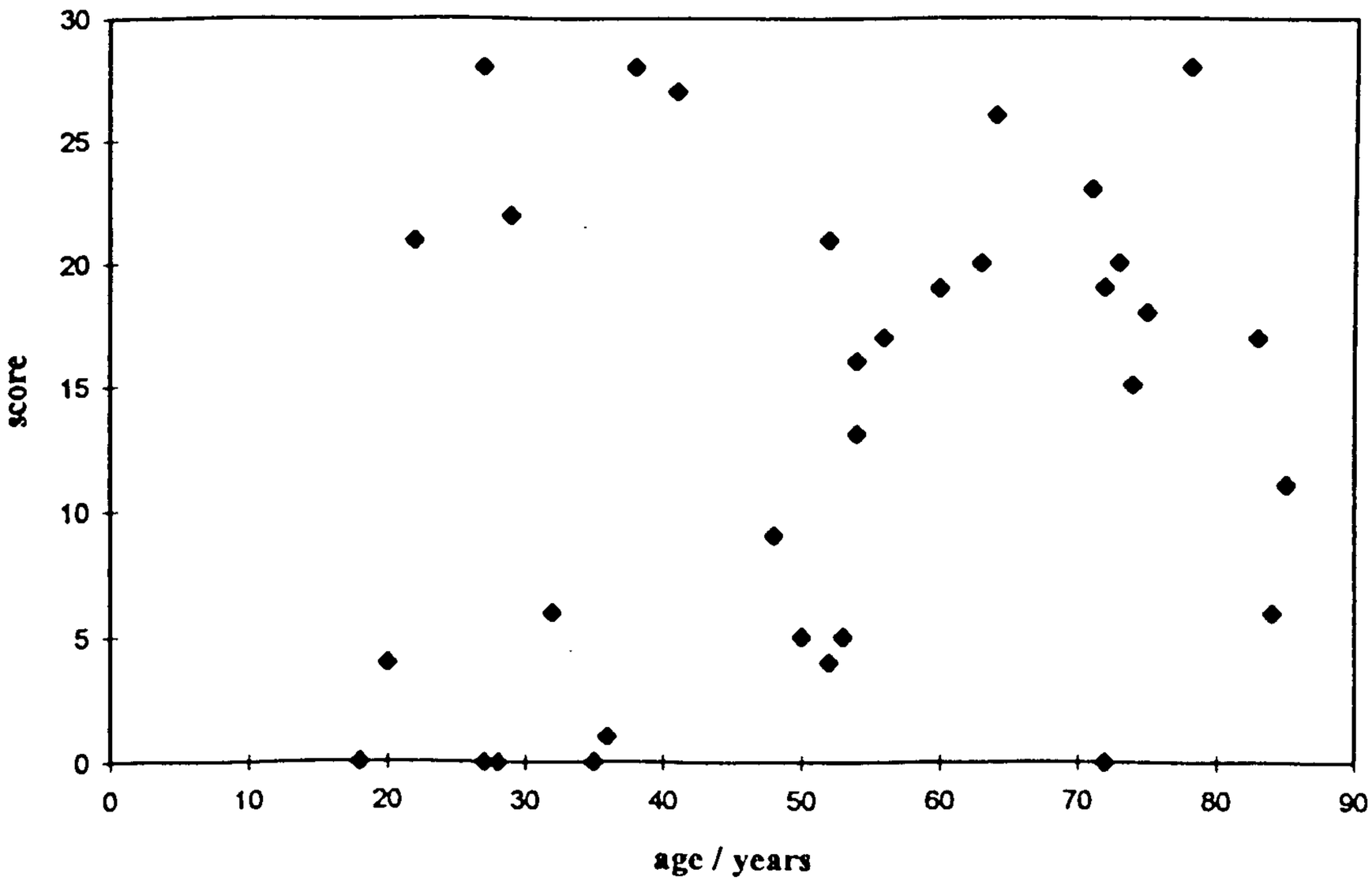


Figure 6.10 Ectocranial suture score against age - pneumonia

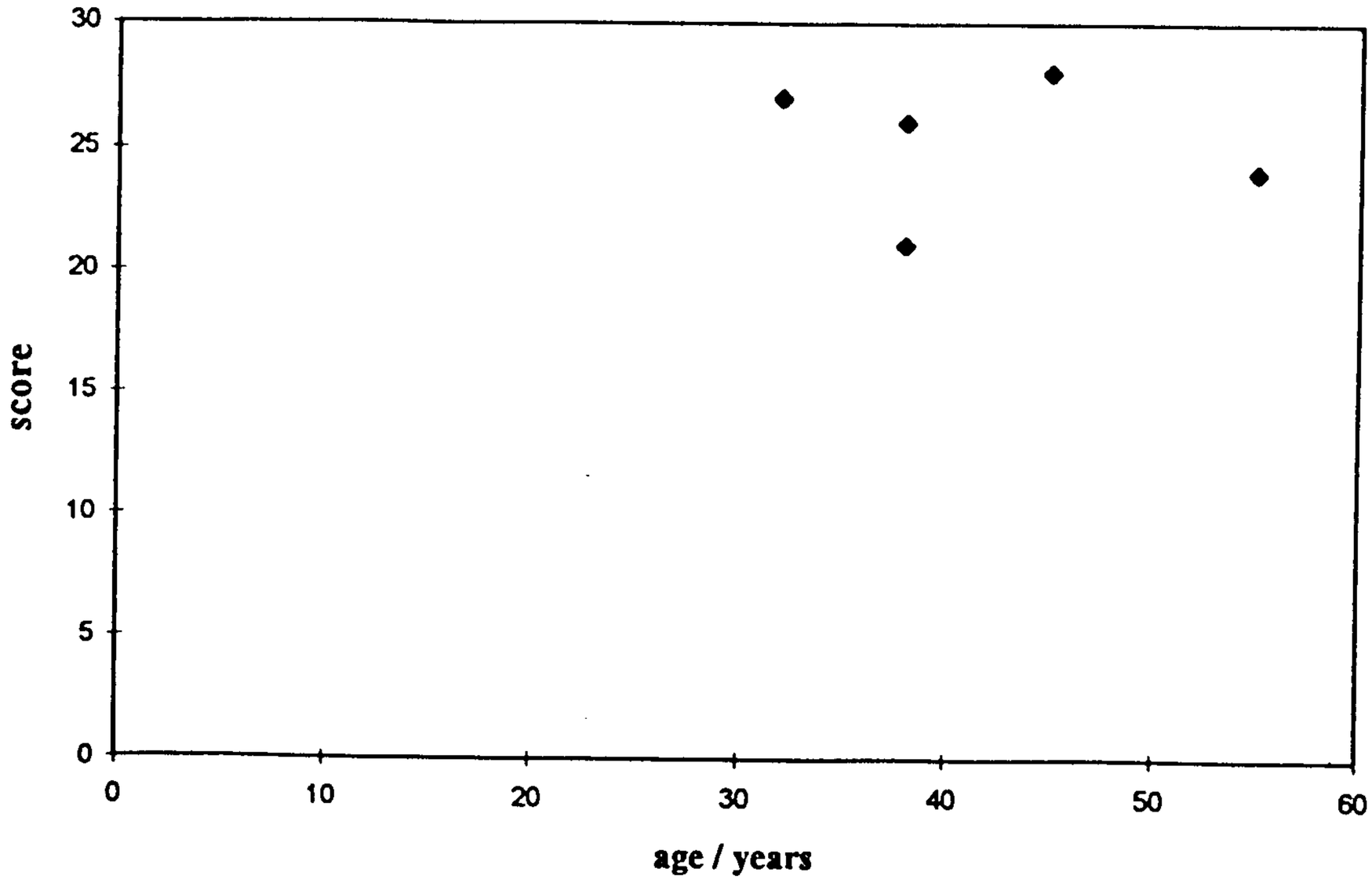


Figure 6.11 Endocranial suture score against age - syphilis

Figure 6.12 Ectocranial suture score against age - syphilis

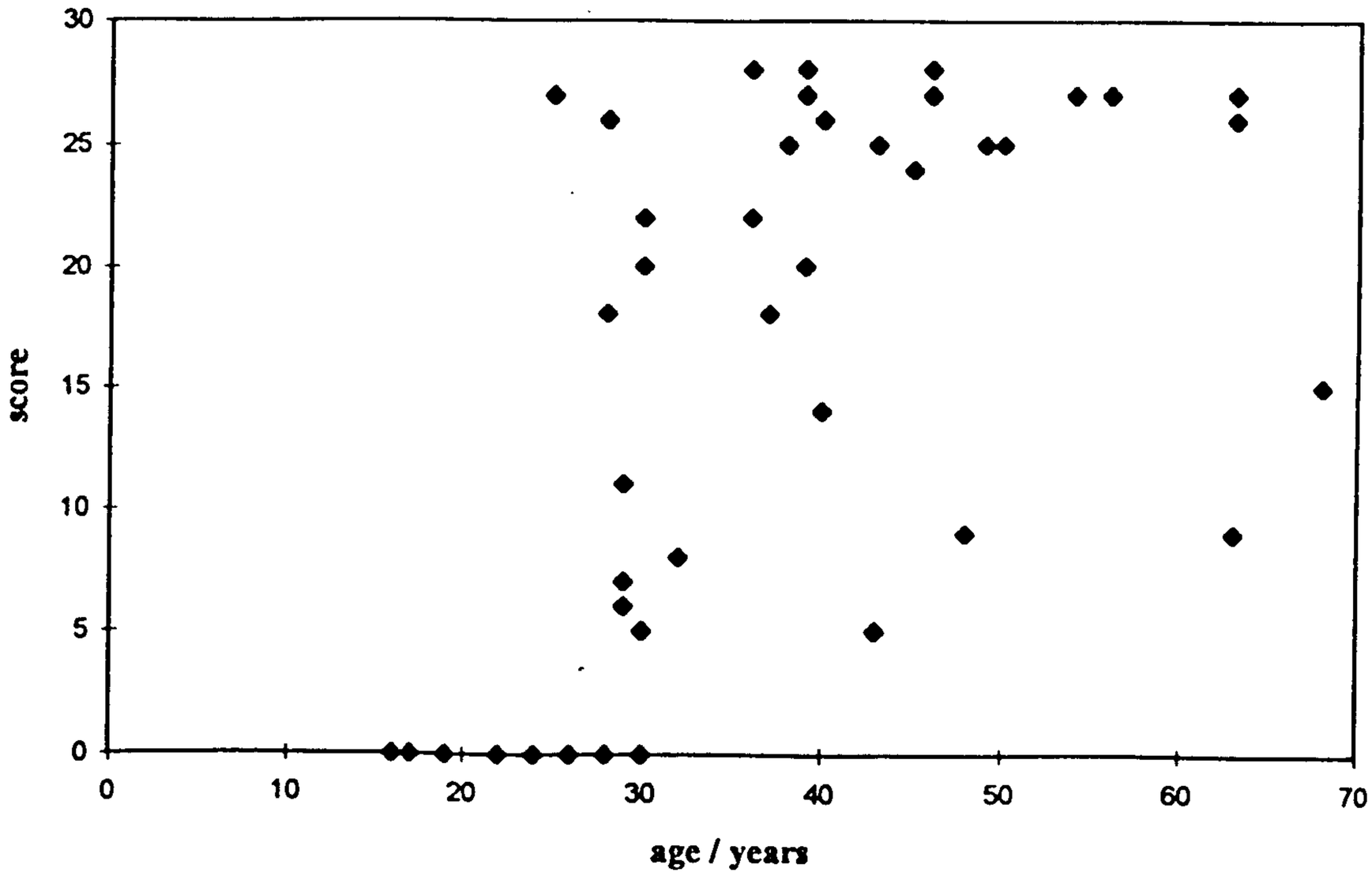


Figure 6.13 Endocranial suture score against age - tuberculosis

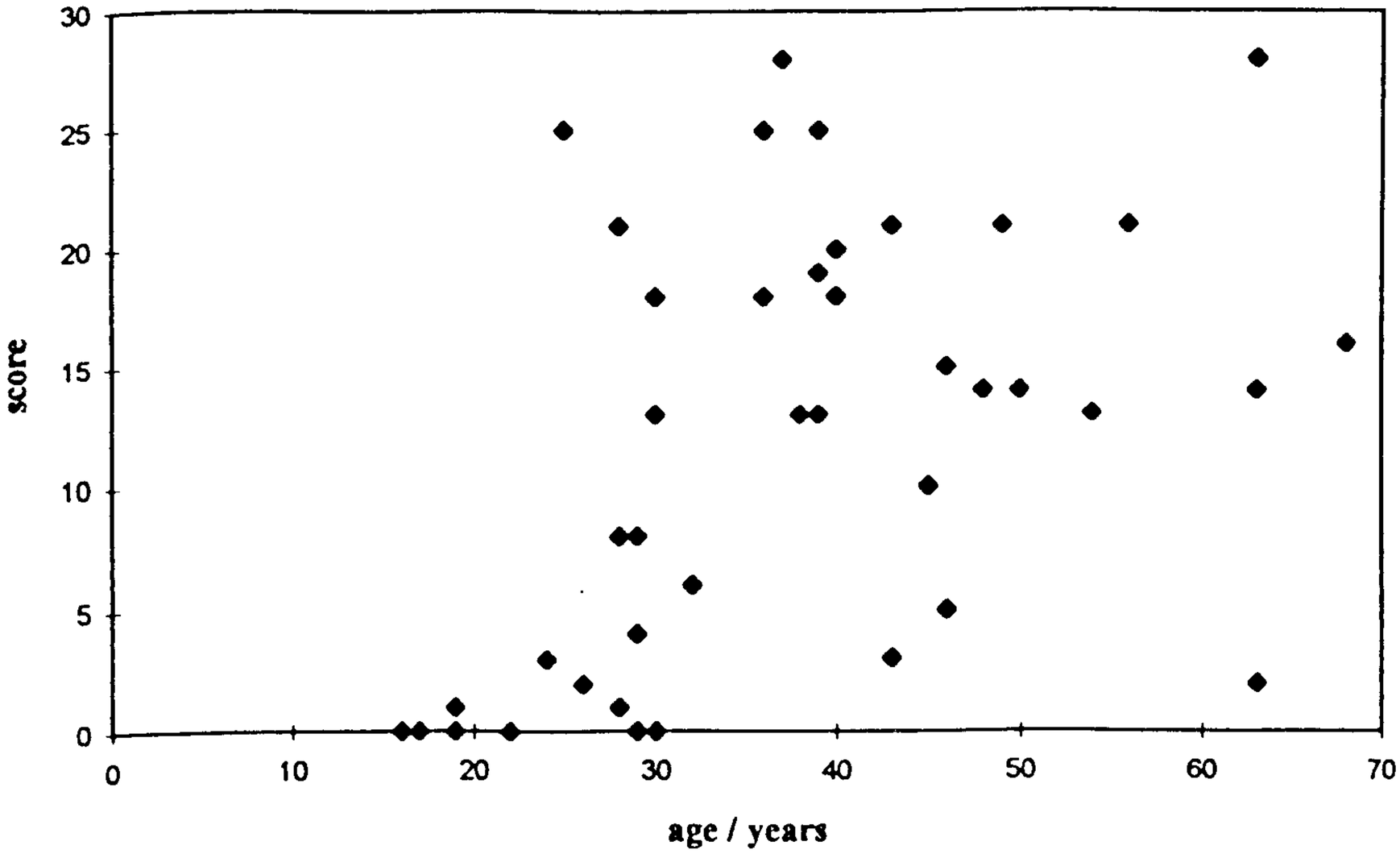


Figure 6.14 Ectocranial suture score against age - tuberculosis

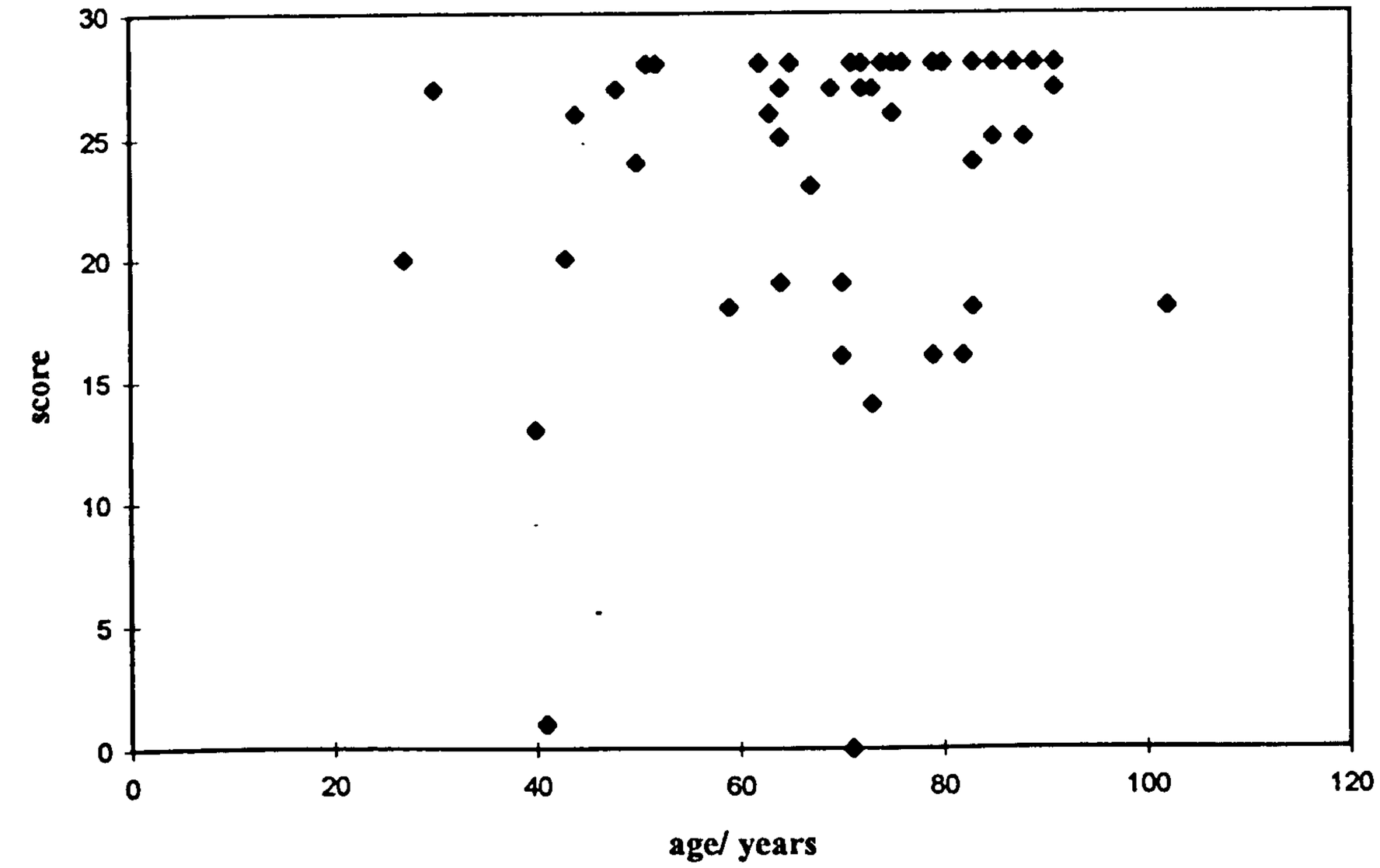


Figure 6.15 Endocranial suture score against age - HFI

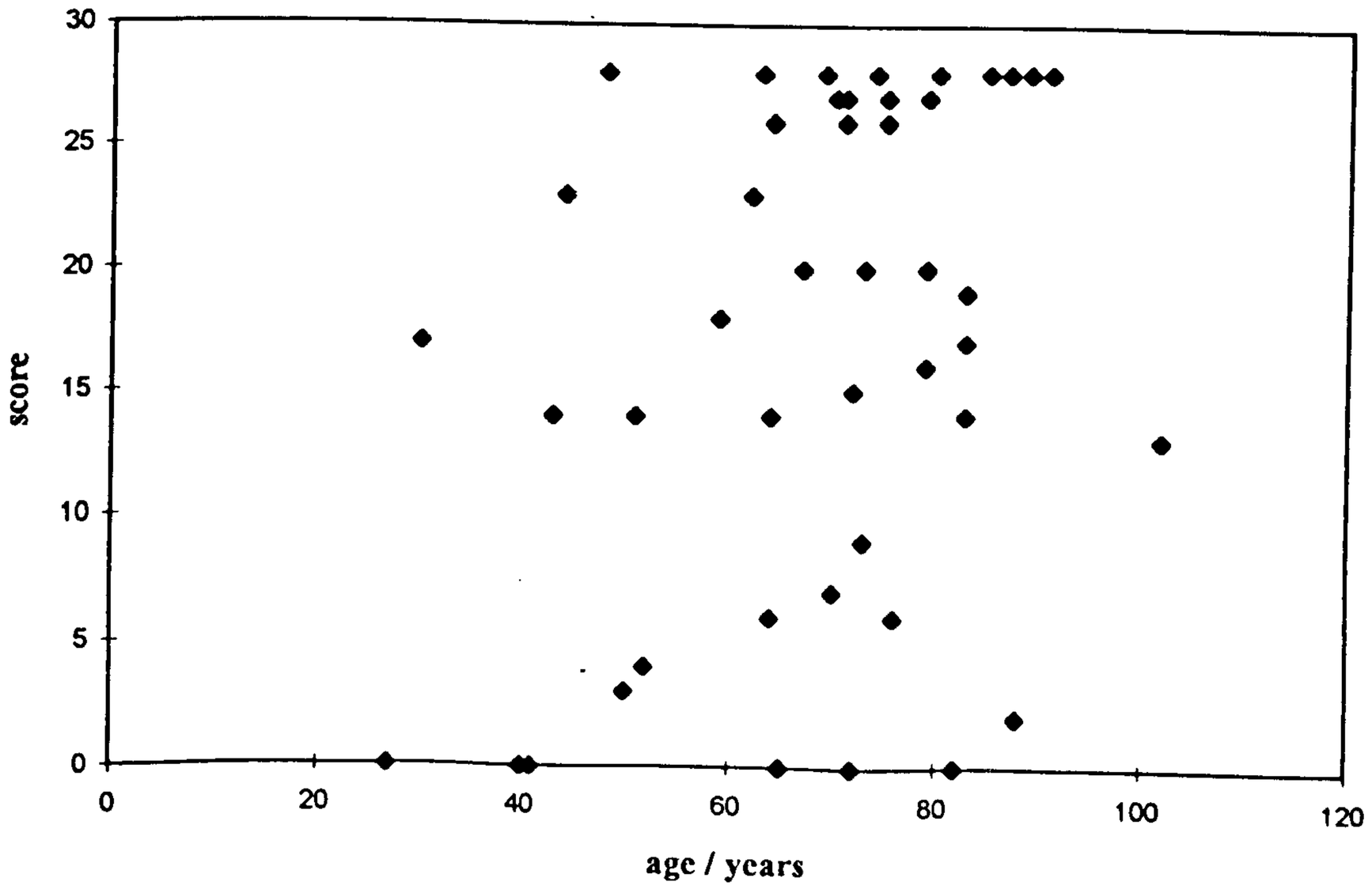


Figure 6.16 Ectocranial suture score against age - HFI

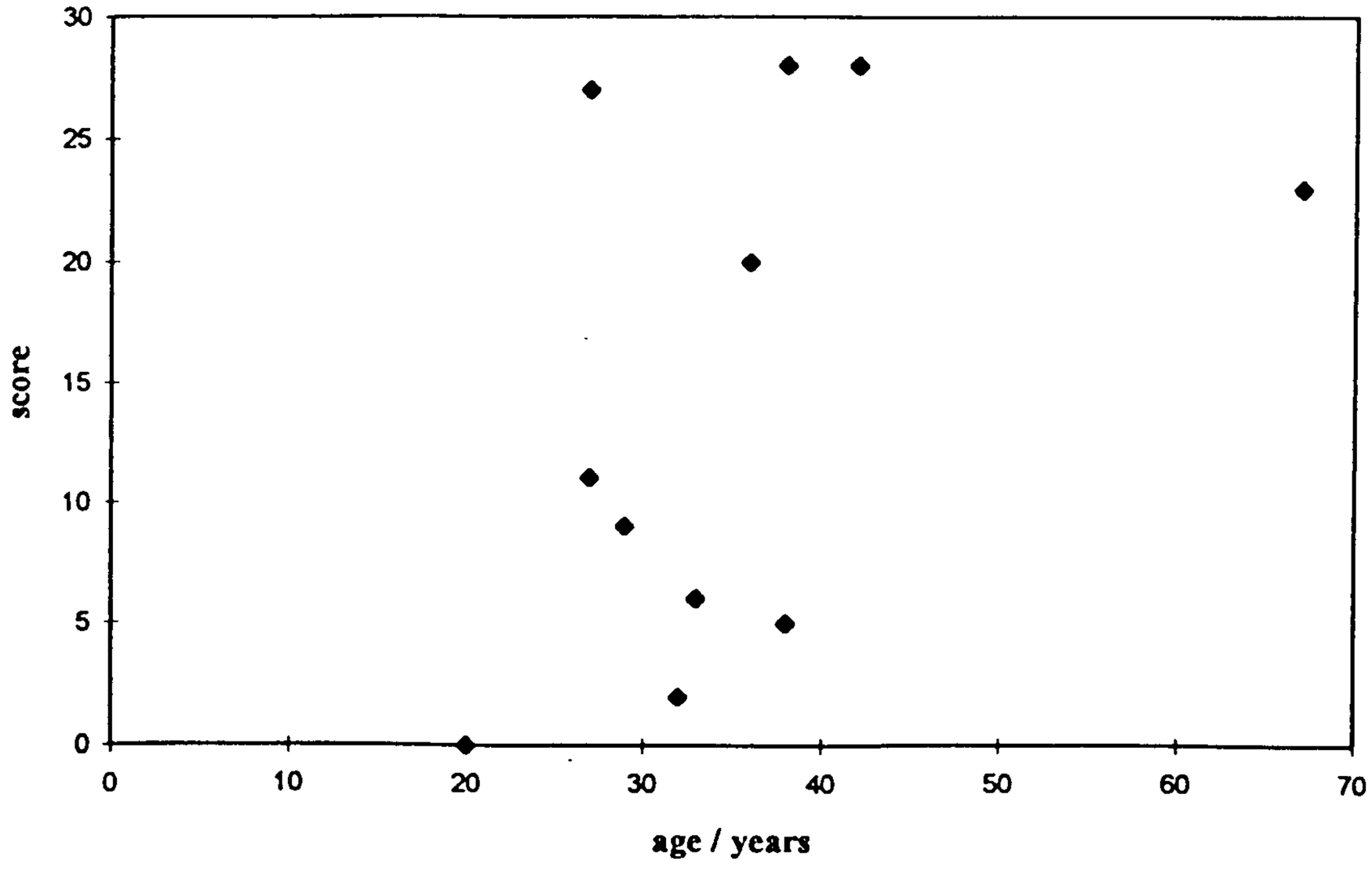


Figure 6.17 Endocranial suture score against age - accidental death

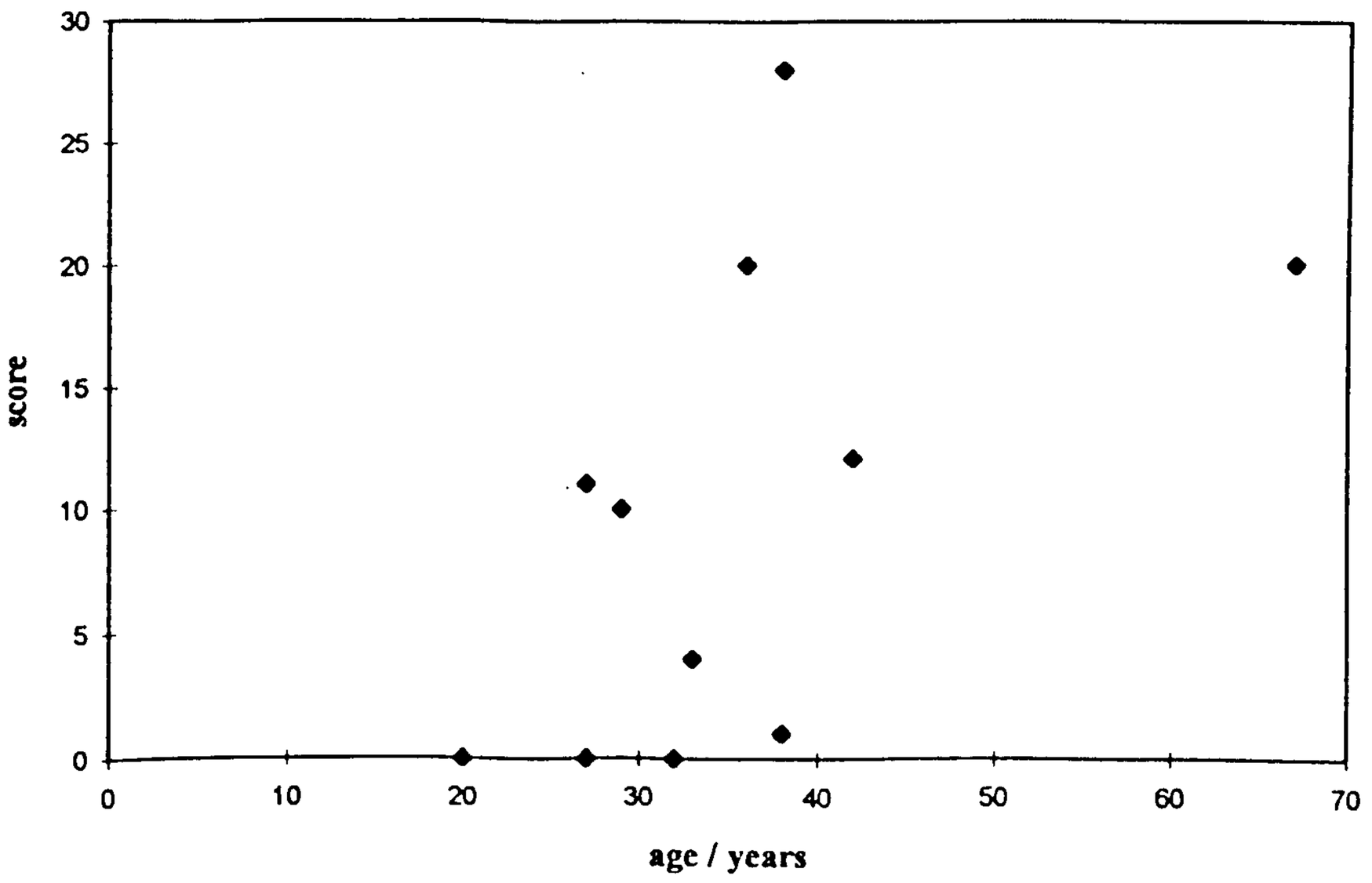


Figure 6.18 Ectocranial suture score against age - accidental death

	Endocranial		Ectocranial	
	p<	R-sq	p<	R-sq
Pneumonia	0.004*	21.2%	0.146	3.7%
Syphilis	0.211	8.6%	0.015*	48.3%
Tuberculosis	0.0001*	32.9%	0.001*	23.3%
HFI	0.160	2.2%	0.012*	11.1%
Accidental death	0.152	12.6%	0.089	20.8%

* significant at 5% or above

Table 6.4 Results of the regression analyses of endocranial and ectocranial suture scores against age, by disease category

Discussion

The graphs and tables above show some surprising results. In every disease category (see table 6.4) at least one of either the endocranial and ectocranial methods shows a highly significant correlation between age at death and suture fusion score. However in the "control" group of accidental deaths, there appears to be no correlation between age at death and suture score. It could be argued that the accidental group are, by nature younger, and do not cover a large enough age range to see the changes with increasing age. Table 6.3 shows that there is in fact little difference in the mean ages (and the maximum and minimum ages) of the accidental death group and the group with syphilis and those with tuberculosis, both of which show significant correlations with age. However, if one looks at the variation in the sample, it can be seen that although the means are similar, the accidental death sample are very closely grouped around the mean (see figures 6.17 and 6.18), whereas the age ranges for the other samples are greater.

A analysis of variance was then performed using a generalised linear model (GLM), to test whether it was the ages of each sample or really the disease categories that were changing the relationship between suture fusion and age. Each disease category, and the HFI group were compared to the accidental death group. Table 6.5 below shows the results of this analysis.

Accidental death compared to:	Endocranial (P=)	Ectocranial (P=)
Pneumonia	0.284	0.890
Syphilis	0.588	0.525
Tuberculosis	0.054	0.269
HFI	0.323	0.037*

* significant below 5% level

Table 6.6 Results of the ANOVA (GLM) comparing disease to suture fusion scores, taking into account the different age ranges for each disease group.

From these results it can be seen that although it initially appeared that disease had some effect on cranial suture fusion, the correlation can be explained by age in all of the disease groups. However, these results show that the ectocranial fusion rates of those may be affected in those with HFI. This might be explained by the new bone growth associated with HFI (see chapter 5), although the changes are endocranial, not ectocranial. This result might be caused by the "vicious union" suggested by Todd and Lyon (1924).

Conclusions

The results given here suggest that there is a relationship between the rate of cranial suture fusion and age, and it has a role to play in age determination although the correlations produced are weak. It would appear that there are many other factors which influence the degree of fusion, other than age, and these may include disease categories not included in this study. From the data presented here it is inadvisable to use suture closure alone for ageing, unless there is no other method available. For very fragmentary material which could not otherwise be aged an attempt could be made using the revised suture scoring method proposed in this chapter, but caution should be used. The most promising future for any cranial suture fusion techniques may be a part of one of the "complex" techniques in use at present (see chapters 1 and 3).

Further Work

A priority for further work would be to carry on the work in study 2 (looking at the effect of disease on suture fusion) of this chapter using much larger samples, with disease

categories not investigated in this study (such as meningitis or trauma, as suggested by Moss, 1957). It would be preferable to use more modern samples as these would have more reliable data on cause of death, as well as supporting soft tissue information. However, there is a great difference in the causes of death of those people dying at the end of this century even when compared to the 1930's and 40's (see chapter 3 for discussion on this). The ideal situation would be to carry out this work in a country which has a much similar range of diseases as earlier populations, such as a third world country, although with the rise in cases of tuberculosis in this country (Bhatti et al. 1995) it may not be long before part of this proposed work could be carried out in the U.K.

Chapter 7. Vascular Channels

Introduction

The endocranial surface of the skull is unique in several ways, as discussed in the introduction to this thesis. The skull is one of the most highly vascularized part of the skeleton (Aiello and Dean, 1990), and it is the only bony area that normally shows any trace of the vasculature which surrounds and interacts with it in life. It has the potential to be the best indicator of the vascular status in the skeleton once the soft tissue is lost.

The largest grooves present on the endocranial surface are on the parietals (see figure 7.1), although the temporal and occasionally the frontal bones can also display grooves (Mc Minn et al., 1981). A summary of the types of vascular grooves seen in the endocranial surface of the calvarium are listed below.

Sagittal sinus

The presence of a definite groove in the skull for the length of the superior sagittal sinus is rare. However, small parts of a groove can be seen in the frontal and in the posterior part of the parietal bones in about 50% of adults. The average width noted for the parietal groove is 6-8mm (Lindblom, 1936).

Transverse sinus

The sulcus for the transverse sinus in the occipital can be seen as a definite groove in 90% of children under 10 years, and at least a portion of the groove in 50% of adults (Lindblom, 1936)

Sigmoid sinus

In all adults and in most children over the age of 1 year a groove for the sigmoid sinus (which is in the occipital) can be seen. It averages 1-2mm wide (Lindblom, 1936)

Middle meningeal artery and vein - collectively called meningeal vessels.

The middle meningeal artery (see figure 7.1) is a branch of the maxillary artery that in turn stems from the external carotid artery (Gray, 1967). It enters the skull through the foramen spinosum in 99% of individuals (Chandler and Derezinski, 1935) and can be seen as a visible groove on x-ray from the age of two years (Lindblom, 1936). In the other 1% of the population it has an ophthalmic (Gabriele and Bell, 1967; Royle and

Motson, 1973) origin, although the branching pattern of channels appears on the parietals in the same way. The width of the grooves lies normally between 1.5 - 2mm. The line of the grooves can be straight to wavy, and is thought to be more markedly tortuous in hypertensive individuals (Lindblom. 1936).

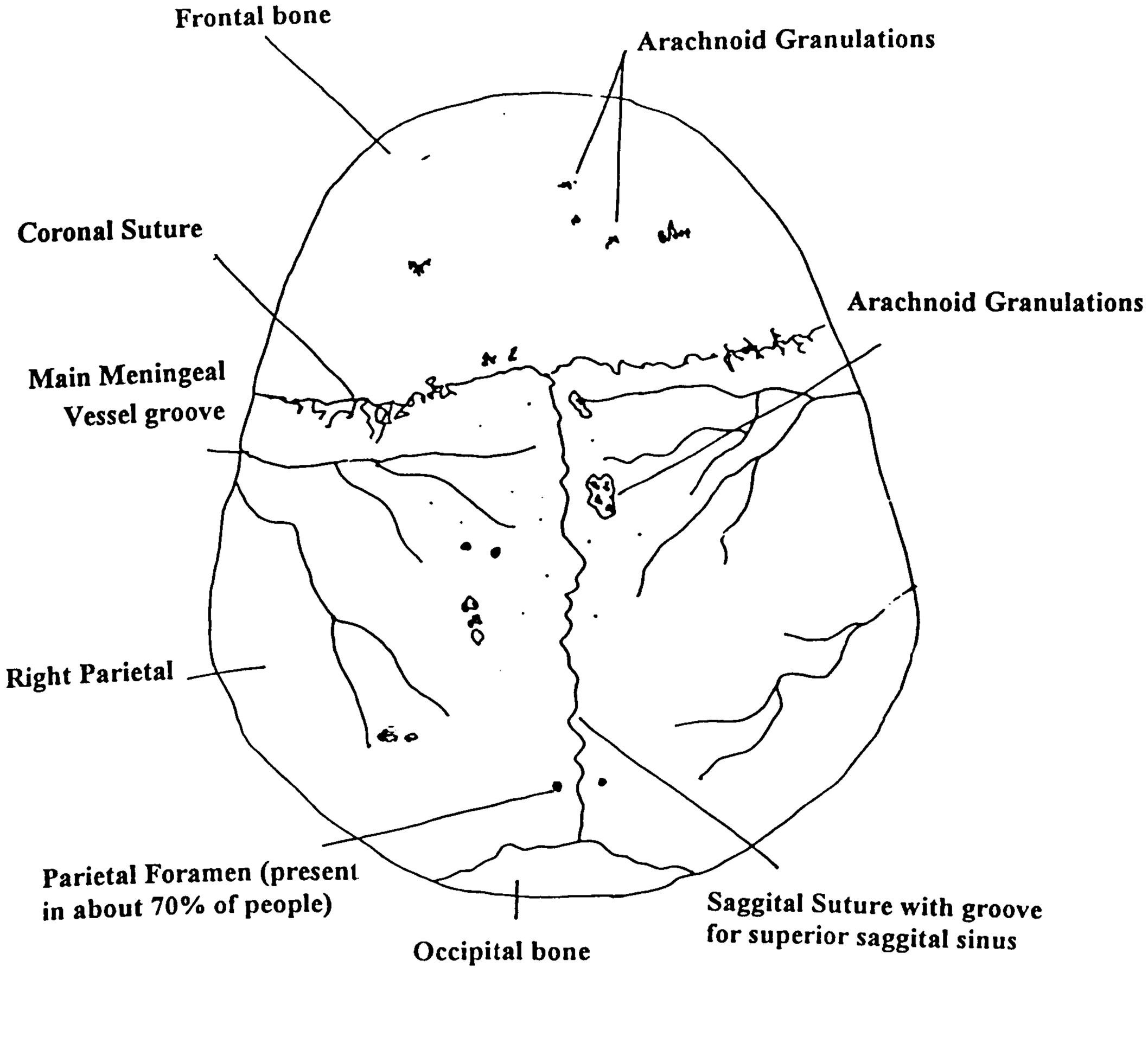


Figure 7.1 A diagram of the endocranial surface of the frontal, parietals and occipital bones, showing some of the normal vascular grooves which can be seen there.

The groove present on the parietals (see figure 7.1) often contains both the meningeal vein and the artery (see below for further details), with the anterior branch of the vein becoming relatively larger than the artery towards the bregma. Bridges of bone of varying length can occasionally be seen to cover parts of the vessel groove. It is thought that this bridging increases with age (Lindblom, 1936), but is a normal feature of the vessel channels.

