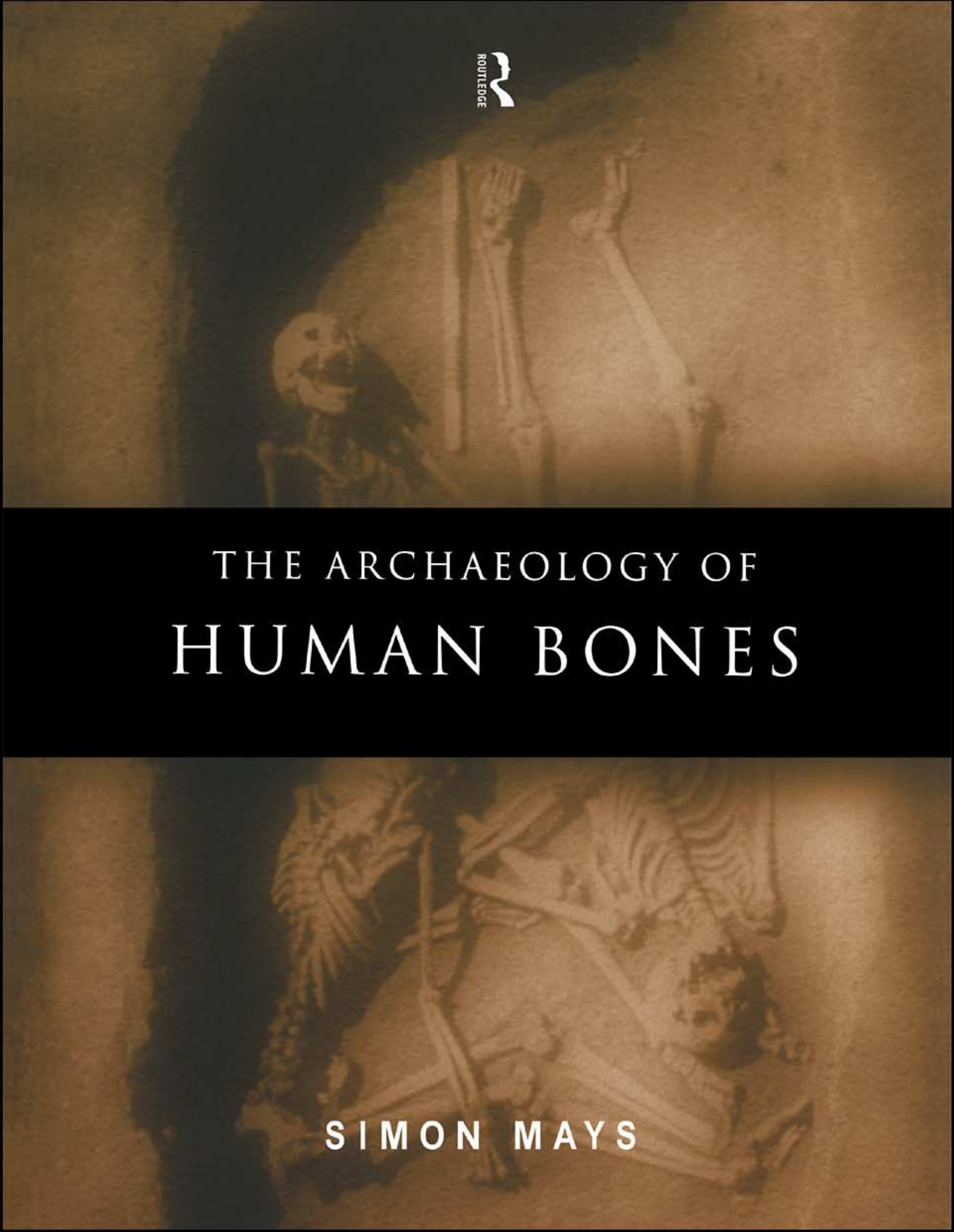

# THE ARCHAEOLOGY OF HUMAN BONES

SIMON MAYS

# The Archaeology of Human Bones

The most direct evidence we have concerning earlier human populations is the physical remains of the people themselves. This volume provides a pragmatic and up-to-date account of scientific analysis of human skeletal remains, and its application in tackling major historical and archaeological issues.

*The Archaeology of Human Bones* starts with a brief introduction to the anatomy, structure and development of bones and teeth. It analyses the biasing effects of decay and incomplete recovery on burial data from archaeological sites, and discusses what we may learn about ancient burial rituals from human remains. Subsequent chapters focus on the demographic analysis of ancient populations, normal skeletal variation, ancient disease and injury, the chemical analysis of bone, the study of ancient DNA, and the study of cremated remains. Examples are taken from archaeological studies around the world.

*The Archaeology of Human Bones* is a well-illustrated textbook for students of archaeology, explaining current scientific methods—technical jargon kept to a minimum—alongside critical discussion of their strengths and weaknesses.

**Simon Mays** is a Human Skeletal Biologist in the Ancient Monuments Laboratory, English Heritage.

# THE ARCHAEOLOGY OF HUMAN BONES

*Simon Mays*

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To Bonnie, who has an enthusiasm for bones

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# PREFACE

Archaeology is about people and how they lived in the past. The study of the physical remains of those people should therefore be a central component of archaeological enquiry. This means studying skeletons, as the bones and teeth are the only human remains to survive in most instances. The aim of this book is to show the sorts of information which can be obtained from the scientific study of ancient human skeletal remains, and how these data can contribute to topics of general archaeological interest. We shall primarily be concerned with the study of the remains of anatomically modern man (*Homo sapiens sapiens*), rather than with the story of human evolution. Although modern man began to emerge about 100,000 years ago, in most areas of the world human remains more than about 5,000 years old are few, so in general the emphasis will be on the study of the last few thousand years of the human past.

Thanks are due to Theya Molleson, Sebastian Payne and James Steele, for comments on draft versions of various chapters. I am also grateful to Theya Molleson for allowing me access to some of her unpublished data. Thanks are also due to Justine Bayley, Don Brothwell, Simon Davis, Sylvia Dean-Mays, John Evans, Fachtna McAvoy, Patty Stuart-Macadam, Martin Richards and Maralyn Webb for furnishing off-prints, answering questions, or giving advice and general encouragement. Any blunders of fact or interpretation which remain are solely my own. I am grateful to the following for illustrations: Suffolk Archaeological Unit (Figure 2.2), Manchester University Press (Figure 2.3), The Wharram Research Project (Figure 2.4), Academic Press (Figures 2.5, 6.5 and 8.8), Council for British Archaeology (Figure 6.6), Central Archaeology Service, English Heritage (Figure 8.10), Nick Bradford (Figure 6.9), Springer Verlag (Figure 6.11), York Archaeological Trust (Figure 6.12), Wiley (Figure 8.9), The Royal Academy of Letters, History and Antiquities, Sweden (Figure 8.13). The remaining photographs were taken by Nigel Corrie of English Heritage Photographic Studio.

# 1

# THE NATURE OF BONES AND TEETH

## THE HUMAN SKELETON

There are more than 200 separate bones in the adult human skeleton (Figure 1.1, Table 1.1). They may be divided into three classes according to their basic shape. Long bones are found in the limbs and take the form of hollow tubes closed at both ends. Flat bones tend to take the form of broad bony plates (for example the bones which make up the skull vault), and irregular bones, as their name suggests, fit into neither of the above categories on account of their irregular shape. Examples of irregular bones are the vertebrae and the bones of the skull base.

## THE COMPOSITION OF BONE

Bone is a composite material formed from an organic and an inorganic (mineral) part. By weight, dry bone is about 70 per cent mineral and 30 per cent organics. The great majority of the organic component is collagen, a protein which forms long fibres. The small crystals which make up the mineral portion of bone are embedded in a matrix of collagen fibres. Bone mineral is chiefly hydroxyapatite, a form of calcium phosphate whose composition approximates to the chemical formula $Ca_{10}(PO_4)_6(OH)_2$. The mineral component gives bone its rigidity, and the organic component lends it a slight 'give' or resilience which gives it its strength. The organic part degrades after death, which accounts for the rather brittle nature of most archaeological bone.

## THE GROSS STRUCTURE OF BONE

In terms of gross structure, there are two different types of bone tissue, cortical and trabecular bone. Cortical bone is the solid, dense part that forms the outer layer of the bones; it is thickest in the diaphyses (shafts) of the long-bones (Figure 1.2). It forms a thin layer around the long-bone ends and around the flat and irregular bones. Trabecular bone is less dense than cortical bone and has a honeycomb structure. Trabecular bone is located within the ends of long-bones (Figure 1.2) and in the interior of the flat and irregular bones.

In living bone, most of the outer surface is surrounded by a thin membrane, the periosteum. The internal walls of the medullary cavities of long-bones are lined with another membrane, the endo-steum, which also lines the network of tiny cavities in trabecular bone.

## THE FORM AND FUNCTIONS OF THE SKELETON

Bones provide a general framework to support the body. They bear ridges for attachment for muscles and tendons, and surfaces which form joints. They also protect vital organs, provide a store of fats and blood-forming marrow, and act as a bank of mineral salts. The form of the bones can be understood in terms of these functions. This point is illustrated below with reference to the general structure of long-bones (Figure 1.2).

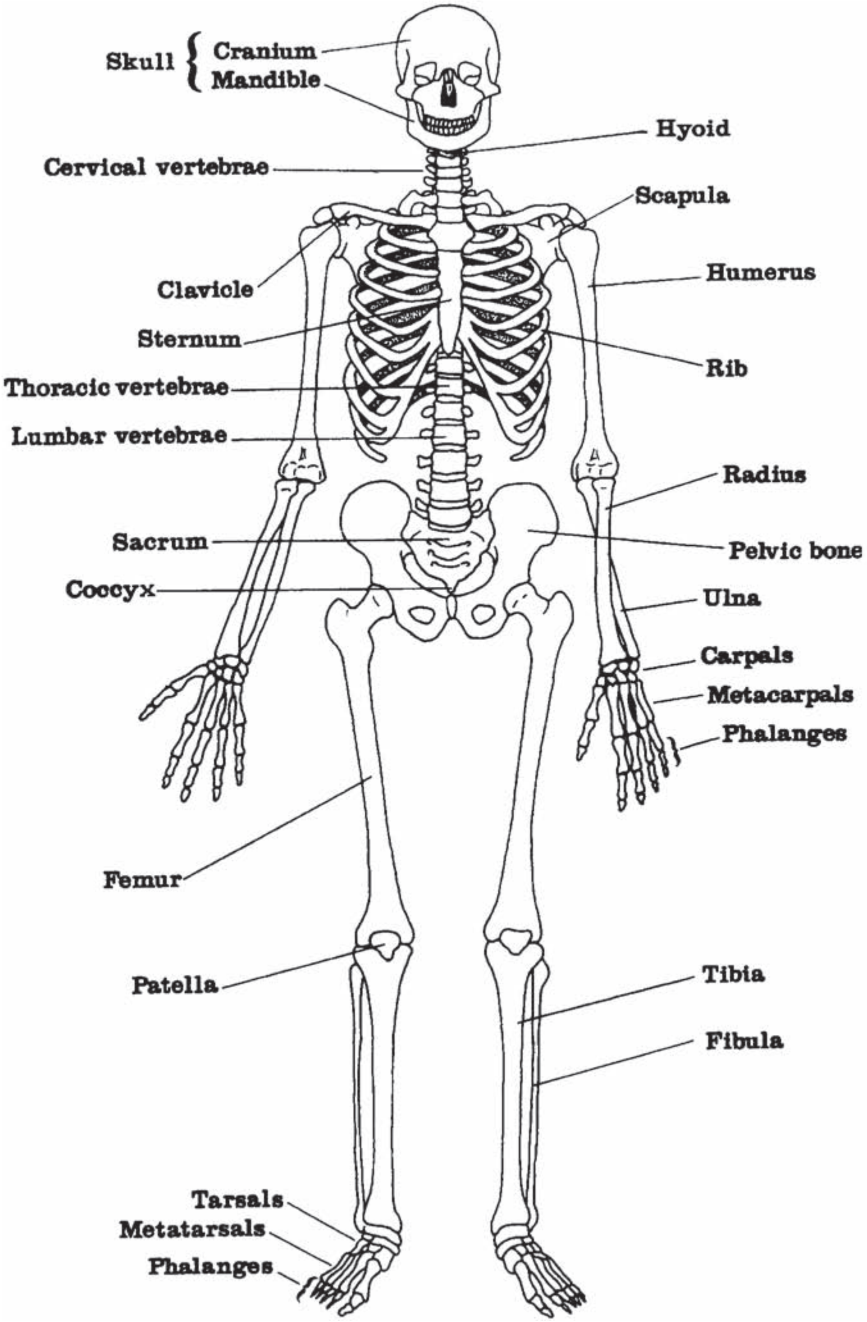


*Figure 1.1* The human skeleton

*Table 1.1* The Bones of the Adult Human Skeleton

| | | | |
|---|---|---|---|
| Skull: | | | 28 (including mandible and ear ossicles) |
| | Hyoid | | 1 |
| Spinal column: | Vertebrae | | 24 (7 cervical, 12 thoracic, 5 lumbar) |
| | Sacrum | | 1 |
| | Coccyx | | 1 |
| Thoracic cage: | Rib | | 24 (12 pairs) |
| | Sternum | | 1 |
| Pectoral girdle: | Clavicle | | 2 |
| | Scapula | | 2 |
| Pelvic girdle: | Pelvic bone | | 2 |
| Limb bones: | Arm bones: | Humerus | 2 |
| | | Radius | 2 |
| | | Ulna | 2 |
| | Wrist/hand: | Carpal | 16 |
| | | Metacarpal | 10 |
| | | Phalanx | 28 |
| | Leg bones: | Femur | 2 |
| | | Patella | 2 |
| | | Tibia | 2 |
| | | Fibula | 2 |
| | Ankle/foot: | Tarsal | 14 |
| | | Metatarsal | 10 |
| | | Phalanx | 28 |
| Total | | | 206 |

Note: In addition to these main elements of the skeleton there are a variable number of small bones embedded in the tendons of the hands and feet, called sesamoids.