Normal vascular grooves

The presence of vessel grooves on the endocranial surface of the skull has been known almost since the study of anatomy began. Both Crooke (1615) and Bartholin (1673) appear to have first hand knowledge of the vascular markings. Willis (1682) notes "within the hollow superficies of the skull there appear many furrows and inequalities imprinted by the protuberance of the vessels". It was at the end of the last century, however that substantial work began in the subject. It was unclear as to what the grooves were carrying - veins or arteries, or a mixture of both. It was generally assumed that the grooves were caused by arterial pressure. Willis (1682) had suggested that the grooves were caused by the continuous beating of arteries which "easily imprint the marks of their tracts". In 1891 Breschet and later Schultze (1899, both quoted in Wood-Jones, 1912) thought that the grooves could also have been caused in part by venous pressure. Elliot-Smith (1905) thought the vessels were clearly arterial in character, and noted that large vessel grooves could increase the chances of fracture following a blow to the skull. Wood-Jones (1912) believed that the problem of what the grooves contained was partly caused by the difference in observation between anatomists and medical artists. He saw that anatomists drew the vascular channels as if they were arterial in origin, with a tapering end to the branching pattern, whereas artists drew them as they saw them with no preconceptions - as becoming wider the further out they spread. Wood-Jones then carried out his own study on a post-mortem subject, as well as looking at an unspecified number of dry skulls. In the dry skulls he noted that the vessel grooves did not taper, but widened with distance from the foramen spinosum. He argued that the size of the foramen spinosum was too small to contain an artery, and in any case not all impressions led to the foramen, several ran towards known venous channels instead. Later work by Chandler and Derezinski (1935) showed that this assumption was incorrect, with the middle meningeal artery going through the foramen spinosum in 99%

of skulls in their study (n=1200). Wood-Jones made casts of the vessels and noticed there were separate markings for both veins and arteries, often in the same vascular groove. In the post-mortem skull he found that again both veins and arteries occupied the same space, but the arteries formed "a very inconsiderable part of the whole vascular channel", although he noted that there was much variation as to the exact position of the artery in the sinus.

Coen (1913) suggested that it was not only the meningeal vessels which caused the parietal grooves, but that diploic veins also played a part in creating the channels. He studied a post-mortem skull and suggested that some of the larger grooves were made by diploic venous tissue which "has come to the surface by the erosion of the inner table of the skull". It is because of all the supporting evidence that the term meningeal vessels is used instead of artery and / or vein. In addition Coen was one of the first researchers to hypothesize that the vessel size increased with advancing age (due, he believed, to atrophy of the skull in senility).

At around the same time other researchers were using endocranial casts to determine the size and form of the brain with special emphasis in determining how primitive early man was (Boule, 1909; Boule and Anthony, 1911) which carried on from Broca's original work in 1866 (the racist context of which is amply dealt with in discussion by Gould, 1981). Symington (1916) used endocranial casts to challenge these earlier speculations, concluding that "the simplicity or complexity of the cerebral fissures and convolutions cannot be determined with any degree of accuracy for endocranial casts...and the various deductions made... with reference to the primitive and simian features of brains of certain prehistoric men, from an examination of their endocranial casts are highly speculative and fallacious". It is unfortunate that however correct his conclusions were, the bulk of the argument in his paper focused on the Piltdown skull which has since been pronounced a fake.

Thompson (1926) looked at the presence of large vascular channels in skulls. He found that they were present in both thick and thin skulls (see chapter 4 for a further discussion on the relationship between skull thickness, age and pathology) and suggests that they could be caused by a process of attrition.

In 1928 Adachi produced a system for the classification of meningeal vessel patterns in man which followed on from a four type category described by Giuffrida-Ruggeri in 1912.

Lindblom (1936) carried out the first major radiological study on the vascular channels of the skull. He studied 450 patients who had been x-rayed to determine the extent of a recent head injury. In addition he looked at 49 cadavers, both post-mortems and dry skulls. He outlined normal patterns for all the main veins and arteries over the dura and inside the skull, as well as producing normal values for the shape and size of most of the foramina in the skull.

Pathological vascular grooves

The work by Lindblom in 1936 was the first x-ray study to look at both normal and abnormal vascular markings in the skull. His findings on normal groove shapes and sizes are outlined above. Although this thesis concentrates on normal vessel patterns, it is important to have a knowledge of what can cause abnormal vascular patterns.

The main pathologies to affect the vascular grooves of the parietals are intracranial tumors (e.g.Gliomas), arterio-venous aneurysums and meningiomas. Increased intracranial pressure can cause widening of the emissarium occipitale, foramen spinosum and other foramina, although not all cases clinically diagnosed may show noticeable changes. A less common sign is the symmetrical decrease in the appearance of vascular markings on x-ray (Lindblom, 1936). A change of vessel shape around meningiomas (especially the frontal or parietal parasaggital ones) can help with location and characterization. Wide arterial grooves can indicate a local tumor, but it may not be observed in every case, and should be used in conjunction with the changes in the foramen spinosum mentioned above.

Age and Vascular channels

In addition to pathological causes of vascular groove changes it is believed by several researchers that increasing age can change the shape of the channels. Wood-Jones (1912) and Coen (1913) were two of the first to mention the changing shape of vascular channels in relation to age. Loeschke and Weinnoldt (1922) and Mair (1926) in Lindblom (1936) thought that the grooves become relatively deeper with increasing age

due to deposition of bone on the endocranial surface of the skull. Cobb (1952) states that the grooves for the meningeal veins show "a deepening and sharpening of their margins" with increased age. Arensberg (1989) looked at the depth of the middle meningeal artery grooves in his study of the endocranial surface of the skull. He recorded the depth of the vessels as shallow (less than 1.5mm) medium (1.5-2.5mm) or deep (over 2.5mm) and he found a trend to an increase in depth in his "old" group of individuals. He noted the range of width of the vessels (from 1 to 5mm) but did not attempt to correlate any differences with age. The sample he used for this study is the same as that used for his work on arachnoid granulations (see chapter 8) which was made up of skeletons of both known age, and those anthropologically aged. The problems inherent in using a sample of this nature is discussed in chapter 3.

Although the apparent increase in vessel size with age is quoted in the literature above no systematic study has been undertaken on a sample of only known age at death individuals to see if there is a measurable correlation between vessel shape (width and depth) and age.

Anthropological / Archaeological work on vascular channels

Studies by anthropologists have focused mainly on three areas;

1. how vessel groove patterns have changed during evolution
2. the extent that cultural practices (such as cradleboards and cranial deformation) have on vessel and skull shape
3. the pathological presence of abnormal amounts of extra vessel markings, often termed "hypervascularity"

Evolution and Vessel Grooves

The literature on vascular markings in hominids is vast, and it is beyond the scope of this thesis to discuss in detail. Work by Tobias (1967, 1968) Kimbel (1984), Falk (1986, 1993) and others have used venous and sinus drainage patterns to support differing theories of hominid phylogeny and evolution.

Cranial deformation

Several papers have mentioned how the practice of deliberate cranial deformation for cultural purposes has changed the ectocranial surface of the skull (such as Holliday,

1993). Less has been written on the changes caused by cranial deformation to the endocranial surface. Grupe (1984) looked at the x-rays of 60 skulls classed as deformed, and found that the vessel grooves in the deformed area were wider, deeper and had altered pathways. Dean (1995) looked at 21 crania from two anthropological collections, six of which fitted the classification of Neumann (1942) as being deformed. Endocasts were made of the skulls and she found that vessels under the area of direct deformation showed the most change, with a compensatory enlargement of the surrounding vessels. Asymmetrical deformation caused asymmetrical changes of the vascular markings.

Hypervascularity

Koganei (1911) first noticed the closely woven patches of bone (see figure 7.2) with many hypervascularized channels, which he termed "internal cribra cranii" and attempted to associate this with external skull changes thought to be caused by iron deficiency anaemia. Henschen (1960) suggested that they were caused by "environmental factors".

Figure 7.2 Endocranial surface of a 6 month old child with endocranial hypervascularity

This changed bone appears most commonly in children between the ages of 6 months and 2 years (Schultz 1993a) and most frequently on the parietals, frontal and then occipital bones. If it appears on x-ray (which is rare, see figure 7.3) the changes are subtle, and have been mistaken radiologically for the woven bone present in the growing skull of young children (du Boulay, 1980).

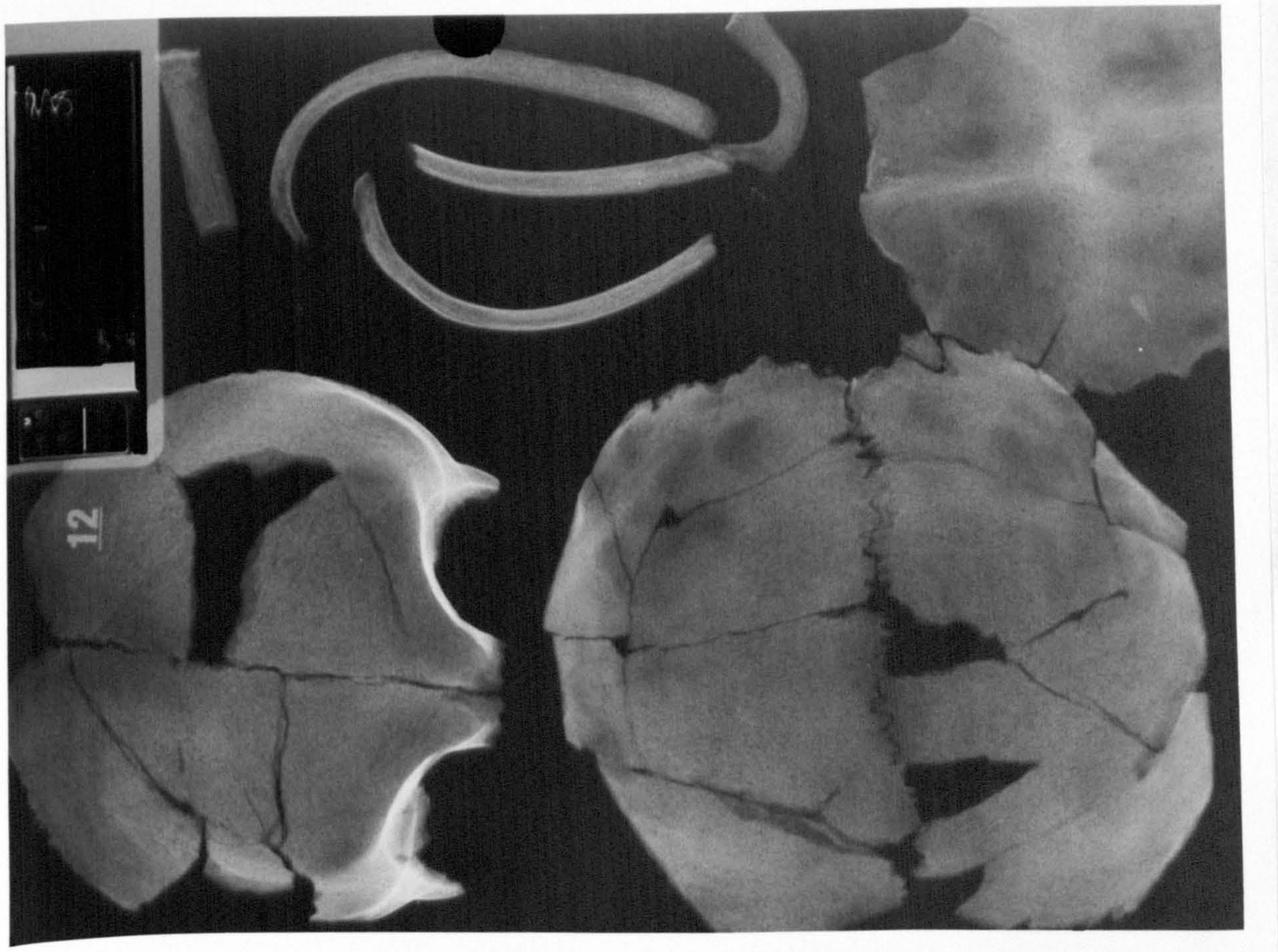


Figure 7.3 x-ray appearance of sk 2021 in figure 7.2 above

More recently work by Schultz (1993a, 1993b) and (Kreutz and Schultz, 1994a,b) has begun to classify types of hypervascularity. The results claim to be able to identify several categories of endocranial bone change caused by specific diseases including bacterial and tuberculous meningitis, based on histological changes. A major problem with this work is that it is based almost entirely on archaeological material, or skulls from an anthropological collections, not from patients of known medical history with soft tissue findings to support the diagnosis. Although Schultz lists 16 modern specimens in his study (1993a) all the cases he discusses are from dry skulls. He lists meningitis (both

tuberculous and bacterial) as one of the most common causes of endocranial hypervascularity, but there has been some debate as to how fast bone reacts to disease (Xth European Meeting of the Palaeopathology Association, Gottingen, 1994). Meningitis is often fatal, and would have been more so in the past, without antibiotic assistance. It is often only a matter of hours between diagnosis and death in modern cases (Lincoln and Sewell, 1963) and this is not enough time for the bone to react. Although it is not known how quickly the endocranial surface of the skull reacts, the standard time given to a young, otherwise healthy patient, to unite a simple fracture of the tibia is 12-16 weeks (Mc Lathchie, 1990).

Schultz counters this argument by pointing out that some forms of meningitis (such as tuberculous) are often chronic in nature, with weeks, possibly months of infection before death. This would provide enough time for bone reaction to occur but others (Lincoln and Sewell, 1963) have argued that most untreated cases are fatal within two days. In addition, Schultz does not explain how he can identify bacterial meningitis without the use of modern clinical samples, and there is still some debate about this diagnosis (1995 and 1996 meetings of the American Association of Physical Anthropologists).

In adults the hypervascular changes are more subtle and are seldom noted. When they are present the sagittal and sigmoid sulci are most frequently affected (Schultz, 1993a). In more recent human bone reports from archaeological sites the frequency of hypervascular changes on the endocranial surface of the skull have been noted, although little analytical comment is made. Mensforth et al. (1978) found that 64% (n= 87) of the children from one of their sites showed endocranial hypervascularity. Brothwell and Browne (1994) suggest that the endocranial changes noted on 15 of the infant skulls from their site at Jewbury might not be due to cribra, as stated by Koganei (1911) but to tuberculous meningitis.

Summary

It can be seen from the literature above that although much work has been carried out in determining the contents of the vascular markings, and how pathology can change vessel (and so the groove) shape and size, there is much which remains unknown. It is a commonly held belief that the vessel grooves change with age, yet little work has been carried out to measure the normal range of the vessel grooves in the skull, and no proper

correlation of measurement and age has been attempted. It has been noted that the extent of vascularity of the grooves can vary with age and also disease, but a more complete survey of the range of vascularity has not been undertaken.

Hypervascularity is a common feature on archaeological infant skulls, and past work has attempted to isolate the cause(s) of this phenomena, all of which points to a pathological aetiology. However, little research has been carried out on adults, and on those of known cause of death, to see if these changes can be tied to specific diseases.

Aims

Three studies to investigate aspects of endocranial vascularity were undertaken:

1. A study of the shape and size of the main meningeal vessel groove in individuals of known age at death

2. A survey of the number of vessel branches on the parietal bones in individuals of known age and cause of death

3. A survey of the types of hypervascularity on the frontal, parietals and occipital and its relationship to known causes of death.

1. Shape and Size of Meningeal Grooves

Choice of site

It was decided to take all measurements from a standardised part of the skull. It must be remembered that the groove is only effectively a portion of the total vessel area (see figure 7.4), and it was not possible to determine that the total area covered by the vessels was represented by the groove. For the purpose of this study it was assumed that each groove accurately represented a set proportion of the size of the vessel(s) originally within it, and that this proportion remained constant both within a skull (i.e. if the vessel cross-section was smaller in one area, this indicates the vessel in that groove is smaller) and between individual skulls (i.e. if a cross section of the groove represents 50% of the total area of the vessel, this figure would be the same for all individuals).

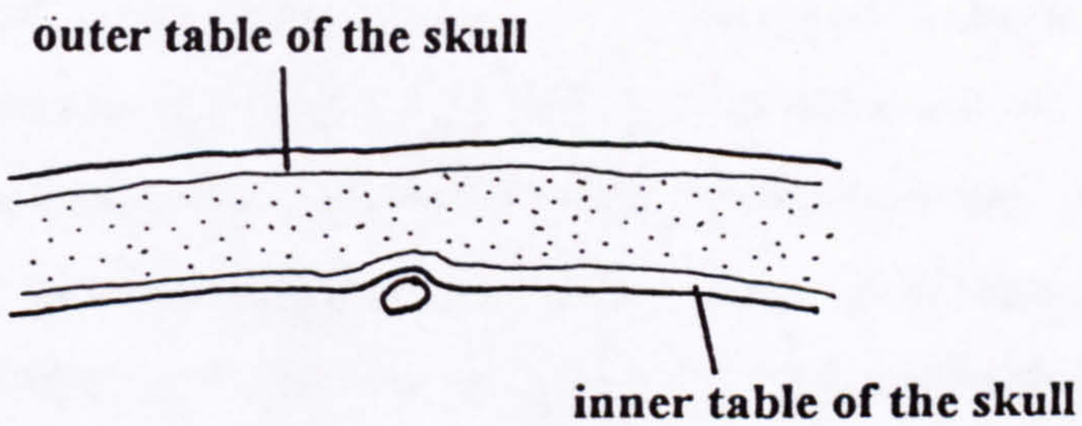


Figure 7.4 Hypothetical cross section of the vessel and groove

After some consideration it was decided to take measurements from a cross-section of the main meningeal groove at the base just before the first branch (see figure 7.5). This point was chosen because it was one of the few points which could be reproduced in each skull, given the diversity of branching patterns. It was also thought to be more representative of the original vessel area (subject to the provisos outlined above) as when the vessel branches, it is assumed that the size of each "daughter" vessel diminishes accordingly.

Figure 7.5 Plaster cast showing the chosen site to measure the main meningeal vessel groove, marked by the line just inferior to the first branch of the main meningeal vessel groove

Methodology

An alginate cast was taken to cover the area outlined above (see figure 7.5) and a stone positive was then made from the cast. A cross section at 90^0 to the groove inferior to the first branch was measured using a reflex microscope (see chapter 3). For each cross - section a minimum of eight measurement points were taken (as advised by the accuracy tests in chapter 3) across two dimensions - length and height, with the width co-ordinate remaining constant. These co-ordinates were then plotted to give a cross-section graph (see figure 7.6 as an example). From the graphs, two measurements were taken;

1. Maximum width of vessel, from edge to edge of the section
2. Maximum depth of the vessel, at 90^0 to the maximum width

and then a third score was calculated - a width / depth index of measurements 1 and 2 to attempt to identify any overall shape in the vessel groove.

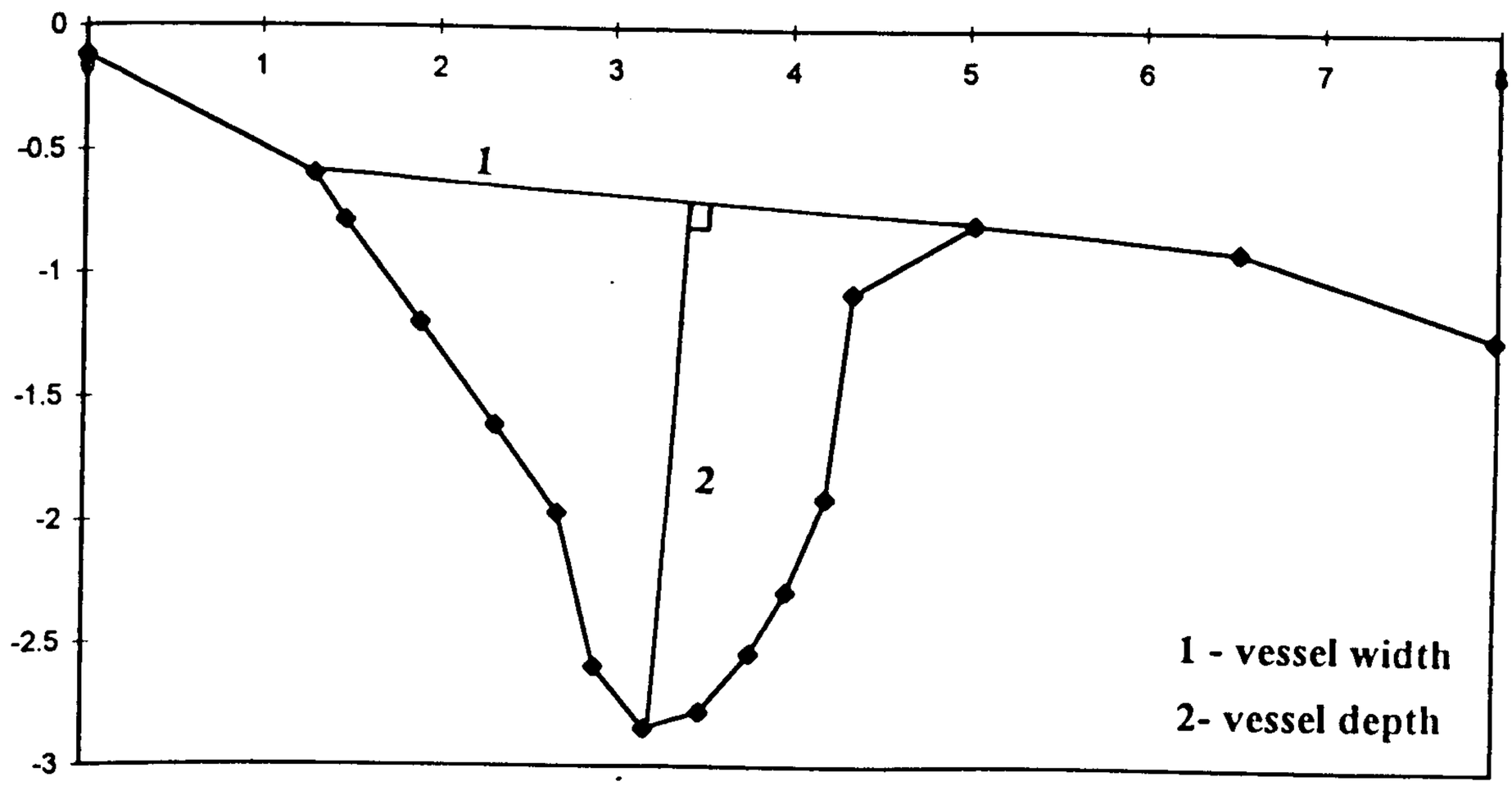


Figure 7.6 Example of a cross section, showing the measurements taken

Reproducibility

For each sample a selection of skulls were re-measured (a test of the accuracy of the casting method itself is given in chapter 3) and cross sections drawn. A comparison of the first and second set of measurements was achieved by calculating an inter-class correlation coefficient. This gave a score of 0.97, indicating excellent reproducibility.

1a Pilot study on modern post mortem cases

Sample and method

Two samples were chosen for a pilot study of known age at death. As the casting and measuring process is very time consuming (it was calculated that to cast and measure one cross-section took 2 hours) and the materials used are difficult to transport, it was decided to use the modern Bristol post-mortem sample first and to test the American sample only if the results appeared promising. The post mortem sample was very small (see table 7.1 showing three left and five right samples from six individuals) as the post-mortem cut to remove the calvarium tended to be above the site chosen for measurements and so couldn't be reached. In addition, as some of the post-mortems were subject to coroners inquest, no alginate (or any other substance that could affect forensic reports) could be used on the bodies.

As the sample was so small it was decided to supplement it with a selection of 27 skulls from the Barton-on-Humber collection. The use of anthropological material to look at age related changes is fraught with problems, as mentioned before (see the discussion on work by Arensberg above). To counteract this problem young individuals were selected as they are easier to age accurately (Brothwell, 1981), and the results are given separately to those of known age in the pilot sample. The mean age of the post-mortem sample was 78.4 years, and the addition of a young sample would give an idea of changes at both ends of the age profile.

It was not always possible to cast both left and right sides of every skull (due to differential preservation in archaeological material, broken skulls or uneven post-mortem cuts). It was decided that a selection of skulls would have their left and right sides cast, and that the others in the sample would then have only one side cast. The best of both sides were chosen for casting, and this was determined by the completeness and state of the skull, and ease of accession to the site of measurement. Where both sides were equally suited for casting, the side cast was randomly chosen.

sample	n=	mean age	min age	max age	left cast	right cast	both left and right casts
Post Mortem	6	78.4	65	96	4	6	4
Barton	27	21.1	0	45	15	14	2

Table 7.1 The pilot study samples

For each of the two pilot samples a plot was drawn of width against age, depth against age and width / depth index. If the plot appeared to show some correlation, a linear regression analysis was carried out for that sub-sample.

Results 1 - The pilot study

Post-mortems

Figures 7.7, 7.8, and 7.9 show age against width, depth and index. The sample was too small to differentiate between left and right measurements , or between male and females.

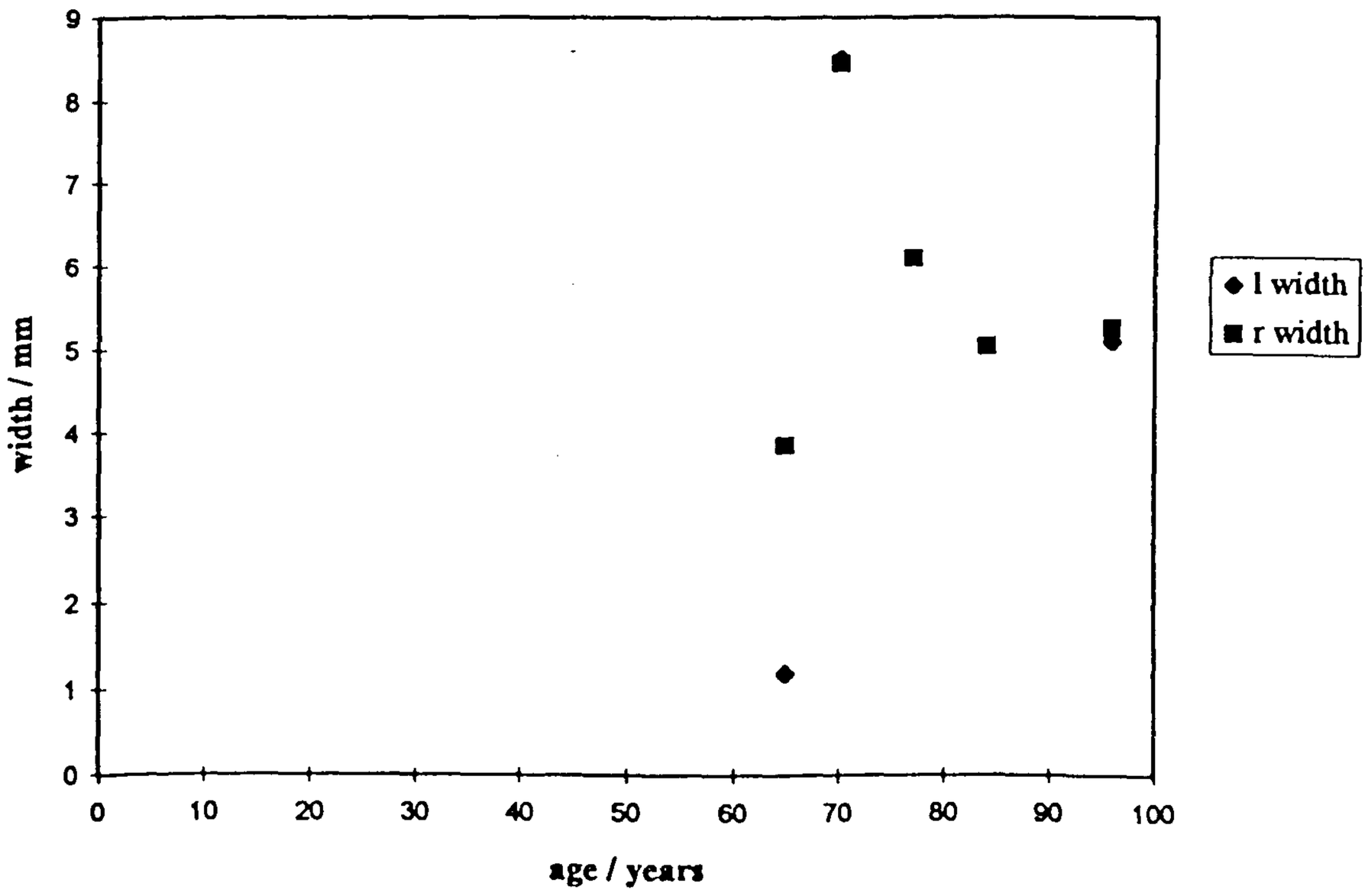


Figure 7.7 Width against age - Post-mortem

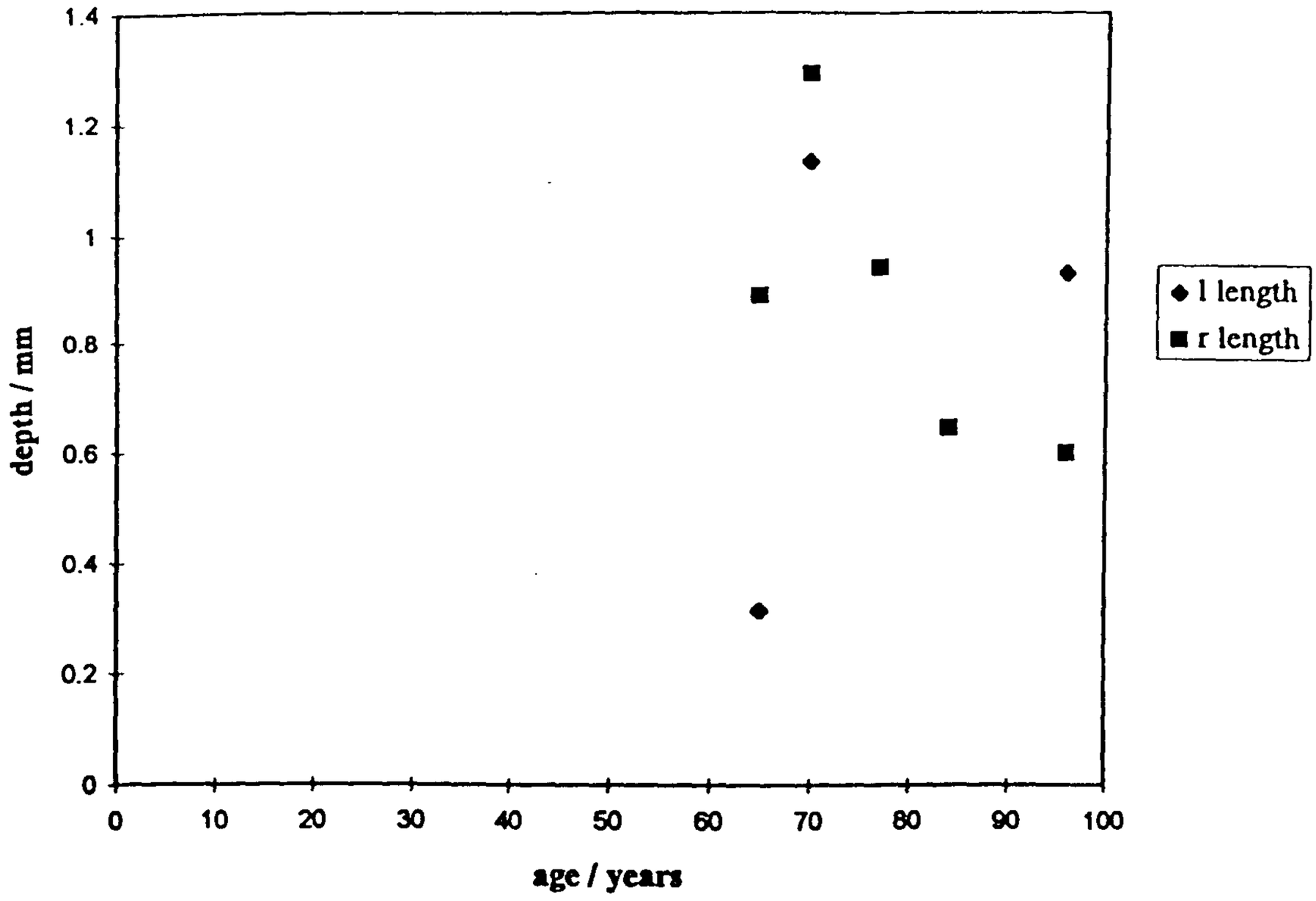


Figure 7.8 Depth against age - Post-mortem

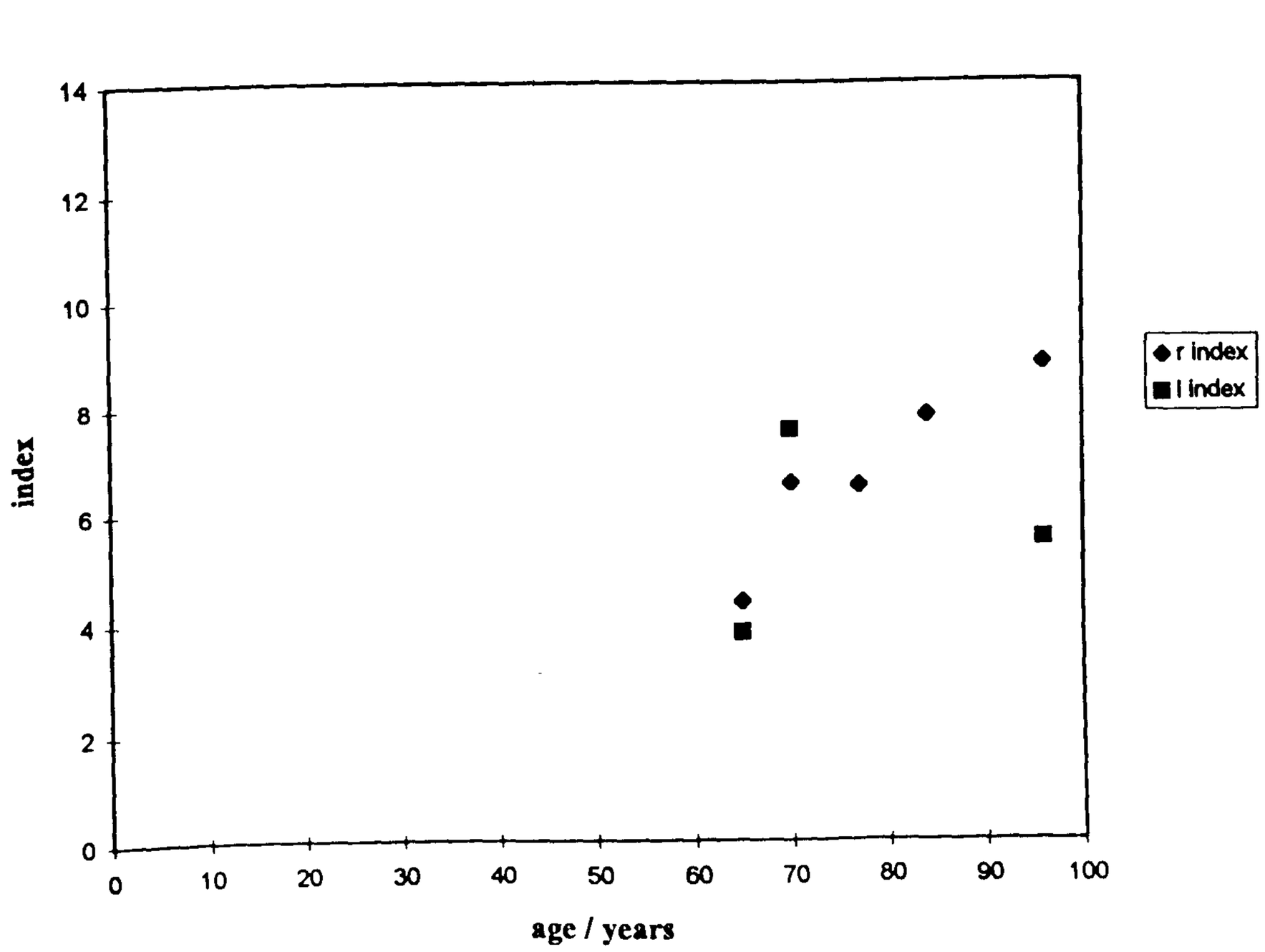


Figure 7.9 Width / depth index against age - Post-mortem

Although the numbers are small, it can be seen that there is no correlation between depth or length and age. However, it would appear that the width / depth index does have some correlation with age. Tables 7.2 and 7.3 below show the results of the regression equation of both left and right indices against age.

Parameter	Co-ef	St dev	t-ratio	p=
intercept	72.1	51.22	1.41	0.393
left index	0.86	8.82	0.1	0.938

Not significant

Table 7.2 Results of the regression equation analysis between left index and age

Parameter	Co-ef	St dev	t-ratio	p =
intercept	32.02	10.5	3.05	0.055
right index	6.83	1.51	4.52	0.020

R-sq. = 8.3%

age = 32.02 + 6.83 (index)

Table 7.3 Results of the regression equation analysis between right index and age

From the tables it can be seen that the right side width / depth index has a strong correlation with age. However there was no relationship between the left index and age.

Barton-on-Humber

Figure 7.10, 7.11 and 7.12 show a plot of age against width, depth and the width/ depth index.

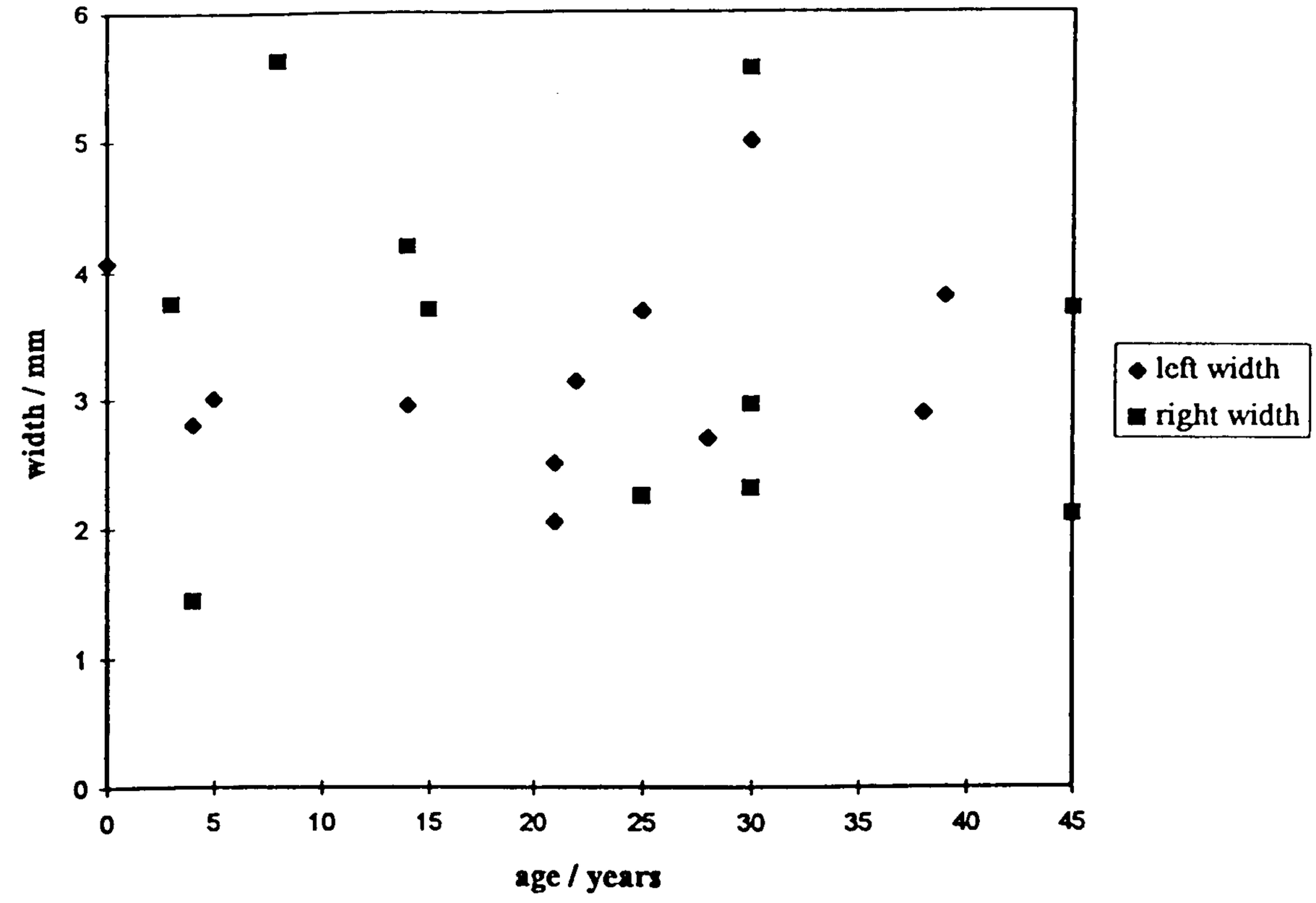


Figure 7.10 Vessel width against age - Barton sample

Figure 7.11 Vessel depth against age - Barton sample

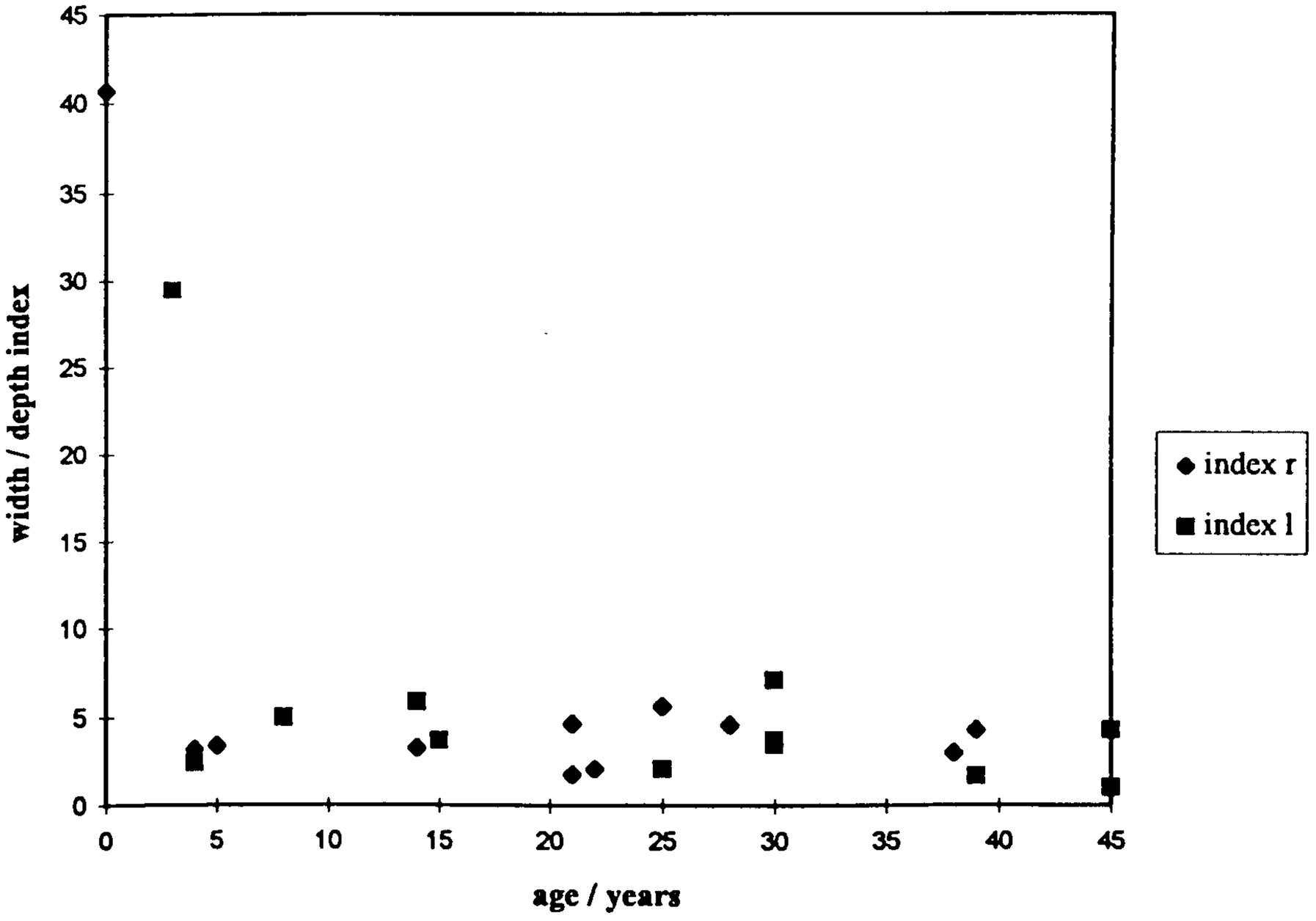


Figure 7.12 Width / depth index against age - Barton sample

From the graphs it could be seen that vessel depth up to the age of 10 increased steadily, especially in the left sided casts. The width / depth index decreases rapidly until adulthood in the Barton sample, where it remains at a roughly stable level, with a slight decrease after the age of 35. Table 7.4 below shows the results of the regression equation between left vessel length and age.

Predictor	**Co-ef**	**St dev**	**t-ratio**	**p=**
constant	5.478	8.601	0.64	0.539
left length	20.108	8.457	2.38	0.039

R-sq. = 36%

Table 7.4 Results of the regression equation between left index and age - Barton sample

In addition there also appeared to be a negative correlation between the right sided index (see figure 7.12). This was borne out by the regression analysis (see table 7.5), which showed a significant correlation between a lower index with increasing age.

Predictor	Co-ef	St dev	t-ratio	p=
constant	-53.25	33.66	-1.58	0.189
right index	26.36	8.28	3.18	0.033

R-sq. = 64.6%

Table 7.5 Results of the regression equation between right index and age - Barton sample

Although very few of the measurements showed any correlation with age, as the cross-sections were being studied two interesting observations were made. Firstly, that in most individuals there was a marked asymmetry between the left and right sides of the cross-section. In left casts the steeper slope was on the left, and vice versa for the right. From this it would appear that casts could be sided by just looking at the cross-sections.

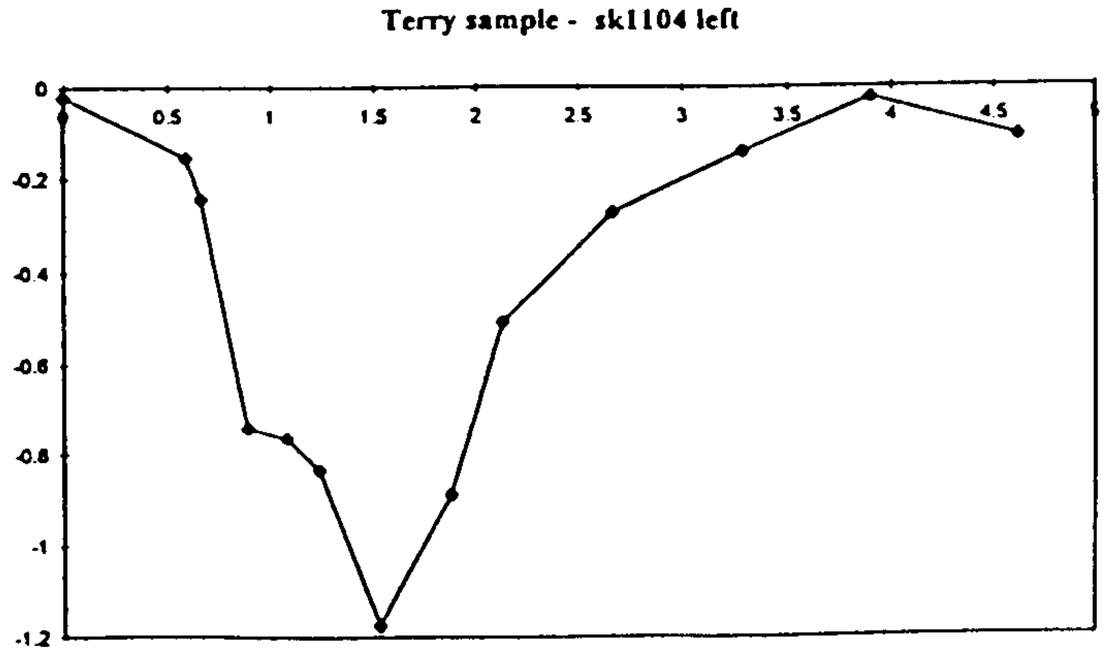


Figure 7.13 Left and right cross-sections drawn from measurement of two casts (note the difference in scale)

Secondly, there appeared to be a change in the shape of the cross sections with increasing age, with older cross-sections becoming more even, or "u" shaped with age (see figure 7.14 below). This trend may account for the significant correlations found with age and the width depth index, rather than either the width or depth measurements separately.

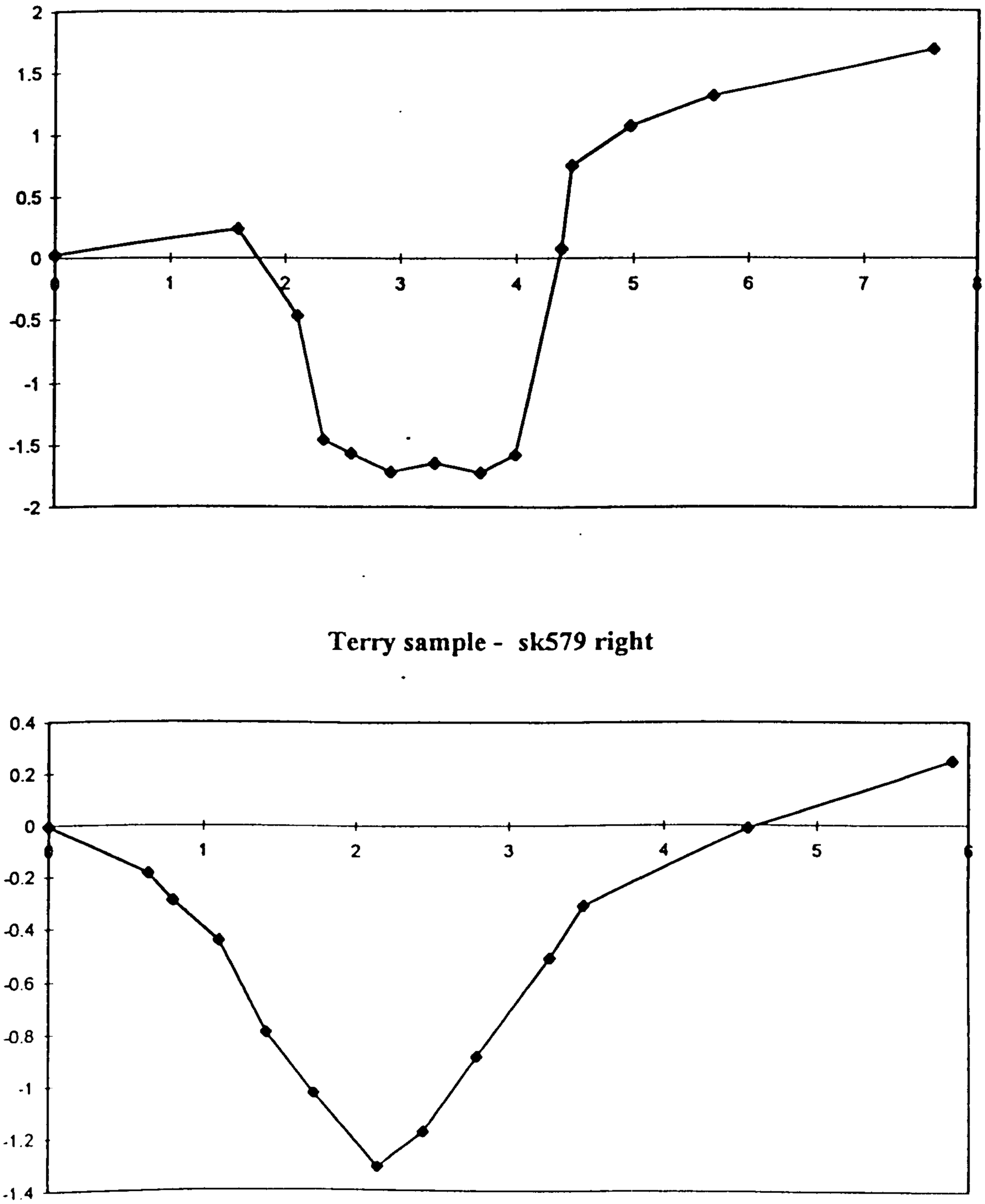


Figure 7.14 Sk 1218 (white male aged 75) compared to Sk 579 (white male aged 17)

Discussion

The samples that formed the pilot study were poor, and this is reflected in the results obtained. The post mortem sample was too small, partly due to a restricted access to the chosen measurement site in the post-mortems, and also due to constraints placed on the use of the alginate on certain bodies. The Barton sample was larger, but these skulls were not of known age, and so any results gained from these must be interpreted with caution. In addition there were many skulls which could not be cast at all due to their poor condition, or because of a missing or broken base of the main meningeal vessel. There were not enough individuals with both left and right sides cast to see whether vessel groove cross-sections display asymmetry. Despite these problems, some interesting results did emerge from the study. In both the samples, there appeared to be some relationship between the right indices and age in the post mortem and in the Barton females, but this is complicated by the fact that it is a positive correlation in the older sample, and a negative one in the younger sample. In the Barton sample there was a fair relationship between age and vessel length, but this is not surprising as sub-adults (under 16 years) made up 33% of the sample, and their skulls and vessels would still be growing and deepening (see chapter 2).

It was decided from this pilot study that further work should be undertaken on a larger sample of known age at death. It was hoped that this further sample would strengthen the apparent relationship between width/depth index and age, and also provide a chance to compare left and right vessels in a number of individuals.

It was not possible to take casts of the Spitalfields sample as they were in too delicate a condition to be used. It was decided instead to use the Terry collection. This would have an added advantage as there are individuals of different races, and being a larger sample it would be easier to select individuals across all age groups and both sexes and races. The main disadvantage of using the Terry sample for this study was that, being in America, there were limitations on how much plaster and alginate could be transported, and the weight of casts returning home. The alginate and stone used for all casts in this thesis (including arachnoid granulation pits) was strictly from one batch (see chapter 3), as a condition of the reproducibility study, so it was not possible to obtain the casting

material in the U.S.A. The casts would still have had to be transported home, as there was no access to a reflex microscope to measure them abroad.

1b - Vessel shape, size and age - the Terry collection study

Sample

Twenty-six individuals were selected for the main study. One each of adult males and females, both black and white, were chosen randomly from the main sample in each decadal group (up to 20, 21-30 and so on up to 71-80). Where there were no representatives from one of the decadal groups, a substitute another category was randomly selected. Table 7.6 below is a summary of those selected.

sub-group	n=	mean age	max age	min age
all sample	26	52	86	17
black males	5*	42.7	85	17
black females	7	55.7	85	17
white males	7	55	75	38
white females	7	55.3	86	30

* 7 casts were taken, but one broke in transit, and a second was unmeasurable

Table 7.6 A summary of the ages of the individuals selected.

Methods

For each individual chosen a cast of both the left and right sides of the main meningeal vessel were made, exactly the same as in the pilot study above. The width and depth measurements of each cast were taken, and the width/depth index was also calculated. These measurements were correlated with age using linear regression analyses. The results of these are given below.

Results

Figures 7.15, 7.16 and 7.17 show the results of a comparison between left and right width, depth and the width / depth indices for each individual.

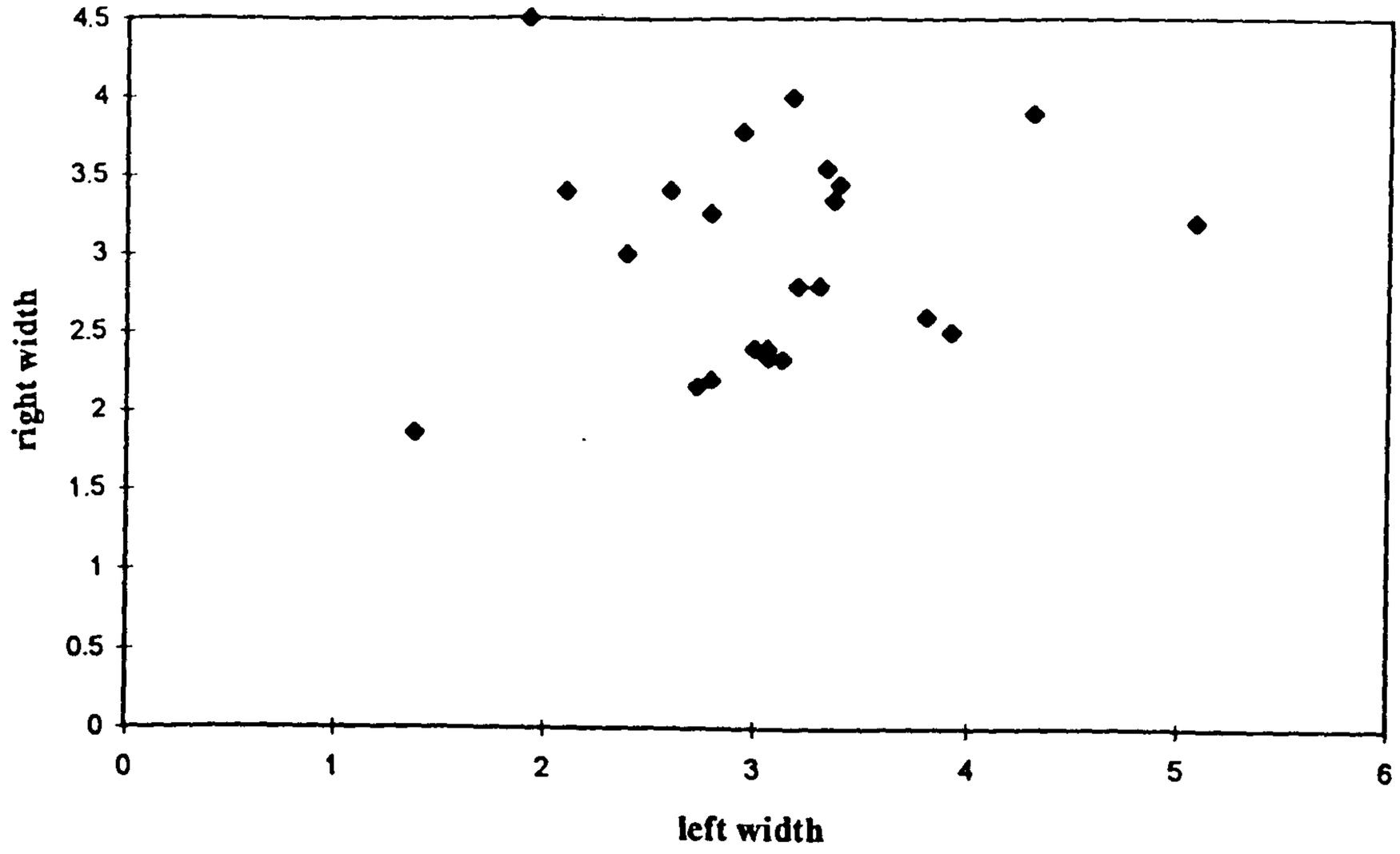


Figure 7.15 Left versus right width- Terry sample

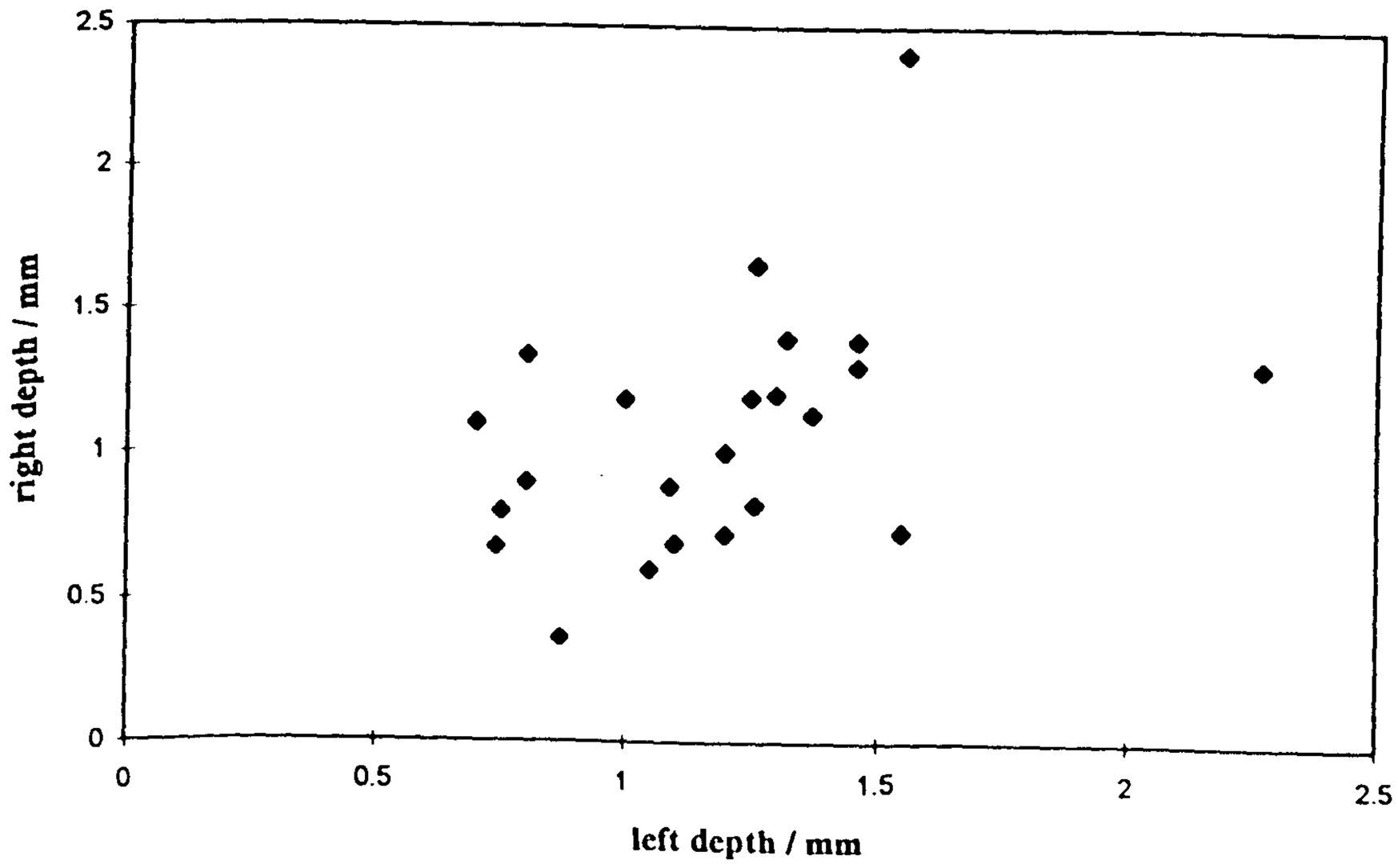


Figure 7.16 Left versus right depth - Terry sample

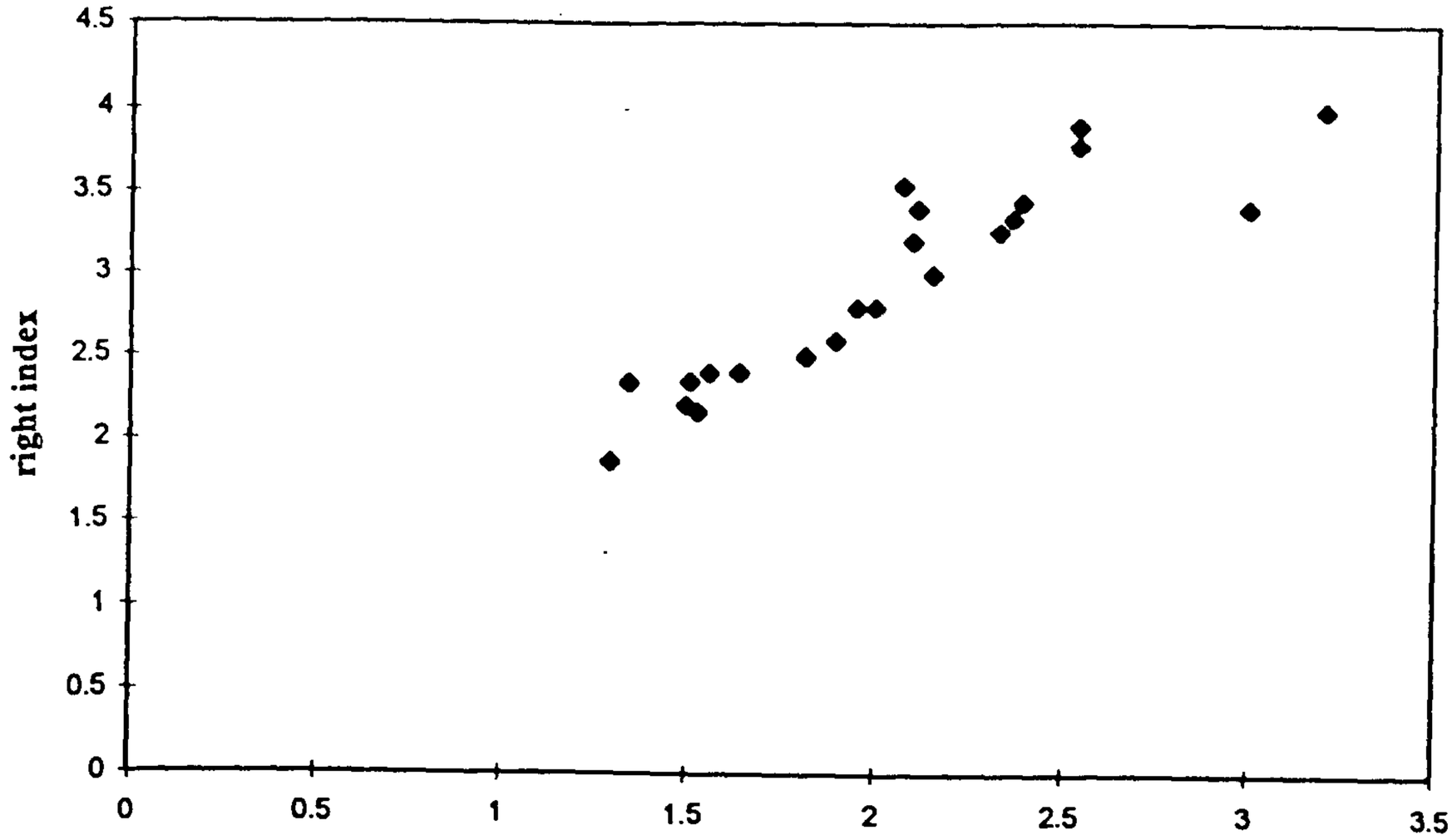


Figure 7.17 Left versus right index - Terry sample

Figure 7.17 shows a superb correlation between the left and right indices, and it can be seen that there is a marked asymmetry in some individuals. To check whether this is statistically significant in the overall sample the mean differences between left and right were calculated. The left and right widths showed no overall difference (mean 0.07; St Dev 0.985; SE mean 0.205) as did the width / depth indices (mean -0.278; St Dev 1.479; SE mean 0.308) but there was a slight asymmetry between left and right with the right being greater on average than the left (mean difference 0.913; St Dev 0.608; SE mean 0.127). It was decided that the mean of each individuals left and right scores would be used in the regression analysis.

Figures 7.18, 7.19 and 7.20 below show the mean vessel width, depth and index against age Table 7.7 gives a summary of p values for the regressions against age.

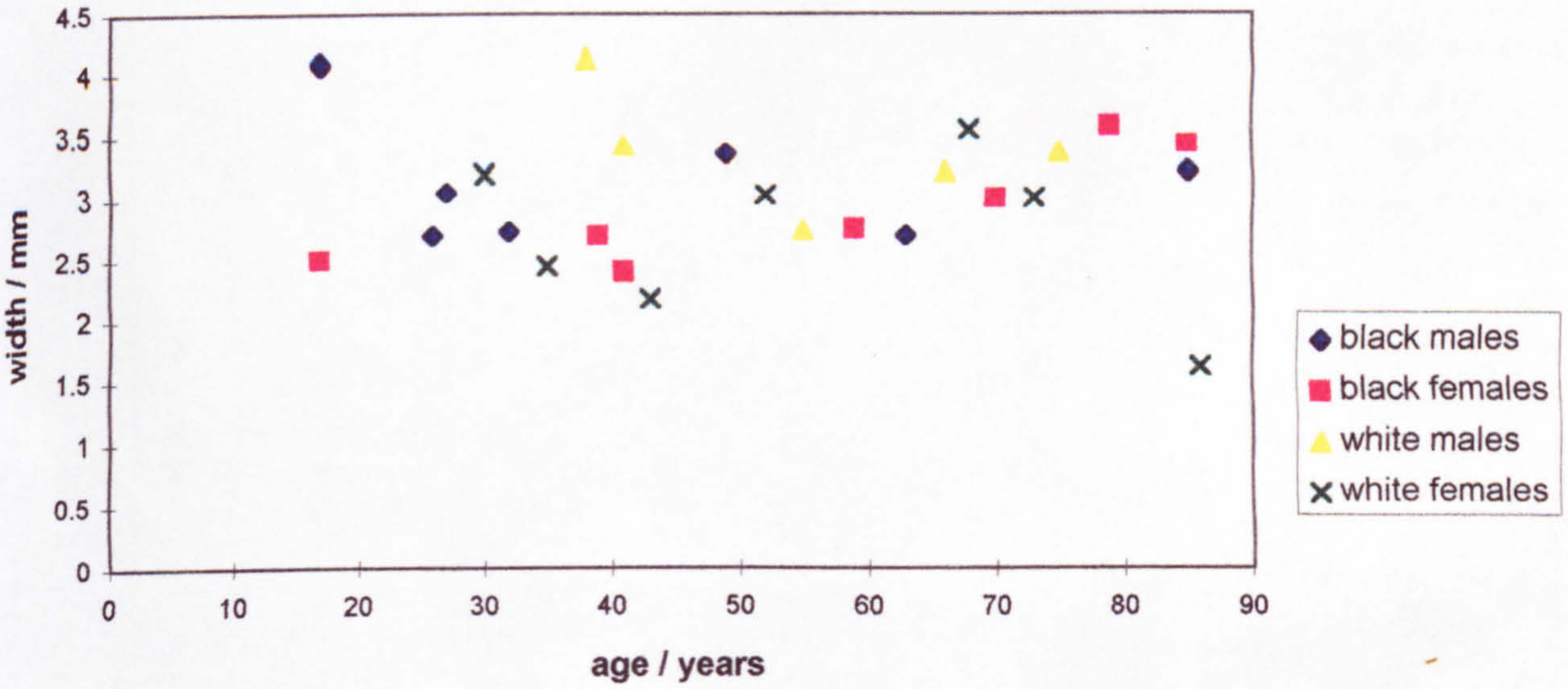


Figure 7.18 Mean vessel width against age

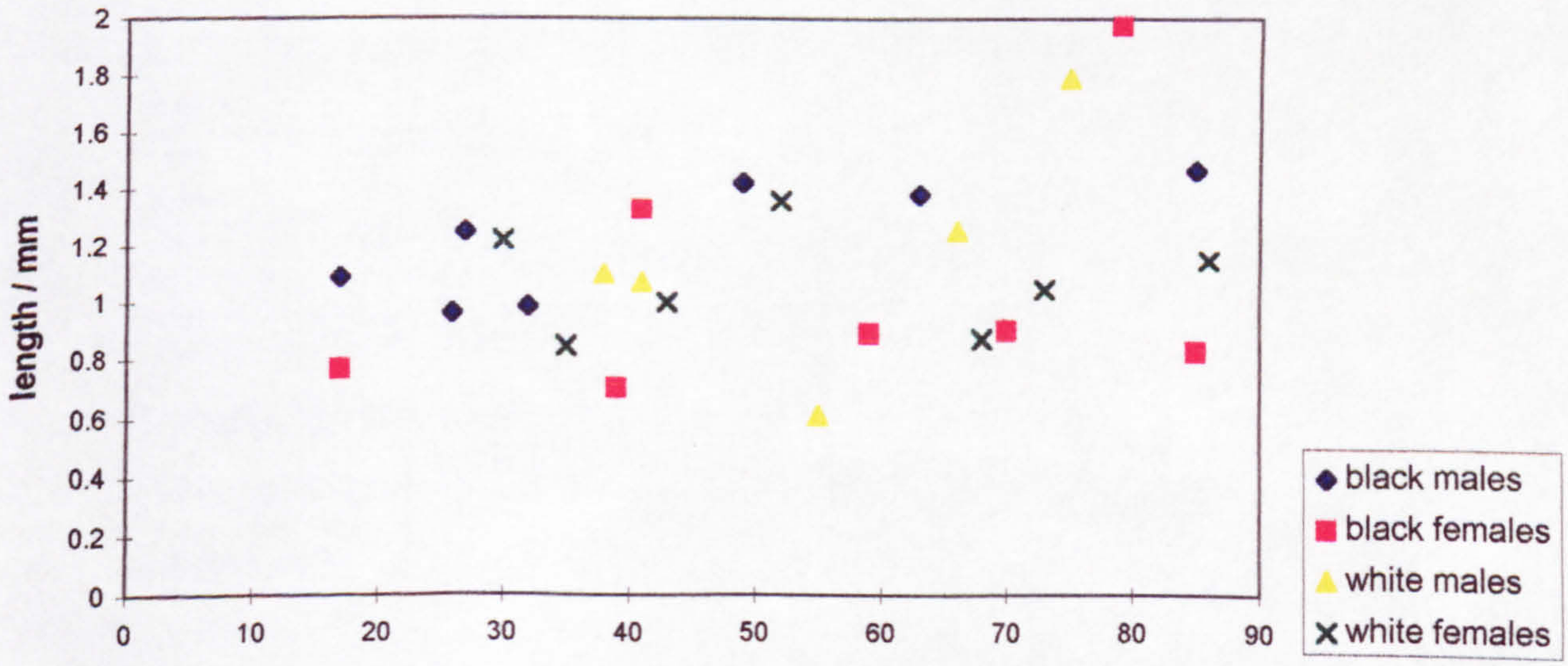


Figure 7.19 Mean vessel depth against age

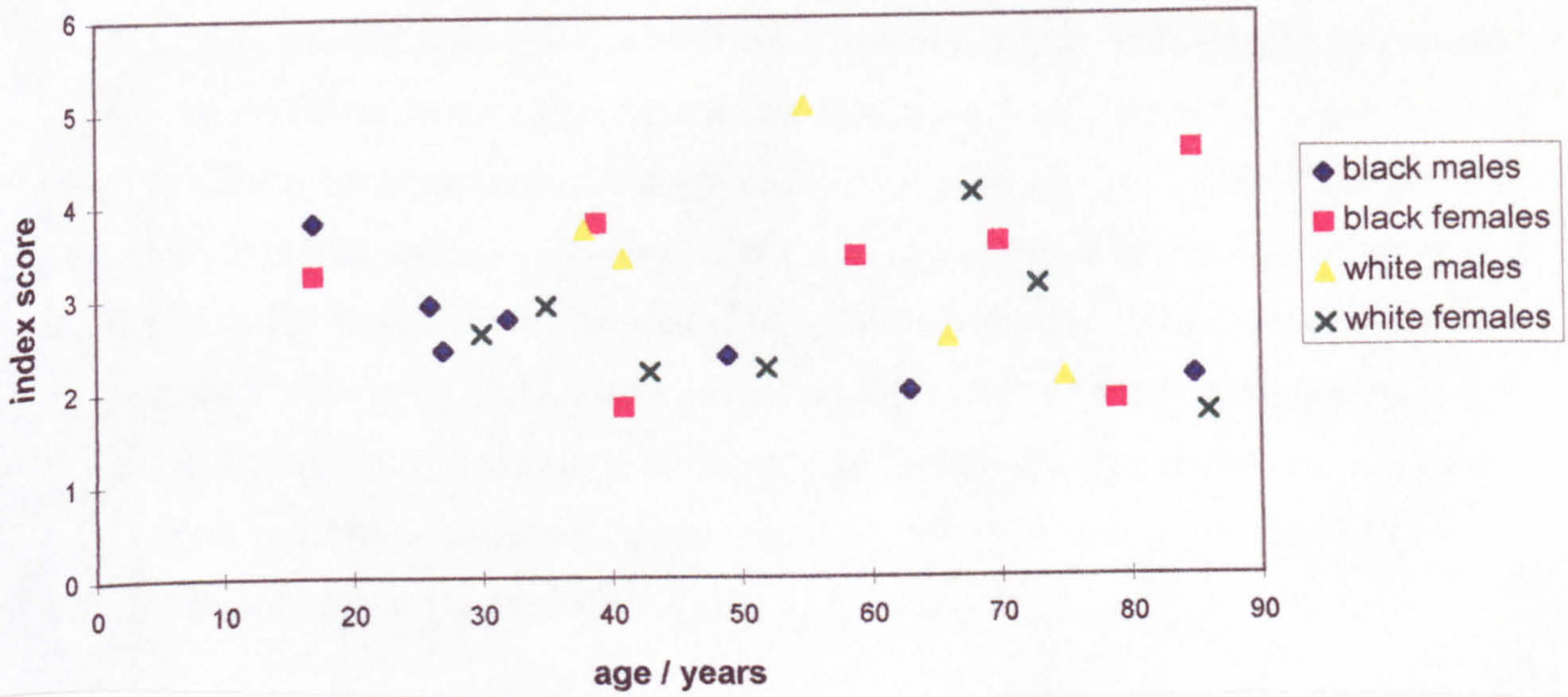


Figure 7.20 Mean width/ depth index against age

	n=	left width	left length	left index	right width	right length	right index	mean width	mean length	mean index
all	26	0.061	0.049*	0.025*	0.088	0.329	0.485	0.958	0.105	0.532
black males	7	0.014*	0.191	0.023*	0.207	0.048*	0.283	0.634	0.032*	0.039*
black females	7	0.335	0.366	0.720	0.031*	0.458	0.656	0.009**	0.415	0.742
white males	5	0.300	0.126	0.014*	0.982	0.865	0.908	0.405	0.29	0.320
white females	7	0.226	0.266	0.273	0.965	0.306	0.357	0.625	0.975	0.987

* significant - below the 5% level

** highly significant - below the 1% level

Table 7.7 Summary of P values for all regression analyses of age and vessel shape, left and right

These results present a somewhat confusing picture of a partial relationship between age and vessel shape. Of the 45 results presented here, one would expect up to 20% of the apparent correlations to be false, but conversely, the same percentage of those results

which are not significant may actually be so. Of all of the measurements, the width/ depth indices appear to have most significant relationship with age, at least in the black and white males. As with the pilot study, the older individuals seem to have more "u" shaped profiles, and the younger "v" shaped ones. This finding suggests that the shape of the vessels is changing over time, rather like the bed of a river as it flows towards the sea - as a young (close to source) river it is fast flowing with an asymmetrical bed, but as it gets older it becomes more u-shaped and slower flowing. Andrew (1971) notes that vessels lose their elasticity with age, and the change in shape may be a consequence of this. Another possibility is that chronic arterial hypertension (which would have been untreated in the past) might be causing these vessel shape changes (Cotran et al. 1989). These findings may challenge also the original hypothesis that the vessel groove is a constant proportion of the whole vessel in each individual, and any further work in this area should address this problem.

There appears to be a strong correlation between measurements of both left and right sides, with the right side being deeper than the left. This may be associated with the handedness of the person, as right handed people have a greater blood supply to their right brain, and vice versa for left handed individuals (Watt, pers.comm.).

The results show that different measurements are significant for different sub-samples - nothing of significance was noted for the white female group, and there appears to be a racial difference with the vessels sizes in blacks being more significant than in whites. These results are weak, perhaps because of the small number of individuals studied in each sub-sample, but it would take a considerable amount of time to cast and measure a larger sample and these preliminary results suggest that it would in any case be of no use in forming a methodology to accurately estimate age at death.

General Discussion

The results show that there is some correlation between the vessel shape and size and age, but it is a far from simple relationship. From these observations, a simple score of the shape of the vessel may be the best indicator of age, rather than the complex and time consuming method of casting and measuring. For practical purposes it would be to expensive to use as a field technique, and the weak results obtained do not justify its use as a specialist method. This study has not taken into account any effect that pathology

may have on the grooves' shape and size because it would be impossible to cast and transport a large enough number of casts of differing types of pathology from the only collection of known cause of death which was available (the Terry sample). There is potential for a number of further studies from this work, which can only be seen as a preliminary investigation. Larger samples of known age at death could be looked at, preferably from a modern post-mortem context, as one can be more certain of the true cause of death (see discussion in chapter 3 on this). The relationship between vessel shape and age should be investigated further.

2. Survey of the number of vessels present on the parietals

The introduction to this chapter has shown that with certain diseases (Lindblom, 1936) the numbers of vessel branches reduces. Others state that vascular loss is a phenomena of increasing age. These ideas are the basis for the second study in this chapter.

Sample

A sub-sample of 148 individuals from the Terry collection were randomly chosen for this study. The cases chosen were all white males and females who had both complete parietals. A smaller sub-sample of black males and females were randomly chosen. It is a smaller sample, as there was not enough time to score every skull, and it was thought that any difference in correlation between races with age would, in any case appear in a sample of 40 individuals. Table 7.8 below gives a summary of the skulls studied.

Sub sample	n =	mean age	min age	max age
black males	12	66	22	98
black females	28	57.8	18	95
white males	58	55.2	20	85
white females	50	61.3	30	91

Table 7.8 A demographic summary of the individuals selected for this study

Methods

Choice of scoring

The literature did not give any quantification to the numbers of vessels present in disease, rather a general indication of numbers of vessels. After looking at several hundred skulls,

and attempts to count the numbers of branches on each vessel groove, it was decided to use categories rather than individual counts. This method was for use only on the main and accessory meningeal vessel grooves, the presence of isolated patches of vessel grooves were termed hypervascular, and are dealt with in study three of this chapter. The following three categories were used (see figures 7.21, 7.22 and 7.23 and transparent overlays for examples):

1. Few - there a few branches from the main and accessory meningeal vessels, but a marked absence of smaller finer branches
2. Medium - both main grooves have several medium sized branches leading off from them, and a few finer branches visible from those
3. Many - the main vessel grooves have many medium or large branches, each in turn having lots of finer branches leading from them. Isolated vessels or patches of hypervascularity do not count, and are scored separately.

This method was chosen as it would be quicker to carry out a survey on a large number of skulls, and that the relative loss of ordinal data would be offset by the strength of a larger sample. It was also thought easier to reproduce a simple scoring method than one involving counts of large numbers of vessel grooves.