The tubular form of the long-bones maximises strength and minimises weight; the medullary cavity within the shaft also provides a space for blood-forming cells and fat storage. The flared ends of the shaft (the metaphyses) support the epiphyses which bear the joint surfaces by which the long-bone articulates with its neighbours. Trabecular bone is located beneath the joint surfaces. It is less rigid than cortical bone so is well adapted for the dissipation of mechanical stresses at the joints. It also forms a site of red blood cell production in the growing skeleton, and its large surface area facilitates the exchange of minerals to and from bone. The cortical bone which forms the walls of the tube provides strength and rigidity.

On excavation, bones have the appearance of solid, inanimate objects. This is deceptive regarding the nature of living bone. Like most other tissues in the body, bone is living tissue. It is permeated with nerves and blood vessels and, in common with most other tissues, is continually being formed and broken down. The fact that bone tissue is constantly being renewed in this way means that it can repair itself following disease or injury. It also means that, within limits, it can adapt its form according to the strains put on it. This last has been recognised since the nineteenth century, when a German anatomist, Julius Wolff, described the response of bone to mechanical forces in a manner which has become known as Wolff's Law. He stated that 'the form of the bone being given, the bone elements place or displace themselves in the direction of the functional pressure and increase or decrease their mass to reflect the amount of functional pressure' (Wolff 1892, quoted in Kennedy 1989:134). In other words, bone is sensitive to mechanical forces such as weight bearing or muscular

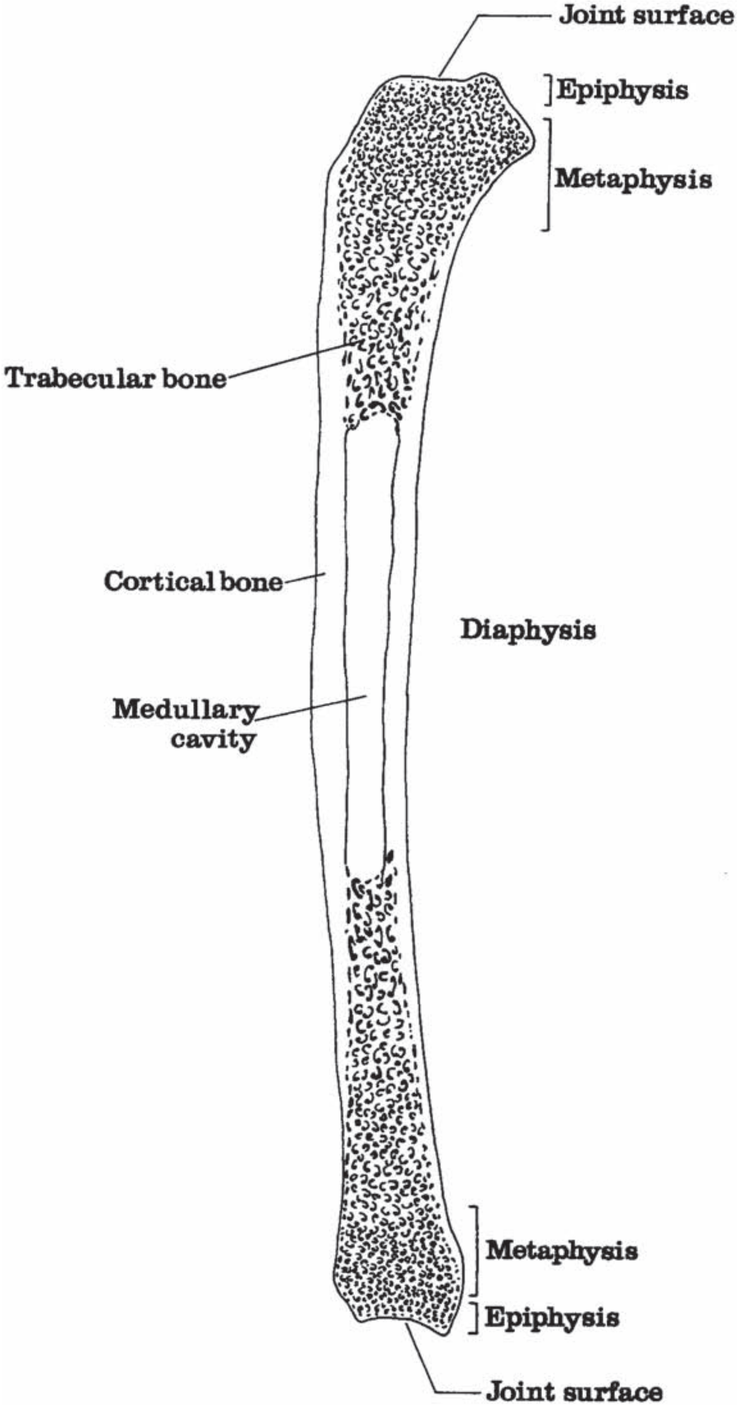


*Figure 1.2* The structure of a long-bone

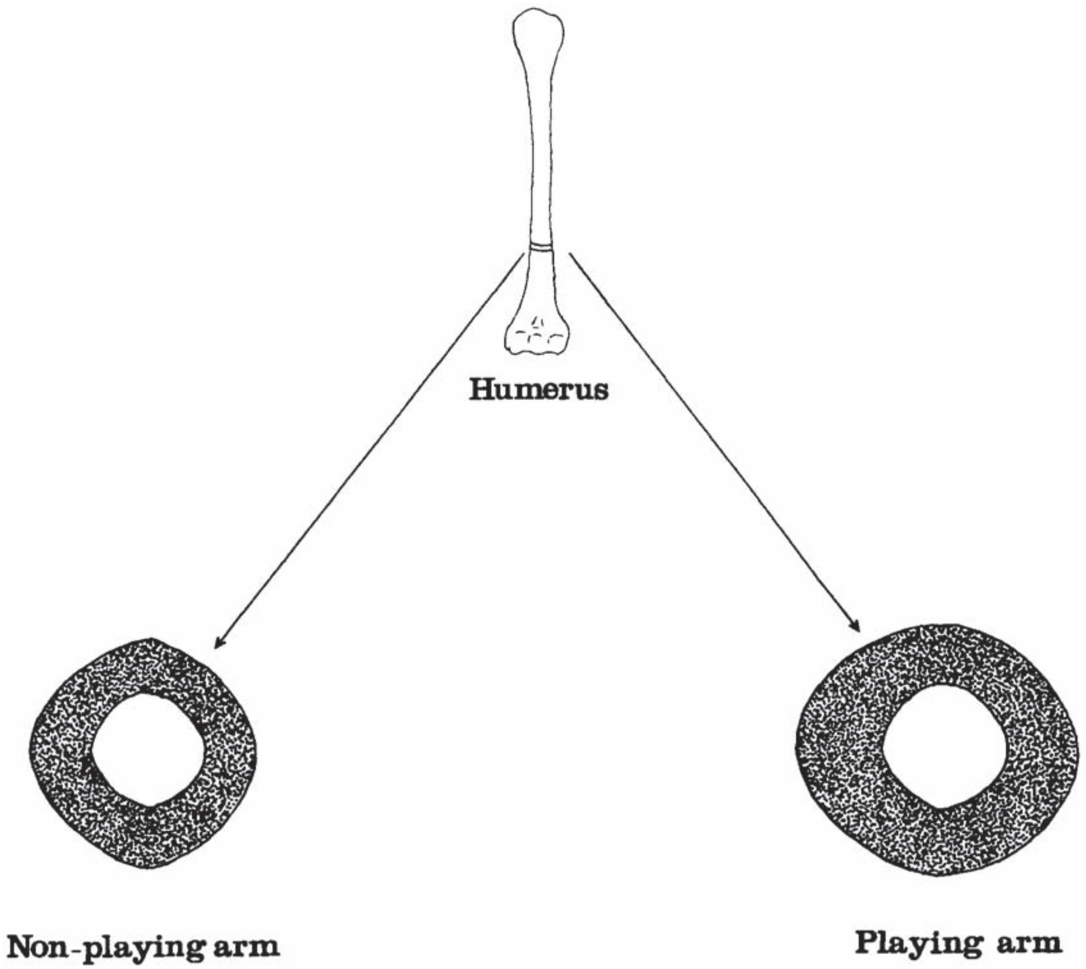


*Figure 1.3* Cross-sections of the humeri of a professional tennis player, as inferred from X-ray data. Note the heavily thickened cortical bone in the racket arm
*Source*: Based on Jones *et al.* (1977: Figure 4).

tension, and these directly influence bone form to a certain degree. An increase in mechanical stress tends to produce bones which are more robust, i.e. are thicker and stronger, with more marked ridges for muscle attachment; a reduction in mechanical forces tends to have the opposite effect (Scott 1957). For example, exercise increases bone strength. This is illustrated by a well-known X-ray study (Jones *et al.* 1977) of the arm bones of professional tennis-players, which found that the thickness of the cortical bone of the humerus in the racket arm increased to the extent that it was on average about 30 per cent greater than that in the non-playing arm (Figure 1.3). Conversely, bone mineral is lost when the physical strains imposed on the bones are les-sened. So, for example, patients who are bed-ridden for some time lose bone mineral (Donaldson *et al.* 1970), but regain it when normal activity resumes.

## MICROSCOPIC STRUCTURE OF BONE

Bone is initially laid down as woven or primary bone; woven bone is a temporary tissue which is gradually replaced by mature, or lamellar bone. Woven bone forms the foetal skeleton, but by the time an infant is a year old it has almost entirely been replaced by lamellar bone. Woven bone may also be produced in the adult skeleton in response to disease or injury: it may form under the periosteum in response to infection, and is produced by some bone tumours, and during fracture repair. Woven bone is coarser and more porous than lamellar bone. The two can be distinguished with the naked eye (Figure 1.4).

Lamellar bone is composed of a series of microscopic layers (lamellae) about 4–12 microns thick (1 micron = one thousandth of a millimetre). It is stronger than woven bone. In the adult, both trabecular and cortical bone have a lamellar structure, but they differ in the way they are organised.

The micro-structure of cortical bone is shown in Figure 1.5. Cortical bone is permeated by innumer-able, interconnected channels, the Haversian system, upon which it relies for its blood supply. Bony lamellae are arranged concentrically around Haversian canals. There are normally about 4–20 lamellae around each Haversian canal; this unit of bone organisation is called an osteon. Haversian canals run parallel to the long axis of the bone, and intercon-nect via transverse or oblique channels called Volk-mann's canals. There are also some lamellae between the osteons (interstitial lamellae), and some, termed circumferential lamellae, encircle the entire outer and inner surfaces of the bone. Trabecular bone does not have a Haversian system—its fine honeycomb structure allows it to receive sufficient nutrients from blood vessels which meander through it.

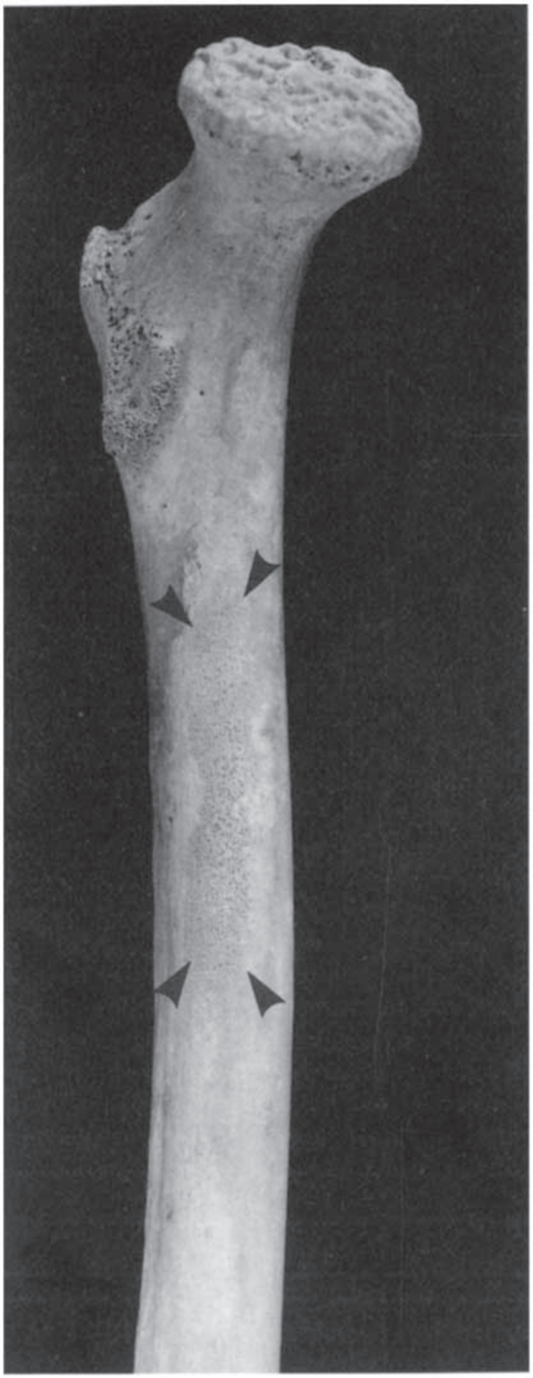


*Figure 1.4* A deposit of woven bone on a femur

## BONE CELLS

There are three main types of bone cells. Osteoblasts are responsible for formation of new bone, osteocytes are involved with the maintenance of bone as a living