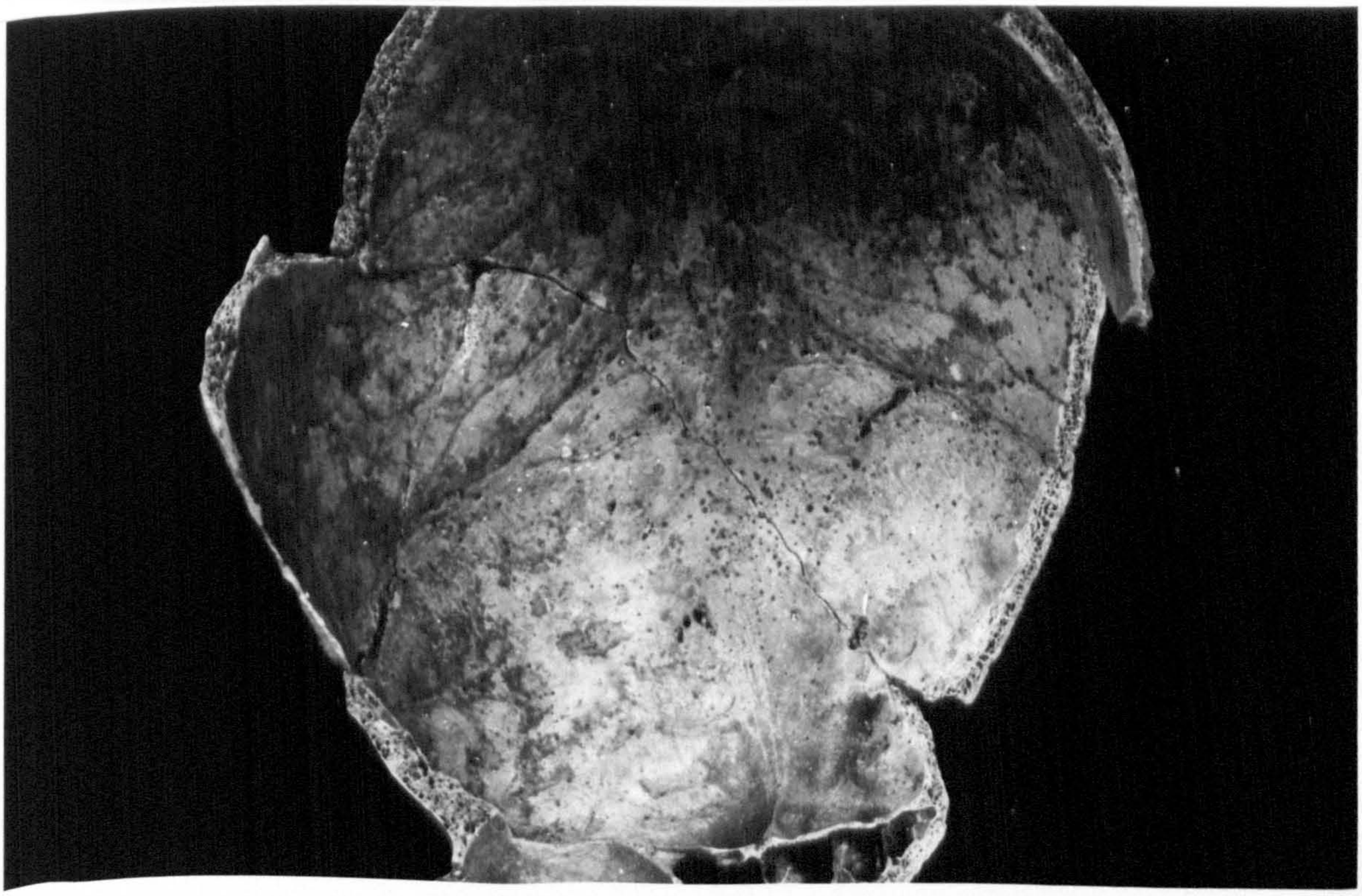


Figure 7.21 An example on a dry skull of category 1 - Few Vessels

and attempts to count the numbers of branches on each vessel groove, it was decided to use categories rather than individual counts. This method was for use only on the main and accessory meningeal vessel grooves, the presence of isolated patches of vessel grooves were termed hypervascular, and are dealt with in study three of this chapter. The following three categories were used (see figures 7.21, 7.22 and 7.23 and transparent overlays for examples):

1. Few - there a few branches from the main and accessory meningeal vessels, but a marked absence of smaller finer branches

2. Medium - both main grooves have several medium sized branches leading off from them, and a few finer branches visible from those

3. Many - the main vessel grooves have many medium or large branches, each in turn having lots of finer branches leading from them. Isolated vessels or patches of hypervascularity do not count, and are scored separately.

This method was chosen as it would be quicker to carry out a survey on a large number of skulls, and that the relative loss of ordinal data would be offset by the strength of a larger sample. It was also thought easier to reproduce a simple scoring method than one involving counts of large numbers of vessel grooves.

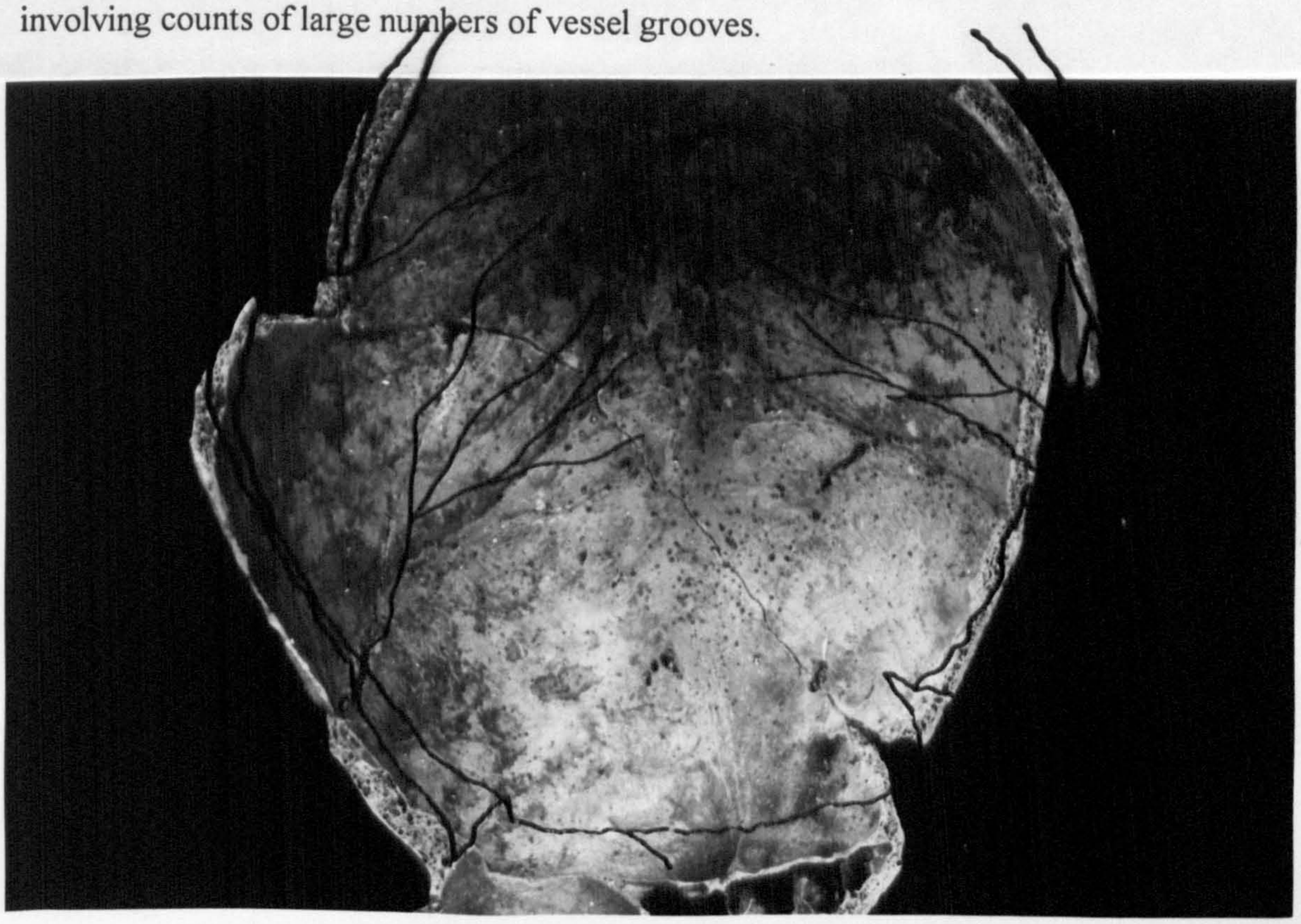
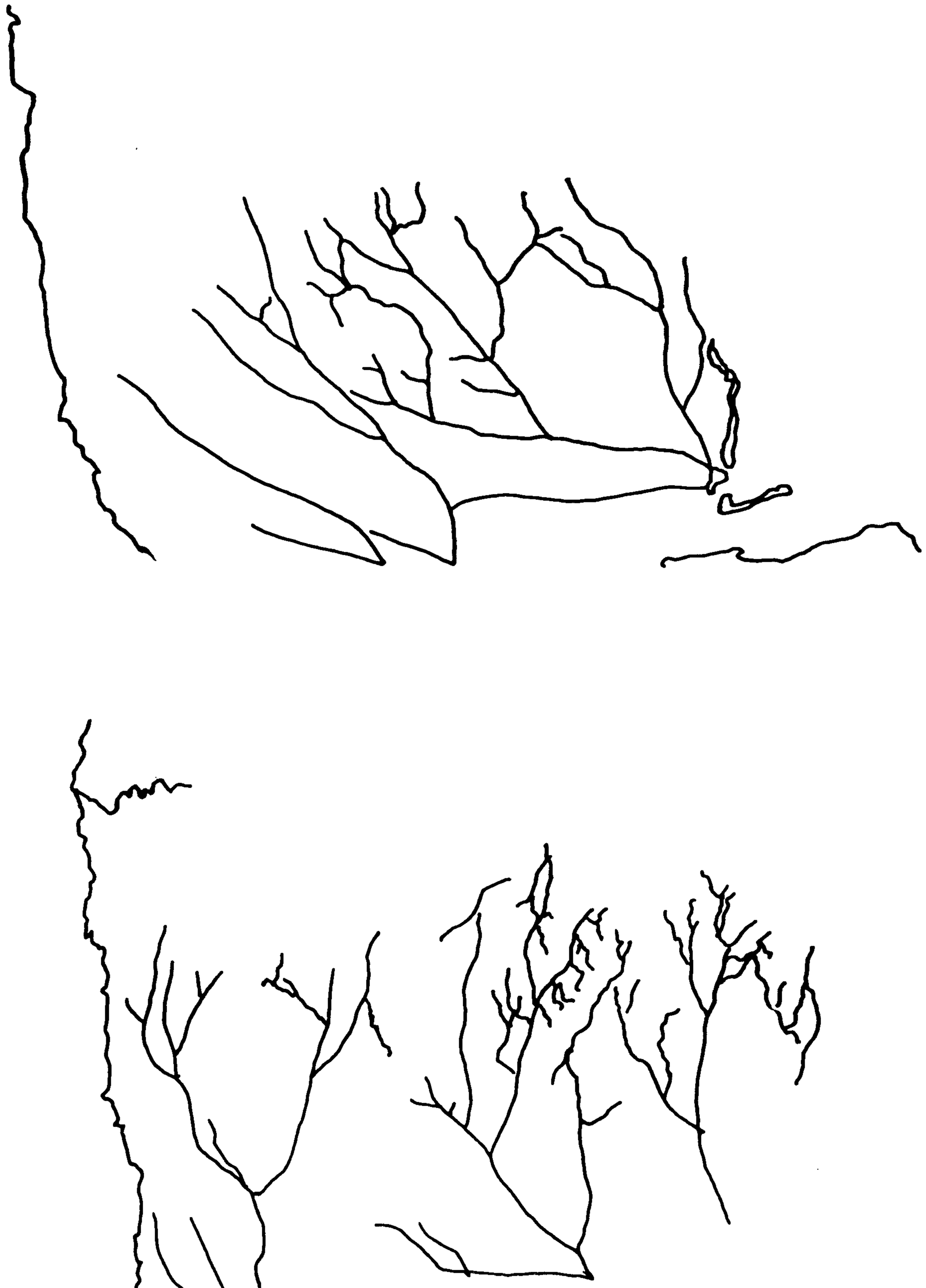


Figure 7.21 An example on a dry skull of category 1 - Few Vessels



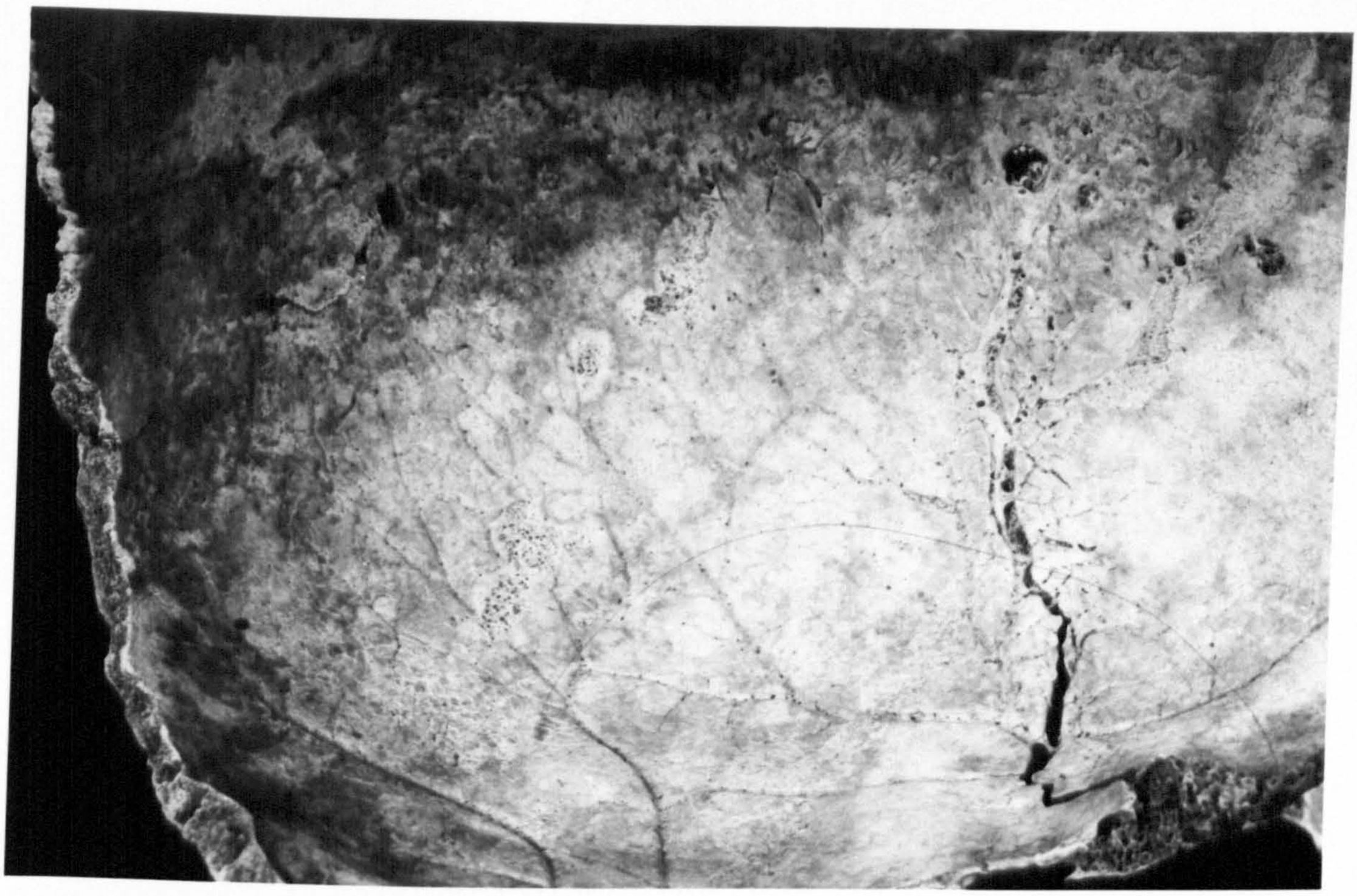


Figure 7.22 An example on a dry skull of category 2 - medium vessels

Figure 7.23 An example on a dry skull of category 3 - Many Vessels

Figure 7.22 An example on a dry skull of category 2 - medium vessels

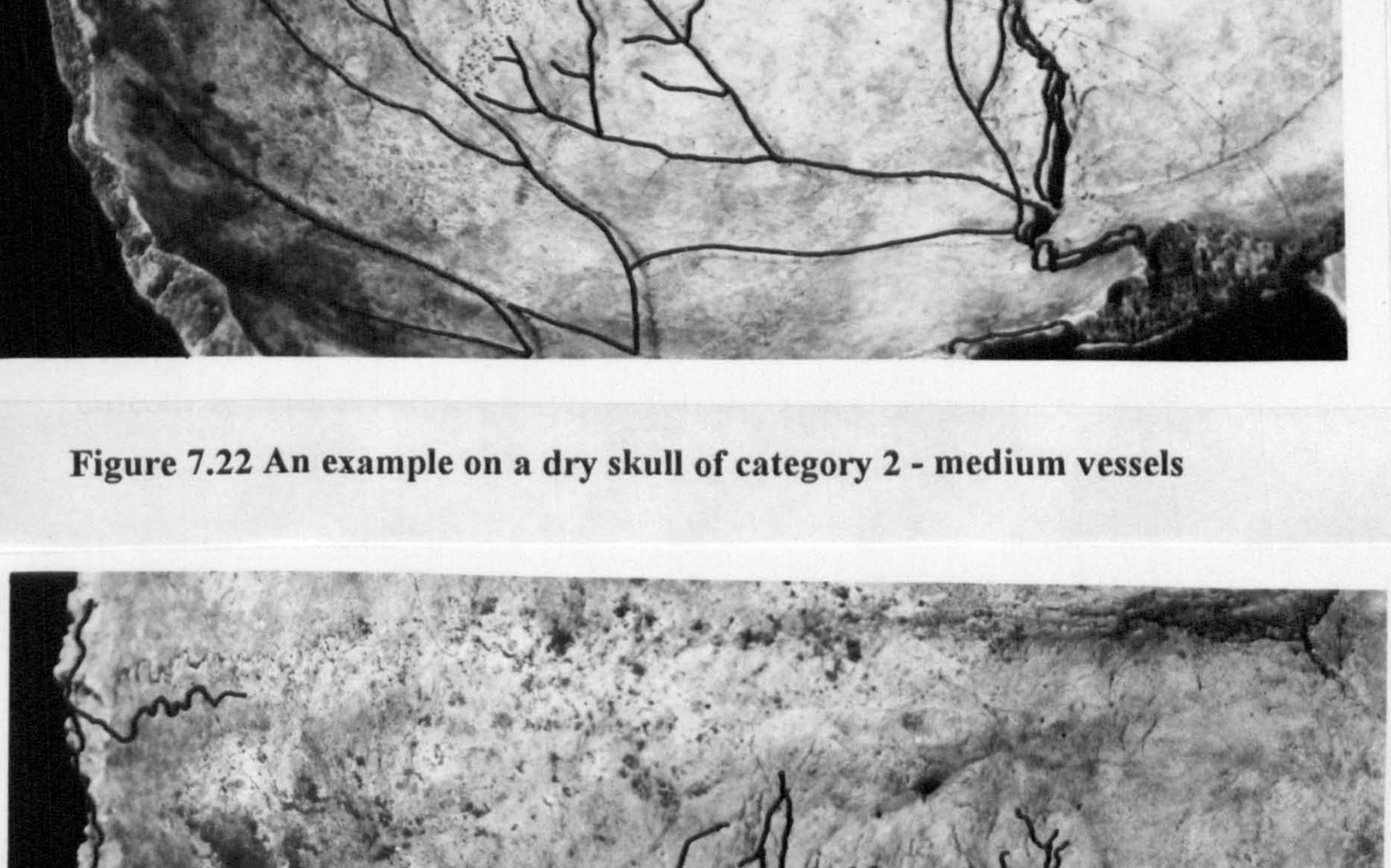


Figure 7.23 An example on a dry skull of category 3 - Many Vessels

For each individual the complexity of branching patterns was placed in to one of the three categories, blind to the age of the individual. The scores for left and right sides of the same skulls were plotted to check for any asymmetry. The vascular scores were then correlated against age.

Reproducibility

A randomly chosen sample of 8 skulls were re-scored at the end of the study. The results of the first and second scores were compared by calculating an intra-class correlation coefficient. This was 0.93, indicating excellent reproducibility.

Results

Left compared to right side

Figure 7.24 is a plot of left against right scores for each skull. There was no difference, with the mean of the two sides being 0 (St Dev 0.435; S.E. mean 0.0356), and no skull differed by more than one grade between left and right sides.

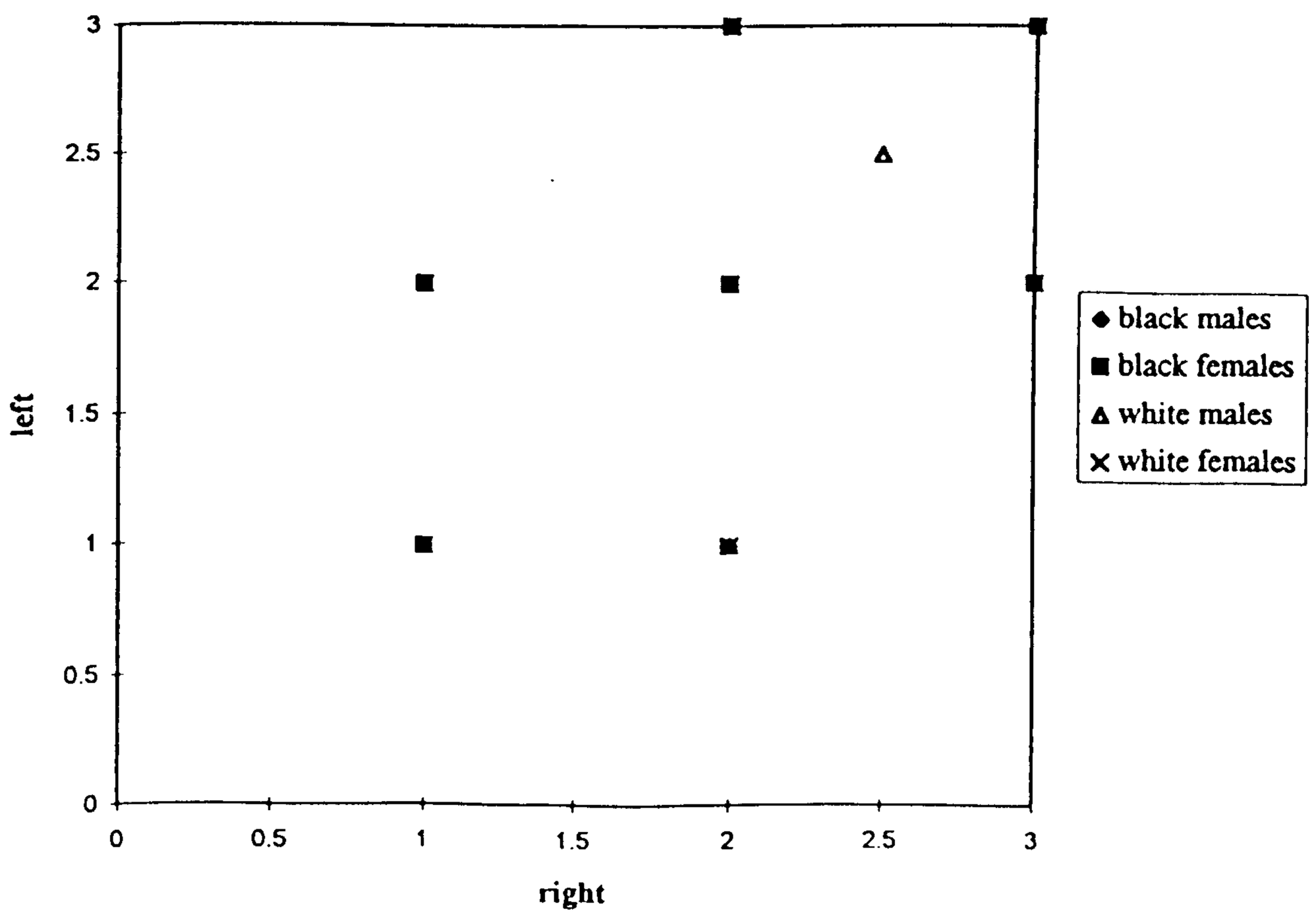


Figure 7.24 Plot of left versus right scores

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Discussion

From these results it appears there is no relationship between the number of vessel branches and age in black and white males and females when such a coarse method as the one used here is applied. There are several reasons for this, it may be that there is no real correlation, and that this phenomenon seen by Lindblom (1936) was a chance coincidence. It may also be that this method is too crude to pick up the subtleties of age related numbers of vessels, but if the correlation is to be of any use in estimating age at death, then a methodology needs to be easy to use and reproducible, as well as accurate. If this phenomena is true, then this method should have at least found a trend, or slightly significant correlation with age. A third possibility, which is perhaps the most likely, is that vessel branches are a complex system, with other factors having as much, if not more bearing on the numbers of vessels visible. Lindblom (1936) also suggested that specific pathologies may have an effect on the number of vessels present. It was decided therefore, to re-analyse the same sample above, but this time by disease.

2b An investigation into the relationship between complexity of vessel patterns and disease

Materials and Methods

The vascular scores of the original sample of 148 individuals from the Terry collection were correlated with age in disease categories. Five disease categories were chosen from those given on the post-mortem records held in the museum (see chapter 3 for a discussion on these records).

Heart disease - any post-mortem form which mentioned the heart or heart failure as a cause of death was placed in this category. This category was unsurprisingly the largest, and most varied, with causes as varied as "cardiac decompensation" to "chronic myocarditis".

Cancer - any which gave cancer of any part of the body as a cause of death

Pneumonia - specifically stating pneumonia as a cause of death

Syphilis - where syphilis (e.g. tertiary lues) was the cause of death

Tuberculosis - tuberculosis as the cause of death

If more than one cause was given on the form e.g. "tertiary lues and heart problems" these were removed from the study at this point.

Results

Figures 7.26 - 7.30 are plots of mean vascular score against age for each of the five disease categories - heart disease, cancer, pneumonia, syphilis and tuberculosis. Table 7.10 is a summary of mean vascular score for each disease category..

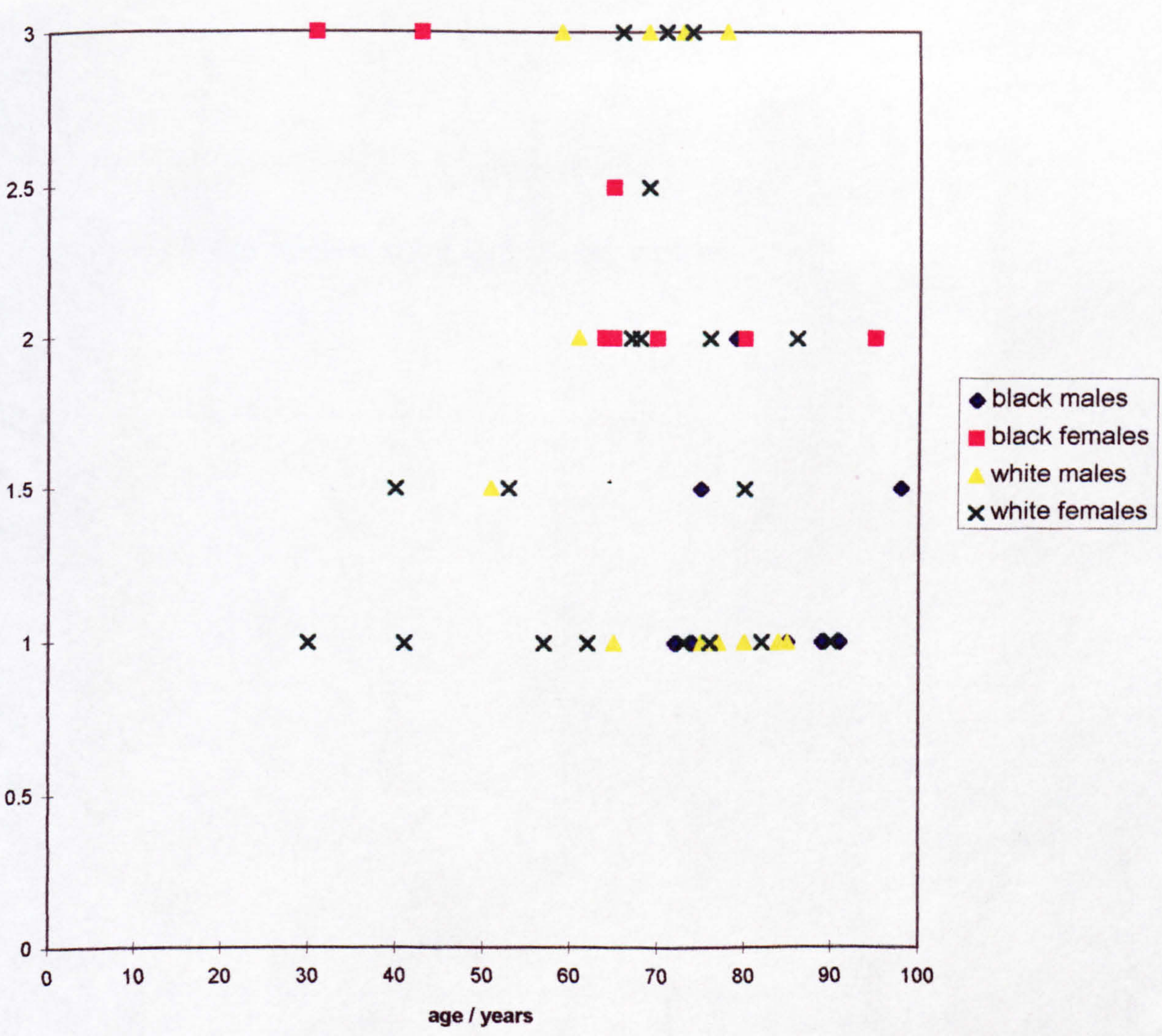

Figure 7.26 Mean vascular score against age - heart disease

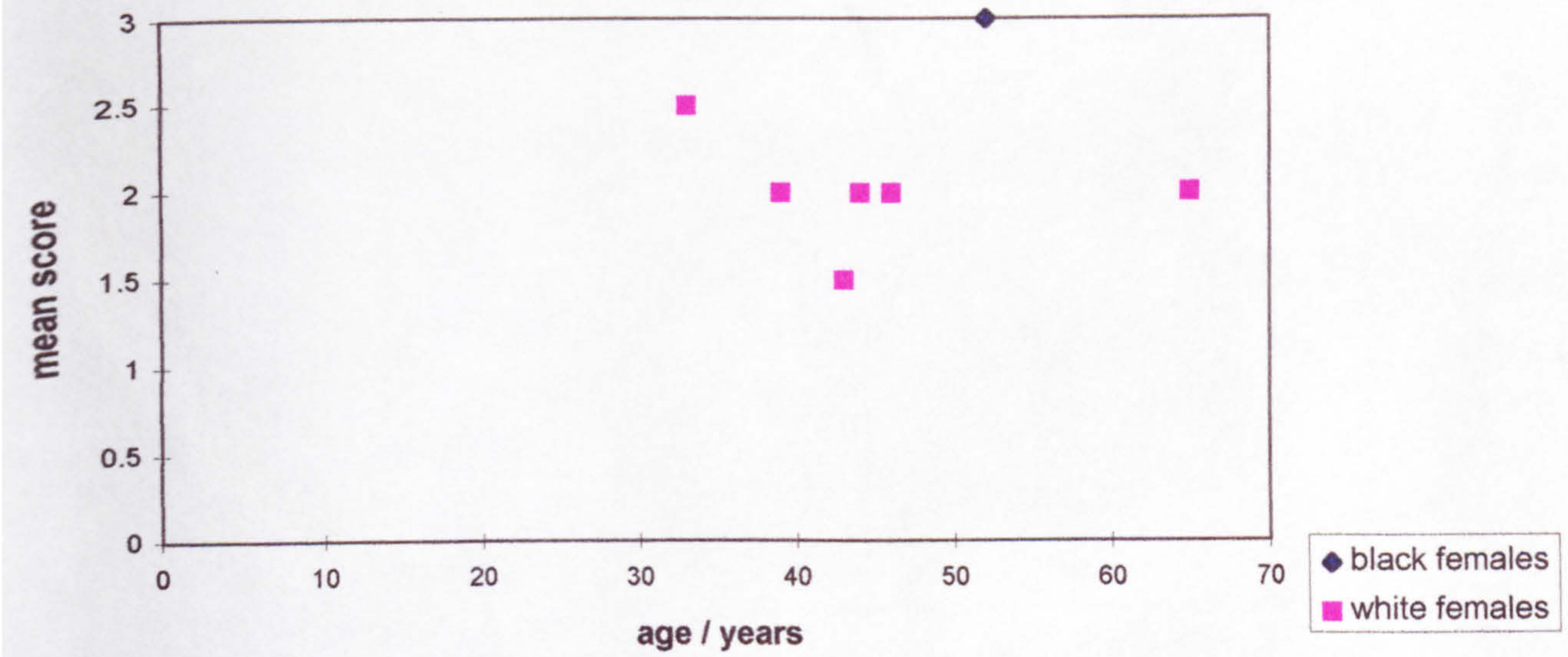

Figure 7.27 Mean vascular score against age - cancer

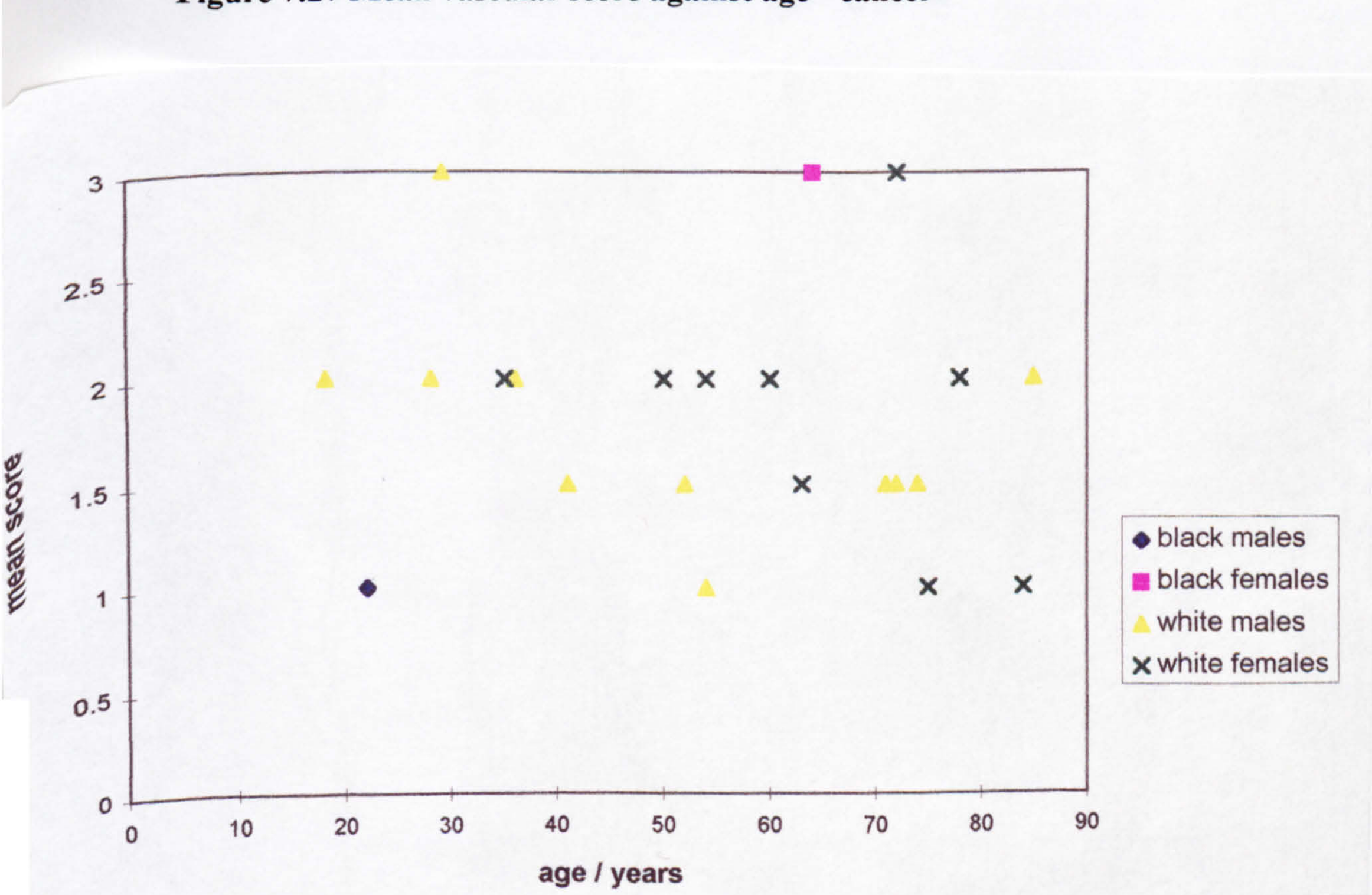

Figure 7.28 Mean vascular score against age - pneumonia

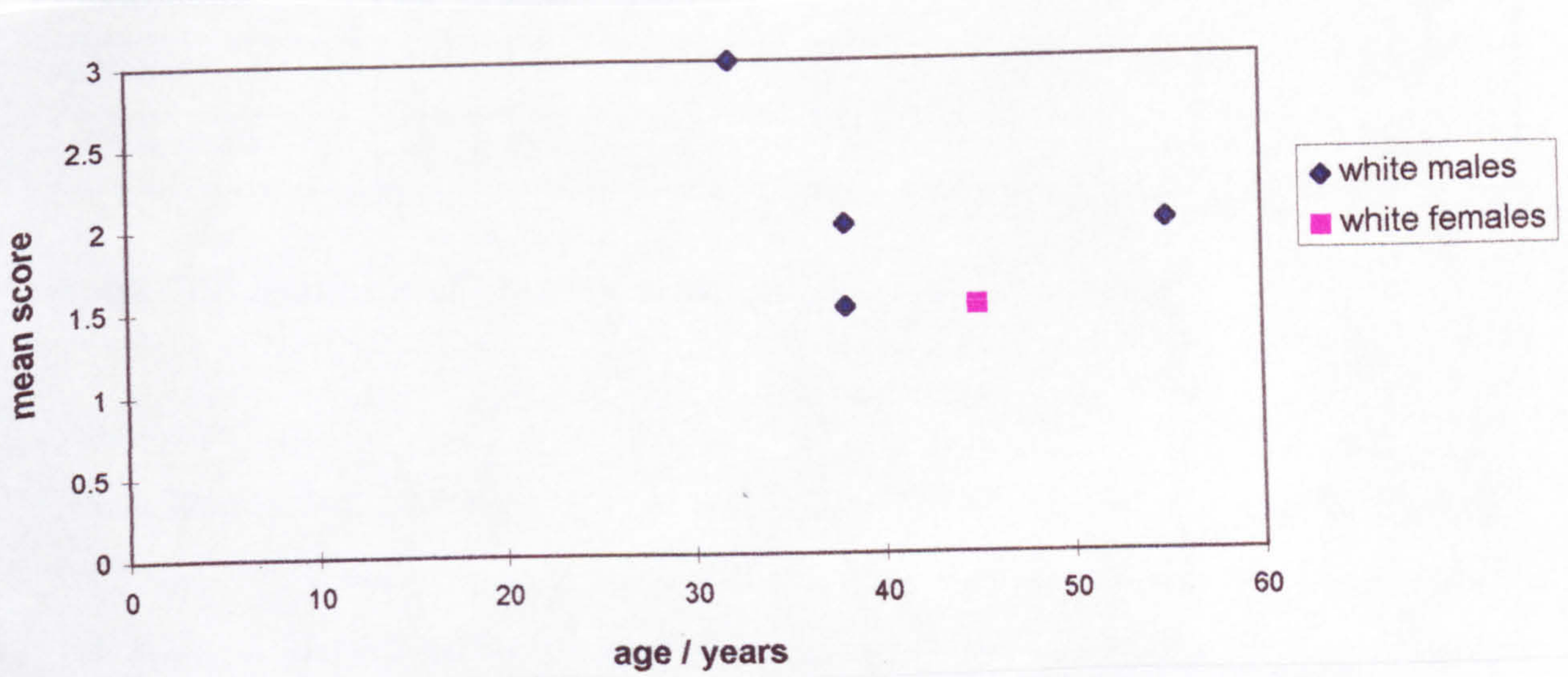

Figure 7.29 Mean vascular score against age - syphilis

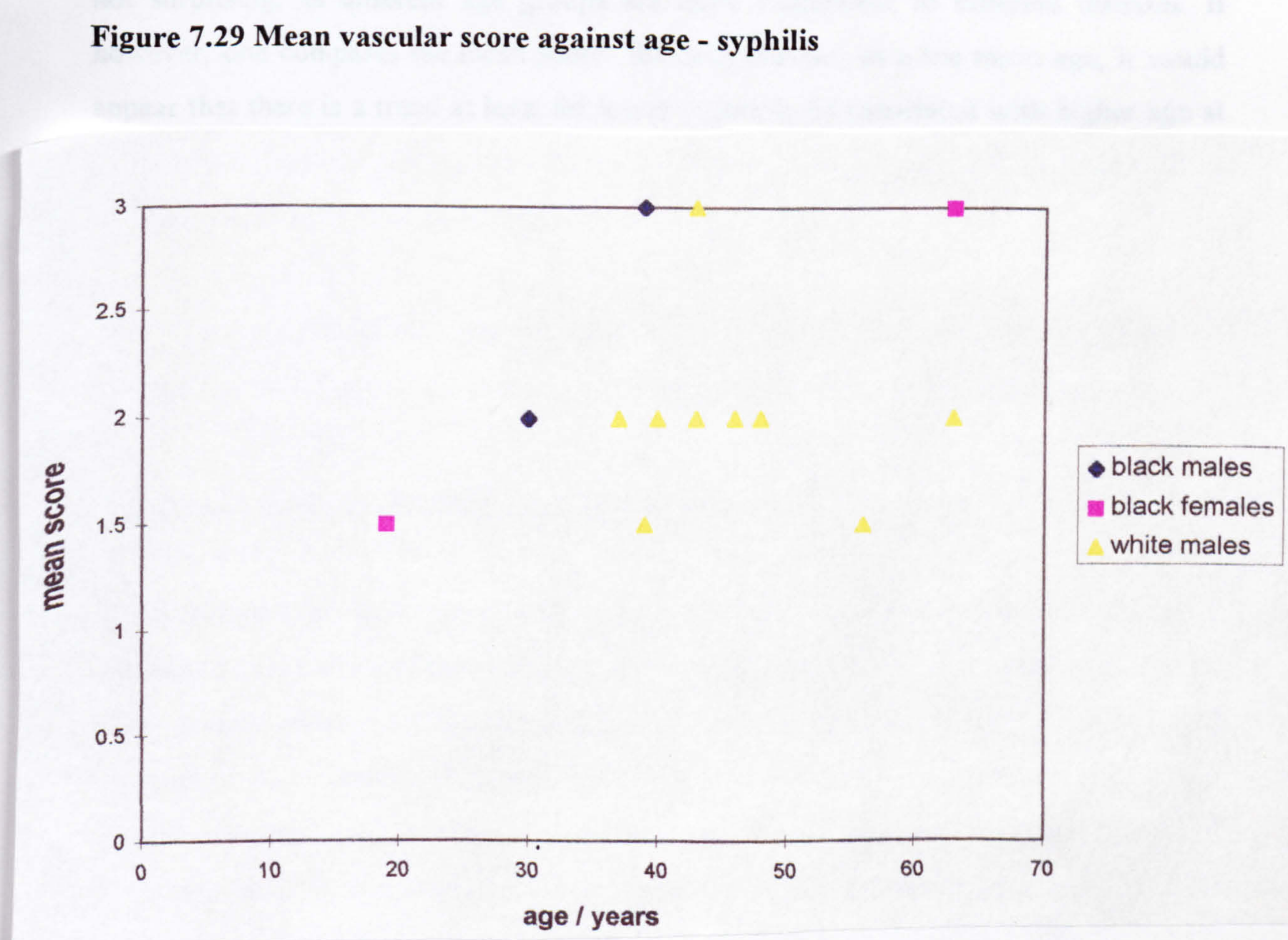

Figure 7.30 Mean vascular score against age - tuberculosis

Disease category	n=	mean age	black males	black females	white males	white females	mean score
heart disease	48	70.2	1.14	2.31	1.79	1.7	1.73
cancer	7	46		3		2	2.5
pneumonia	22	55.3	1	3	1.77	1.83	1.90
syphilis	5	41.6			2.13	1.5	1.81
tuberculosis	14	44.9	2.5	2.5	2		2.33

Table 7.10 Summary of results of mean vascular score by disease

Discussion

It can be seen from both the graphs and the table of results that all five specific diseases have very similar mean vascular scores and that none of them correlate significantly with age at death. The age at death for each disease varies from 41.6 years to 70.2, which is not surprising, as different age groups are more susceptible to different diseases. If however, one compares the mean score for each disease, with the mean age, it would appear that there is a trend at least for lower scores to be associated with higher age at death, although the small numbers in the highest scoring category (cancer) leave these results open to several interpretations.

Although these results may suggest trend, the relationship between numbers of vessels and age / or pathology is too complex and inaccurate to use as an ageing technique.

3. A survey of the presence of hypervascularity

3a Pilot study

The literature reviewed at the beginning of this chapter suggests that hypervascularity of the endocranial surface of the skull is caused by disease. There is no consensus, however, as to exactly which disease causes the changes. It is most likely, given the range of observation and opinions (Koganei, 1911; Schultz, 1993a,b and Henschen, 1960) that several diseases are involved. If this is so, there may be different types of hypervascularity in the skull, indicating different disease processes (e.g. erosion, new bone formation).

Sample

A pilot study was carried out on 100 skulls from the site at Barton-on-Humber to see if there were different categories of hypervascularity present on the endocranial surface of the skull.

Methods

From this pilot survey three different types of hypervascularity were initially noticed:

1. "Wormcasts" - (see figure 7.31) these are isolated patches of hypervascularization, so called because they often resemble the casts left by lugworms on a beach. This hypervascularization correlates well with the description of "frosting" described by Brothwell and Browne (1994) and the changes seen by Schultz (1993ab) and attributed to various forms of meningitis.

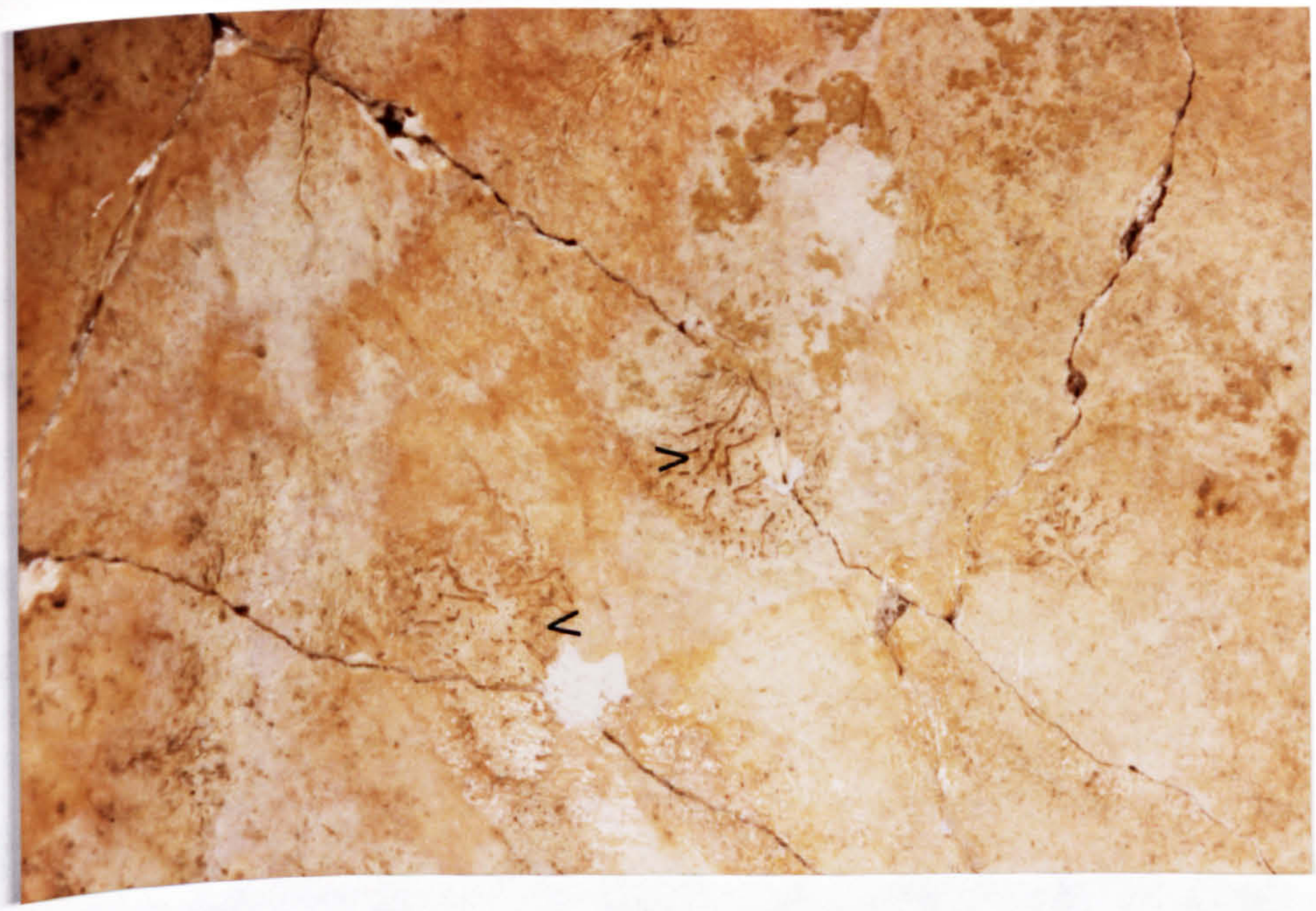

Figure 7.31 Parietal bone with "wormcasts" (arrowed) grade 2

2. "Lightening streaks" - unlike wormcasts, these are very similar in form to the normal branches of the meningeal grooves and can appear anywhere on the parietals (see figure 7.32). Two features separate them from normal vessel grooves. Firstly, they are isolated branches, which look like forked lightening (hence the name) and are not attached to any of the normal vessel grooves. Secondly, whereas the meningeal grooves start at the base of the parietal and taper off towards the sagittal sulcus, lightening streaks point away

from the saggital suture and branch posteriorly towards the temporal suture. In addition these vessel grooves, when they appear, are often more tortuous than the meningeal grooves they lie beside. These grooves have not previously been noted as a separate phenomena from either normal vessel groove or hypervascular casts by other workers.

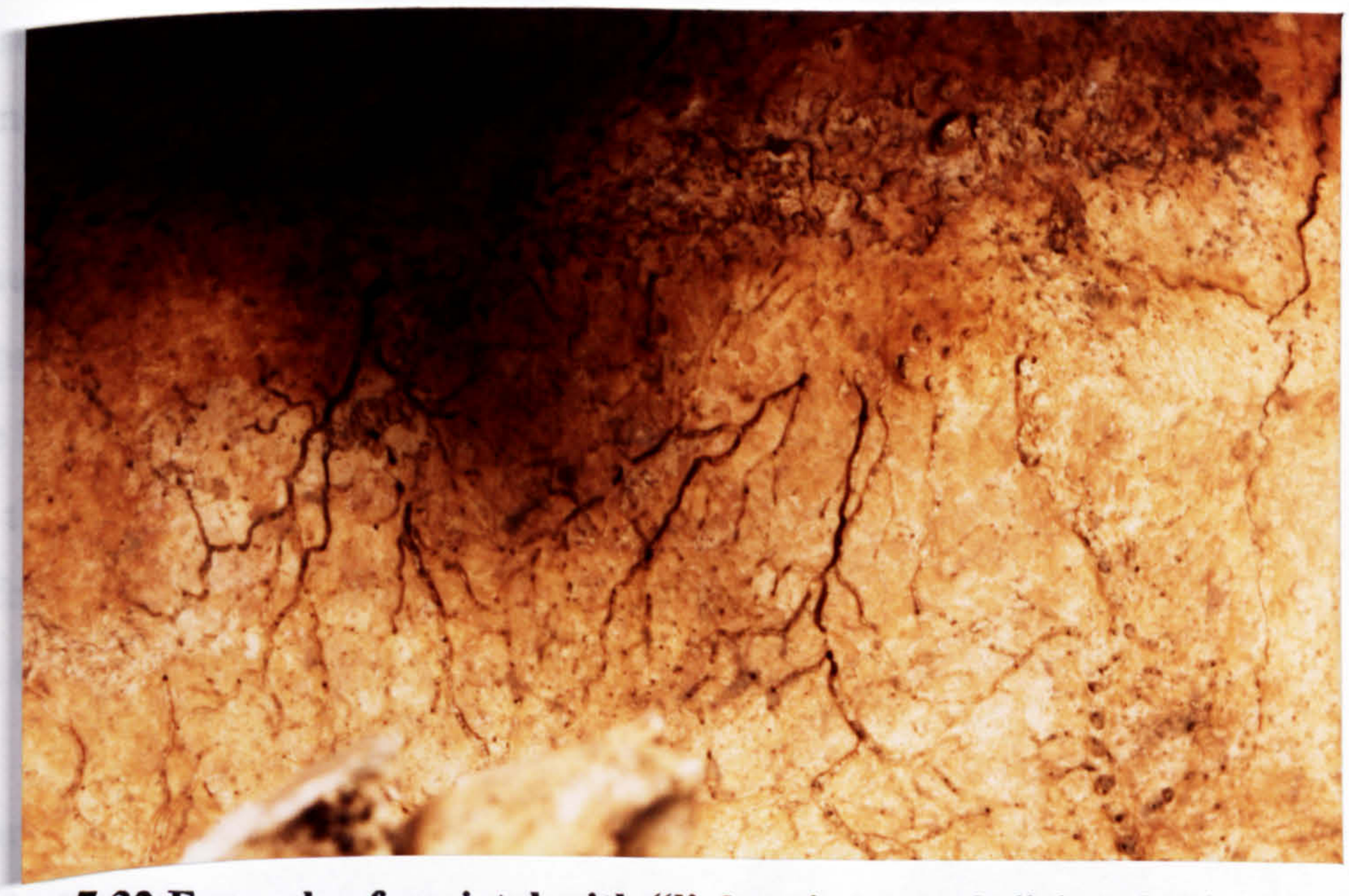

Figure 7.32 Example of parietal with "lightening streaks" (grade 3)

3. "Pin holes" - these are not true vessel grooves, but when seen in a post-mortem skull they have blood vessels within them. Found all over the parietals, they average 1-2mm in diameter and appear as if the endocranial surface of the bone has been pricked with a fork. Figure 7.33 below show the appearance of pinholes on the parietals.

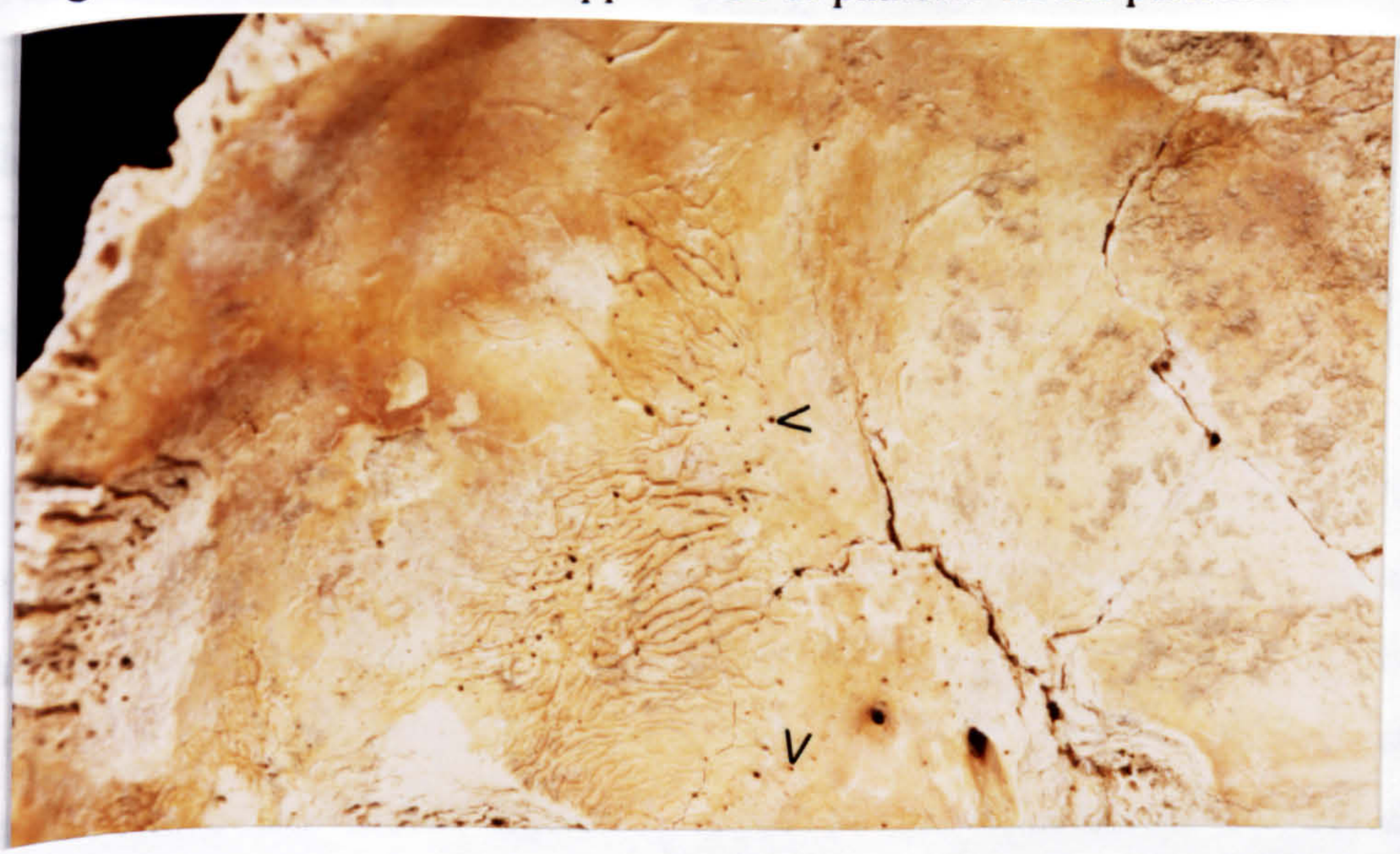

Figure 7.33 Example of parietal with "pinhole" vascularity (grade 2) arrowed and "lightening streaks" (grade 2)

The presence of wormcasts, lightening streaks and pinholes on the parietals were graded for each of the 100 skulls in the pilot study as either 0,1,2 or 3 as below:

0 - none present

1- one or two patches only present

2 - several patches present across the parietal

3- most of the surface of the parietal covered

Results

Reproducibility

The left and right sides of five skulls were re-scored at the end of the study. For each of the three types of hypervascularity an intra-class correlation coefficient. The results were 1 for wormcasts (all skulls had the same score both times), 0.89 for lightening streaks and 0.93 for pinholes, indicating excellent reproducibility for each type.

Scores

Table 7.11 below shows the results of the numbers of each types of hypervascularity scored in the pilot study of 100 skulls.

Hypervascularity type	Grade 0	Grade 1	Grade 2	Grade 3
Wormcasts	84	6	4	6
Lightening streaks	70	12	14	4
Pinholes	76	18	4	2

Table 7.11 Results of the range of hypervascularity scores in the pilot study

From this pilot study it could be seen that the three different types of hypervascularity were present in different quantities. Although the results were not analysed specifically by age at this stage (because the sample could be aged only by anthropological methods - see chapter 3) it appeared that children had the highest percentage of wormcasts present, whereas adults had more "lightening streaks" and "pinholes". Anecdotally, those skeletons with post-cranial pathological bone changes (especially osteomyelitis and non-

specific infections) appeared to have the highest scores of "wormcasts" and "lightening streak" (but not "pinhole") vascularity.

It was decided therefore to undertake a larger study involving the other three (known age) samples to see if the types of hypervascualrity identified, scored and counted correlate with age, and to see what is the relationship between hypervascularity type and disease.

3b Scores of hypervascularity - wormcasts, lightening streaks and pinholes against age

Samples and method

All three of the known age at death samples used in this thesis (see chapter 3) were investigated for the presence of "wormcasts", "lightening streaks" and "pinholes". A summary of the numbers of each sample used in this study are given in table 7.12 below.

Sample	N=	mean age	max age	min age
Post-mortem - males	27	64.5	92	1.5
Post-mortem - females	22	72.7	96	15
Spitalfields - males	30	53.4	81	19
Spitalfields - females	21	50.5	86	16
Spitalfields - children	45	2.3	15	0
Terry - black males	69	49.4	98	17
Terry - black females	79	56.8	102	16
Terry - white males	60	54.5	85	18
Terry - white females	53	60.3	91	30

Table 7.12 Demographic details of each of the samples used in this study

Results

The left and right sides of each skull were graded for each type of hypervascularity from 0 to 3 (as outlined in the pilot study). Table 7.13 show the mean differences in scores for left and right sides.

Type of hypervascularity	mean difference	St Dev	S.E. mean
wormcasts	0	0.261	0.016
lightening streaks	0.015	0.337	0.021
pinholes	0.113	0.402	0.025

Tables 7.13 comparison of left and right sides

The results show that there is no statistical difference between the left and right sides, and so it was decided to use a mean score for each type of hypervascualrity in the regression analysis. Table 7.14 below gives the results of the regression analysis.

Sample	wormcasts p=	lightening streaks	pinholes
Post-mortem males	^	0.471 (0%)	0.658 (0%)
Post-mortem females	0.892 (0%)	0.301 (0.8%)	0.566 (0%)
Spitalfields males	0.414 (0%)	0.483 (0%)	0.485 (0%)
Spitalfields females	0.894 (0%)	0.266 (1.6%)	0.548 (0%)
Spitalfields children	0.463 (0%)	0.869 (0%)	0.796 (0%)
Terry - black males	0.075 (3.3%)	0.738 (0%)	0.115 (2.3%)
Terry - black females	0.132 (1.7%)	0.773 (0%)	0.199 (0.9%)
Terry - white males	0.123 (2.4%)	0.066 (4.1%)	0.008 (10%)*
Terry - white females	0.459 (0%)	0.157 (2%)	0.036 (6.5%)*

R-sq (adjusted) in brackets

^ all cases had the same score - 0

Table 7.14 P values obtained from the regression equations

Of all the regression analyses only two proved to show any statistical relationship between age and hypervascularity. They are the white males and females of the Terry collection. Both of these have an inverse correlation of age with increasing score of pinholes. Given the fact that none of the other samples show any significant correlation between age and score, especially the other white adult samples, these apparently

significant results are probably due to chance and not to any real correlation. It was decided to undertake a brief survey of vascular score by disease to test the theories of Schultz (1993a,b) and the other outlined in the introduction of this chapter.

3c Survey of vascular scores by disease

Method

For each of the skulls from the Terry collection that were scored in part 3b of this study, the cause of death was noted. Any skull which scored a grade 2 or over on at least one parietal in each of the three types of hypervascularity were analysed by cause of death. The numbers of each type of disease were counted, and were given as a percentage of the numbers of cases in the whole sample. The results of the most common causes of death for each type of hypervascularity is given below.

Results

"Wormcasts"

Eleven people had grade 2 or more "wormcast" hypervascualrity. Of these a high proportion had tuberculosis as the given cause of death (7 out of 43 - 16% of all cases of tuberculosis). No single other disease showed a common frequency.

"Lightening streaks"

Twenty five cases were given a grade 2 or more score for "lightening streak" vascularity. Of these 5 (12% of all cases) had tuberculosis as the cause of death, but a greater number, 12 (17% of all cases) gave heart problems, notably myocarditis, as the cause. No other disease featured significantly in this group

"Pinholes"

Thirty-two individuals were given a score of 2 or more for "pinhole" hypervascualrity. No one disease predominated this group - causes of death as varied as cancer, hemiplegia (stroke) and nephritis were given. The most common cause of death was tuberculosis, but there were only 4 cases (9% of all cases of tuberculosis).

Discussion

The results show that the hypervascular changes seen in this study are not caused by age related change. The results of the analysis by cause of death produced some interesting

information. It would appear that disease plays a major part in the formation of hypervascularity - especially tuberculosis. Not every case of tuberculosis showed hypervascular changes, and this is reflected when one looks at skeletal remains for evidence of tuberculosis (Kastert and Uehlinger, quoted in Ortner and Pustchar, 1985) as only 3% of all cases show any bony reaction to the disease.

The relationship between heart conditions and lightening streaks is confusing. As with TB, the effect is partial, and may be due to chance. With both of these types of hypervascularity more work needs to be done on modern samples with better case notes and soft tissue findings.

There seems to be no obvious relationship between pinhole hypervascularity and any specific disease. The analysis presented in part 3c of this study, however cannot by any means claim to be exhaustive, and more work on modern samples should be done to confirm these results, but it is beyond the scope of this thesis to investigate the relationship between the different types of hypervascularity and age in more detail.

Further work

The results of these three studies present many opportunities for further work. The results of the vessel shapes and sizes are tantalizing. A much larger sample of casts could be taken to see how far the results showing that vessel grooves become more "u" shaped with increasing age can be reproduced, although this study in itself would be very time consuming and would require a long study of a sample of known age at death (the only ones large enough would be abroad - which is why it was not undertaken for this thesis) or a large post-mortem sample. It must be remembered that even if this method eventually produced an accurate ageing method, it would be too time consuming and expensive to be used as a standard anthropological technique, although it may have useful forensic applications.

The vessel branching study provided few positive results. This may be due, as discussed earlier, to the crude nature of the technique. It would be interesting to look at meningeal vascular grooves by using fractal analysis of the branching patterns. If the branches were to show a repetitive fractal signature in most skulls, any differences would indicate a change in the vascular patterns, and might indicate some sort of pathology.

The third study of hypervascularity clearly needs much more investigation. The results show that the changes seen are not due to age, but pathology. A repeat of the study on the hypervascular skull changes could be undertaken using modern cases of known cause of death (including children) concentrating on diseases such as bacterial and viral meningitis, using histology and soft tissue findings as a means of supporting the diagnosis.

No work has been carried out in this study to investigate the prevalence of bony bridges in vessel grooves, which Lindblom (1936) believes are also age related, nor any work looking at the supposed pathological origin of tortuous vessel branches. Further investigation in these areas could provide useful information, especially if carried out on a large sample of known age and cause of death.

Chapter 8. Arachnoid granulations

Introduction

Arachnoid Granulations

Arachnoid granulations (also known as Pacchionian bodies) were noted by Vesalius (1543) and Willis (1682) but were first described in detail by Pacchioni in 1741. They are composed of numerous microscopic villi, the function of which is to drain cerebrospinal fluid from the brain (see figure 8.1). These villi are formed in the arachnoid, but they project through the dura and can cause indentations of varying sizes on the endocranial surface of the skull.

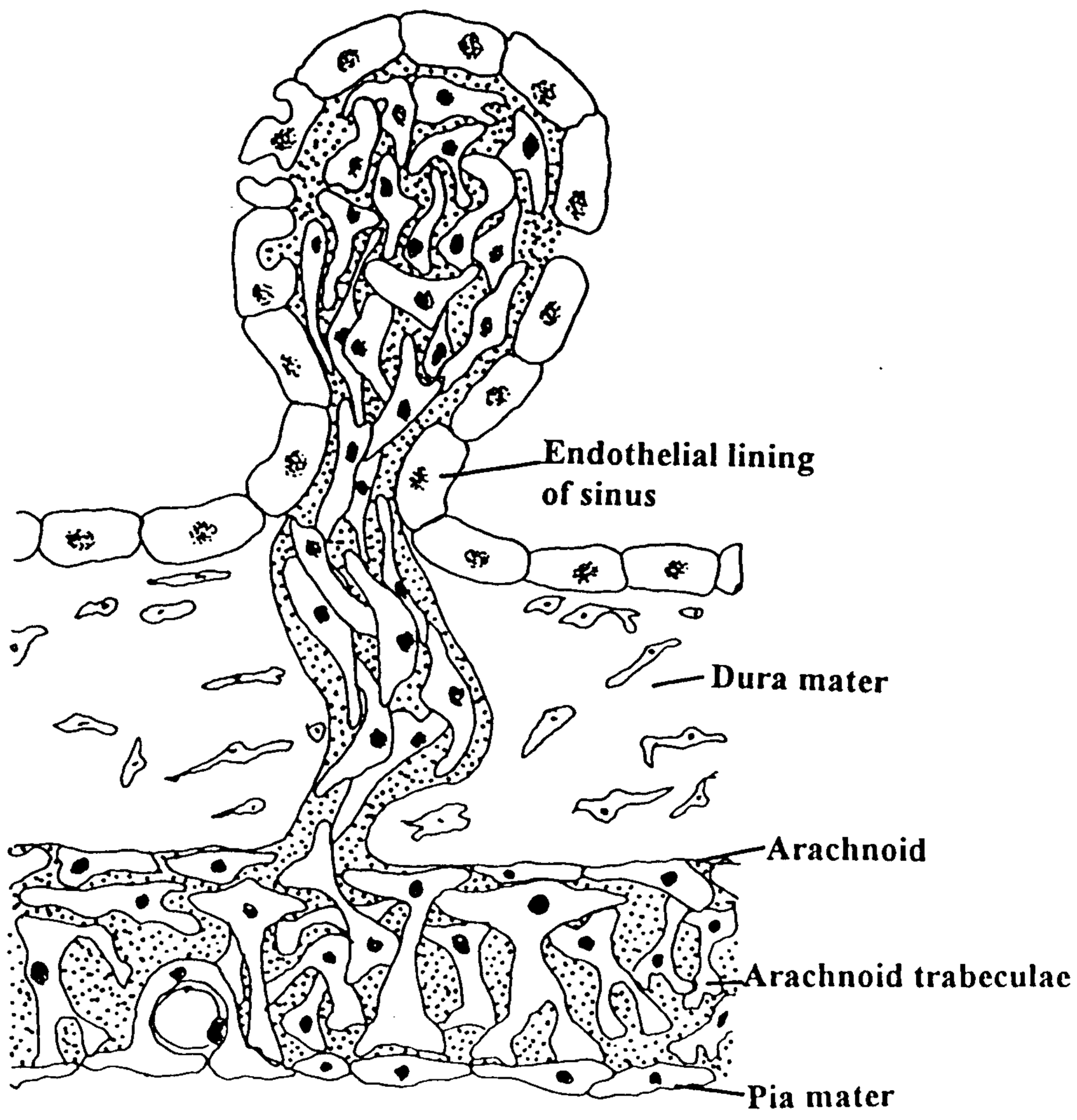

Figure 8.1 Diagram of a cross-section of an arachnoid villus. After Nolte (1988)

Almost from birth, as an individual gets older, these villi become larger. At the age of four they are conspicuous as nodules on the surface of the dura, but they do not form any impressions on the skull until early adulthood (Le Gros Clarke, 1920). As age increases, the relative proportion of cells decreases (Turner, 1958). The bodies begin to calcify (Nolte, 1988) and the indentations on the skull become larger and more numerous. The pits form slowly over time (Le Gros Clarke, 1920) and appear to be caused as pressure defects, rather than as an erosive process, but the histological appearance of the table of the skull has not been investigated in detail. There is no evidence to suggest that this process stops at any age or that the rate of progression differs significantly between individuals.

Key and Retzius (1875) noted the relative frequency of arachnoid granulations across the surface of the brain. They found (in decreasing order of frequency) - superior longitudinal sinus, transverse sinus, cavernous sinus, superior petrosal sinus, and the venae meningiae media. The pits seen on the surface of the skull vary in shape and size and are most commonly situated up to 30mm on either side of the sagittal sinus on the left and right parietals (see figure 8.2). Arachnoid granulation pits also appear in the frontal bone, but these are much smaller and more numerous in number (Le Gros Clarke, 1920).

The majority of research in the field of arachnoid granulations has been either to determine the exact method by which the CSF is drained and returned to the venous system (Potts et al., 1972; Grossman and Potts, 1974; d'Avella et al., 1980; Gomez et al., 1981; Kida et al. 1988 and others) or case studies of abnormally sized arachnoid granulations which need to be differentiated clinically from pathological lesions (Chaudary et al, 1984; Beatty et al. 1989; Mamourian and Towfighi, 1995 and others). The presence of arachnoid granulations on a x-ray is a normal finding, and is not normally commented upon, although unusually large arachnoid granulations have been implicated as a cause of adult-onset spontaneous CSF otorrhea (Gacek, 1990).

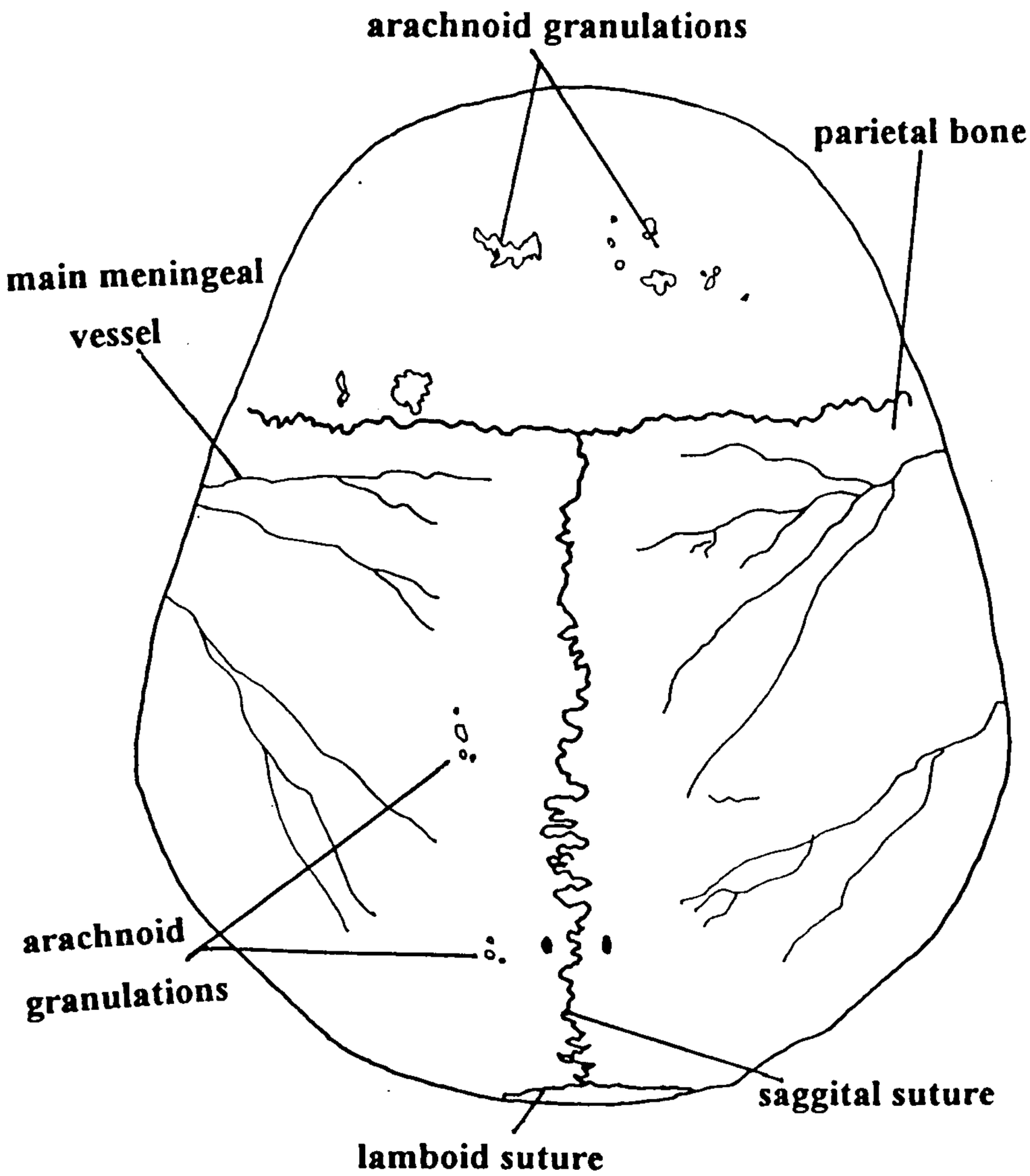

Figure 8.2 Diagram of the endocranial surface of the skull showing the pits caused by arachnoid granulations

Arachnoid Granulations and Age

In the radiological literature it has been occasionally noted that on a lateral skull x-ray the number and size of pits caused by arachnoid granulations increases with age (Grossman et al. 1974, du Boulay, 1980), but no specific x-ray based study attempting to correlate these findings has been undertaken.

The literature on the direct visual appearance of arachnoid granulations on the endocranial surface of the skull is scant. Basmajians work in 1952 attempted to correlate the dimensions of arachnoid granulation pits with age to assess the potential for the method in forensic science. Although the results showed a positive trend, Basmajian concluded that this method was not accurate enough for forensic use. Arensburg (1989) categorised arachnoid granulation pits as small, medium or large and correlated these with age in a sample of 88 individuals. He found that the older individuals had on average larger pits than the younger.

Both of these studies concentrated more on the size and shape of the pits, rather than their exact number, and they did not take any measurements of the pits. In addition, they looked at the pits present on the frontal bone as well as both parietals. This could lead to inconsistencies in categorization as many older individuals, especially women, are affected by hyperostosis frontalis interna (HFI - see chapter 6). This phenomenon of billowing symmetrical new bone on the endocranial surface of the frontal can obliterate the original surface of the bone including any arachnoid granulation pits. As Basmajian and Arensburg counted and measured the pits on the frontal bones as well as the parietals, the presence of HFI (which must have affected at least some of the sample) may be the reason why they did not get such conclusive results.

Not everyone agrees that the size of arachnoid granulations correlates with age. Cobb (1952) states in his summary of ageing the skeleton that "contrary to general belief no significant change has been found occurring solely as a result of advanced age in depth or extent of Pacchionian depressions". He does not, however, source this claim, nor mention whether the number of arachnoid granulations increases with age.

Summary

From the literature reviewed above several points arise. Although the structure and function of arachnoid granulations has been investigated in detail, the effects of the villi on the endocranial surface of the skull has been rarely investigated. Radiological literature suggests some correlation between the size and number of arachnoid granulations and increasing age, but the field concentrates mainly on the identification of the clusters of villi to exclude them from more serious pathological causes of skull table

erosion. The research that has been carried out on correlating arachnoid granulations and age has produced some positive results, but not everyone has been convinced.

In light of these conflicting arguments it was proposed that a study be undertaken to see if the results suggested by radiologists would correlate with direct observations on the skull, and if these observations could be accurate enough to form a model for a new ageing technique.

Aims of the study

This chapter contains 4 studies

1. A histological and morphological study of arachnoid granulation pits and their effect on the table of the skull

2a. Correlation of the number of arachnoid granulations in a modern post-mortem population with age at death

2b. Test of correlation produced on a large archaeological population of known age at death

2c. Use of Spitalfields to create better regression model to test on another sample of known age at death

2d. Use of the Spitalfields regression equation to compare demographic profiles produced by different anthropological methods in the Barton-on-Humber sample

3. Investigation of racial variation of arachnoid granulations

4. Test of arachnoid granulation size and shape on age

1. Morphological and histological studies of arachnoid granulation pits

To prove that the pits seen on the endocranial surface of the skull were actually caused by the pressure of growing arachnoid granulations and to identify potential areas for further work two investigations were carried out. Firstly, a dissection of one of the post-mortem heads was carried out to study the villi in situ, and to take a sample for histology. Secondly a pilot study of 50 dry archaeological skulls was undertaken to determine the variety of shapes, sizes and placement of the arachnoid granulation pits.

1a Dissection

Materials and Methods

Two of the 15 Department of Anatomy cadavers (see chapter 3) were randomly chosen for a detailed dissection. The skullcaps were removed using an electric saw, handsaw and chisel.

A. Male, aged 92 (cause of death - senile cardiovascular degeneration) 6-92

The brain, still covered with the dura was removed. The surface of the dura was studied with a bright light and a magnifying glass. On the surface of the dura several lobulated granular lumps could be seen, of varying sizes and degrees of protrusion from the dura, the largest of which measured approximately 50mm in diameter (see figure 8.3). On examination of the endocranial surface of the skull the pits present were found to correspond directly with the larger lobulated lumps on the dura. There were more lumps on the dura than there were pits on the skulls surface, with several of those visible by eye on the dura not being represented by corresponding skull pits.

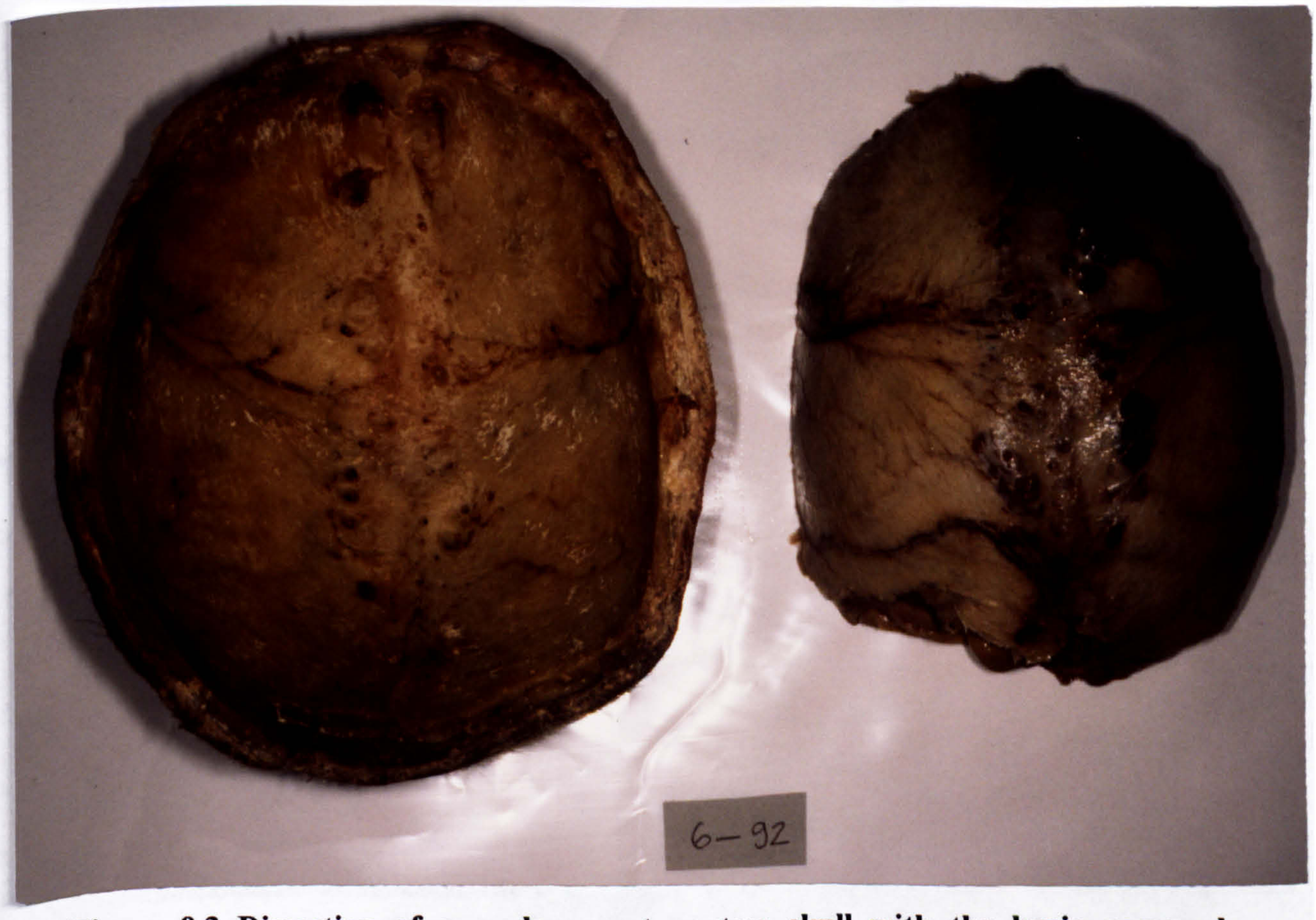

Figure 8.3 Dissection of a modern post-mortem skull with the brain removed showing clearly the arachnoid granulations protruding through the surface of the dura, and the pits on the endocranial surface of the skull that they cause.