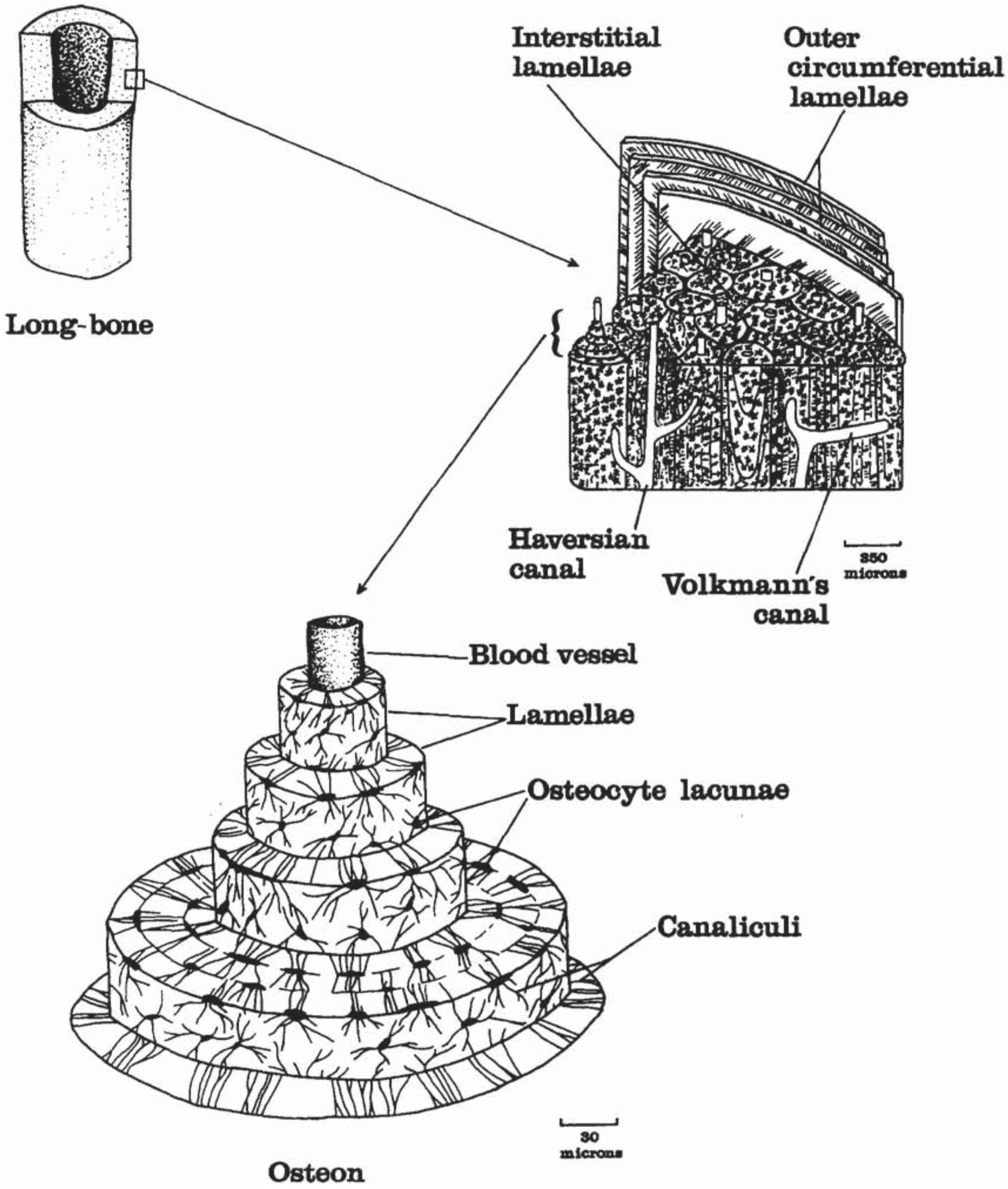


*Figure 1.5* The microscopic structure of cortical bone
*Source*: After White (1990: Figure 2.7).

tissue, and osteoclasts are responsible for resorbtion (removal) of bone.

Osteoblasts are often concentrated on bone surfaces (for example, beneath the periosteum), and are responsible for producing the organic matrix, osteoid, which is then mineralised to form bone.

Osteocytes are situated in spaces (lacunae) within the bony tissue, and receive nutrients via minute channels (the canaliculi) which connect osteocyte lacunae within the same or neighbouring lamellae (Figure 1.5).

Actively resorbing osteoclasts are located in shallow depressions in bone surfaces called Howship's lacunae.

## BONE GROWTH

Formation of the skeleton begins early in foetal life. Ossification commences at about the fifth week following fertilisation, the clavicle being the first bone to ossify. At birth most bones are at least partially ossified but some of the smaller bones (e.g. the carpals and the patellae) only mineralise during infancy and childhood.

Bones form from an embryonic tissue called mesenchyme. Mesenchyme may undergo ossification directly, or it may be replaced by a cartilage model which is then ossified to form bone. The former is intra-membranous ossification; the latter is termed endochondral ossification. Most of the bones in the human skeleton develop via endochondral ossification, but some, including the clavicle and most of the bones of the skull, are formed via intra-membranous ossification. The mineralised nature of bone means that it cannot expand; all bone growth is by apposition, the deposition of bone upon some pre-existing surface.

In intra-membranous ossification, osteoblasts lay down bone within a membrane which will eventually form the periosteum. Bone grows in this way from a single ossification centre or from multiple centres which subsequently fuse together.

Endochondral bone growth for a typical long-bone is illustrated in Figure 1.6. Initially the bone is pre-formed as a cartilaginous model (Figure 1.6a) within a membrane, the perichondrium. The perichondrium is analogous to the membrane surrounding intra-membranous centres of ossification and likewise later forms the periosteum. The cartilage model grows through the proliferation of cells derived from the perichondrium and the first ossification takes the form of a thin sleeve of bone around the centre of this model (Figure 1.6b), and subsequently calcium is deposited upon the cartilage within this sleeve (Figure 1.6c). Blood vessels pene-trate the bony sleeve (Figure 1.6d), conveying, among other things, osteoblasts and osteoclasts, allowing the calcified cartilage within to be converted to bone. This initial centre of bone formation is termed the primary ossification centre. Most long-bones have developed a primary ossification centre by the end of the second month of foetal life. As the cartilage cells grow outwards from the primary ossification centre, ossification of the calcified matrix proceeds behind them. This, together with the elon-gation of the periosteal sleeve, results in longitudinal growth of the bone (Figure 1.6e). The interior of the shaft is initially filled with bone, but as growth continues it is hollowed out by osteoclasts to form the medullary cavity. During the first few years of postnatal life, secondary centres of ossification, the epiphyses, appear at long-bone ends (Figure 1.6f, g), united with the shaft via cartilages—the epiphysial growth plates. When growth is complete, the growth plate ossifies, fusing the epiphysis with the shaft (Figure 1.6h, i). The age at which the epiphyses fuse with the shaft ranges from about the mid-teens to the mid-twenties, depending on the epiphysis.

The growth in width of a long-bone takes place in a different way. In the diaphysis, bone is deposited on the outer surface beneath the periosteum, and resorbed from the internal surface under the endo-steum. In a growing bone, the rate of bone resorbtion from the endosteal surface is generally exceeded somewhat by the rate of deposition beneath the periosteum. Thus, as well as an increase in width, there is an increase in thickness of the walls of the diaphysis during growth.

Since the metaphyses are flared, their width needs to be reduced during longitudinal growth as meta-physis

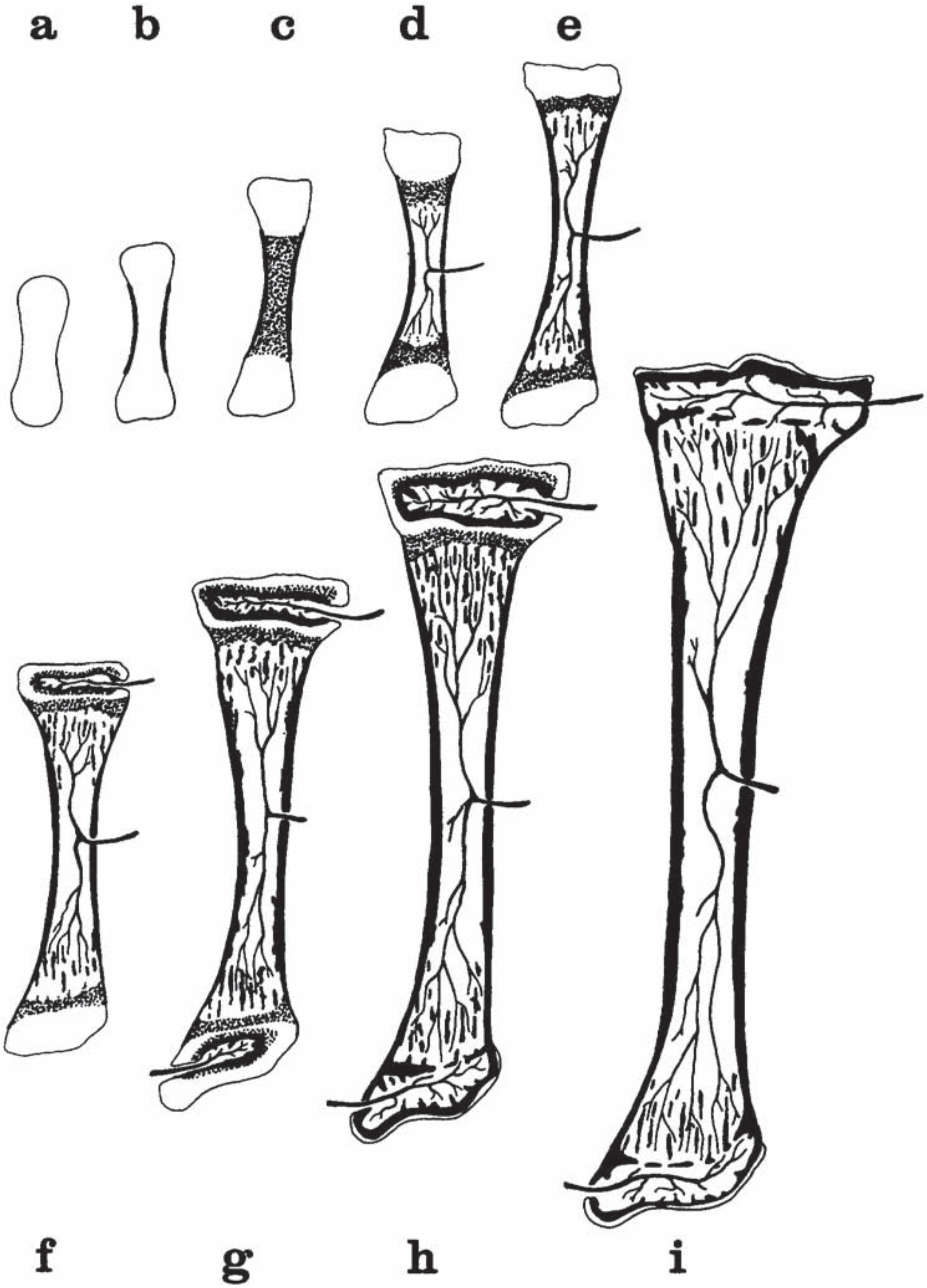


*Figure 1.6* Development of a typical long-bone.
Cartilage is clear; calcified cartilage is stippled; bone is black
*Source*: Redrawn from Jee (1988).

becomes diaphysis. To achieve this, bone is deposited on the internal surface of the cortex and removed from the periosteal surface.

## THE TEETH

Human teeth are classified into four types according to their shape and function. Incisors are chisel-like teeth for cutting food. The more conical canines are for puncturing and tearing. Premolars and molars have broad, flattened surfaces for crushing and grinding.

Man develops two sets of teeth. The milk or deciduous teeth, which are smaller than their adult counterparts, appear during infancy and early childhood. During middle childhood they are gradually replaced by the permanent teeth. The permanent dentition is complete by about 18 years with the eruption of the third molars or wisdom teeth.

There are 20 teeth in the deciduous dentition. The upper jaw (maxilla) and lower jaw (mandible) each contain four incisors, two canines and four molars (Figure 1.7). There are no deciduous pre-molars.

The adult mouth normally contains 32 teeth. Each jaw has four incisors, two canines, four pre-molars and six molars (Figure 1.8).

### Tooth Structure

Each tooth consists of a crown projecting above the gum and one or more tapering roots which occupy sockets (alveoli) in the jaw (Figure 1.9). The junction between the crown and the root is termed the neck or cervix of the tooth.

Teeth consist of three hard tissues: enamel, cementum and dentine, enclosing the dental pulp (soft tissue which includes nerves and blood vessels) in the pulp cavity and the root canal (Figure 1.9). The dental hard tissues lack a blood supply and are not continually turned over as is bone. Thus Wolff's Law does not apply to them, they cannot re-shape themselves once formed and they are unable to repair themselves to any great extent in response to injury or disease.

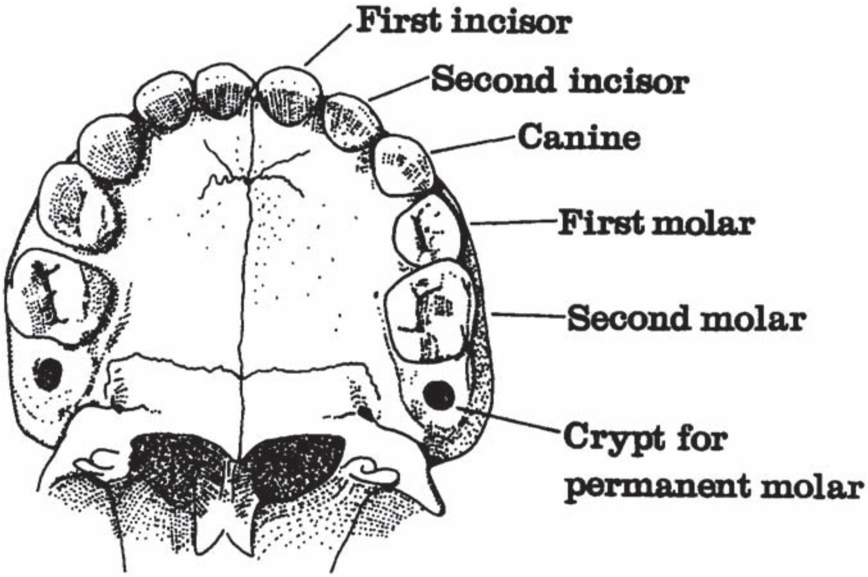


*Figure 1.7* The deciduous dentition of the upper jaw

Enamel is almost entirely composed of inorganic matter, whose chemical composition approximates to that of bone mineral (hydroxyapatite), and is arranged in thin rods, or prisms. Enamel lacks a cell structure and, unlike other skeletal hard tissues, is not living tissue.

Dentine consists of about 75 per cent inorganic material (mainly hydroxyapatite) along with a mainly collagen organic component. Unlike enamel, dentine is living tissue and does show a cell structure. It is penetrated by microscopic tubules which run from the pulp cavity to the outer margins of the dentine. The composition of cementum is similar to that of bone. Cementum is living tissue and some of it shows a cell structure.

## Tooth Formation and Development

Formation of the dental hard tissues starts at about the twentieth week of foetal life. Dentine starts to form—first. Cells called odontoblasts secrete an organic matrix, which is then mineralised to form dentine. Dentine, like the other dental hard tissues, is formed in microscopic layers. Dentine formation proceeds in a progressive fashion from the crown towards the root tip.

Enamel formation, or amelogenesis, consists of three phases, the formation of an organic matrix, the mineralisation of that matrix and a maturation phase in which the enamel loses most of its organic component. The enamel-forming cells are called ameloblasts. Enamel formation begins near the tip of the crown so that the crown grows progressively back towards the cervix until it is complete. As with the other dental hard tissues, cementum is formed as a result of the laying down of an organic matrix followed by mineralisation of that matrix. It continues to be formed throughout life, the cementum layer thus increases in thickness with age.

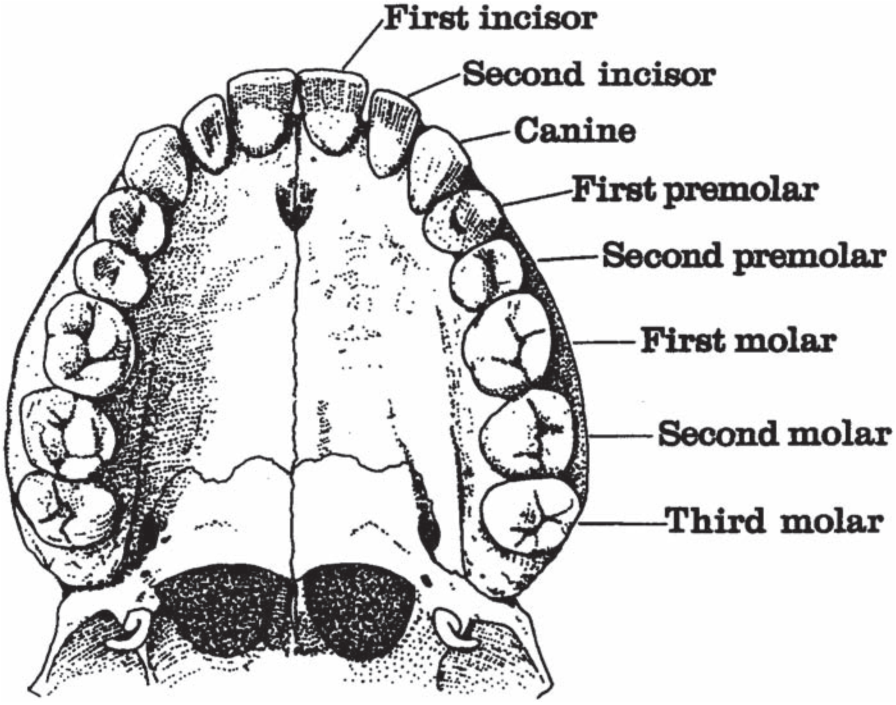


*Figure 1.8* The permanent dentition of the upper jaw

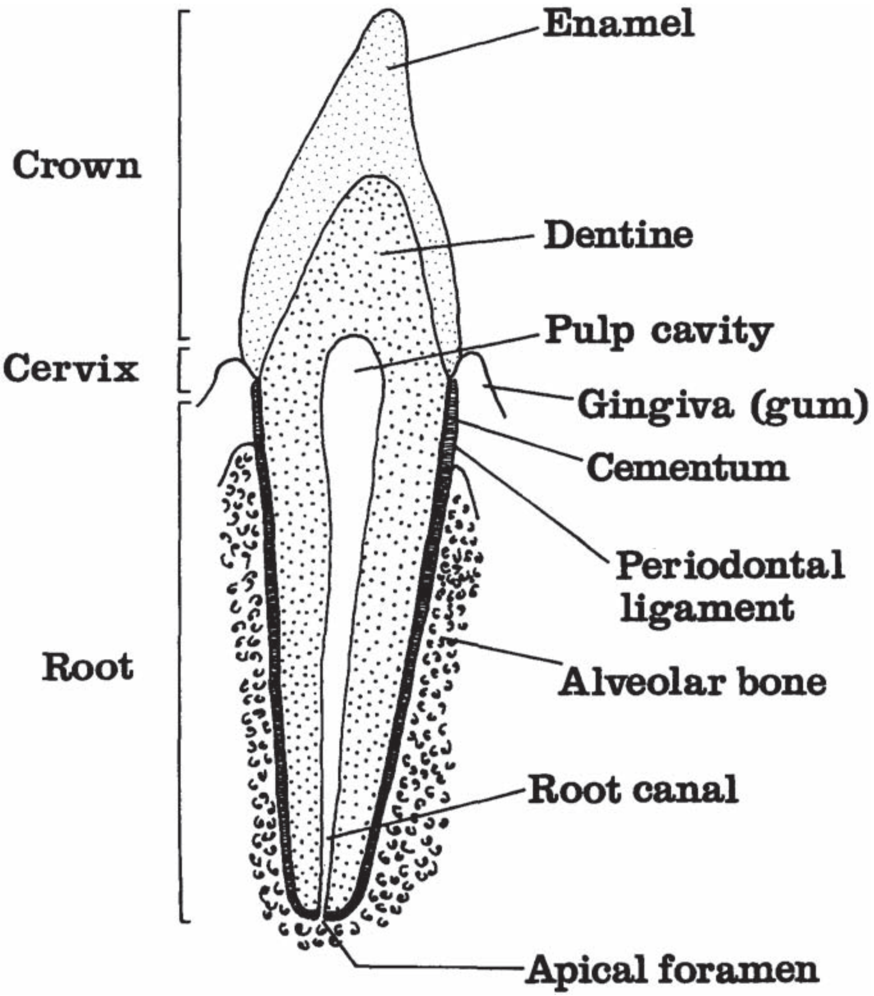


*Figure 1.9* The structure of a tooth

## FURTHER READING

For further information on the of bones and teeth the reader is referred to Bloom and Fawcett (1986), Gray (1988) and Weiss (1988). White (1990) forms a good introduction to bone biology and anatomy biology and identification, written with the archae-ologist in mind:

# 2

# THE NATURE OF AN ARCHAEOLOGICAL HUMAN BONE ASSEMBLAGE

There are many ways to dispose of a dead body. The great variety of funerary practices used routinely by human groups around the world bears witness to this (Kroeber 1927; Ucko 1969). Many of these, such as disposal in rivers, exposure in trees or on platforms, or abandoning the corpse to be eaten by wild animals, would leave little trace in the archaeological record. Only if ancient funerary rituals culminated in the burial of human remains beneath the soil or within a tomb would they usually survive down the centuries to be studied by archaeologists.

In many instances burials simply involve the straightforward interment of a corpse, so that when it is excavated by archaeologists it is found as a discrete, articulated skeleton. In other cases there may be some pre-treatment accorded to the body before burial. For example, provided there has been no post-depositional disturbance, commingled, disarticulated bones indicate that the flesh had been allowed to rot or had been otherwise removed prior to burial of the bones. As we shall see this type of burial treatment was practised by some earlier human populations. Archaeological finds of burnt human bone show that cremation was another funerary practice used at various periods in antiquity.

Before attempting to infer anything about a past human group from a collection of bones (often termed an assemblage) excavated from an archaeological site, we need to consider the relationship between the assemblage and the ancient human group from which it is derived. The aim of this chapter is to discuss some of the factors which affect the composition of an assemblage of human bones from an archaeological site. They can be divided into two groups (Figure 2.1). Firstly there are those over which archaeologists have no control, including the mortality patterns of the ancient human group and the nature of their burial practices, and losses of bones due to destruction in the soil. A second set relates to excavation strategy and techniques, and so can, to a greater or lesser extent, be controlled by archaeologists.

As we move down Figure 2.1 each successive factor potentially introduces another set of losses and biases into the assemblage, so that each stage in the diagram represents but a sub-sample of the preceding one.

Biases introduced as a result of the archaeologists' strategy and excavation methods can be viewed as inconvenient 'noise' tending to obscure patterning in the remains which might otherwise tell us about ancient life-styles. The strategy of excavators should, where possible, be to try to minimise the effects of these biases on the assemblage.

The factors outside archaeologists' control can likewise be thought of as sources of unwanted bias on skeletal data. However, as we shall see, bone losses due to poor survival in the soil to some extent follow predictable patterns, so can to a degree be allowed for in data analysis. Factors associated with ancient burial practices can, if recognised and given appropriate consideration, provide us with additional information from our assemblage.

The other factor listed in Figure 2.1 which is outside archaeologists' control is that of mortality. A

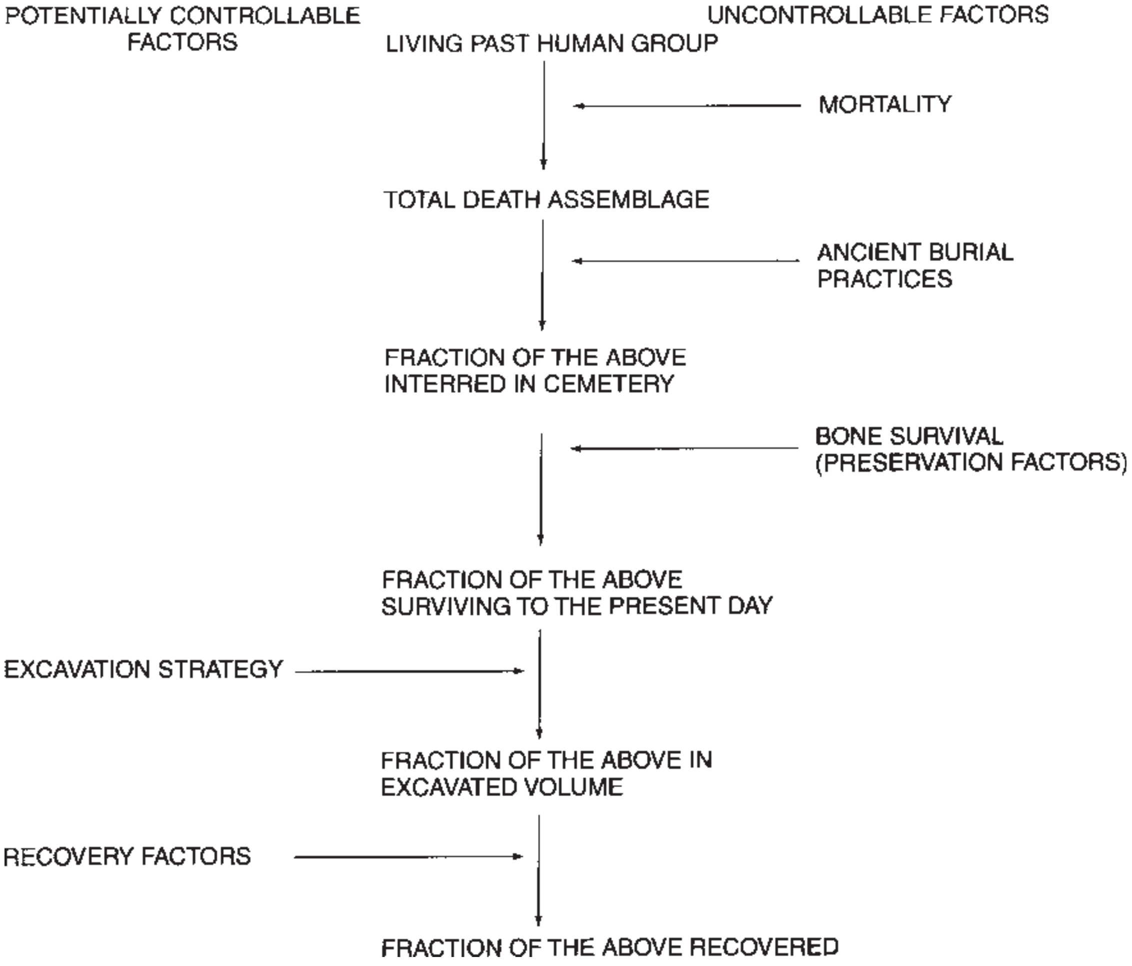


*Figure 2.1* Factors affecting an excavated collection of skeletons
*Source*: Adapted from Meadow (1980).

skeletal assemblage is derived from a living population via the intervening variable of mortality, or, to put it more succinctly, skeletal collections are collections of the dead (Cook 1981). This may not seem like a particularly stunning revelation, but, since mortality clearly does not affect a human population randomly, it does in fact have some important implications for the interpretation of a wide variety of osteoarchaeological data. The work-ings of the mortality bias are something to which we shall return in the next chapter.

## RECOVERY OF HUMAN BONES FROM ARCHAEOLOGICAL SITES

Most human burials on archaeological sites are found as articulated skeletons. When excavating an articulated skeleton, the fill of the grave should be carefully removed with a trowel and hand-brush. As the skeleton is exposed, care should be taken not to disturb the positions of any of the bones. Soil may be cleaned from the upper surfaces of smaller or more delicate bones using a paint brush and dental tools. The end result of this process should be an undisturbed, cleaned skeleton (Figure 2.2).

Once the exposed skeleton has been photographed, planned and recorded onto a context or skeleton sheet, the bones can be gently lifted by hand, removing any surrounding soil as necessary to loosen them. Bones from an articulated skeleton should be kept separate from any re-deposited material found in the grave fill which does not belong to the articulated individual, and if more than one skeleton is interred in a single grave, strenuous efforts must be made to avoid bones from different individuals becoming mixed. Once bones from several skeletons become mixed it is often very difficult to separate them out once more into discrete individuals.

It has been shown (e.g. Payne 1972) that when archaeological material is recovered by hand, smaller items are often overlooked. During hand recovery of human remains it is almost inevitable that some small bones, bone fragments and loose teeth will be missed. Sieving of the soil remaining in the grave after the bones have been lifted helps to recover these small elements. At Hooper Street Romano-British cemetery, London, Keiley (1989) demonstrated that sieving soil from the hand and foot regions of the burials through a 1-mm mesh improved the recovery of the small bones of the extremities. The recovery of the small bones of infant burials was also improved by sieving the soil from the graves. These experiments reinforce the idea that smaller bones may be under-represented in hand-recovered assemblages due to their being overlooked during excavation. Sieving may also recover tapeworm cysts (Wells and Dallas 1976), kidney stones (Morris and Rodgers 1989) or material such as calcified blood vessel walls, lymph nodes or pleural plaques (Baud and Kramer 1991). These appear as small bone or bone-like fragments and are seldom found in hand-collected material.