B. Female, aged 94 (cause of death - left ventricular failure) 5-92

In this dissection the skull cap was removed, leaving the dura still attached to the endocranial surface of the skull. Dark red areas which were presumed to be arachnoid granulations were visible through and under the dura. To check that these really were arachnoid granulations the right side of the dura was carefully removed along the line of the saggital suture, to expose the saggital sinus and the right parietal. All the dark patches seen on the right hand side before the dura was removed corresponded to arachnoid granulations below it. The arachnoid granulations (see figure 8.4) could be seen to communicate with the saggital sinus, but not with the meningeal vessels. A section was taken through the uncovered left parietal to include one of the arachnoid granulations (confirmed by dissection as being the dark red patch) for thin-section histology (see figure 8.4). It was decided to take only one section for histology, as the resources for histological analysis were limited (see chapter 3) and it was not possible to take more samples without ethical approval (see chapter 3 for a discussion on why investigations requiring ethical approval were not undertaken).

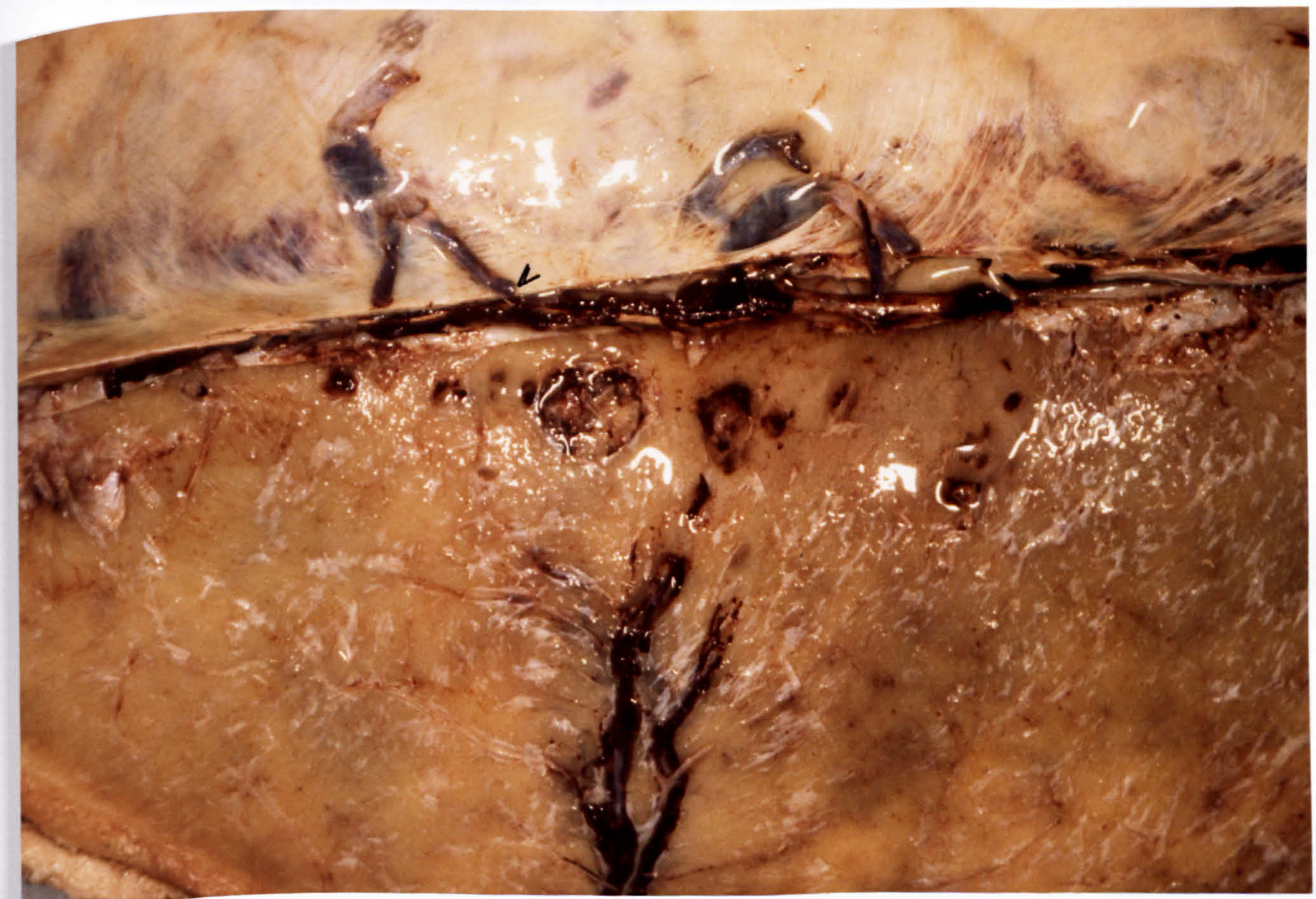

Figure 8.4 Dissection showing partial removal of the dura. Arachnoid granulations can be seen to communicate with the saggital sinus (arrowed), but not with the meningeal vessels.

Histology results

In the thin section (see figure 8.5) the edge of an arachnoid granulation (arrowed A is the edge of the villius) can be seen. A series of Haversian systems (arrowed H) indicate an area of cortical remodelling caused by the growing arachnoid granulation.

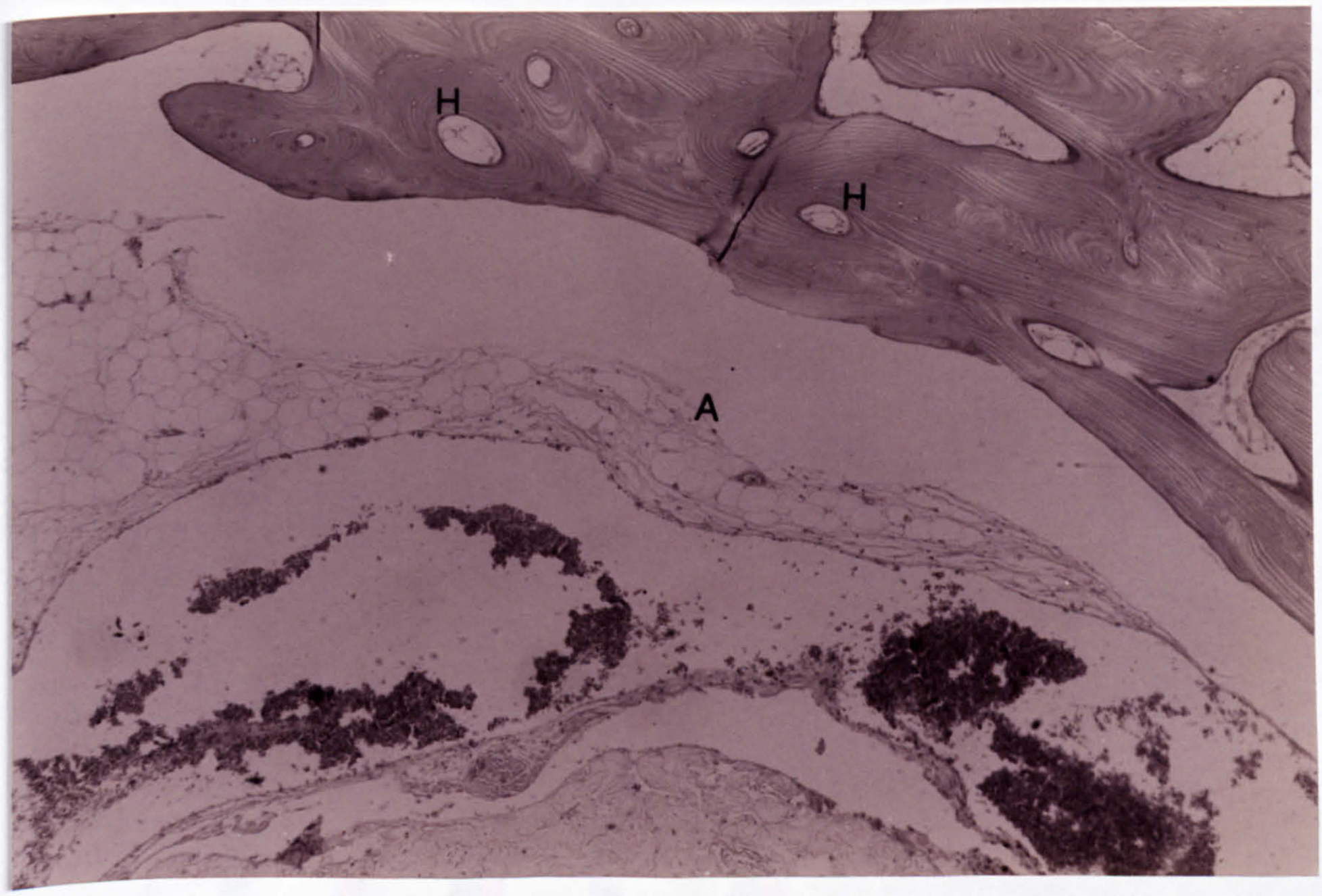

Figure 8.5 Histological section through the table of the skull, and an arachnoid granulation pit.

1b Pilot study

Once the pits had been confirmed as being caused by arachnoid granulations a larger study on the situation and numbers of the pits present was undertaken on dry skulls.

Materials and Methods

A sample of 50 skulls from the Barton-on-Humber sample (see chapter 3) were chosen to look at the variety of morphology of arachnoid granulation pits. The archaeological skulls used for the pilot project were chosen according to the following criteria:

1. Calvaria with both parietals, the frontal bone (above the brow ridges) and at least the proximal 2/3rds of the occipital present (with transverse sulcus present), in clean unabraded condition
2. Calvaria which have been broken enough at the base to get a good view of at least 50mm either side of the sagittal suture

3. Any calvaria with HFI above grade 2 (see chapter 6 for details) that has spread to the parietals (Hyperostosis Parietalis Interna) were ignored

4. Any skulls which had a worn/abraded endocranial surface were discarded

5. Any skulls with obvious internal lesions e.g. syphilis or cranial metastases were discarded

The first 50 skulls which fitted the above criteria from the Barton sample were used in this study. Figure 8.6 below shows the age and sex profile of those selected.

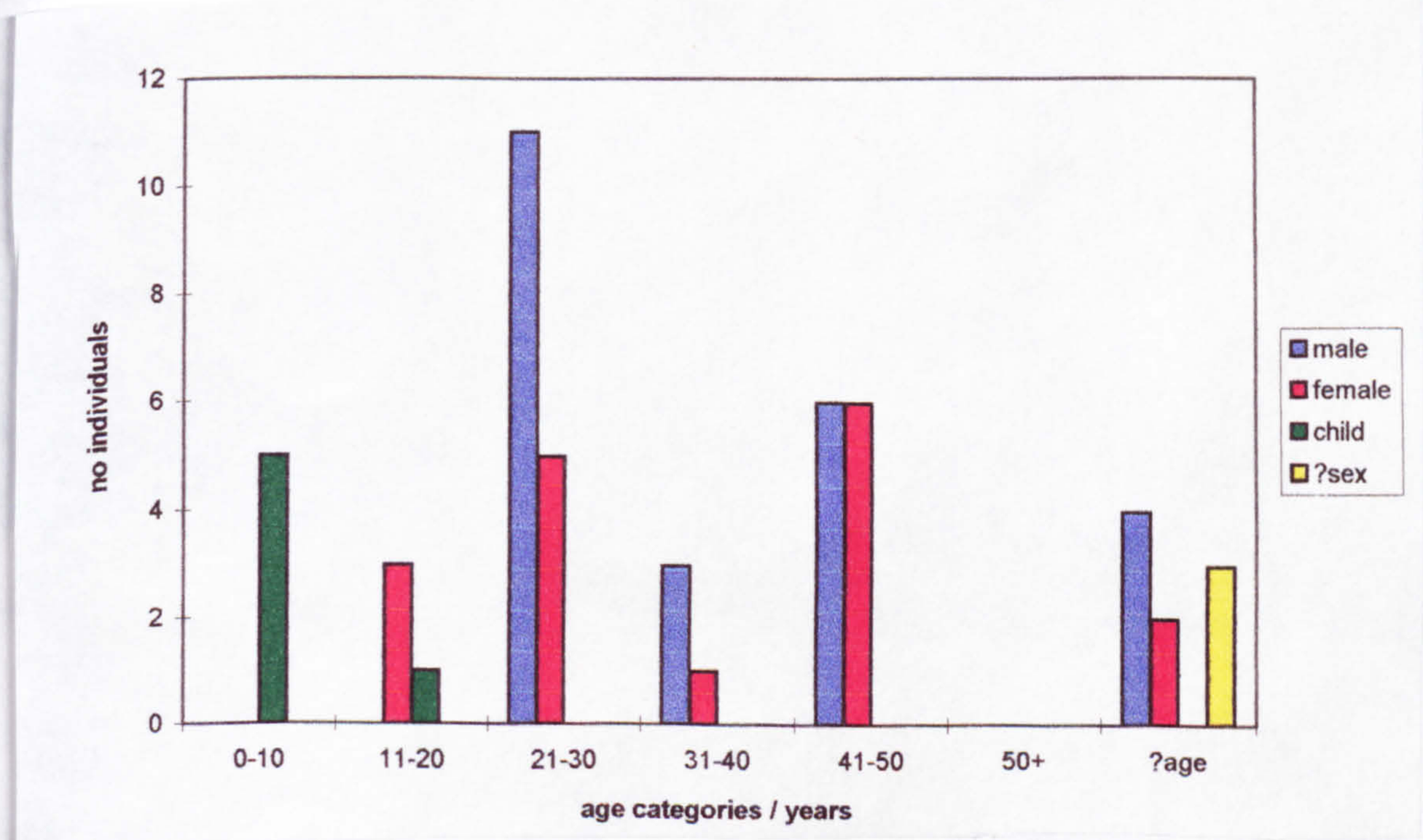

Figure 8.6 Age and Sex Profile of the Barton-on-Humber Pilot study

The shape and size of the pits was recorded on a visual map of the endocranial surface of the skull, without taking any detailed measurements. The numbers of pits present on the frontal, parietals and occipital bone were drawn on this chart at approximately the right size and in the right area of the skull (scaled down by eye for size). Sheet 1 in appendix A is an example of the recording sheet used.

Results

In the pilot study of 50 individuals from this sample it was noted that the arachnoid granulations presented endocranially on the parietals as one of two phenomenon which were termed "pits" and "depressions"(see figure 8.7).

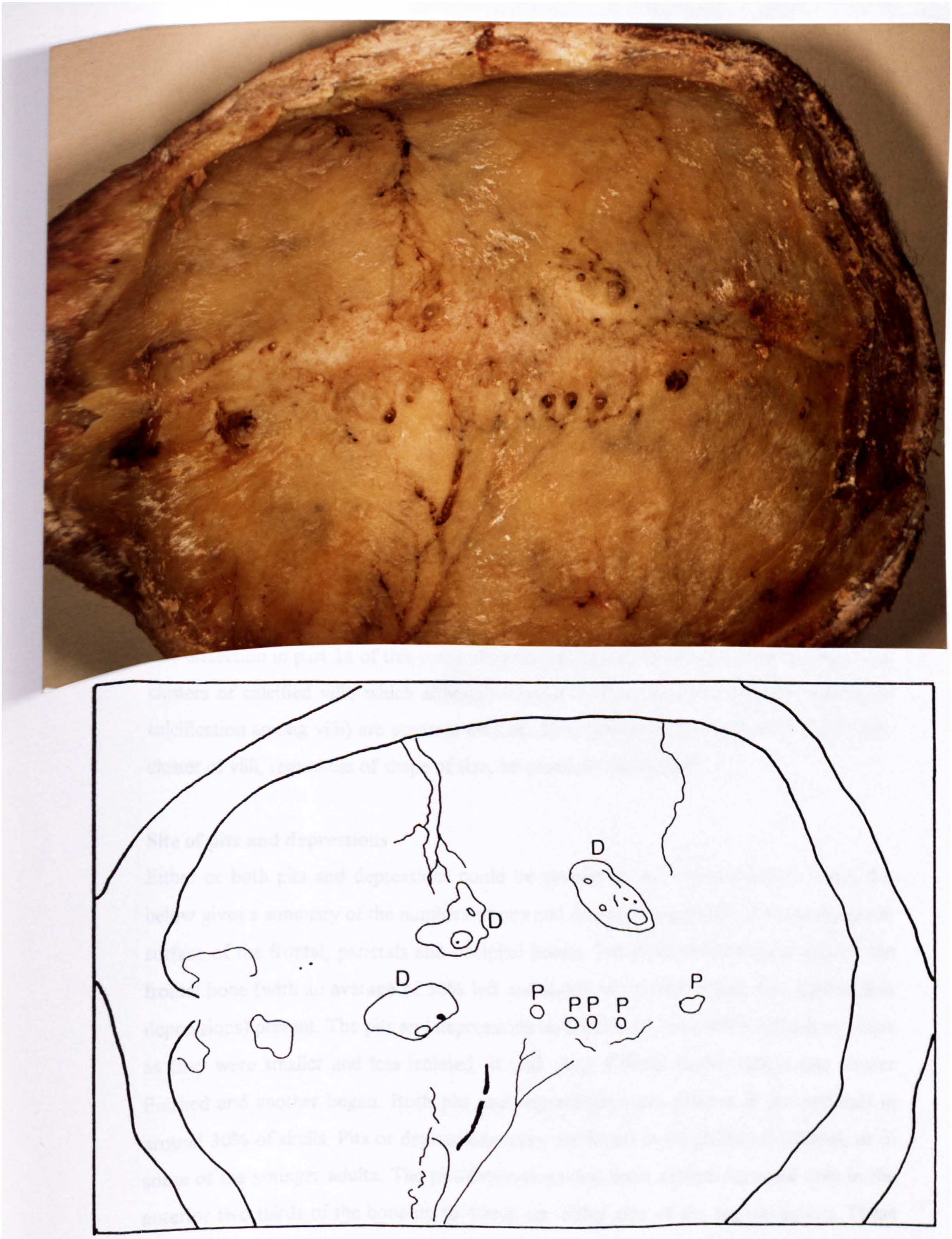

Figure 8.7 Post-mortem skull (with line drawing) showing well defined pits (P) and depressions (D)

Pits (See fig 8.7)

These are small indentations of varying depth which tend to be deeper than they are wide. The bottom of the pit is usually uneven, often with smaller pits inside it. The shape of these pits varies, often they are round or oval, but they can be figure-of-eight shaped.

Depressions (see figure 8.7)

These are larger indentations, wider than they are long. They can be felt easily with the finger, and do not normally contain smaller pits inside them. Depressions are round or ovoid in shape. They are more difficult to count than pits, which are striking and discrete. Depressions can often be felt more easily than they can be seen. These depressions must not be confused with the convolutional impressions often seen in children's skull which appear as a response to growth. These convolutional markings tend to be confined to the base and lower two-thirds of the vault (du Boulay, 1956;1980) whereas the depressions are always close to the saggital sulcus.

Counting Pits and Depressions

The dissection in part 1a of this study showed that arachnoid granulations are individual clusters of calcified villi, which although uneven in shape and size (due to differential calcification among villi) are separate entities. This method proposes that each definable cluster of villi, regardless of shape of size, be counted / scored as 1.

Site of pits and depressions

Either or both pits and depressions could be present in any one individual. Table 8.1 below gives a summary of the numbers of pits and depressions present on the endocranial surface of the frontal, parietals and occipital bones. The most common site was on the frontal bone (with an average of 50% left and right), which had mainly pits (rather than depressions) present. The pits and depressions on the frontal bone were difficult to count as they were smaller and less isolated. It was often difficult to tell where one cluster finished and another began. Both pits and depressions were present in the parietals in around 30% of skulls. Pits or depressions were not found in the skulls of children, or in some of the younger adults. The pits/depressions that were scored occurred only in the anterior two thirds of the bone up to 40mm on either side of the sagittal sulcus. These pits/depressions were easier to score than those in the frontal bone. Only pits were found on the occipital bone , and then in only 10% of individuals (all adults).

Score	Pits frontal left	Pits frontal right	Depres frontal left	Depres frontal right	Pits parietal left	Pits parietal right	Depres parietal left	Depres parietal right	Pits occip all	Depress occip all
0	26 (52%)	24 (48%)	50 (100%)	47 (94%)	34 (68%)	36 (72%)	34 (68%)	33 (66%)	45 (90%)	50 (100%)
1	11 (22%)	14 (28%)	0	3 (6%)	7 (14%)	5 (10%)	11 (22%)	10 (20%)	2 (4%)	0
2	4 (8%)	3 (6%)	0	0	3 (6%)	5 (10%)	3 (3%)	5 (10%)	2 (4%)	0
3	6 (12%)	3 (6%)	0	0	2 (4%)	1 (2%)	1 (2%)	2 (4%)	1 (2%)	0
4	2 (4%)	5 (10%)	0	0	2 (4%)	3 (6%)	1 (2%)	0	0	0
5	0	1 (2%)	0	0	1 (2%)	0	0	0	0	0
6	1 (2%)	0	0	0	1 (2%)	0	0	0	0	0

Table 8.1 Numbers of individuals displaying pits and / or depressions on the frontal, parietal and occipital bones. Percentages in brackets.

It appeared from this pilot sample that the number of pits and depressions did increase with anthropological age, so a correlation of age and number of pits was undertaken. Table 8.2 below shows the results of these correlations.

Site	Pits frontal left	Pits frontal right	Depres frontal left	Depres frontal right	Pits parietal left	Pits parietal right	Depres parietal left	Depres parietal right	Pits occip all	Depres occip all
n=	50	50	50	50	50	50	50	50	50	50
p=	0.097	0.24	nd	0.429	0.012*	0.030*	0.041*	0.082	0.170	nd
R-sq^	0%	1.1%	nd	0%	13.1%	9.3%	8%	5.2%	2.4%	nd

*significant at 5% level

nd = no data for analysis

^ adjusted score

Table 8.2 Results of the regression analysis of numbers of pits and depressions by age

From the results it can be seen that the numbers of pits and depressions on the parietals correlate well with age, but not the frontal or occipital bones. There appeared to be little

difference in the scores for left and right sides (except perhaps the right parietal depressions) so it was decided to pool the scores for left and right pits and depressions separately, and to correlate these with age. The total score of all pits and depressions together was also correlated with age, because at this stage it was not known if there was any true difference between pits and depressions, other than size.

site	all pits	all depressions	all pits + depressions
n=	50	50	50
p =	0.011	0.036	< 0.0001
R-sq (adj)	13.4%	8.5%	30.7%

Table 8.3 Results of the regression analysis of pooled left and right pits and depressions, and total score of all pits and all depressions.

The results of the pilot project showed that in this sample at least, the total number of pits and depressions correlate well with age. It must be remembered that the ages used in this study are anthropologically determined (see chapter 3), and may well be inaccurate, being subject to maximum age ranges and large standard deviations. As there is a maximum cut-off age of 45+ for females and 60+ for males in the methods used on this sample, these results may well underestimate the strength of the correlation. This study did not determine exact relationship between pits and depressions, nor any proper investigation of any differences in pit and / or depression counts between left and right sides of the same skull.

Reproducibility

Before any proper correlations could be carried out the methodology devised in study one of this chapter had to be tested to see how reproducible it is. In order to test the repeatability of this method, an intra- and inter-observer study was carried out. Twenty-five of the fifty Barton-on-Humber pilot skulls were randomly chosen. The protocol outlined below was followed:

1. Only the pits and depressions on the parietals were counted - anything anterior to the coronal suture or on the frontal bones themselves was ignored. Care was taken to

identify the correct area of study as the coronal suture line is more diffuse internally than externally, but is not completely obliterated internally in most individuals.

2. For each individual the numbers of pits and depressions were counted on the left and right sides separately.

3. All observations were made blind to age, sex and any post-cranial pathology, which were only noted after the examination was complete.

These skulls were chosen to cover the entire range of types seen in the pilot study 1b- some with many pits, some with none, and in a variety of soil stained colours and states of preservation. Each skull was numbered from 1-25, and the number of pits and depressions present were counted in each skull, blind to the age and sex (see chapter 3 for details) of the skeleton from which it came. The skulls were put away for a month, with their numbers still attached, and were then re-examined again exactly as before, but this time in random order (as they came out of the box).

The same skulls were also presented to a group of five other individuals. None of the individuals had used this method before. A short verbal description was given to them outlining the method exactly as in the text, and an example was shown on a skull not used in the study. A few minutes was allowed for questions and for the participants to familiarise themselves with the skull that was not being used in the study. A handout of a diagram (see figure 8.2 on page) of the inside of the skull with the relevant bones and sutures labelled was available for those who were not familiar with the anatomy of the skull.

Each participant was given a recording sheet and asked to count the number of pits and depressions for the left and right sides of each of the numbered skulls. In addition they were asked for their level of familiarity with skeletal material in general (novice, intermediate or expert). If they had used any other ageing technique in the past they were asked to rate the new technique against it in terms of ease of use (easier, the same, harder). They studied the skulls in any order they chose to, and were instructed not to confer with any other participant (including the lecturer) once the trial had started.

The participants were told to take as much time as they needed to get a satisfactory result for each skull. They could return to any skull as many times as they needed to. Unknown to them they were timed to see how long they took to finish all 25 skulls.

Results of the inter- intra-observer study

The first authors two attempts at the 25 skulls were compared, and the modulus difference was used to see how many were identical, and how many were 1-off, 2-off until all the skulls were accounted for. Table 8.4 shows these results. An intra-class correlation coefficient was also calculated. This was 0.882, indicating good within observer reproducibility.

Difference between first and second observations	**Number of hits (cumulative % accuracy)**
0	16 (64%)
1	5 (84%)
2	1 (88%)
3	0 (88%)
4	1 (92%)
5	1 (96%)
6	1 (100%)

Table 8.4 Results of the intra observer study

The mean of the two scores for each skull was used as the "Gold Standard" to which the other observers were compared. Table 8.5 below shows the results for each observer. An intra-class correlation was also calculated to further assess between observer reproducibility. This was 0.67, indicating good agreement.

Observer	all correct	within 1	within 2
1(1st attempt)	64%	96%	100%
1(2nd attempt)	76%	92%	100%
2	68%	68%	80%
3	36%	64%	80%
4	36%	64%	80%
5	36%	76%	96%
6	32%	76%	92%

Table 8.5 Accuracy between observers

There was no systematic bias to either under- or over- estimating the number of pits and depressions between observers. Those skulls with larger numbers of pits and depressions were as accurately counted as those with none or few.

All those who had used another type of aging technique compared it favourably or at least as easy to use. The quickest person took 15mins, the slowest 35 mins to complete the examination of the 25 skulls, confirming this method as quick and easy to use. For a first attempt the participants were acceptably accurate, and with training these figures could be improved.

2a. Investigation of the relationship between pits and depressions and age in a population of known age at death.

Sample

The sample consisted of the 50 post-mortem individuals selected at random from the mortuary at the Bristol Royal Infirmary between 1993-1995 (see figure 8.8). For each individual the age, sex, cause of death and past medical history were noted. See chapter 3 for full details of the sample.

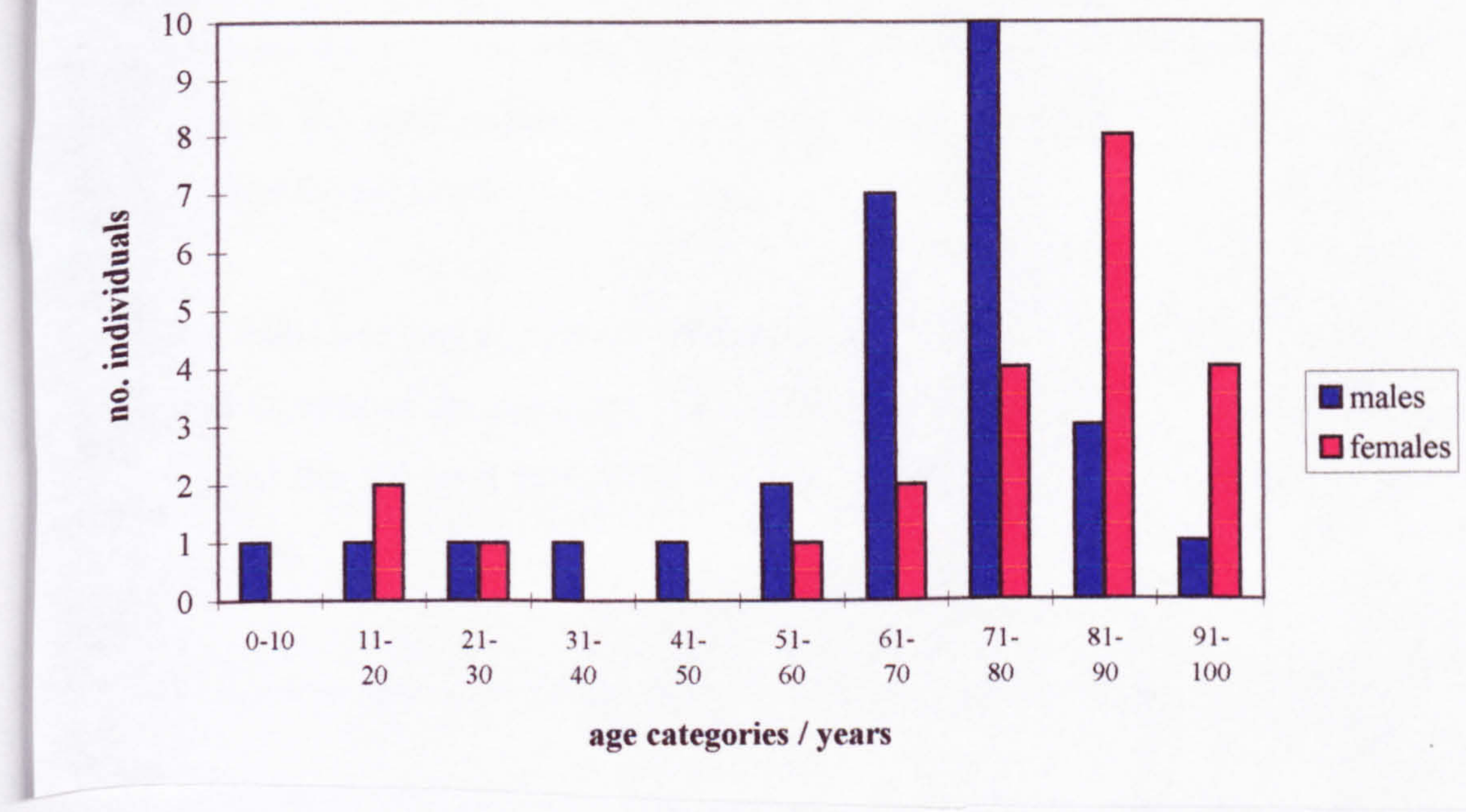

Figure 8.8 The demographic profile of the post-mortem population

Method

For each of the individuals the number of pits and depressions present on the left and right parietals was counted using the methodology outlined in study 1b of this chapter, with the following additions:

1. Only the pits and depressions on the parietals were counted - anything anterior to the coronal suture or on the frontal bones themselves was ignored.
2. For each individual the numbers of pits and depressions were counted on the left and right sides separately. The total number of pits and depressions from both sides were then added together to obtain a score.
3. All observations were taken blind to the age, sex and cause of death, which were noted after the examination was complete.
4. The score (the total number of pits and depressions present) for each individual was then examined in relation to the actual age at the death.

Results

A Mann-Whitney test was used to determine if the number of pits in a skull is greater than the number of depressions, or vice-versa. There was no statistical difference between them ($p = 0.773$, Mann-Whitney test). Neither was there any evidence of a difference in the total number of pits and depressions between the left or the right parietals ($p = 0.916$, Mann-Whitney test).

To see if there was any significant difference in the numbers of pits and depressions in males and females of the same age a Mann-Whitney test was used. The result was non-significant at the 5% level ($p=0.713$). The median number of pits in males was 6 and in females it was 5.5.

Figure 8.9 below shows the results of a plot of total numbers of pits against age.

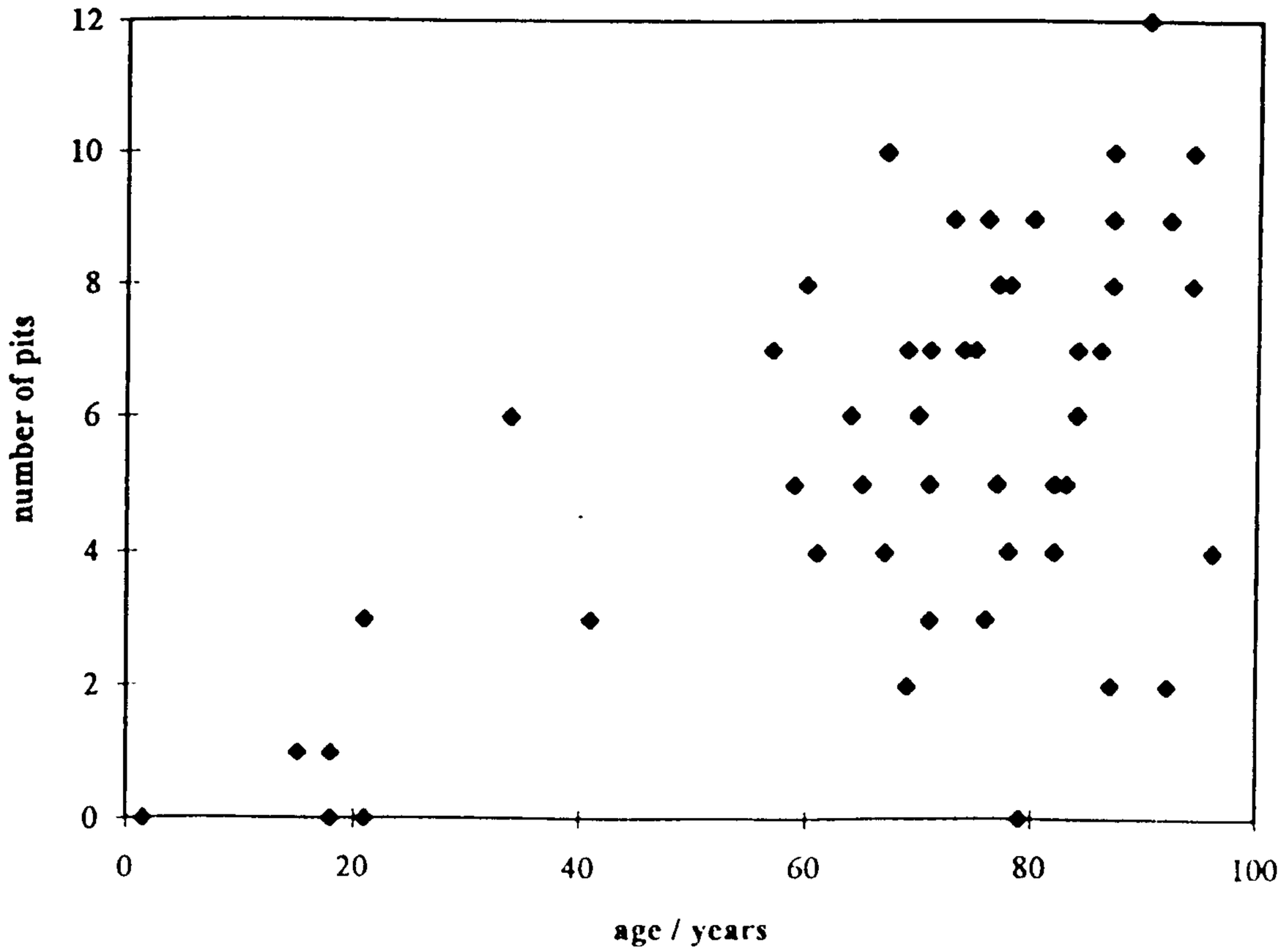

Figure 8.9 A plot of total pits and depressions against age at death - post-mortem sample

The plot clearly shows a relationship between total number of pits and depressions with age. To investigate this relationship further, a regression analysis was made on both males and females (separately), and then in the sample as a whole. Tables 8.6 to 8.8 below show the results of these correlations.

Parameter	Co-ef	StDev	t-ratio	p<
intercept	41.176	8.056	5.11	0.0001
total	4.226	1.297	3.26	0.003

R-sq (adj) = 27%

age = 41.2 + 4.23 (pits + depressions)

Table 8.6 Summary of results of the correlation between age and total score of pits and depressions in males

Parameter	Co-ef	StDev	t-ratio	p<
intercept	47.003	8.162	5.76	0.0001
total	4.669	1.28	3.65	0.002

R-sq (adj) = 37%

age = 47 + 4.67 (pits + depressions)

Table 8.7 Summary of results of the correlation between age and total score of pits and depressions in females

Parameter	Co-ef	StDev	t-ratio	p<
intercept	43.66	5.74	7.61	0.0001
total	4.44	0.913	4.81	0.0001

R-sq (adj) = 32.1%

age = 43.7 + 4.45 (pits + depressions)

Table 8.8 Summary of results of the correlation between age and total score of pits and depressions in both males and females

Discussion

This study using individuals of known age at death strengthens the original hypothesis that the number of pits and depressions increases with increasing age. However, a drawback with the sample studied is that most of the post mortem individuals examined were aged over 50 years (see chapter 3 for details on attempts to ameliorate this problem) and probably do not have the same demographic profile as the archaeological populations for which its use is intended. This is a continuing problem when using modern material, as a random selection of adult individuals in any mortuary will give a ratio of about 15:1 over 50's to under. Arensburg also encountered this problem with his study, and to counter it he included individuals from the anatomy collection in his university which had been aged by standard anthropological techniques. This can cause problems if one subsequently tries to compare ageing techniques currently in use with any new one formulated from that population, as it cannot be said for certain that those skulls aged using the anthropological methods are 100% accurate.

In addition, those in the mortuary population aged under 50 years are often accident victims of some sort, i.e. those who skeletally "should not be dead" (see chapter 7 for more discussion on this), and it may be that these individuals do not display the same formation of pits over time as those who have died of chronic diseases.

It was decided that the best way to test this method would be to apply the regression equation obtained from this study to an archaeological population of known age at death. The Spitalfields sample was chosen as it covers a much larger (n=204) number of individuals, and includes a more even spread of ages at death.

2b. Application of the regression equation to a large population of known age at death

For any ageing technique to be a useful addition to those already in current use, three criteria must be fulfilled. Firstly, the method has to be practical enough to use on archaeological material. Even the most accurate of methods is of little use if it can only be used on a very small percentage of individuals. Secondly, it must be at least as

accurate as the other techniques in use, or include an age range not adequately covered by current methods. Thirdly, it must contain as little age specific bias as possible (i.e. when tested the technique should regularly over or under age as little as possible). This is a problem, as age specific variations do not always change at a constant rate over time, and techniques with a maximum cut-off age tend to suffer from a bias towards under-ageing (see chapter 3).

Materials and Methods

The sample

It was decided to use the Spitalfields sample to test the accuracy of the post-mortem regression equation. Spitalfields was chosen as it was an archaeological collection, which is the "target" sample on which any final methodology would be used. It is the closest known age sample in racial and geographical terms to the post-mortem group, although the demographic structure of the two samples is markedly different.

The Spitalfields collection had 240 of the 383 named, aged individuals available for examination (see chapter 3). Each skeleton was aged where possible by tooth attrition, pubic symphysis and by the post-mortem regression equation. Table 8.9 below is a summary of what percentage of the total sample available for study was suitable for each examination.

Ageing technique	**number suitable**	**% of total sample**
Tooth Attrition	70 / 240	29
Pubic symphysis	14 / 106*	13
Arachnoid granulation counts	106 / 240	44

*due to time constraints only those with suitable crania were checked for their suitability of pubic symphysis aging

Table 8.9 A summary of the suitability of each method on the whole Spitalfields sample.

For the tooth attrition and arachnoid granulation counts the main reason for unsuitable skeletons was a missing skull. In the tooth attrition method, many of the crania that were

available were also unsuitable as they were edentulous or did not have a complete set of occluding molars (on one side at least). The second reason why not all of the crania were suitable for arachnoid granulation counts was that they were whole skulls. A score of the number of pits and depressions was taken from the whole skulls using a pen torch through the foramen magnum, but this was a difficult process and led to many inaccuracies.

As there was a limited amount of time tooth attrition and pubic symphysis ages were estimated only for the sample which was selected for arachnoid granulation ageing. Of this sub-sample of 106 individuals 43 were children or sub-adults. These were removed from the study as both tooth attrition and pubic symphysis ages could not be estimated for them and this would unfairly bias the results towards the arachnoid granulation counts (in terms of how many individuals were suitable for ageing). Figure 8.10 below is a summary of the demographic profile of those individuals suitable for the arachnoid granulation counts method.