## EXCAVATION STRATEGY

Only rarely are cemeteries excavated in their entirety, due to lack of funds or because only part of the burial area is threatened with destruction. Archaeologists often cannot choose which part of a site to excavate—in most cases it is determined by the part of the site which is under threat. The proportion of the cemetery lying within the excavated area is frequently not known with any certainty. The skeletons in the excavated area may not be representative of those in the cemetery as a whole. This may be a particular problem if status or gender groups or other sectors of the community were buried in discrete areas of the cemetery, a problem which will be further considered in the section on burial practices (see pp. 23–25).

## SURVIVAL AND DECAY OF HUMAN TISSUES

### Soft Tissues

In most archaeological burials, only the bones and teeth survive, the soft tissues having long since decayed. Save in conditions of extreme cold or dryness, decomposition of a corpse begins immediately after death. Decomposition consists of two distinct processes: autolysis (the destruction of tissues by enzymes released after death, without intervention of bacteria) and putrefaction (the degradation of the soft tissues by micro-organisms). At death, bacteria which normally inhabit the gut invade the tissues, and in the later stages of decomposition some bacteria may come from the surrounding soil or the air. Initially aerobic species are active, but when these have depleted the tissues of oxygen, they create a favourable environment for the more destructive anaerobic organisms. Putrefaction results in the production of gases, bloating the corpse, and the softening, and eventual liquefaction and disintegration of the soft tissues (Watson 1989:59ff; Marshall 1976; Garland and Janaway 1989; Evans 1963).

Different soft tissues show differing resistance to

*Figure 2.2* A medieval skeleton from the Ipswich Blackfriars site after removal of the grave fill

decomposition. Those with ample collagen fibres, such as ligaments and tendons, are slow to decay. Another soft tissue with a relatively high resistance to decomposition is hair. The major constituent of hair is a protein, keratin. The structure of keratin makes it highly resistant to chemical degradation (Sandford and Kissling 1993). Hair is probably the most common soft tissue to survive in archaeological burials, but even so it is only present occasionally unless the climate is very arid. In temperate climates it rarely survives, although some instances of substantial hair survival are known from interments in coffins packed with gypsum, as may be found on Roman sites in some parts of Europe (Green *et al.* 1981). Smaller amounts of hair may survive where it is in contact with copper or bronze objects interred with the corpse: copper poisons the micro-organisms which would otherwise break down the hair (Janaway 1987).

The rate of decay of a corpse varies with temperature, length of time between death and burial, whether the body is fat or thin, adult or child, the availability of water, whether the body is coffined or not and if so the construction of the coffin, whether the body is covered by clothing, the availability of oxygen, the depth of the burial, the nature of the soil and whether decomposition accelerants, such as straw, wood shavings or other vegetable matter are buried with the body (Mant 1987). Given the myriad factors influencing decay it is hardly surprising that the amount of time needed for a buried corpse to be reduced to a skeleton is extremely variable. However, Marshall (1976:91) states that (for temperate climates) '[it] is about 10 years before the adult body, buried in well drained soil becomes reduced to the bony skeleton, but a child's body decomposes to its skeleton in about half this time'.

## Hard Tissues

Some demineralisation of bone may occur as a result of the action of organic acids released during decomposition of the soft tissues (Childe 1995); however, it is the character of the soil environment to which the bones are exposed following the decay of the flesh which plays a major part in determining their survival on archaeological sites. Although much remains to be learnt about specific aspects of the burial environment which influence bone survival, among those which have been identified as important are soil acidity, the activities of soil-dwelling micro-organisms, the availability of water and soil temperature.

### Soil Acidity

Acidity is measured on the pH scale, which ranges from 1 to 14. Values above 7 are alkaline, values below 7 are acid. Most soils and sediments range from about pH 3.5 (very acidic peats) to about pH 8.5—some soils on chalk geology (Evans 1978:67). Using sites from Illinois, USA, Gordon and Buikstra (1981) conducted a study on the effect of soil acidity on the preservation of skeletons. They scored preservation into six categories on the basis of visual examination of the bones. Their categories varied from 'strong, complete bones' (termed category 1) through various degrees of superficial erosion of the bones, to total destruction of the skeleton (their category 6). Gordon and Buikstra found that as soil pH decreased (i.e. the soil became more acid) destruction of bone increased. This finding is consistent with some observations on the chemical properties of bone mineral: according to Lindsay (1979:181–182) hydroxyapatite (the major constituent of bone mineral) is relatively insoluble at pH 7.5 but becomes more soluble as pH decreases to 6.5 and is very soluble at pH values below 6.

Gordon and Buikstra's study is also consistent with findings from other burial sites. For example at Sutton Hoo, Suffolk, England the burials were generally only present as soil stains with no survival of bone (Figure 2.3). The soils here were very acidic —pH 3.8–4.9 (Barker *et al.* 1975). In contrast to Sutton Hoo, the preservation of bones at Wharram Percy, North Yorkshire, appeared from gross inspection to be very good (Figure 2.4), the bones generally being strong with negligible erosion of external surfaces (i.e. they would generally fall into Gordon and Buikstra's

*Figure 2.3* Two superimposed burials from Sutton Hoo, UK. The bones have been destroyed by the soil acidity at the site; only soil stains indicate their positions

*Source*: From Bethell and Carver (1987: Figure 2.3).

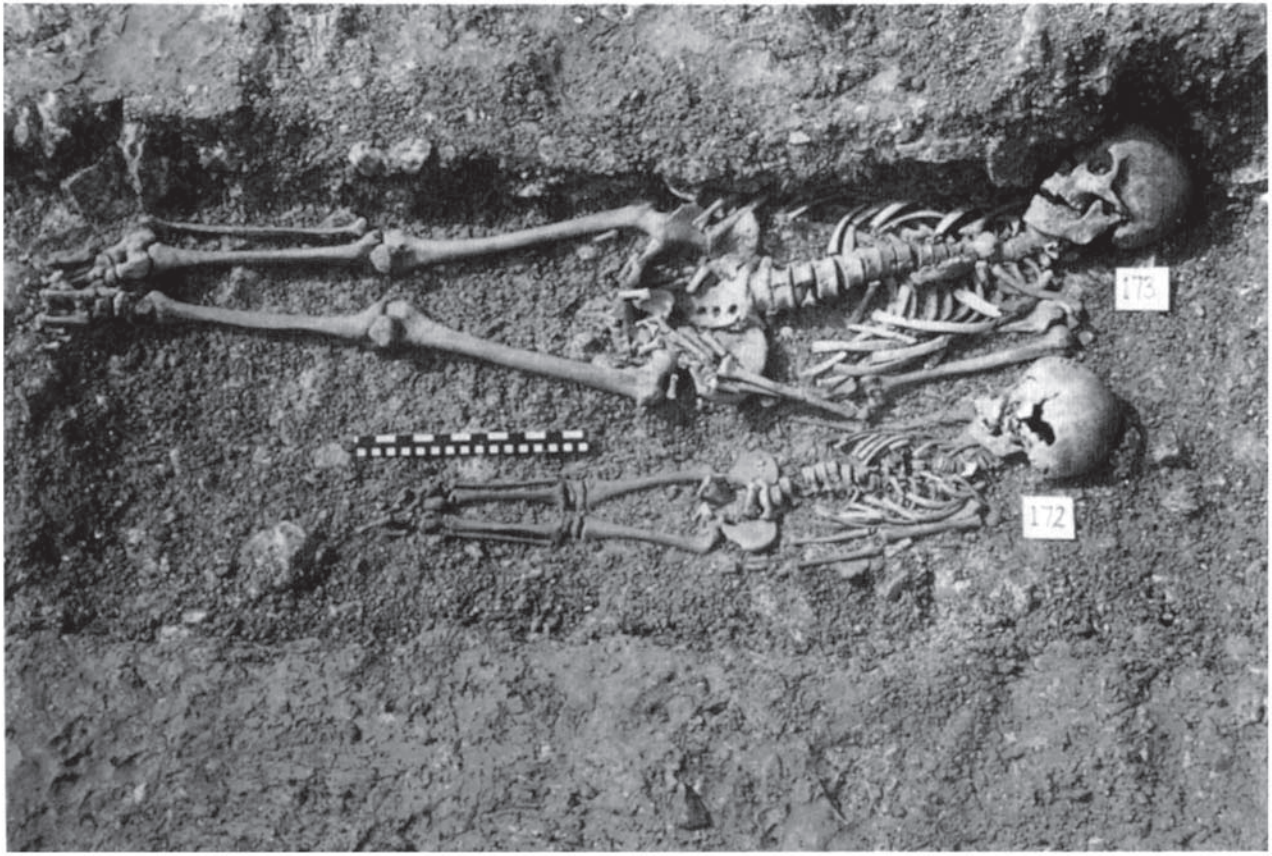


*Figure 2.4* Well preserved skeletons of a child and an adult from the medieval churchyard at Wharram Percy

category 1). The soil pH at this site was 7.3–8.0 (Keeley n.d.). In a cemetery in Zimbabwe, dating to about the twelfth/thirteenth century AD, there was a large termite mound which seemed to pre-date the burials (Watson 1967). The soil at the site was quite acidic (pH 4.8–5.4), whereas within the termite mound it was approximately neutral (pH 6.2–7.5). Bones survived in the soil of the termite mound but skeletons buried in the acidic natural soil had been completely destroyed. Indeed, the 700-year-old skeletons from the termite mound were rather better preserved than animal bones buried for only 20 years in the acidic natural soils of the area.

## Activities of Soil-Dwelling Micro-Organisms

Buried bone is subject to decay as a result of the actions of soil-dwelling micro-organisms including fungi, bacteria and algae. Micro-organisms invade the bone, breaking down the collagen. This leads to the production of acidic by-products which start to dissolve the bone mineral (Hackett 1981; Marchiafava *et al.* 1974; Hanson and Buikstra 1987; Herrmann and Newesley 1982), producing areas of bone destruction visible at the microscopic level. A thin section showing areas of bone destruction is illustrated in Figure 2.5. These begin as discrete foci, several of which can be seen, particularly in the osteon on the left in the photograph. These

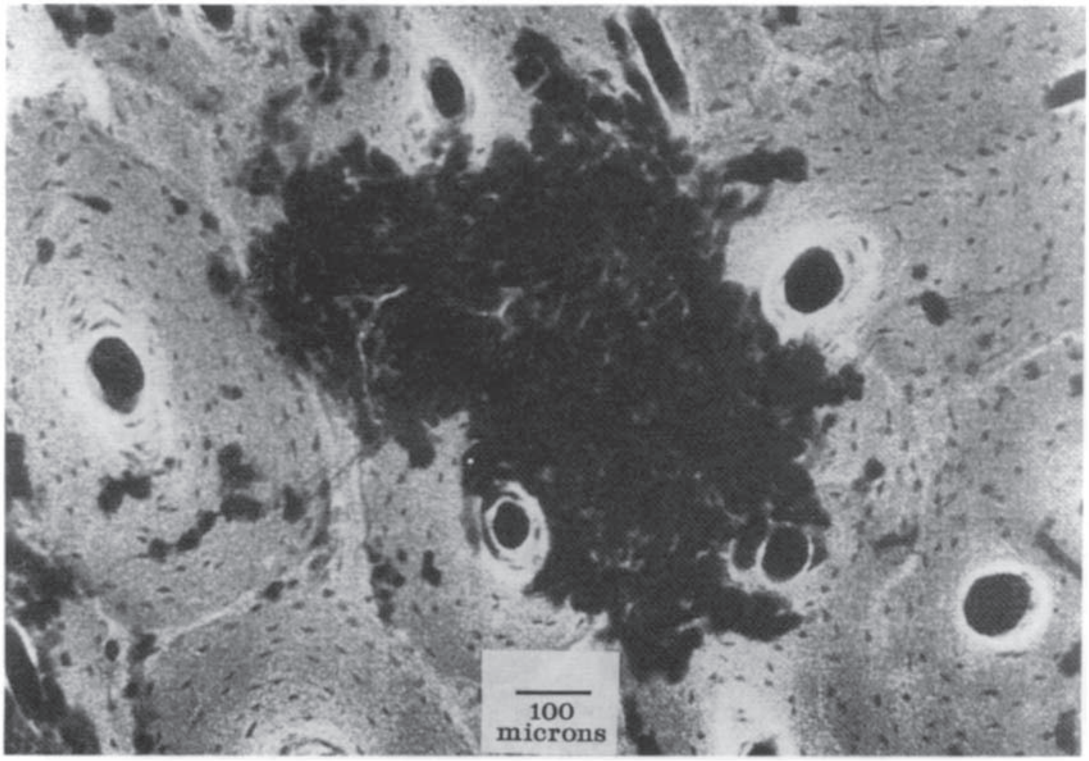


*Figure 2.5* A photomicrograph of a bone from an archaeological site in the USA showing some destruction of its osteonal structure. The dark area in the centre of the photograph is a large area of bone destruction. Smaller foci are also present, particularly towards the left of the picture

*Source*: Reproduced from Hanson and Buikstra (1987: Figure 7).

eventually enlarge and coalesce as decay proceeds to produce larger areas of destruction like that visible in the centre of the picture. The acidic environment produced by the invading micro-organisms is also conducive to the conversion of the hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) of bone to another mineral, brushite ($CaHPO_4.2H_2O$). Brushite occupies more space than the apatite from which it is formed so that the expanding brushite masses may, if they are large, tend to crack the bone apart.

Hanson and Buikstra (1987) found that of the 119 bone samples they analysed from femora excavated from sites in Illinois, 27 showed evidence for this type of bone decomposition. They found that focal destruction begins within the cortex; it might be quite advanced even when the outer surfaces of the bone were intact. Preservation of the microscopic structure of bone varied independently of the gross preservation of the specimen—a sample displaying severe destruction at the microscopic level was just as likely to come from a macroscopi-cally well-preserved bone as from one which appeared poorly preserved to the naked eye.