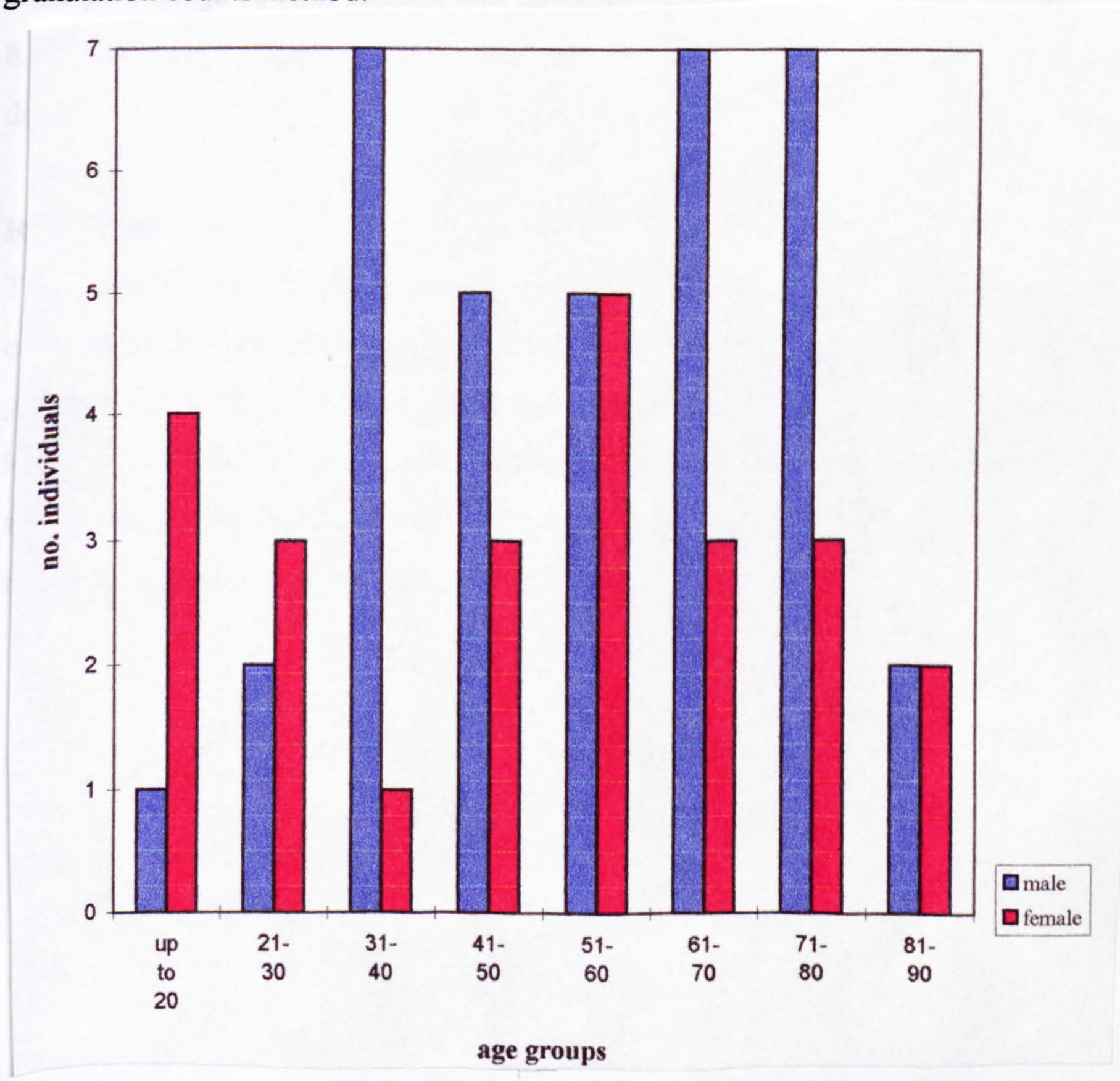

Figure 8.10 Demographic profile of the Spitalfields sample - children removed

The estimates of each ageing method were compared to the actual known age at death. The methods were then compared to each other in terms of accuracy. Both the pubic symphysis and tooth attrition techniques were scored by choosing the visual category to which it is most similar (see chapter 3). The estimated age used to compare to the real age was chosen by taking the mean age of the category from which the best comparison was made. For example a skull aged 25-35 using Brothwells technique would be given an age of 30. For the results estimated ages were compared to real ages to within +/- 10 and +/- 20 years. These categories were chosen because many palaeodemographic studies use 10 year age groups (Ascádi and Nemeskéri, 1970), and to cover the fact that age ranges, not specific ages are given for the tooth attrition and pubic symphysis methods.

Table 8.10 below shows how many individuals were finally suitable for each method, and what percentage of each method was accurate to within + or - 10 and 20 years. Figure 8.11 below is a graph comparing each of the ageing techniques to the known age at death.

Reproducibility

Ten skeletons were randomly chosen and the number of arachnoid granulations were re-counted at the end of the study. An intra-class correlation coefficient was calculated, giving a result of 0.89. This indicates excellent inter observer reproducibility. As the level of reproducibility for the estimation of age using tooth attrition and pubic symphysis ageing had been calculated in chapter 3 of this study, it was not thought necessary to repeat this exercise.

Results

	arachnoid granulation counts	pubic symphysis ageing	tooth attrition
N=	63 (100%)	14 (22%)	30 (48%)
+ / - 10 years	22 (35%)	7 (50%)	10 (33%)
+ / -10 to 20 years	25 (40%)	3 (21%)	10 (33%)
total aged within +/- 20 years	47 (75%)	10 (71%)	20 (67%)
mean bias of ageing / years	+9.8	-12	-16.7

Table 8.10 Results of the comparison of the three ageing techniques to real age at death.

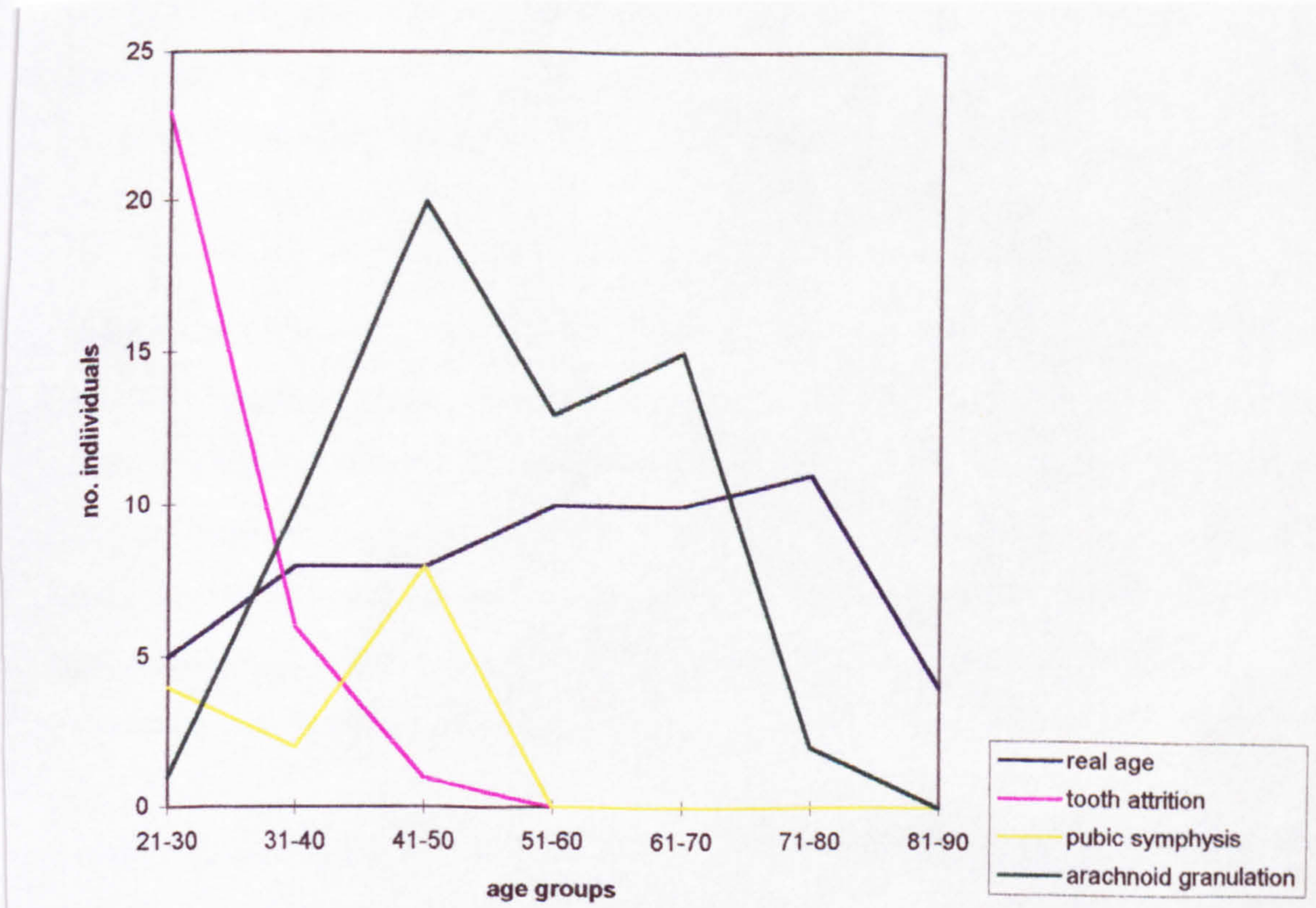

Figure 8.11 Graph comparing each of the three techniques to the real age at death.

Discussion

In retrospect, this was an unsuitable way to test the original post-mortem regression equation. The original sample, although large in the first instance (240) was reduced considerably by the selection criteria and the removal of all of the children, leaving an inadequate sample of only 63 individuals. As an archaeological sample Spitalfields is somewhat unusual (see chapter 3) as it is a well protected crypt, and had a higher proportion of whole, unbroken skulls than that of a normal burial site which led to a smaller number of appropriate skulls available for this study. In addition, this protective environment led to a higher percentage of children being preserved which again reduced the percentage of the sample that could be used.

These results indicate that the arachnoid granulation count technique appears to work, but at this stage only in a limited way. Only 75% of the sample was aged to within a generous age limit of plus or minus 20 years. There is a marked bias towards over-ageing of an average of 10 years, and from figure 8.12 it can be seen that this occurs mostly in the younger age category. The regression equation used has a zero pits age of 43.7 years. In this sample 18 adult individuals are below this age, which means they will automatically be over-aged. The reason for the relatively old starting point is due to the old mean age of the post-mortem population (68.2 years), and the lack of younger individuals.

Despite these problems, if the results of the three techniques are compared, then the arachnoid granulation counts method appears to be the best in terms of largest potential number of individuals for which age estimation can be attempted; numbers of individuals accurately aged, and lowest mean bias. The arachnoid granulation count method has another distinct advantage over the pubic symphysis and tooth attrition methods, that is, it has no maximum cut-off point, so it can be used to age those individuals usually missed by the other current techniques.

It must be noted that the design of this study is biased towards the arachnoid granulation method in several ways. Only those individuals which fitted the arachnoid granulation selection criteria were aged by the other two methods when possible. There may well have been several skeletons not suitable for the arachnoid granulation method which

could have provided an estimation of age using tooth attrition and / or pubic symphysis changes. A better estimation of the suitability of each technique is provided in table 8.9 which shows that in almost half of the whole sample an arachnoid granulation count could be attempted, whereas only in 29% (tooth attrition) and 13% (pubic symphyses) of the sample the other methods could be used. This again is not entirely fair to the tooth attrition method. Brothwells criteria (1981) was designed for use on Neolithic to Medieval samples, and Spitalfields is later than this. Post-medieval populations suffer more caries than earlier ones (Hardwick, 1960) and also a greater proportion of the Spitalfields sample is edentulous than a medieval one (Whittaker, 1993), which excludes any estimate of age using the tooth attrition method. The pubic symphysis method used in this study also suffers from the fact that women were not aged (see chapter 3 for a discussion on why this was so), which lowers the percentage of the sample available for age estimation. The pubic symphysis is often broken, abraded or lost during excavation, as it is one of the highest points of a recumbent / supine skeleton, and is most prone to destruction caused by soil pressure (Henderson, 1987).

Bearing in mind these problems when the three techniques are compared several points arise. The first is the depressing fact that all the methods are not very accurate. Of the three the arachnoid granulation count method appears to be the best at ageing within +/- 20 years, but still only 75% of all skeletons were aged to within this range. The pubic symphysis method appears to be the most accurate of the three techniques in estimating age to within +/- 10 years (but only 7 individuals were aged). The arachnoid granulation method has the least bias of the three samples, and this could be reduced further by producing a regression equation from a sample similar in demographic profile to an archaeological sample as discussed by Maat (1987) and Konigsberg and Frankenberg (1992, 1994). This in itself poses a problem, as one can only postulate about the demographic profile of a dead archaeological population. It is after all, why ageing techniques were invented in the first place.

Conclusions

Although this study has several flaws it shows that the arachnoid granulation count technique is comparable in accuracy to the two other techniques used, if not slightly better. The use of a better base sample with a more even age range (such as Spitalfields

itself) may provide a better regression equation, and so get more accurate estimations of age at death.

It was decided to use the Spitalfields sample (N= 63, excluding the children) to produce a new regression equation which could then be applied to another sample of known age at death (the Terry collection). The Terry collection could be also used to investigate any racial differences in numbers of arachnoid granulations.

2c. Correlation of the total number of pits and depressions against age in the Spitalfields sample.

The sample

Sixty-three individuals were selected (all adult individuals that fitted the original criteria set out in study 2 of this chapter) from the Spitalfields sample of 240. The mean age of the sample was 31.8 years. The maximum was 86 years and the minimum 0 months. Figure 8.12 shows a demographic profile of the Spitalfields sample.

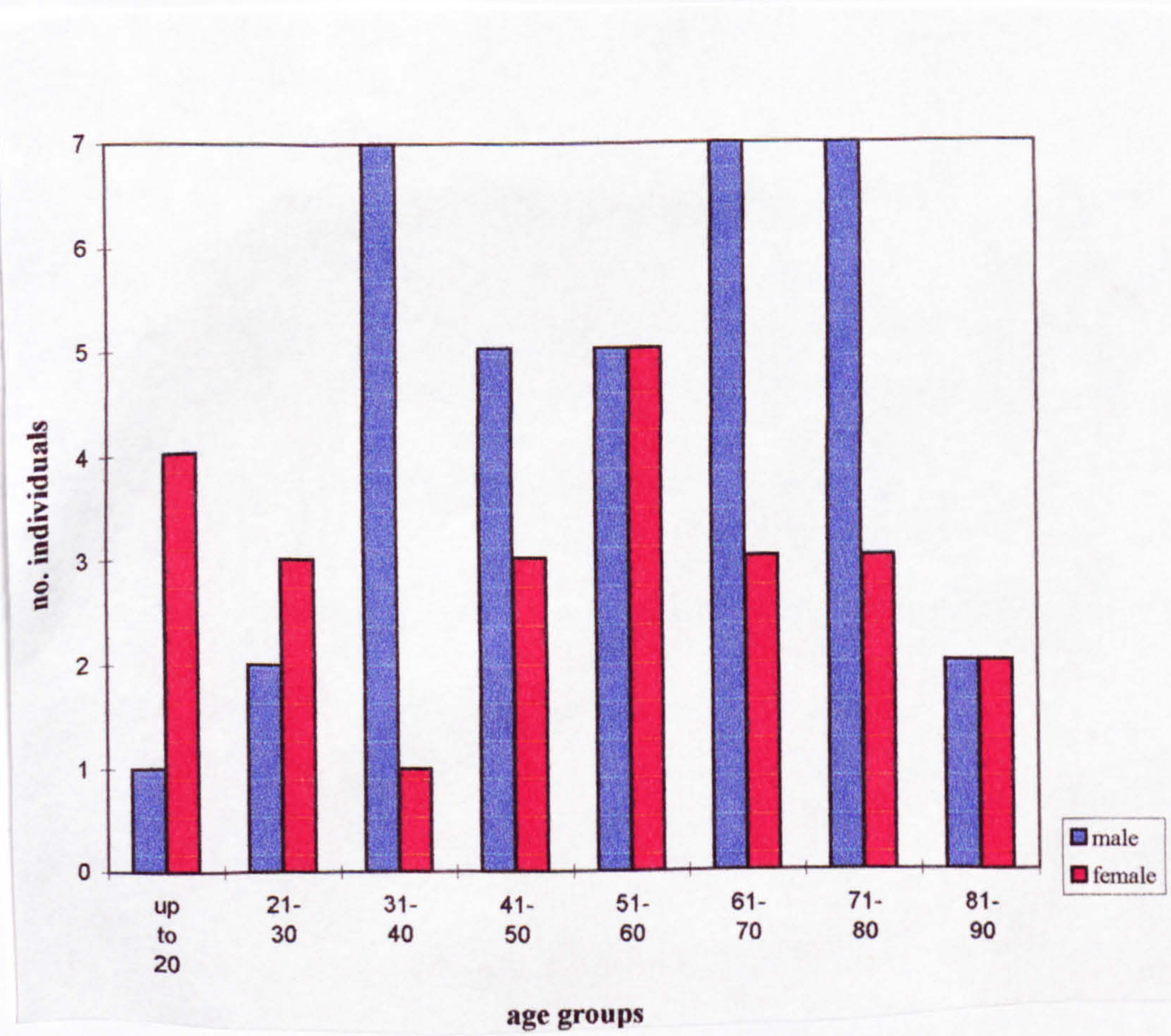

Figure 8.12 Demographic profile of the Spitalfields sample

Method

The total number of pits and depressions present on the left and right parietals were correlated against age in the Spitalfields sample, using exactly the same methodology as set out in studies 1 and 2 of this chapter. Table 8.11 below gives the results of the correlation of the total score of pits and depressions against age. This regression equation was then used to estimate age at death in the 261 individuals from the Terry collection (see previous chapters, especially 3, for demographic details). As a comparison the individuals from the Terry collection were aged, where possible, using the anthropological tooth attrition and pubic symphysis ageing methods, as outlined in chapter 3 of this thesis. For each method the number of individuals that could be aged using each method were noted, as were numbers of cases that could be aged to within +/- 5, 10 and 20 years.

Results

Table 8.11 below gives the results of the correlation of the total score of pits and depressions against age for the Spitalfields sample. Figure 8.13 is plot of the total score of pits and depressions against age.

Parameter	Co-ef	StDev	t-ratio	p<
intercept	24.689	4.76	5.19	0.0001
total score	6.784	1.039	6.53	0.0001

R-sq (adj) = 40.5

age = 24.7 + 6.78 total score of pits and depressions in the skull

Table 8.11 Results of the regression equation - the Spitalfields sample

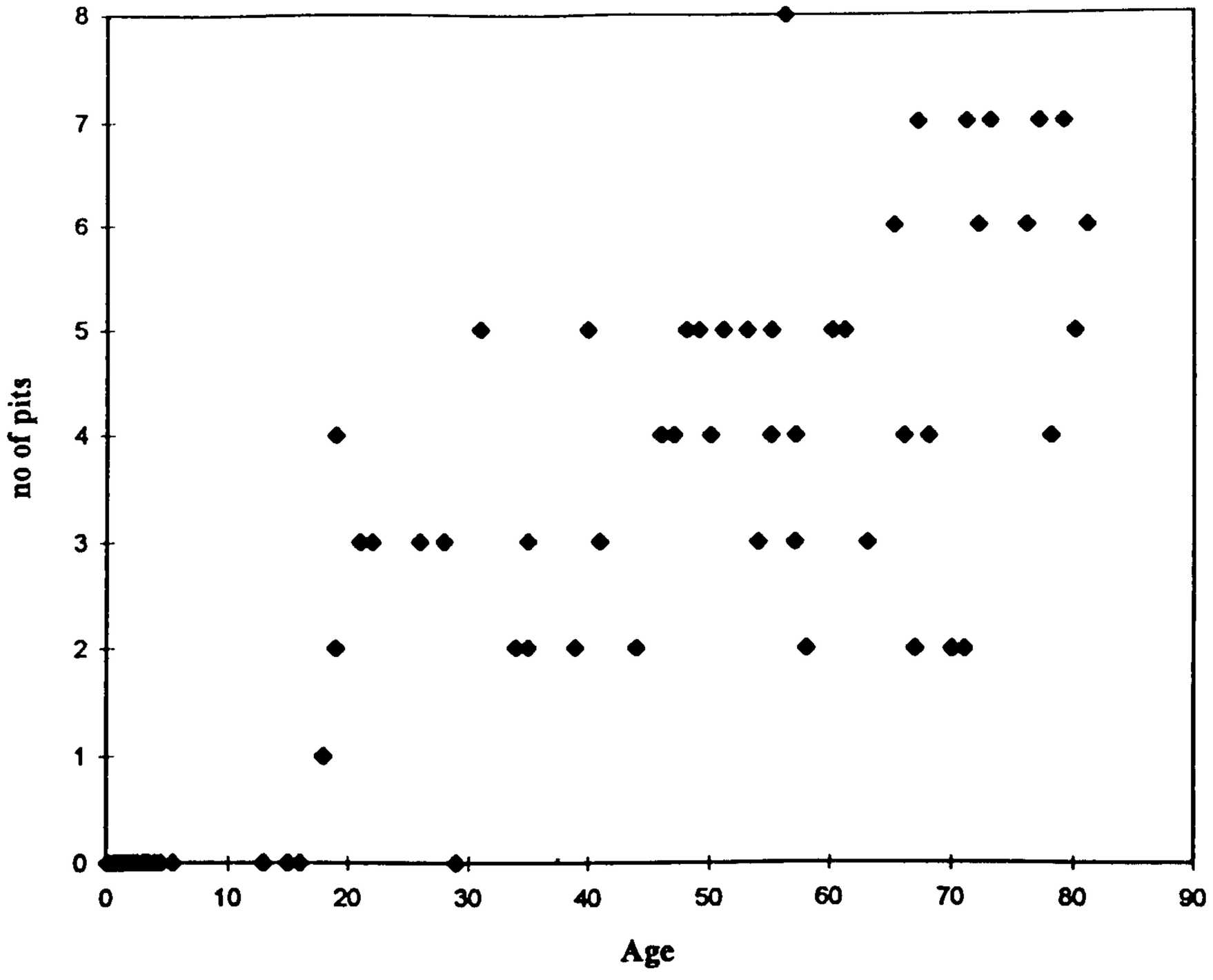

Figure 8.13 Plot of total pits and depressions against age - the Spitalfields sample

Tables 8.12 to 8.14 give the results of the comparison of accuracy of the three techniques - arachnoid granulation counts (based on the Spitalfields regression analysis), tooth attrition and pubic symphysis scores in the Terry collection.

	black males	black females	white males	white females
+/- 5 years	17 (25%)	15 (19%)	15 (25%)	13 (25%)
+/- 10 years	14 (20%)	11 (14%)	14 (23%)	12 (23%)
+/- 20 years	15 (22%)	23 (29%)	17 (28%)	14 (26%)
over +/- 20 years	23 (33%)	30 (38%)	14 (23.5%)	14 (26%)
mean bias	0.3	7.6	-2.5	5.4
N=	69	79	60	53

Table 8.12 Arachnoid granulation counts - accuracy of age estimation in the Terry sample using the Spitalfields regression equation

	black males	black females	white males	white females
+/- 5 years	5 (16%)	9 (37.5%)	5 (45%)	0
+/- 10 years	10 (32%)	5 (21%)	1 (10%)	2 (25%)
+/- 20 years	13 (42%)	2 (8%)	5 (45%)	4 (50%)
over +/- 20 years	3 (10%)	8 (33.5%)	0	2 (25%)
mean bias	-11.5	16.4	7.2	18.1
N=	31	24	11	8

Table 8.13 Tooth attrition score - accuracy of age estimation in the Terry sample

	black males	white males
+/- 5 years	15 (31%)	16 (44%)
+/- 10 years	13 (26%)	7 (19.5%)
+/- 20 years	16 (33%)	6 (17%)
over +/- 20 years	5 (10%)	7 (19.5%)
mean bias	5.3	7.6
N=	49	36

Table 8.14 Pubic symphysis score - accuracy of age estimation in the Terry sample

Discussion

What is striking from all of these results is the wide scale inaccuracy of all of the ageing techniques in estimating actual age at death. All three techniques produced roughly similar levels of accuracy, 75-80% of individuals aged to within +/- 20 years.

Using the arachnoid granulation count method the level of accuracy is similar to the results in study 2b of this chapter, although the bias in this study is much lower. This is due to the fact that the demographic profiles of the sample forming the regression equation and the sample it was tested on are very similar, as mentioned earlier. The two advantages that arachnoid granulation counts have over tooth attrition and pubic symphysis methods in estimating age in this sample is that it can be used on a larger

proportion of the sample, and not having a maximum cut-off point, it can be used to age older individuals which have been previously been under-aged or ignored. The method can also be used on both males and females with equal accuracy.

It would appear that the regression equation could at this stage form the basis of an acceptable ageing technique. It would be difficult to apply a more complex, but more accurate predictive model (with prediction as well as confidence intervals) to the arachnoid granulation method as it stands, as there is variance of pit numbers with age. However, other methods currently in use are not based on models which give prediction intervals. The Katz and Suchey (1986) method gives only confidence intervals, which are rarely quoted (see chapter 3).

This study has used pits and depressions together as the total score provided a higher correlation than either of them separately. It may be that depressions, being larger, have taken longer to produce, and so should have a greater weighting in any subsequent model produced, this could be addressed in any further work.

In the case of partial or poorly preserved material it may be possible to use arachnoid granulation counts to give a minimum age or a larger age range (e.g. "older adult") if no other method is available to the investigator.

If only one parietal is present, an age can still be attempted, as there are normally no differences in total numbers of pits and depressions in left and right sides, but these ages must be used with more caution than those estimated on one with both sides available for examination. A complete parietal is not needed, as long as the top 30-40mm of the whole parietal next to the saggital suture is present (as outlined in the text, and figure 8.2). As this method works best on broken, but complete material (as described in the methods section) it lends itself well to the fragmentary nature of most archaeological remains. Approximately 70% of the 2,000 adult crania from the multi-period burial site at Barton-on-Humber fitted the criteria suggested for this method. It must be remembered as shown from the intra-observer error study that this method is only as accurate as the person using it, and the better the condition of the material the greater the chance of a more accurate estimation.

One reason that it is difficult is that what is actually being measured in this study is skeletal age at death, which is not always compatible with chronological age at death, as many previous workers (e.g. Tonna, 1985 and McKern, 1970) have pointed out (see chapter 1). It may be that individuals show more pit count variation with increasing age. These results are comparable to those from Spitalfields, (Molleson and Cox, 1993) where it was found that some individuals have skeletal changes which would make them much younger (or older) than their real (chronological) age.

It would appear that there is a slightly better degree of estimating age at death accurately in the white over the black sub-samples. This may indicate some racial difference, which needs to be investigated further.

It is not possible as yet to apply this technique to whole, unbroken skulls, as the nature of many of the depressions at least needs to be felt more than seen to be counted. Further work suggested by these results could include the construction of a calibration that can be used on whole skulls, but this may be at the cost of slightly less accuracy.

2d. A comparison of age at death profiles produced by arachnoid granulation counts, compared to that produced by pubic symphysis and tooth attrition methods

The results from the studies above suggest that the strength of the arachnoid granulation count method is in ageing older individuals. It was decided that it would be useful to see what effect, if any, the method would have on an archaeological age at death profile compared to that using the standard methods of tooth attrition and pubic symphysis ageing.

Sample

100 adults and children were chosen from the Barton-on-Humber sample (see chapter 3). The 100 individuals were randomly selected from those adults which could be aged using at least one of the two standard anthropological techniques of tooth attrition and pubic symphysis changes. Any children included in the study were aged using tooth eruption (using the chart in Brothwell, 1981) and long bone lengths (Maresh, 1955).

Method

The adult skeletons were first aged using only the tooth attrition and / or the pubic symphysis methods. The same adult skulls were then re-aged using the arachnoid granulation count method only. Figure 8.14 and 8.15 below shows the demographic profiles of age at death for each of the two methods. The mean age at death for each sample was also calculated.

Results

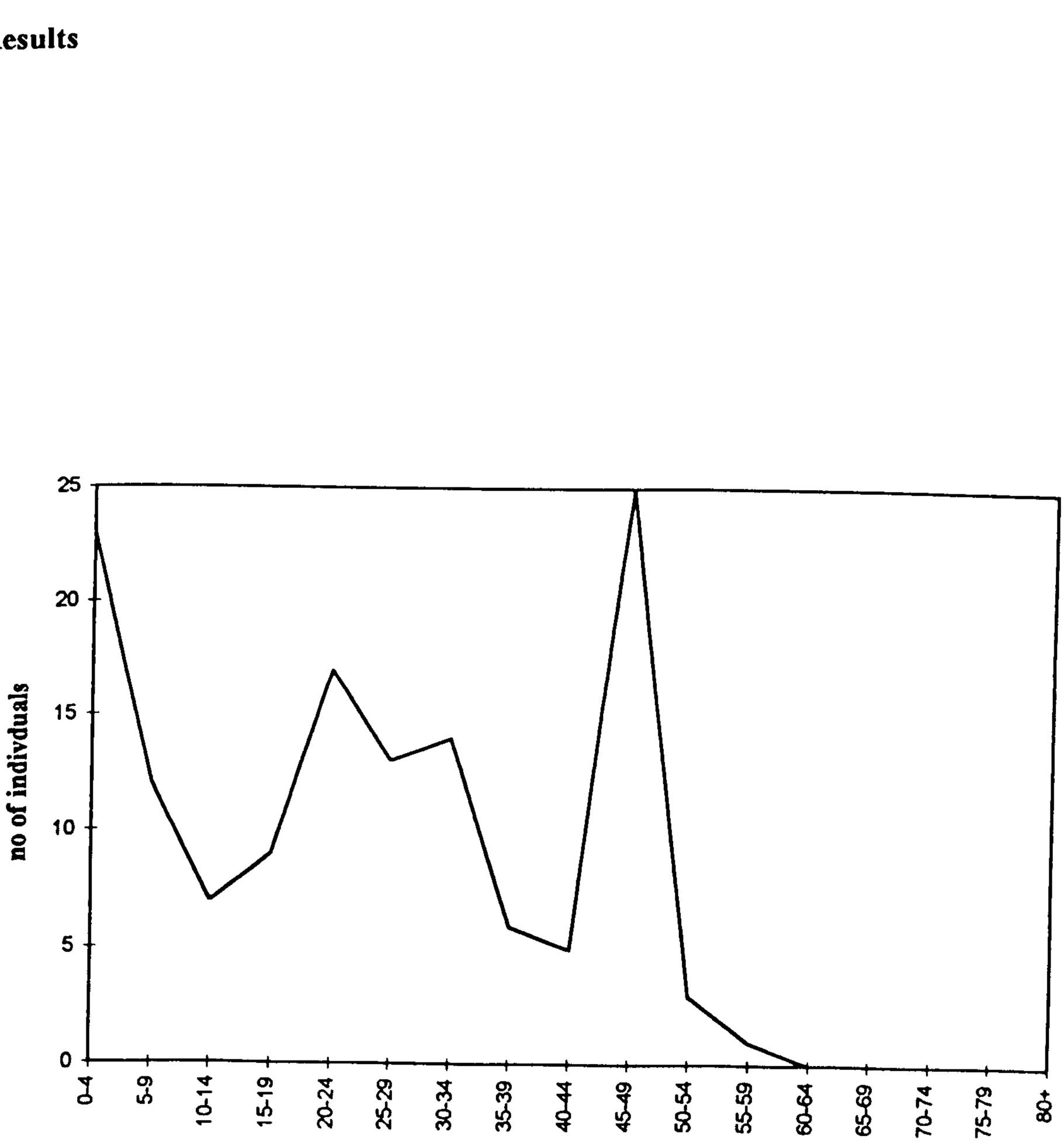

Figure 8.14 Demographic profile of age at death for the Barton sample - Tooth attrition and pubic symphysis methods only (children aged using long bone lengths and tooth eruption)

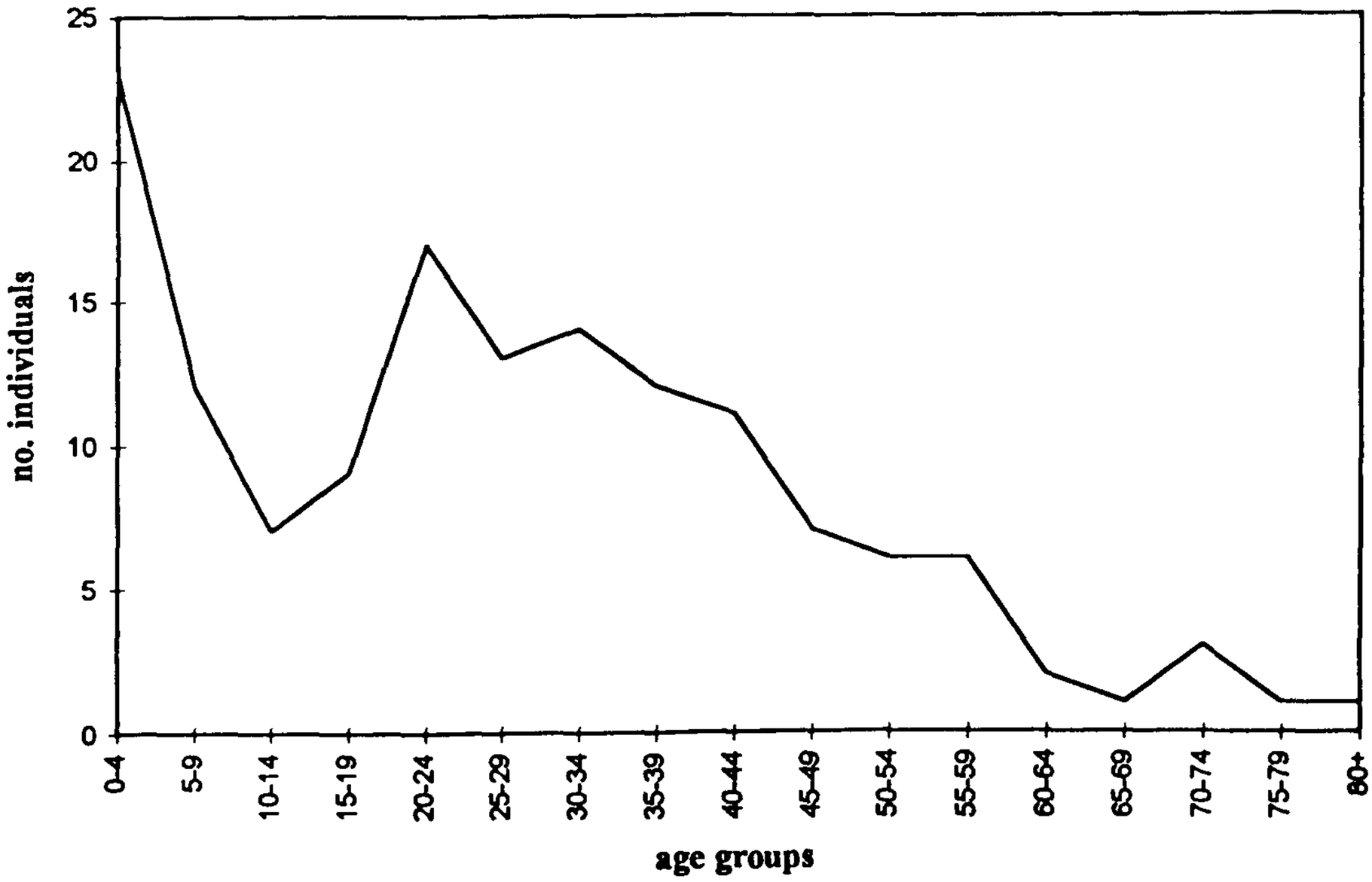

Figure 8.15 Demographic profile of age at death for the Barton sample - Arachnoid granulation method only (children aged using long bone lengths and tooth eruption)

Discussion

The two graphs presented in the results show a striking difference in the shape of the profile and the mean age at death when using different methods. The arachnoid granulation count method used appears to flatten the peaks that one finds at 45 years (the maximum age using the tooth attrition method) and 65 (the maximum cut-off for the male pubic symphysis changes), and ages some individuals to older ages (above 75 years). These results suggest that using the arachnoid granulation method, older adults can now be aged with increased accuracy, and that when used it may change both the age at death profile and the mean age at death in anthropological samples.

3. An investigation of racial differences in the relationship between arachnoid granulation counts and age

It was decided to investigate the possibility of any race - related differences between the numbers of arachnoid granulations and age. The literature supporting different

morphological features in those of different ethnic origins have been discussed in detail already (see especially chapter 7).

Sample

All 261 individuals from the Terry collection (see above and chapter 3 for demographic details) were selected for this study. As it has already been shown that there is no statistical difference between males and females in the number of pits present, it was decided to do only two analyses; black males and females and white males and females. This also had the advantage of making the mean ages of death of each sample more similar, at 53.3 and 57. 2 years respectively (see chapter 3)

Method

The number of pits and depressions on each skull (as outlined in studies 1 and 2 of this chapter) were correlated with age at death for the black males and female group, and the white males and females group. Tables 8.15 and 8.16 and figure 8.16 below show the results of both regression analyses and a plot of age against total pit score for both samples.

Reproducibility

The reproducibility of counting pits and depressions has already been calculated (with an intra-class correlation coefficient of 0.882 in study 1b) so it was not thought necessary to repeat this work.

Results

Parameter	Co-ef	StDev	t-ratio	p<
intercept	40.152	4.271	9.40	0.0001
total score	3.7	0.8564	4.32	0.0001

R-sq (adj) = 13.6%

age = 40.2 + 3.7 (total score of pits and depressions in the skull)

Table 8.15 Results of the regression equation - White males and females

Parameter	Co-ef	StDev	t-ratio	p<
intercept	42.505	3.838	11.08	0.0001
total score	3.006	0.948	3.17	0.002

R-sq (adj) = 5.8%

age = 42.5 + 3.01(total score of pits and depressions in the skull)

Table 8.16 Results of the regression equation - Black males and females

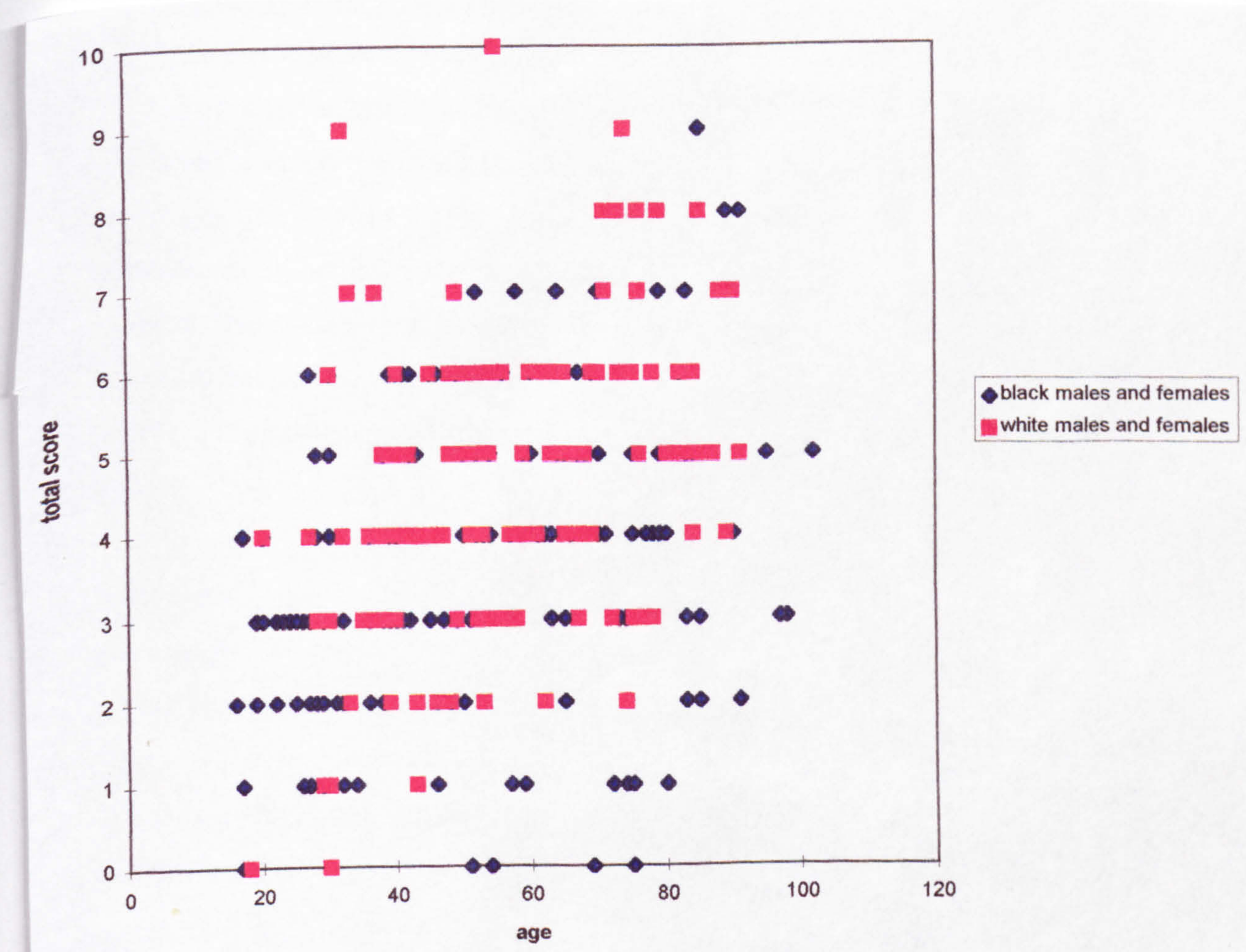

Figure 8.16 Plot of total pits against age - Black and white Terry collection sub-samples

Discussion

From the results above it can be seen that there is little variation between the linear regression analyses for blacks and whites in the Terry sample. It can be concluded from this that the regression equation formulated on the Spitalfields sample (as outlined and tested in parts 3b and c of this chapter) can be used on other black American populations with some confidence. Further work in this area could concentrate on looking at other ethnic groups to see if they produce similar results. Study four in this chapter (below) investigates the relationship between shape and size of arachnoid granulation pits and depressions to age in racially different populations.

4. Study of the effect of age on the shape and size of arachnoid granulation pits

All of the previous studies investigating the relationship between arachnoid granulations and age have concentrated on the size of the pits, not the number. However, the methods of scoring have not been very specific. Basimajian (1952) recorded the degree of depth of the pits using scores 1 to 4. Arensburg (1989) categorised pits as small (less than 2mm) medium (2-4mm) and deep (over 4mm). Rogers et al. (1997 discussed in chapters 4 and 5) has shown that individual bone forming capacity can vary, and that some aspects of bone shape and size can vary with races (Brothwell, 1981) but no studies have investigated if there is any racial variation in the shape and size of arachnoid granulation pits.

4a Pilot study on the Terry sample

The sample

A pilot study was undertaken to investigate to what extent the shape of each pit is related to age. It was decided to carry out this pilot study on a sub-sample of the Terry collection, as it was the largest sample available of known age, and in addition it afforded an opportunity to investigate any race related differences in pit size, as discussed above.

The other samples were discounted from the pilot study for the following reasons. The Barton sample was not chosen because the skeletons were not of known age at death (see chapter 3). It was not possible to carry out this study on the Spitalfields sample as it was too fragile to cast (see chapter 3), nor was it possible to use the Bristol post-mortem sample as the cases were often subject to a coroner's report which meant that no

unnecessary addition of foreign substances (such as dental alginate) were allowed. In addition it was too time consuming to cast every pit of each individual, given the time constraints imposed on each post-mortem.

128 of the skulls from the Terry collection were selected for this study, 57 black and 71 white individuals. They were selected to have roughly the same numbers of individuals in each decadal group (see chapter 3), Table 8.15 below gives a summary of the demographic profile of the sample.

	N=	mean age	min age	max age
black males	26	53.6	23	98
black females	31	53.1	22	95
white males	36	54.8	18	18
white females	35	61.8	30	91

Table 8.17 Demographic profile of the Terry collection

Methods

Given the limited amount of time available for casting (see chapter 3) and the difficulties of transportation of so many casts (an average of 6 per skull) it was decided to concentrate only on two dimensions - length and width. For each skull a tracing was made of the edge of each arachnoid granulation pit and depression using small pieces of overhead projection film. Included on the drawing was the site of the coronal suture for orientation. These were then photocopied on to plain paper for ease of measuring (they were photocopied at 100% with a pre-measured scale - this was used to check that there was no magnification or reduction of the drawing). An example of the recording sheet is given in appendix A sheet 3.

The maximum length (anterio-posteriorly) and maximum width (at 90° to the maximum length) were measured for each pit, and an area score was obtained by multiplying the maximum width and length of each pit.

For each skull the average pit size was calculated between the number of pits in that skull, and for each sub-sample the average minimum and maximum area scores were calculated. The average width and lengths, as well as the minimum and maximum lengths and minimum and maximum area scores were all correlated against age using separate linear regression analyses. The results of these analyses are given in table 8.18 below. Table 8.19 shows the average pit size per skull for each of the sub-samples, as well as the average minimum and maximum area scores.

Reproducibility

The measurements of four randomly chosen skulls were repeated at the end of the study. One of the transparencies got lost during transit. An intra-class correlation coefficient was calculated to test how repeatable this method was for average maximum length, average maximum width and average area score. The results were 0.97; 0.74 and 0.91 respectively indicating good to excellent reproducibility.

Results

Tables 8.18 and 8.19 below shows firstly, the results of the regression analyses for each measurement against age at death in each sub-sample, and 8.19 shows the average pit size recorded for each of the groups.

sample	Ave length	Ave width	Max length	Min length	Max width	Min width	Min score	Max score
black males	0.379	0.354	0.878	0.383	0.930	0.490	0.790	0.585
black females	0.103	0.403	0.878	0.084	0.192	0.122	0.350	0.718
white males	0.205	0.311	0.963	0.518	0.963	0.518	0.620	0.552
white females	0.364	0.757	0.436	0.540	0.436	0.110	0.187	0.368

All are non-significant

Table 8.18 Results (p values) of the linear regression analyses of each dimension against age

	average pit size	min score	max score
black males	14.7 x 11.1	80	299
black females	12.7 x 9.1	81	258
white males	13.4 x 8.7	17	258
white females	12.6 x 9.1	25	303

Table 8.19 Pit size and shape - all samples

Discussion

Using only the two dimensions of length and width, the average size of the arachnoid granulation pits does not increase with age in any of the sub-samples. It must be remembered that the depth of the pit has not been taken into account in this analysis. Any further work in this area should attempt to obtain a three-dimensional score when comparing pit shape. This work would be very time consuming, with an average of ten hours work to provide the measurements from a skull with five pits, and the results presented here do not indicate that such a huge effort would produce any positive results, or provide much more information on the relationship between size of pit and age of death.

The results do, however show that there is a marked difference in the shape and size both between sexes and between races in this sample. Males have larger pits than females on average, which is not surprising as males usually have larger skulls (Brothwell, 1981). The difference between the races is interesting. Both black males and females have a much larger minimum pit size score. This apparent racial variation ties in with the work by Rogers (pers. comm.) which discusses an individuals capacity to form bone, which preliminary results suggests differences between ethnic groups. If a persons' ability to form bone varies, it follows that ones capacity to calcify arachnoid villi (which is what determines the size of the pits and depressions on the skull) might also vary between races. Millen and Woollam (1958) looked at the relationship between vitamin A and the cerebrospinal fluid, and this work suggests that vitamin A toxicity (which is caused by excess vitamin A, characterised by new bone formation, Cotran, Kumar and Robbins, 1989) may have an effect on the size of arachnoid granulations. Further work on this

subject could compare age and sex matched individuals in the same racial groups which are classified as "boneformers" against those that are not, to see if there is any difference in either the number or size of pits produced.

General Discussion and Conclusions

This chapter has produced a series of investigations in to the relationship between arachnoid granulations and age. The visual appearance of arachnoid granulation and their effect on the skull has been demonstrated by both soft tissue dissection and histological sections in study 1 of this chapter.

Studies 2a,b and c have shown that the number of pits and depressions caused by arachnoid granulations correlates highly with age. The potential for use as an ageing technique has been outlined, and a regression equation for use in archaeological samples has been produced. The results here show clear promise for a method which is non-destructive, cheap and rapid to use, and requires little training. The correlation applies equally well for both males and females and has no maximum cut off point. The technique has been shown to be reproducible, both within and between observers. Study 2d, although small, has produced results which may explain the apparent lack of older individuals in the archaeological record, despite evidence to the contrary (see chapter 1 for detailed discussion).

Studies 3 and 4 has shown while there is little difference in the number of pits present and their relationship with age between racially different groups, the shape and size of the pits does differ.

Further Work

The data presented in this chapter shows a lot of promise for future work, most of which has been outlined at the end of each section. An investigation into the effect of different diseases in affecting the shape, size or number of pits and depressions should be undertaken, using a large population of known age at death, with detailed notes on the cause of death and soft tissue findings. It may be useful to investigate the shape of the pits and depressions 3-dimensionally, although the problems inherent in this study have been discussed above.

The work outlined here may have applications on much older material, such as Neanderthal or older hominid remains. Often the calvarium is the only part of the skull (or even skeleton) recovered (Stringer and Gamble, 1993) and there have been problems in ageing this material.

Chapter 9. Discussion and Conclusions

The aim of this thesis was to investigate age related changes to five aspects of the endocranial surface of the skull. This necessitated division into five separate studies: skull thickness, hyperostosis frontalis interna, cranial suture fusion, vascular markings and arachnoid granulations. These areas were chosen after a search of the literature suggested that they may show age dependent change. For each aspect the normal range of observed variation was measured, abnormal observations were further investigated and the potential of any age related changes observed for use as new ageing methods were assessed.

The data presented in the preceeding chapters have shown many positive results, the most important of which is the production of a new ageing technique based on counting arachnoid granulation pits (see chapter 8). This method will significantly change the way that skeletal material is aged and is an important contribution in itself to physical anthropology.

Summary of findings from chapters 4 to 8

Skull thickness

Chapter 4 investigated the relationship between skull thickness and age. A comparison of true and x-ray measurements from the same set of skulls showed that it is unwise to compare results from x-ray studies to those using direct measurements, even when using the standard magnification equations.

A new site for measuring skull thickness was produced after the literature suggested that most recordings were taken at sutural landmarks, which do not necessarily represent the true thickness of the table of the skull. The site chosen is especially suitable for broken skulls, which are common in archaeology. Using this new method on samples of known age at death it was found that in one group (the black females from the Terry collection) the average thickness of the mid parietal increased significantly with age. In the other samples a trend was observed, but it was not statistically significant.

These results were not conclusive enough to suggest that skull mid-parietal thickness is a good indicator of age at death. However, the study did produce some levels of normative

data which will be of use to other researchers when looking at skull thickness. Abnormal specimens selected using this method were investigated further using x-rays, and some were given probable diagnoses. If skull thickness had not been measured, these pathologies would have remained un-noticed, suggesting that a standard measurement of mid-parietal skull thickness should be part of every skeletal investigation where possible.

HFI

The main achievement of the work presented in Chapter 5 was to have devised a new method for grading HFI, which directly compares radiological scoring to visual observations. The subsequent application of this new method on the other archaeological samples chosen for study in this thesis has shown that HFI is a much more common phenomena in past societies than previously thought (Anderson, 1994), and that it is not necessarily increasing in prevalence with modernity.

The results given in this chapter show women are much more likely to be affected than men, but it must be remembered that males can also have HFI. The data showed that some people can suffer from HFI at an early age (mid 20's onwards), a fact that appears to be ignored in anthropology and palaeopathology. Evidence was presented that showed an increased prevalence in the 50-60 year old females in one sample, which correlates with data produced by other researchers (Moore, 1955 for example). These data suggests the phenomenon of HFI may be able to decrease as well as increase in proliferation which would exclude its use as an estimator of age at death in anthropological studies. If HFI continues to be used by anthropologists as an indicator of age at death (Armelagos and Chrisman, 1988) though the data presented in this chapter does not suggest this approach, then one must use a method which compares directly to radiological criteria, such as that devised in this study. The data produced in this chapter would benefit from further work on both larger and more ancient samples.

Cranial suture fusion

The major achievement of this area of study was to produce a revised method of estimating age at death using endocranial and ectocranial suture fusion. This is important to anthropological studies as many excavated skulls are recovered broken or incomplete. The new method correlates well with age, and although it compares in accuracy to those currently in use (Meindl and Lovejoy, 1985; Key et al., 1994) the findings do not

recommend suture fusion as a sole indicator of age at death, except where there is no alternative. This revised method was then used to investigate the relationship between specific diseases and the rate of suture fusion. It was found that none of the diseases chosen changed the rate of suture fusion. However, the presence of grade 2 or more HFI was found to affect the rate of suture fusion, causing premature fusion of the ectocranial surface of the skull. These results suggests the presence of "vicious union" as described by Todd and Lyon (1924).A priority for future work in this is to repeat this analysis using larger numbers and to look at the other disease categories suggested by Moss (1957) which may affect the rate of suture fusion.

Vessel shapes and hypervascularity

Chapter 7 investigated the relationship between endocranial vessel grooves and age. It was found that the shape of the indentations in young people are mostly "v" shaped, and are slightly asymmetrical in profile (the inferior slope of the groove being steeper). In older adults a more uniform "u" shape is observed. The method described to investigate this phenomenon is complicated, time consuming and expensive, and although it may not be useful as a field technique, it may have a useful application in the fields of forensics (Hunter, Roberts and Martin, 1996) or in evolutionary anthropology. Both of these areas focus on individuals (not collections of skeletons) and it is vital to have an accurate estimation of age at death (especially in forensic anthropology, where identification is the primary aim). The change in shape of the vessels may have more to do with disease, such as hypertension, than with age. Another explanation is that individuals have a vascular "age", independent of their chronological age.

The study which looked at the number of vessel branches found no correlation with either age or specific diseases.

Three types of abnormal hypervascularity were observed in the samples studied, of which two had not been previously described. Two of these, "wormcasts" and "lightening streaks", were found to appear more commonly in those individuals suffering from tuberculosis, although not all cases of tuberculosis showed this change, and not all of the changes were only seen in those with tuberculosis. None of the types of hypervascularity noted correlated with age at death.

The results from this study suggest that though vessel shape (and perhaps size) may have a relationship with age, the use of vessel grooves may have more relevance in the field of palaeopathology rather than physical anthropology.

Arachnoid Granulations

Chapter 8 produced the most novel method of this thesis and the most promising results in terms of devising a new ageing technique. The relationship between the number of arachnoid granulations and age was explored using samples of known age at death. From this a regression equation was produced and was tested on another sample of known age at death. It was found to compare very well in terms of accuracy, bias and numbers of individuals on which the method could be used to two of the most popular ageing techniques currently in use. The arachnoid granulation method has several strong points, including its ease of application, reproducibility and the fact that it has no maximum cut-off age (unlike the other two methods compared to it).The morphology and race related variation of arachnoid granulations has also been investigated. The use of this method on some samples may change significantly the age at death profile of the sample.

A recurring theme in this thesis is the marked difference in some individuals in their biological and chronological ages. It may be that people have internal biological "alarm clocks" as suggested by Elandt -Johnson and Johnson (1980), based on the theory of programmed cell death (as discussed in chapter 1). It may be that a persons true life expectancy is indicated by the skeletal age. The evidence discussed in chapter 6 from Spitalfields also supports this (Molleson and Cox, 1993). Louisa Courtauld (who was buried at Spitalfields) apparently had a skeleton of someone much younger than her 77 years, and in the Bristol post-mortem room sample a girl of 15 who died from Rubella had the skull of a 70 year old. These cases are only anecdotal and though several more of them are scattered through this thesis, they are too few to be tested by statistical analysis. It is unwise to draw too much inference from them at present, but it is interesting to speculate. As mentioned above the results of the study on endocranial hypervascularity would suggest that in addition to chronological and biological "ages", one also has a vascular "age" which may vary between individuals of the same age. This would support the findings of Borkan (1986) and Comfort (1969) which show we have many "ages" (see chapter 1 for details).

The sheer quantity of the data presented means that a full discussion of every regression result and of every individual in every sub-sample was not possible. All of the investigations chapters (4 to 8) still have great potential for further work which could be undertaken. The use of regression analyses as the main form of statistical investigation can be problematic. The method assumes that the correlation between two variables is linear, and has uniform confidence intervals along the line. This is not necessarily the case, age related changes are not necessarily constant across time (see discussion in chapter one, and figure 1.1) and it may be that the data produced in this thesis would benefit from a different approach which could emphasize the more chaotic nature of these relationships.

One problem when studying skeletal remains, especially when looking at disease, is trying to define what a "lesion-free" skeleton actually means. Apart from the fact that only few diseases can be seen on the skeleton, it has long been held that skeletons without bony pathology were the "healthy" ones (this word is used in reports and discussions, even though the skeletons by nature are not healthy - they are dead), those who had little pathological insult before death, and those with many bone changes were the least disease resistant members of society. Ortner however, (1996) suggests that the lesion-free individuals may have in fact been the weakest, dying before they even begin to show any bone change. It is not known whether an individuals capacity to fight disease (and, as Ortner suggests, show pathological bone alteration) will affect the rate at which the skeleton ages.

Although the aim of this thesis was to concentrate on normal age related variation, the major findings in this thesis show that pathology and age are related in a complex manner, and it is perhaps naive to assume that the two can be entirely separated. The line between senescence and pathology is a blurred one. It is said that if all people lived long enough they would get osteoarthritis (OA) in at least one joint (Bittles and Collins, 1988). This does not mean though, that OA can be used as an ageing technique (see discussion by Kirkwood, 1996). The work presented here does not suffer completely from this naiveté, as it discusses pathological changes and their affect on the skull where possible. To do justice to the subject of pathology related change in the skull would, however, require another thesis twice the size of this one.

As mentioned earlier in this discussion, there is a great deal of further work which can be continued from this thesis. Individual studies have been discussed in each of the chapters, and it would be pointless to list them all again, but from each chapter an underlying theme has arisen. The hypotheses produced in this thesis would all benefit from being tested on a large (n=200+) sample of known age at death with full soft tissue supporting data, x-ray findings and medical case histories. A control group of aged and sex matched individuals that had died accidentally (described above, also in earlier chapters as those who "skeletally" should not be dead) is also necessary to attempt to separate pathological changes from age related ones. This approach is not without its problems, however. How does one define disease? The discussion in chapter 1 shows how different researchers have different definitions of ageing and senescence. In a sample of accidental death, should one include suicide, or alcoholism? People who die in accidents can also have underlying disease, and may not all be examples of people in perfect health. These problems would need to be addressed before a study of this nature could take place.

These studies have provided enough data to suggest a re-evaluation of mean age at death estimations in anthropological collections. The arachnoid granulation technique especially may become an important tool in the field of palaeodemography. This in turn may lead to the provision of more accurate estimates of past life expectancy and how or if it has changed over time. It is hard to calculate past life expectancies using only ageing techniques with maximum cut-off points. Perhaps the application of this method will go some way to helping future gerontological studies and to solving the problem outlined in chapter one, where we have graveyards full of very old people, and contradicting archaeological reports (Ascádi and Nemeskéri, 1970) which commonly show life expectancies of 17 to 20 years of age.

Each of the studies summarised above has produced results which will add to the knowledge in the field of ageing studies, but there is still much scope for further work. In retrospect, a different approach would have been to concentrate on one or two aspects of the age related variation, such as the vascular markings or arachnoid granulation studies, but this would not provide the overview that the author wished to achieve. It is hoped, that by reading this thesis and the papers that have (and will) arise from it, others will attempt to replicate the results in archaeological and anthropological collections of their own.

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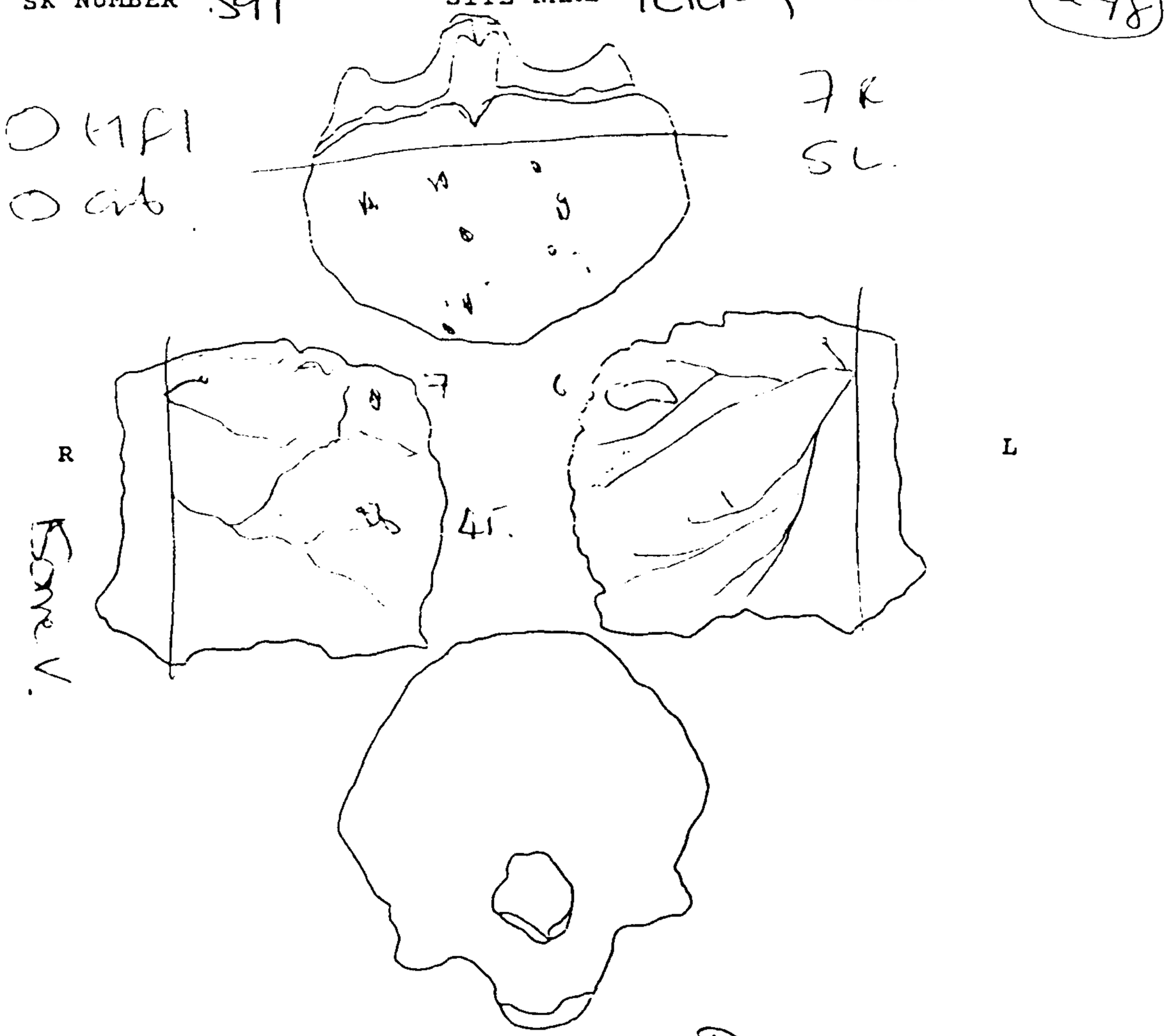
Appendix A. Recording sheets

Example of recording sheet 1 (reduced)

SK NUMBER 591 SITE NAME TERRA PERIOD 4278



AGE 28 SEX M CAST MADE D

NOTES

MEASUREMENTS		R		L	
ANGLE MAIN MEN. VESSEL					
MAX THICKNESS OF SKULL		5.5.		8.4 6	
WORMIAN BONES		2.		4	+ astrio.
WIDTH/DEPTH OF MAIN VESSEL					
WIDTH/DEPTH OF MAIN VESS.2					
WIDTH/DEPTH OF ACCESS. V.					
GRADE W/CASTS	L/STREAKS	0	0	0	0
GRADE PINHOLES		0		0	
NO. PITS		2.		0	
NO. DEPRESSIONS		0		1	
MAX LENGTH OF F. OVALE.		X		8.4	

Appendix A Recording sheets

Example of recording sheet 2 (reduced)

Age

Pubic Symphysis	35-39
Tooth Attrition	NEM
Other	

State of Skull

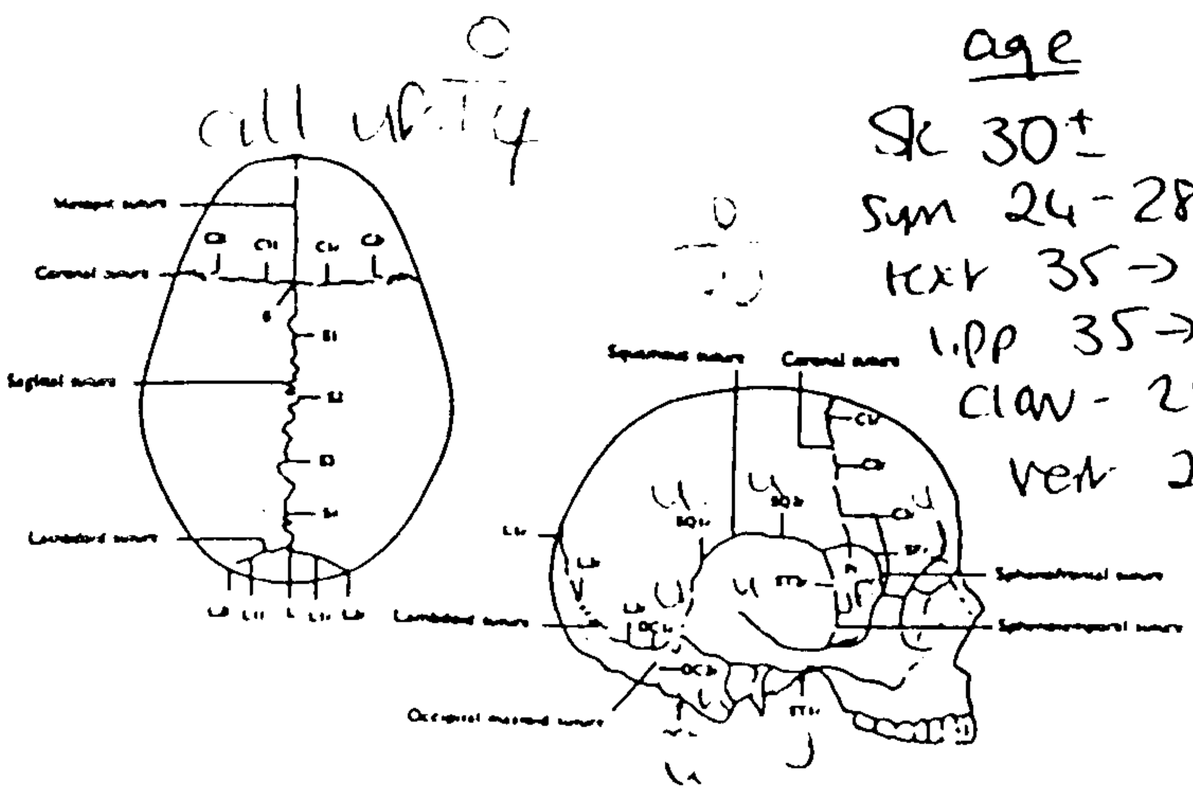
Complete	Broken	
Left	Right	
Worn	Fair	Good

Pathology

OA	
DISH	
BF	
INFECTION	
PERIOSTITIS	
TRAUMA	
TB	
SYPH.	
OTHER	

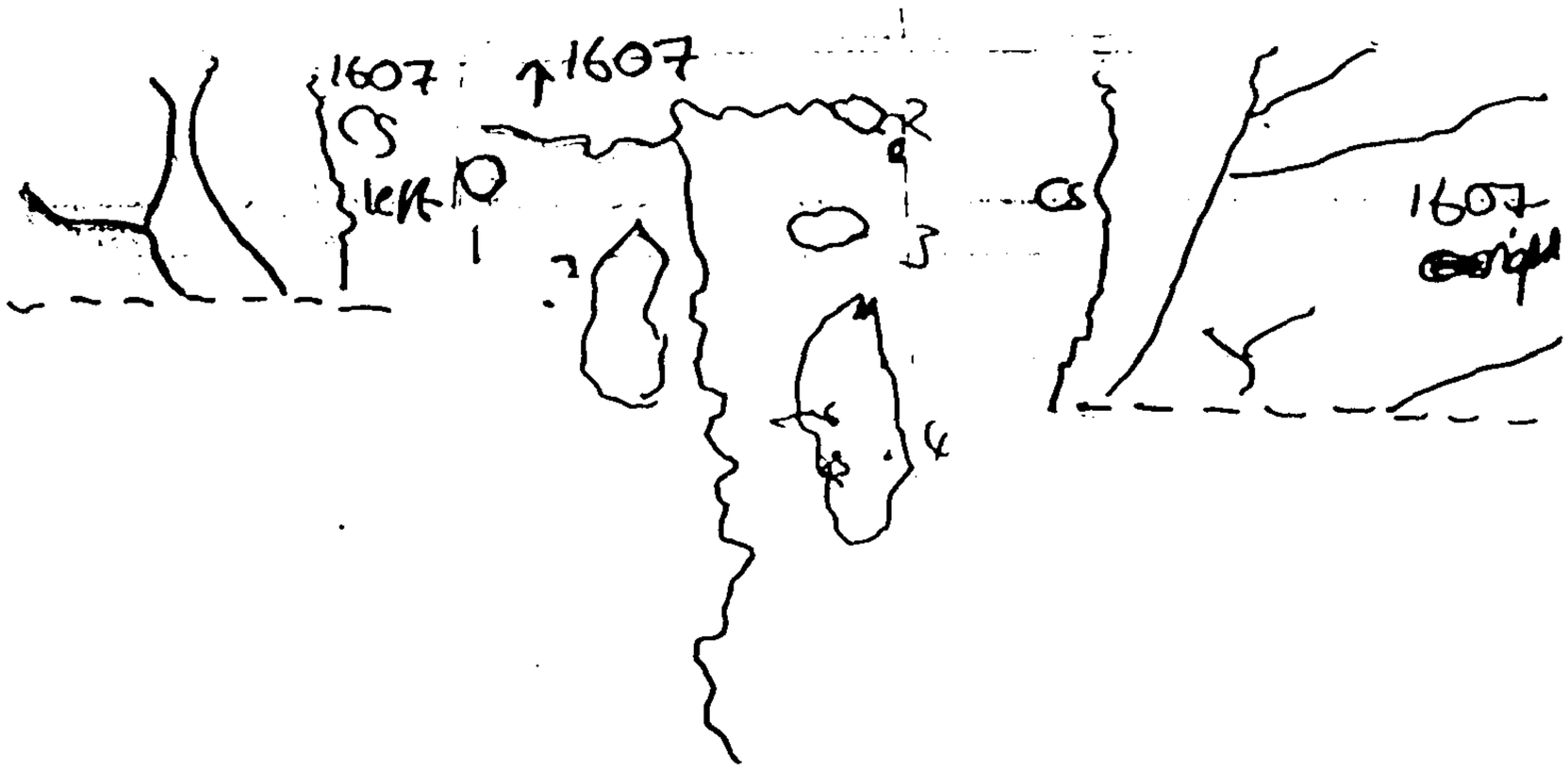
Notes WHM

Name	Terry Hansen (Norwegian)
Age	28
Occupation	
Death Cert	3-7-29
Cause	Pneumonia
Other	

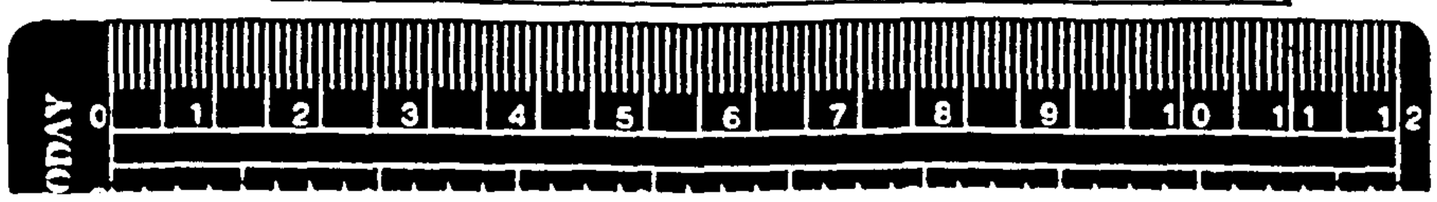


Appendix A Recording sheets

Example of recording sheet 3 (reduced)



pit no	max length	max width	
1	4.5	4.3	19.3
2	3.5	5.1	17.8
3	4.4	7.8	34.3
4	24.8	10.7	265.4
	9.3	7	



Appendix B Ageing and sexing accuracy

Sexing Accuracy

53 individuals* were sexed using only the pelvic shape (Brothwell, 1981). Three were inaccurately sexed indicating an overall accuracy of 94.5%

* the rest of this sample were either infants or had no post-cranial skeleton to examine, or were in too poor a condition to study

Ageing accuracy

Ten dentitions with at least one row of complete occluding molars were chosen at random from the Barton-on-Humber sample. In addition ten male pubic symphyses were selected from the same sample. Three observers independently aged each dentition and pubic symphysis using the methodologies described in chapter 3.

Tooth attrition
91% agreement between the three observers to the same age category
100% agreement between observers to within one category

Pubic symphysis
86% agreement to the same age category
100% agreement to within one category

Appendix C Notes on the casting and reproducibility

Notes on the formulation of the casting method

a. Two different types of alginate were tested to see which one performed best on the bone surface. The brand chosen was "Blueprint Cremix", and 2kg of the same batch number was donated for the project by the company which manufactures it, Dentsply.

b. The amount and temperature of water used in this study was reached by a series of experiments. Different quantities of water of different temperatures were applied to the same amount of alginate until the desired consistency was reached. This was slightly runnier than that used in dental practice, and of that suggested by the manufacturers, as more time was needed to correctly place the alginate mixture in the skull than it would in a patients mouth.

c. In clinical practice a plastic or metal mould is used to position the alginate correctly in the mouth, which saves time. A mould was made for placing the alginate in the skull but this method was abandoned as skulls vary in curvature, and a new mould would be needed for almost every cast which would be prohibitively consumptive of both time and resources. The main purpose of the mould on clinical practice is to stop distortion of the cast at the edges, but as all measurements and observations were to be taken from the center of the casts it was not thought relevant. In contrast it was easier to remove the set cast of there was no mould, as some skulls had only very small spaces to work in, and the alginate cast was flexible enough to remove from these smaller areas. If a mould had been used it would have been impossible to cast many of the skulls.

d. Five of the archaeological skulls were cast in the same area on five separate occasions to test the reproducibility of this method. This was done by measuring the casts using a reflex microscope (see chapter 3).

Reproducibility of measuring the casts

Summary of individual measurements taken at the start of each cross-section. The machine was focused on a point, then set to zero, and the height (z) plane was moved. After refocusing a second measurement was taken (these are listed below - 0.00 means 100% reproducibility) the average accuracy is given at the end of the list of measurements.

-0.004	-0.003	-0.048	0.054
-0.022	0.043	0.019	-0.112
-0.05	0.027	-0.02	-0.012
-0.06	-0.091	0.03	0.034

-0.019	0.205	0.007
-0.007	-0.021	-0.025
0.053	0.059	0.034
-0.021	-0.033	0.01
-0.036	-0.008	-0.009
0.014	-0.059	-0.03
-0.072	0.035	0.025
0.011	-0.003	0.119
0.023	0.06	-0.019
0.135	-0.015	-0.068
0.015	-0.091	-0.066
0.039	-0.116	-0.033
-0.003	0.032	0.033
0.018	0.016	-0.129
-0.069	-0.034	0.054

mean point accuracy -0.001
maximum error 0.205
minimum error -0.129

Appendix D Major causes of increased skull thickness

After du Boulay, 1981

Generalised

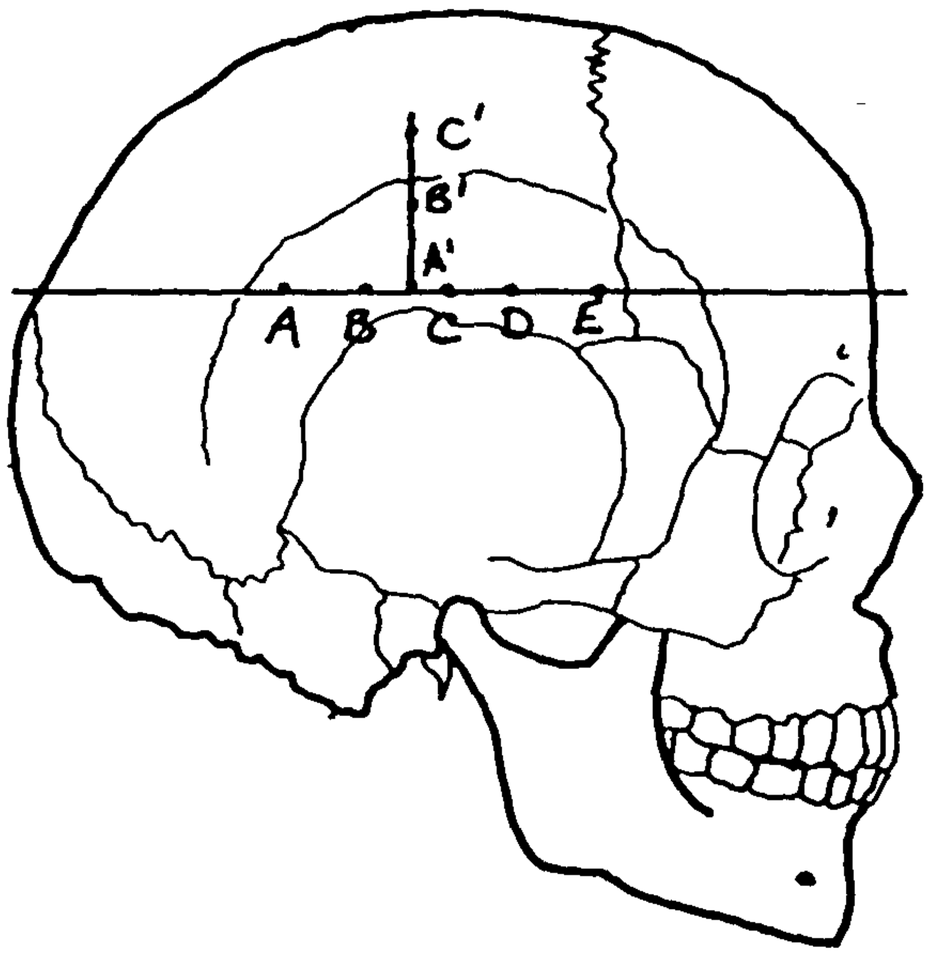
Acromegaly
Pagets disease
Cerebral atrophy
Dystrophia myotonica
Arteriovenous malformation
Relief of raised intracranial pressure
Prolonged medication for epilepsy
Severe chronic anaemia
Myelosclerosis
Albers-Schonberg disease
Englemann's disease
Uehlinger's disease
Dwarfism with dense bones
Hyperostosis corticalis generalisata familiaris (von Buchem's disease)
Craniometaphysical dysplasia
Melorrheostosis
Toulouse-Lautrec syndrome
Chronic fluorine poisoning
Caffey's syndrome
Chronic syphilitic osteitis
Vitamin D poisoning
Hyperostosis corticalis generalisata congenita
Chronic idiopathic hypercalcaemia
Vitamin D resistant rickets
Hypoparathyroidism

Localised

HFI
Meningioma
Fibrous dysplasia
Arteriovenous malformation
Chronic osteomyelitis
Metastatic carcinoma
Pagets
Osteoma
Osteoid osteoma
Cephal-haematoma
Cerebral atrophy
Tuberose sclerosis
Radiation necrosis
Neurofibromatosis

Appendix E Reproducibility of skull thickness

Reproducibility results for skull thickness



horizontally

1st attempt

skull no	a	b	c	d	e
1	4.6	4.7	4.6	5.5	5.5
2	5.1	6.1	6.1	5.6	6.5
3	3.9	3.6	3.3	2.8	4.7
4	3.0	3.4	4.2	4.2	5.8

2nd attempt

skull no	a	b	c	d	e
1	4.4	4.5	4.6	5.1	5.1
2	5.3	5.9	6.1	5.8	7.8
3	4.2	3.6	3.4	3.1	4.8
4	4.2	3.2	4.8	6.7	6.2

vertically

skull no	a'	b'	c'
1	4.5	5.6	5.5
2	6.1	6.2	7.6
3	3.3	3.9	4.8
4	3.4	3.7	4.6

2nd attempt

skull no	a'	b'	c'
1	4.5	4.8	6.1
2	6	6.6	8.2
3	3.2	3.8	5
4	3.4	4.2	6.4

These measurements were all taken from the left side of the skull

Intra-class correlation coefficients for each measurement

horizontal measurements

a 0.64
b 0.99
c 0.96
d 0.6
e 0.79

vertical measurements

a' 0.99
b' 0.91
c' 0.74

The general area of measurement chosen is a box which covers horizontal measurements b to c, and vertical measurements a' to b'

Appendix F. Papers and abstracts based on this project

Papers

Barber, G., Watt I. and Rogers, J. (1997) A comparison of radiological and palaeopathological criteria for diagnosing hyperostosis frontalis interna. International Journal of Osteoarchaeology (in press)

Barber, G. Shepstone, L. and Rogers, J. (1996) A new method to estimate age at death using arachnoid granulation counts. Submitted.

Abstracts

Barber, G, (1997) Estimating age at death using skull mid-parietal thickness. Abstract to be presented at the American Association of Physical Anthropologists meeting, St Louis.

Barber, G. (1996) A comparison of radiological and palaeopathological criteria for diagnosing hyperostosis frontalis interna. Abstract presented at the American Association of Physical Anthropologists meeting, North Carolina.

Barber, G. (1996) Arachnoid granulation pits and age in an American population. Abstract presented at the 1996 European meeting of palaeopathologists, Maastricht.

Barber, G., Shepstone, L. and Rogers, J. (1995) A methodology for estimating age at death using arachnoid granulation counts. Abstract presented at the American Association of Physical Anthropologists meeting, San Francisco.

Barber, G. (1994) Arachnoid granulations: a new method for estimating age at death? Paper presented at the 1994 European meeting of palaeopathologists, Gottingen.