### Availability of Water

As well as being necessary for the survival of micro-organisms which attack bone, water provides a necessary medium for the transport of ions to and from bone and hence plays a direct part in its chemical degradation. At the early Saxon cemetery at Mucking, England, the natural soil had a pH of about 6.6–6.8 (Barker *et al.* 1975). These values are much more favourable to bone survival than the Sutton Hoo site, but nevertheless skeletal survival at Mucking was very poor, a few scraps of bone were all that remained from most burials. The soils at Mucking were very free-draining sands and gravels lacking a fine particle fraction, and it seemed likely that this was an important cause of the poor bone survival at the site; the passage of water had almost completely leached out the bone mineral.

### Temperature

The rates of most chemical reactions are affected by temperature in a fairly predictable manner—as a general rule of thumb reaction rate approximately doubles for a 10°C rise in temperature. Micro-organisms are also more active at warmer soil temperatures (Edwards 1975). It might therefore be anticipated that the chemical degradation of bone would be affected by the temperature of its environment, and this has been confirmed by experiment.

Von Endt and Ortner (1984) investigated the effect of temperature on the rate of decay of bone samples under laboratory conditions. They found that decay of the organic component was faster at higher temperatures. Consistent with this Nelson *et al.* (1986) ascribed the relatively good preservation of collagen in bone samples from Greenland to the low temperatures of the depositional environment, contrasting this with bones from the tropical Tehuacan valley in Mexico where much greater losses of collagen had occurred.

In a laboratory investigation into chemical changes in the mineral part of the bone, Lambert *et al.* (1985) confirmed that chemical exchange between bone samples and solutions of metal ions in water were faster at higher temperatures.

## THE EFFECTS OF PRESERVATION AND RECOVERY FACTORS ON THE COMPOSITION OF ARCHAEOLOGICAL ASSEMBLAGES

In addition to the factors associated with the burial environment, bone survival also depends on the intrinsic resistance to decay of the bone itself. Because bones differ in their resistance to decay, factors which result in destruction of bones in the soil, as well as causing losses, also have the potential to introduce certain biases into the assemblage.

It is often asserted (e.g. Angel 1969; Weiss 1973) that the thinner, more fragile bones of juveniles, and particularly of infants, may survive less well in the soil and hence be under-represented in skeletal assemblages. There is some evidence to support this idea. Gordon and Buikstra (1981), in their study of gross bone preservation and soil acidity, found that the preservation of juvenile bones declined more rapidly with increasing soil acidity than did the preservation of adult bones. They also found that the age at death of the immature individuals was correlated with bone preservation, younger individuals tending to have more poorly preserved bones. These observations led Gordon and Buikstra to state that 'at marginal pH ranges all or most of the infants and children may be systematically eliminated from the mortuary sample by preservation bias' (1981: 569).

However this under-representation of infants and children does not seem to hold true for sites where soil conditions are less hostile to bone survival. Five hundred and ninety-seven burials were excavated from the Anglican church cemetery in Belleville, Ontario, Canada (Saunders 1992). The proportion of subadults in the skeletal assemblage tallied closely with the proportion expected from the burial records. At this site, where soil pH was approximately neutral, there was no evidence for under-representation of infants or children amongst the burials. This led Saunders to suggest that differential burial practices and poor recovery of small bones may be more important than poor bone survival in the soil in instances where infants are under-represented in skeletal assemblages. The implication of recovery factors is consistent with the results from the soil-sieving experiments of Keiley (1989), discussed above, which showed that some small infant bones tend to be missed when recovery is by hand collection rather than sieving.

Different parts of the skeleton also show differential resistance to destruction in the soil. The enamel of the tooth crowns is, whilst not invulnerable, the most resistant skeletal tissue and may survive even when the bones do not. At the Mucking site, enamel tooth crowns were frequently recovered from graves where no bone survived (Mays 1992a). Furthermore, as enamel is almost entirely inorganic it does not appear to be decomposed by soil-dwelling micro-organisms, unlike bone and dentine (Hackett 1981).

Trabecular bone seems to decay more rapidly in the soil than does cortical bone. Lambert *et al.* (1982) and Grupe (1988) found that trabecular bone showed greater susceptibility to chemical changes whilst in the soil than did cortical bone and this seemed, at least in part, to be due to the larger surface area of trabecular bone favouring chemical exchange between bone and soil. Consistent with this is a frequent observation that in hostile soil conditions the compact bone of the midshaft parts of long-bones may often survive even when the ends, which are predominantly composed of trabecular bone, do not.

Bone losses from archaeological contexts may also occur due to the cutting of later features through pre-existing graves. Losses in this way will be fairly random with respect to the different parts of the skeleton. However, it is possible that damage to a cemetery site as a result of natural erosion or human activities such as ploughing might selectively remove more of the (often shallower) infant than the (often deeper) adult interments, and hence bias the demographic structure of the assemblage.

## A Case Study Illustrating the Effects of Recovery Factors and Bone Survival on the Composition of a Skeletal Assemblage

At the majority of archaeological cemetery sites the interments were made as complete corpses. Thus the numbers of each skeletal element originally present in the assemblage can be taken as known. By studying such assemblages, patterns of loss of the different bones of the skeleton through poor survival in the soil and recovery factors can be investigated. Using a group of 226 medieval (thirteenth to sixteenth century) adult burials from the Blackfriars site in Ipswich, England, I calculated the representation of each element of the skeleton by expressing the total number of an element present as a percentage of that expected if all burials were represented by complete skeletons (Mays 1992b). The skeletons from this site were carefully excavated by hand. No sieving for small bones was carried out. The representation of the various skeletal elements in the Ipswich adults is shown in Figure 2.6.

As might be expected, the bones which are in general more poorly represented are the smaller ones and/or those with high trabecular and low cortical bone contents. Many of the bones of the hands and feet are poorly represented, consistent with the likelihood that many of them are easily missed if sieving is not carried out. Fewer foot than hand phalanges are present, and fewer carpals than tarsals. This is consistent with the idea that losses of hand and foot bones are primarily deficiencies of recovery: hand and foot phalanges differ little in their relative trabecular and cortical bone contents, and the same is true of carpals and tarsals, but they do differ in size —carpals are smaller than tarsals and foot phalanges are smaller than hand phalanges. The least frequent bones in Figure 2.6 are the foot sesamoids, the smallest of the bones listed and hence the most easily overlooked during excavation.

The sternum, vertebrae, ribs and hyoid are elements which have high proportions of trabecular bone and these tend to be under-represented compared with, for example, the limb bones, which have high proportions of dense, strong cortical bone. This is as expected given the lesser resistance of trabecular bone to destruction in the soil; the patterning here is probably largely a reflection of differential bone destruction. The hyoid bone is particularly poorly represented; this may be because it is rather more fragile even than other bones with high trabecular bone contents, but may also be because it is often omitted from standard skeleton recording sheets used in the field, and hence overlooked by excavators unaware of its existence.

Another bone which is rather under-represented is the patella. Patellae are rounded bones appearing as flattened discs several centimetres in diameter. They are quite dense and strong—given their size and ratio of cortical to trabecular bone, patellae might be expected to be found in similar numbers to calcanei and tali (the two largest tarsal bones), but as Figure 2.6 shows this is far from being the case. An explanation here may be that patellae appear rather undistinctive to excavators and, if dislodged from their anatomical positions during excavation, may not be recognised as bones, particularly if the soil is rather light coloured or stony.

## BURIAL PRACTICES

Different sectors of a human group may receive different treatment in death. As well as ‘biasing’ our assemblage this may also potentially provide insights into burial practices in antiquity. Differences in burial treatment may take many forms, such as interment with different grave goods, but in the present context we are concerned with those which affect the bones themselves or the overall composition of an assemblage. Into the former category come mutilations or dismemberments characteristic of some ancient funerary rituals, and into the latter fall practices whereby some sector of society was confined to particular parts of cemeteries or was disposed of elsewhere.

In most human groups there are cultural rules governing aspects of burial, such as the orientation of the corpse in the grave, the grave goods, if any, with which it should be buried, the location of the grave itself and so on. Thus, just as we would not expect grave goods to be interred with different individuals on a random basis, we should not expect the location of graves in a cemetery to be random, but rather that their placement should be governed by certain principles. Those governing the placing of graves may be difficult or even impossible to determine archaeologically. For example, a combination of several factors may have been taken into account, or the criteria for grave placement may have changed over the period of use of the cemetery.

The burials within the excavated area may therefore be a non-random sample of those on the site as a whole. Whether this affects the conclusions of the osteoarchaeologist depends on the organising principles at the particular site under study. In some

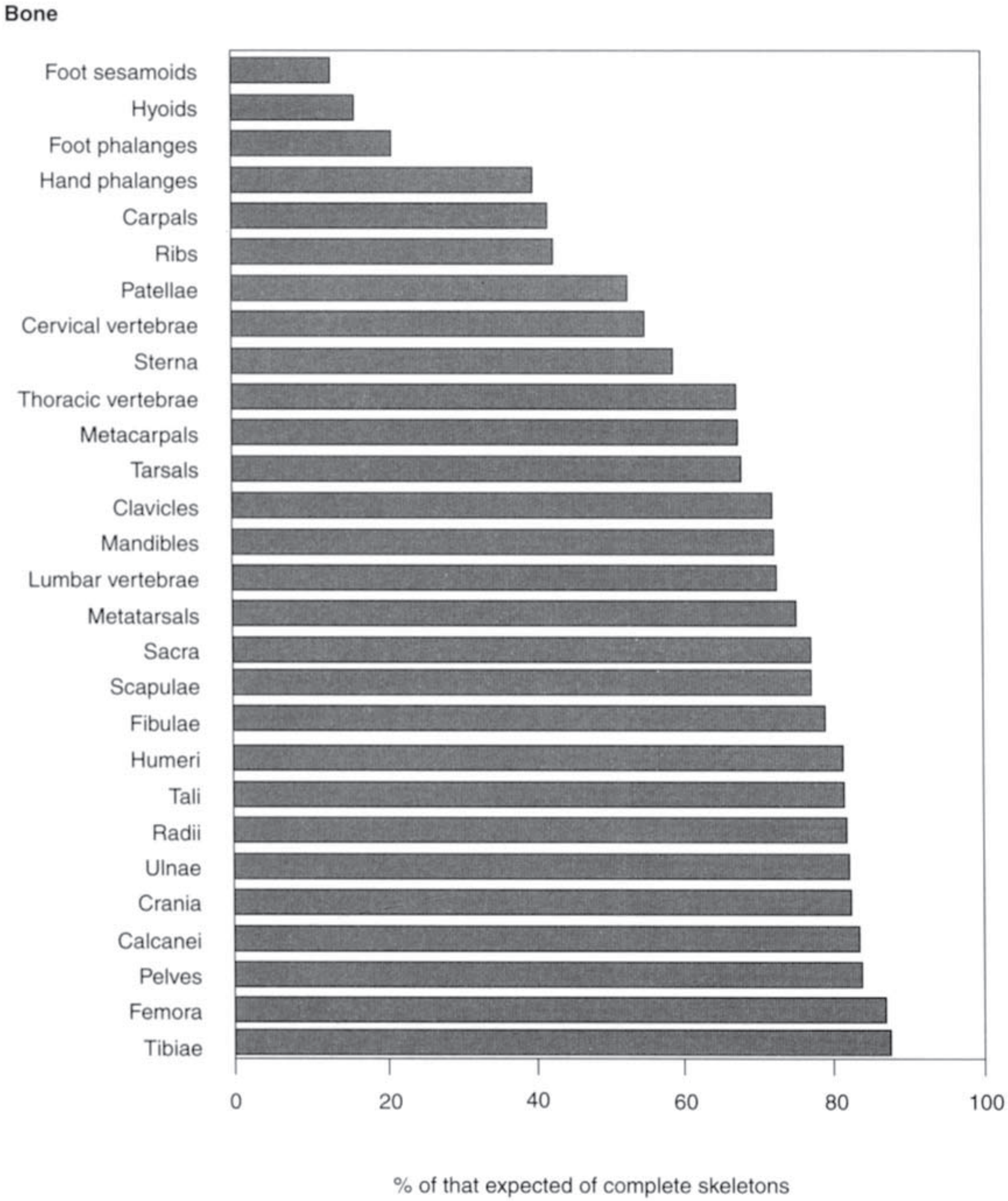


*Figure 2.6* Frequency of various skeletal elements in the medieval burials from the Ipswich Blackfriars site

instances the grave location depends on the age or sex of the deceased. For example, in Sweden in medieval times, ecclesiastical codes specified that women should be buried in the northern part of the churchyard, men in the south, a pattern which has been confirmed archaeologically at some sites (Gejvall 1960). Of course, when such sites are incompletely excavated a biased impression of the sex ratio is likely.

Cemeteries may show spatial patterning with respect to social rank, status or wealth. Mainfort (1985) studied the bones from the mid-eighteenth-century Native American cemetery at the Fletcher Site, Michigan, USA. The burials here appeared to be laid out in several rows. Historical evidence suggested that these rows probably corresponded to the burials of different clans or lineages. The Fletcher Site burials were interred with grave goods, the eighteenth-century trade value of which, in terms of beaver pelts, could be determined from documentary evidence. Mainfort found that the mean 'value' of the grave goods from burials in the westernmost row (Row one) was approximately 53 beavers. The grave wealth decreased towards the eastern part of the cemetery, the mean for Row two being 33 beavers, Row three 18 beavers and Row four 14 beavers. Mainfort interpreted this patterning as indicating that the rows corresponded to the burials of clans of different wealth or social ranking, the highest ranking ones being buried towards the western part of the cemetery. In cases like the Fletcher Site, where grave location varies with social status, the potential clearly exists for obtaining a distorted picture if a site is only partially excavated.

If some part of society was excluded from a cemetery then even if the entire cemetery was excavated, the data may not be representative of the whole community. In medieval Britain, most burials were made in the local churchyard, but some of the more wealthy members of society elected to be buried in the religious foundations of monks or friars. In cases such as this, a biased view of a past population may be obtained if we are reliant on data from one type of site. Conversely, however, if it is known from other evidence that burial in a particular cemetery was the prerogative of a particular social group then this increases the value of studying the burial data as it allows us to focus on one particular stratum of society.

Ethnographic evidence (Gorecki 1979; Ucko 1969) shows that sufferers from disfiguring diseases such as leprosy, smallpox or dropsy may be excluded from normal burial areas. Historical data (e.g. Clay 1909) show that in medieval Europe lepers were generally buried in the cemeteries associated with leper hospitals to which they had been confined upon diagnosis of the disease, rather than being returned for burial to the communities where they had previously lived. Clearly this type of practice has important implications for osteoarchaeologists try-ing to study the prevalence of various diseases in the past using burial evidence.

In many societies, infants may be excluded from cemetery burial. They may be buried outside recognised cemetery areas or may not be given earth burial at all, being disposed of in water or simply being left exposed in the countryside. Molleson (1991) attempted to investigate whether infants were excluded from burial in cemeteries, using British archaeological material. She studied the infant (under 2 years old) to juvenile (2–19 years old) ratios for skeletons excavated from various cemeteries dating from AD 100–1300. Using ranges of mortality rates likely to be applicable to rural non-industria-lised societies, she estimated the range of ratios of infant:juvenile deaths likely in antiquity. In the sites she studied only one Romano-British (AD 100–400) site fell outside this range, but most of the Anglo-Saxon (AD 400–1066) cemeteries did, showing a deficiency of infants. It seemed unlikely that this pattern could be an artifact of preservation or recovery biases, so Molleson interpreted it as suggesting that infants were generally excluded from burial on British Anglo-Saxon sites. Infant burials are only rarely found on non-cemetery sites from the Saxon period in Britain, so it would seem that their bodies were disposed of in such a way as to leave no trace in the archaeological record. Using historical evidence, Molleson suggests that disposal may often have been in water.

## Burial Practices in the Neolithic of Southern Britain

The pattern of representation of different parts of the skeleton may also help provide evidence for funerary practices in the past. This is illustrated using a case study of human remains from the Neolithic of southern Britain (*c.* 4000–2200 BC). Human remains are regularly found at several different types of Neolithic site, including long barrows and causewayed enclosures.

Long barrows take the form of long mounds of earth or chalk rubble, flanked by quarry ditches (Figure 2.7). The bones excavated from beneath these monuments are generally not articulated as discrete skeletons but are, to a greater or lesser extent, disarticulated and mingled.

Causewayed enclosures consist of a ring ditch or a series of concentric ring ditches. The ditches are not continuous but were dug in separate sections, resulting in ditch segments interrupted by narrow cause-ways. The function(s) of these sites are unclear, but they have variously been interpreted as settlements, meeting places, ritual centres or cattle enclosures (Evans 1988). Quantities of human bone, generally in a disarticulated state, are often found at these sites.

Study of the human remains from Neolithic sites can shed light on many aspects of burial practices. The specific question we will be considering here is why bones in long barrows are generally found in a disarticulated state. One possibility is that burials were originally made as fleshed corpses, and the mingling of bones resulted from moving of the bones within the tomb once the soft tissue had decayed, either for 'ritual' reasons or simply to make way for additional interments. A second possibility is that these monuments functioned as ossuaries, repositories for bones from corpses which had previously been buried or stored elsewhere until the flesh had decayed (a practice termed 'excarnation'). The possible relationship between human remains in long barrows and those deposited at causewayed enclosures is also discussed.

Wayland's Smithy I (Figure 2.8) is a small, unchambered long barrow in Oxfordshire (Atkinson 1965; Whittle *et al.* 1991). Beneath the barrow were found human bones in varying degrees of articulation, from almost complete skeletons, through articulated parts of bodies to completely disarticulated remains. The bones were studied by Brothwell and Cullen (1969, report reproduced in Whittle *et al.* 1991). Following the basic identification of the bones, an important step in the analysis was to estimate the numbers of individuals buried beneath the monument.

When dealing with a cemetery of discrete, articulated skeletons the number of individuals is clearly equal to the number of skeletons. However, with an assemblage which wholly or partly consists of disarticulated bones, determining the number of individuals present is less straightforward. As was stated above, it is not normally feasible to separate out the bones into discrete skeletons once they have become mingled. Thus alternative methods of estimating the number of individuals present are needed. One frequently used measure is the minimum number of individuals (MNI).

MNI is derived from the number of each bone present. There are a variety of methods for calculating MNI, which differ in detail (see, for example, Grayson 1979). In the method presented here the count of the most abundant element, taking into account its anatomical frequency, gives the minimum number of individuals which must have con-tributed to an assemblage.

For skulls the MNI estimate is simply equal to the number of bones, but for paired elements (the long-bones in the present case) MNI is generally the number of either left or right elements, depending which is the greatest. At Wayland's Smithy (Table 2.1) a slight complication occurs with the MNI estimate from the fibulae. When fibulae lack their proximal (upper) and distal (lower) ends, as was often the case at Wayland's Smithy, it may be rather difficult to determine to which side of the skeleton the bone belongs, hence the fairly large number of unsided fibulae in Table 2.1. The MNI based on fibulae is not seven, as the number of unsided fibulae needs to be taken into account. The minimum number estimate

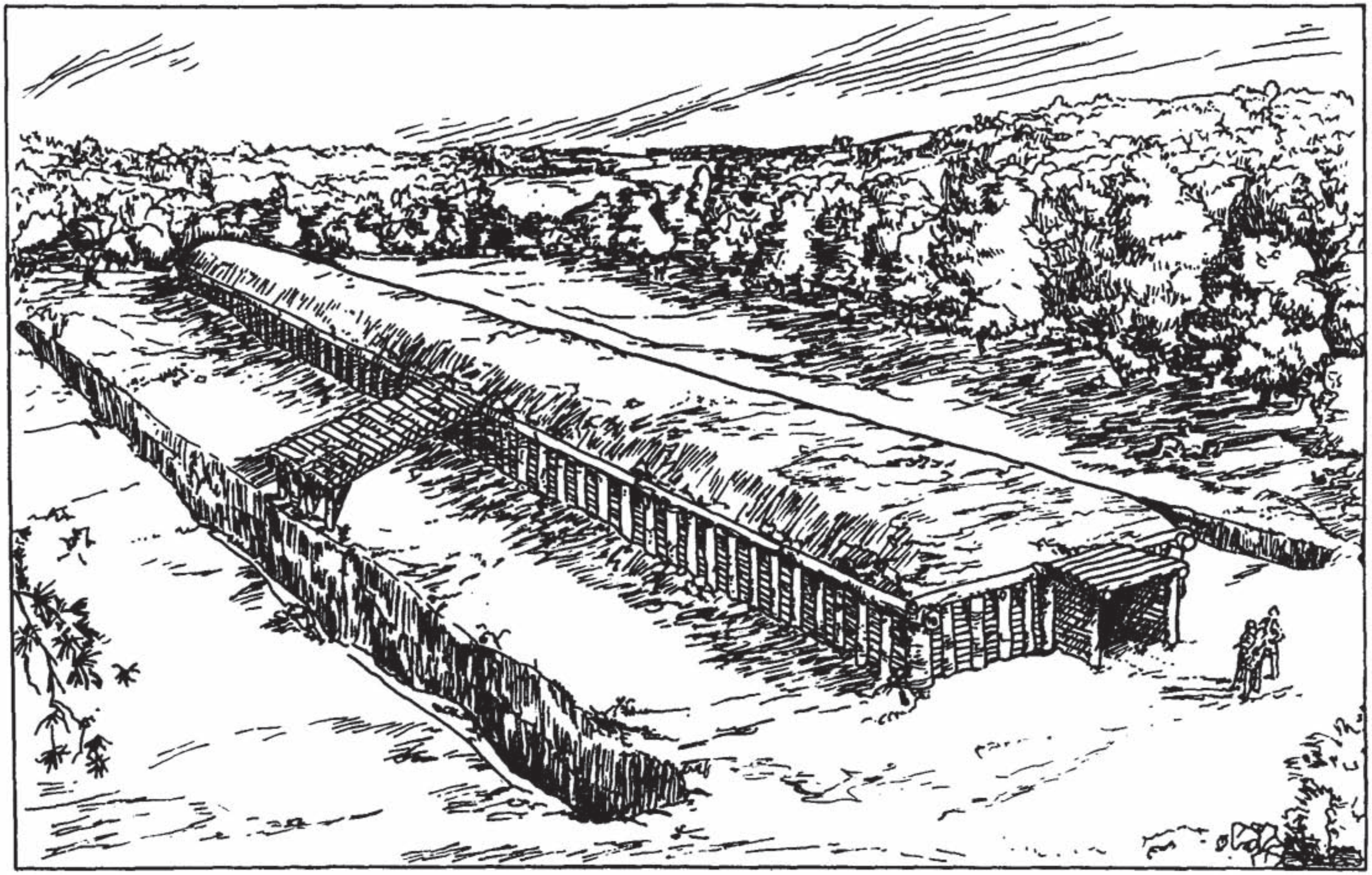


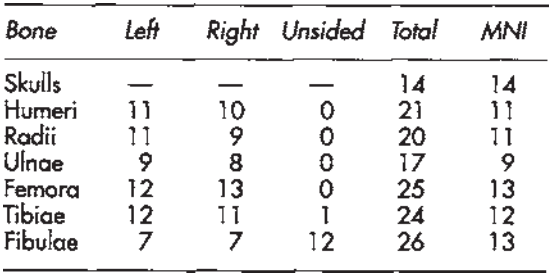
*Figure 2.7* An artist's impression of Fussell's Lodge long barrow as it may have appeared when first constructed

*Source*: After Ashbee (1966: Figure 9).

*Figure 2.8* Wayland's Smithy, Barrow 1. The human remains were located on the stone pavement in the area indicated by the cross-hatching

*Source*: After Atkinson (1965: Figure 1).

*Table 2.1* Frequencies of Some Major Skeletal Components at Wayland's Smithy I, Together with MNI Derived from them



| *Bone* | *Left* | *Right* | *Unsided* | *Total* | *MNI* |
|---|---|---|---|---|---|
| Skulls | — | — | — | 14 | 14 |
| Humeri | 11 | 10 | 0 | 21 | 11 |
| Radii | 11 | 9 | 0 | 20 | 11 |
| Ulnae | 9 | 8 | 0 | 17 | 9 |
| Femora | 12 | 13 | 0 | 25 | 13 |
| Tibiae | 12 | 11 | 1 | 24 | 12 |
| Fibulae | 7 | 7 | 12 | 26 | 13 |

*Source*: Based on the data of Brothwell and Cullen (in Whittle et al. 1991:72–75.

from this bone will be achieved if we assume that the 12 unsided fibulae are in fact six left and six right; the MNI figure based on fibulae is thus 7 + 6 = 13 individuals. It should be noted that in order to calculate MNI the elements counted have to occur in the skeleton with known frequency —in other words we need to count bones not bone fragments.

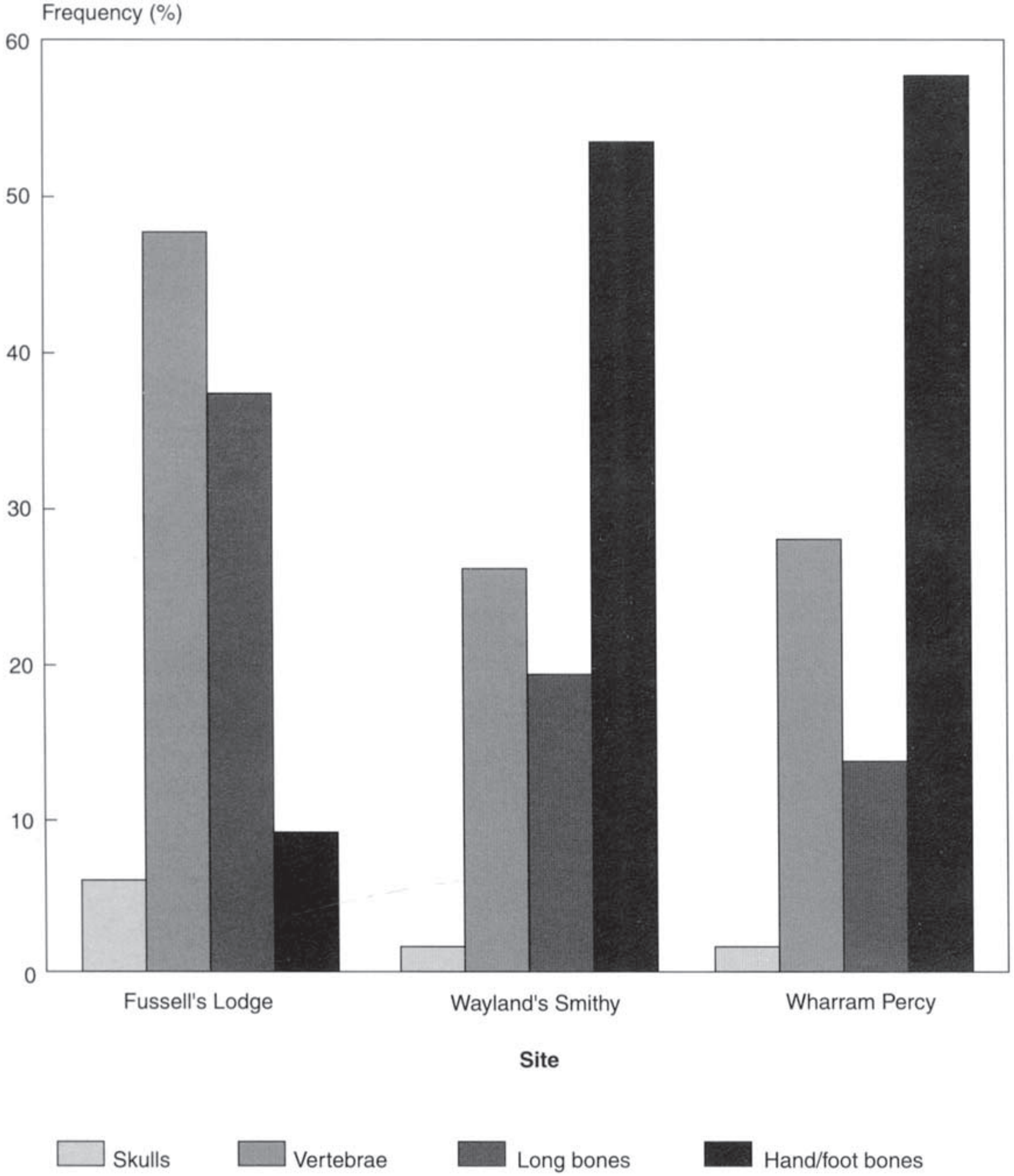
In order to produce our MNI estimate we assume that all left and right bones may be pairs (whereas an estimate of the *maximum* number of individuals would involve the assumption that none were pairs), but if we are able to determine, based on observations of bone size etc. whether or not it is possible in particular cases that a left and right bone could come from the same individual, then we could refine our MNI estimate. However, for mixtures of bones from adult skeletons, where differences in bone size etc. are often slight, it is very difficult to determine reliably matches between left and right bones for any particular element. At Wayland's Smithy the collection was predominantly of adult bones so the conservative strategy for calculating MNI would be not to attempt to discern possible matches between left and right elements. Pursuing this strategy, Brothwell and Cullen determined the MNI at 14 individuals. Table 2.1 shows that this figure comes from the total number of skulls present. Of this minimum of 14 individuals, 13 were adults and only one was a child.

Fussell's Lodge (Figure 2.7) is an earthen long barrow in Wiltshire (Ashbee 1966). Human bones were found in several discrete groups beneath the eastern end of the barrow. Unlike the situation at Wayland's Smithy, nowhere were the bones in articulation. Using information from the report on the bones (Brothwell and Blake 1966:49–53) it seems that the collection represents a minimum of 16 adults, together with a similar number of children.

The composition of the adult parts of the bone assemblages from Wayland's Smithy and Fussell's Lodge, in terms of the numbers of skulls, vertebrae, long-bones and hand/foot bones expressed as a percentage of the total numbers of bones from these four regions of the skeleton, are given in Figure 2.9.

In order to use the composition of the assemblages from the long barrows to help assess whether, at each site, the burials were likely to have originally been made as complete, fleshed corpses, it is necessary to have some idea of the composition by skeletal parts we might expect if this were the case. A way of estimating this is to use the composition of an archaeological assemblage where we know that the interments *were* made as complete bodies. Because preservation and recovery biases clearly might be expected to vary from site to site, we need to be careful to select a suitable site to use as a comparison with our two long barrow assemblages. An assemblage from a churchyard, at Wharram Percy, was chosen for this purpose, as the site is located on similar geology to the two barrows (chalk) and similar recovery techniques were used (hand excavation with no sieving for small bones). The composition of the Wharram Percy assemblage is also shown in Figure 2.9.

In a complete adult skeleton there is one skull, 24 vertebrae, 12 long-bones and 106 hand/foot bones. At Wharram Percy the ratio of skulls to vertebrae to long-bones to hand/foot bones is 1:20:10:41. Thus the ratios of skulls to vertebrae to long-bones are approximately as expected from their anatomical frequencies. As expected from their greater anatomical frequency, the hand/foot bones are present in the largest numbers of the four classes of bones, but they are in fact under-represented



*Figures 2.9* Composition of assemblages from Fussell's Lodge, Wayland's Smithy and Wharram Percy in terms of numbers of skulls, vertebrae, long-bones and hand/foot bones expressed as percentages of the sum of the bones from these four regions of the skeleton

compared with what might be expected from complete skeletons. As we have seen, this is to be expected in hand collected archaeological assemblages and is probably due mainly to recovery biases. The Wharram Percy assemblage gives an idea of the composition expected of an assemblage of complete corpses once preservation and recovery factors have taken their toll.

The distributions for Wharram Percy and Way-land's Smithy show a striking resemblance (Figure 2.9). That from Fussell's Lodge, on the other hand, is very different, with a striking deficiency in hand and foot bones—they are six times less frequent in the Fussell's Lodge assemblage than at the other two sites.

The relative dearth of hand and foot bones at Fussell's Lodge needs some explanation. In this instance there is no reason to suspect that preservation or recovery biases could be responsible for the more marked deficiency in hand and foot bones at Fussell's Lodge than at the other two sites as the excavation techniques and soil conditions were similar. In any event, at other British sites (Cox 1989; Mays 1989, 1991) the percentage of hand and foot bones, as calculated in Figure 2.9, ranges from about 40–65 per cent. Fussell's Lodge is far outside this range at about 9 per cent hand/foot bones. The missing hand and foot bones at this site could be interpreted as consistent with the entry of the bones to the tomb in a defleshed, disarticulated state.

If the bones were given temporary earth burial to allow the flesh to rot prior to their exhumation for final deposition in the tomb, then it might be likely that those carrying out the exhumations would tend to overlook small bones or might only bother to retrieve larger ones provided it was not an important part of funerary rituals to collect every scrap of bone. In effect, the assemblage would have been exposed to recovery biases twice over—once in the Neolithic and once when excavated by the archaeologists. If the bodies were exposed above ground to allow the flesh to decay, it is also easy to imagine small bones being lost prior to or during collection of remains for final disposal in the tomb. The lack of any articulated bones at Fussell's Lodge is also consistent with deposition as dry bones rather than fleshed bodies.

Clearly the few fairly complete articulated skeletons from Wayland's Smithy must have been introduced as fresh corpses, but the similarity between Wayland's Smithy and Wharram Percy in terms of overall assemblage composition suggests that this may be true for all of the Wayland's Smithy interments. The patterns of bone loss at Wayland's Smithy are those expected from the actions of preservation and recovery factors on an assemblage interred as complete individuals. The remains at Wayland's Smithy which are in a partly or entirely disarticulated state probably became so as a result of rearrangement of bones within the tomb when they had been there long enough for the soft tissues partly or completely to decay.

At the long barrow at West Kennet, Wiltshire human remains were found in several chambers situated at the east end of the monument (Piggott 1962; Thomas and Whittle 1986). The bones were, like those at Wayland's Smithy, found in varying degrees of articulation from almost complete skeletons, through articulated parts of bodies to completely disarticulated bones. As for Wayland's Smithy the almost complete articulated skeletons at least must have been inserted as fleshed corpses. Analysis of the bones (Wells 1962) revealed a rather different pattern of representation of the various parts of the skeleton in the assemblage than was the case at either of the two barrows discussed above. Wells observed that there was a marked deficiency of skulls and long-bones; for example, there were not enough femora and tibiae in the assemblage for the number of foot bones. Since it is the smaller bones of the hands and feet that tend to be under-represented as a result of recovery biases, and skulls and long-bones are among those most resistant to destruction in the soil, the pattern at West Kennet is hardly explicable in terms of preservation or recovery biases. Wells and Piggott interpreted the West Kennet evidence as suggesting selective removal of skulls and long-bones from the tomb after the flesh had partly or completely decayed.

If Wells and Piggott are correct in their suggestion that some bones were selectively removed from the tomb at West Kennet, what happened to them? Piggott (1962) suggested that a reason for removal of bones from West Kennet may have been for their use in Neolithic rituals. This view was supported by Thomas and Whittle who, in their reconsideration of the tomb, point out that the practice of removing selected skeletal material from burials is well known in the ethnographic literature. It has been suggested by Smith (1965), and since by others, that some of the bones abstracted from long barrows may have been deposited at causewayed enclosures. Smith (1965:137) noted that skull fragments were frequent findings in the ditches at the causewayed enclosure at Windmill Hill. She suggested that these might represent some of the 'missing' skulls from West Kennet which is only 3 km away.

If one accepts that the bones from some long barrows, such as Fussell's Lodge, were interred in a defleshed state then the question arises as to the location of the sites of excarnation. It has been suggested that some causewayed enclosures may be implicated in the excarnation process too. Excavations at a causewayed enclosure at Hambledon Hill, Dorset (Mercer 1980, 1988) revealed large quantities of human remains in varying states of articulation. In an interesting reversal of the suggestion made by Smith (1965), Mercer (1988:95) suggests that the Hambledon Hill causewayed enclosure may have been a place of exposure of corpses for the flesh to rot prior to the interment of the disarticulated bones in a long barrow.

Clearly the relationship between causewayed enclosures and long barrows may be a complex one; however, many workers (e.g. Kinnes 1992: 127–128; Thomas 1988; Thorpe 1984) seem to accept that some sort of circulation of human remains may have taken place between some long barrows and some causewayed enclosures. Although this seems possible, there is as yet no proof— perhaps the only way to demonstrate a conclusive link between the two classes of site would be if adjoining fragments of the same bone were to be found at a long barrow and at a nearby causewayed enclosure.

# 3

# THE DETERMINATION OF AGE AND SEX

## DETERMINATION OF SEX

### Sex Indicators in the Adult Skeleton

Male and female adult skeletons differ sufficiently for the sex of burials to be determined. Although the whole skeleton should be taken into account when determining sex, sexual dimorphism (differences in form between males and females) is most pronounced in the skull and pelvis. The latter is the single most reliable area, and hence should be given most weight in sex determination because differences here are directly related to functional differences between the sexes. In general the female pelvis is broader than the male. A narrow pelvis is more efficient for locomotion, but in females a broader pelvis is dictated by the fact that it forms the birth canal. Women with very narrow pelvises are more likely to experience potentially life-threatening problems during childbirth, thus most researchers agree that the principle reason for the evolution of pelvic sexual dimorphism in man and other primates is natural selection in relation to childbirth in females (discussion in Tague 1995).

The greater width of the female bony pelvis manifests itself in a number of ways. An important area is the sub-pubic angle of the pubic bone, part of the front of the pelvis. The sub-pubic angle is that formed between the left and right inferior pubic rami, the lower parts of the pubic bones (Figure 3.1). In females it tends to be wider and more U-shaped, whereas in the male it tends to be narrower (generally less than 90 degrees) and more V-shaped (Figure 3.1). Several further features of the pubic bone are also useful in sex determination (Phenice 1969). Females generally show development of the ventral arc, a ridge of bone which sweeps down the anterior surface of the pubic bone to merge with the border of the inferior pubic ramus (Figure 3.2). Males characteristically lack the ventral arc. The formation of the ventral arc in females appears to be linked to the observation that the pubis continues to grow at the symphysis for longer in the female (Budinoff and Tague 1990), again associated with the broadening of the female pelvis. Other aspects pointed out by Phenice (1969) to be of value in sex determination are the sub-pubic concavity (present in females), and the medial (inner) border of the inferior pubic ramus, which generally shows a ridge in females but is blunter in males. These aspects are also depicted in Figure 3.2.

Unfortunately the pubic bone is a rather fragile part of the skeleton, and lies uppermost in a supine burial so is vulnerable to damage during excavation. In archaeological material, the pubic bones are often too damaged to permit observations to be made. An important sex indicator situated in the stronger, posterior part of the pelvis is the sciatic notch (Figure 3.3). The sciatic notch is wider and shallower in females, another manifestation of the broader female pelvis (Hager 1996).

In general, the male skeleton is larger and more robust (i.e. has thicker bones with more developed areas for muscle attachment) than the female. The

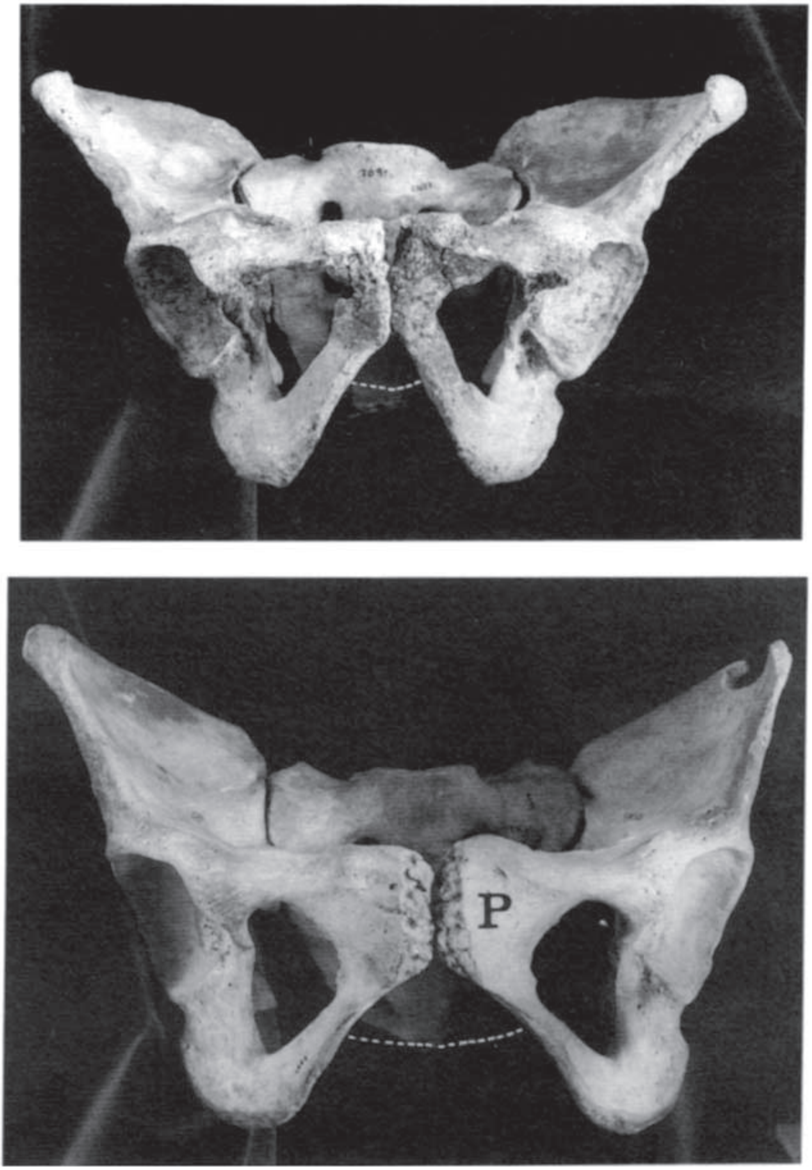


*Figure 3.1* Adult female (above) and male (below) pelvic girdles. 'P' denotes the pubic bone. The sub-pubic angle is indicated by the dotted line

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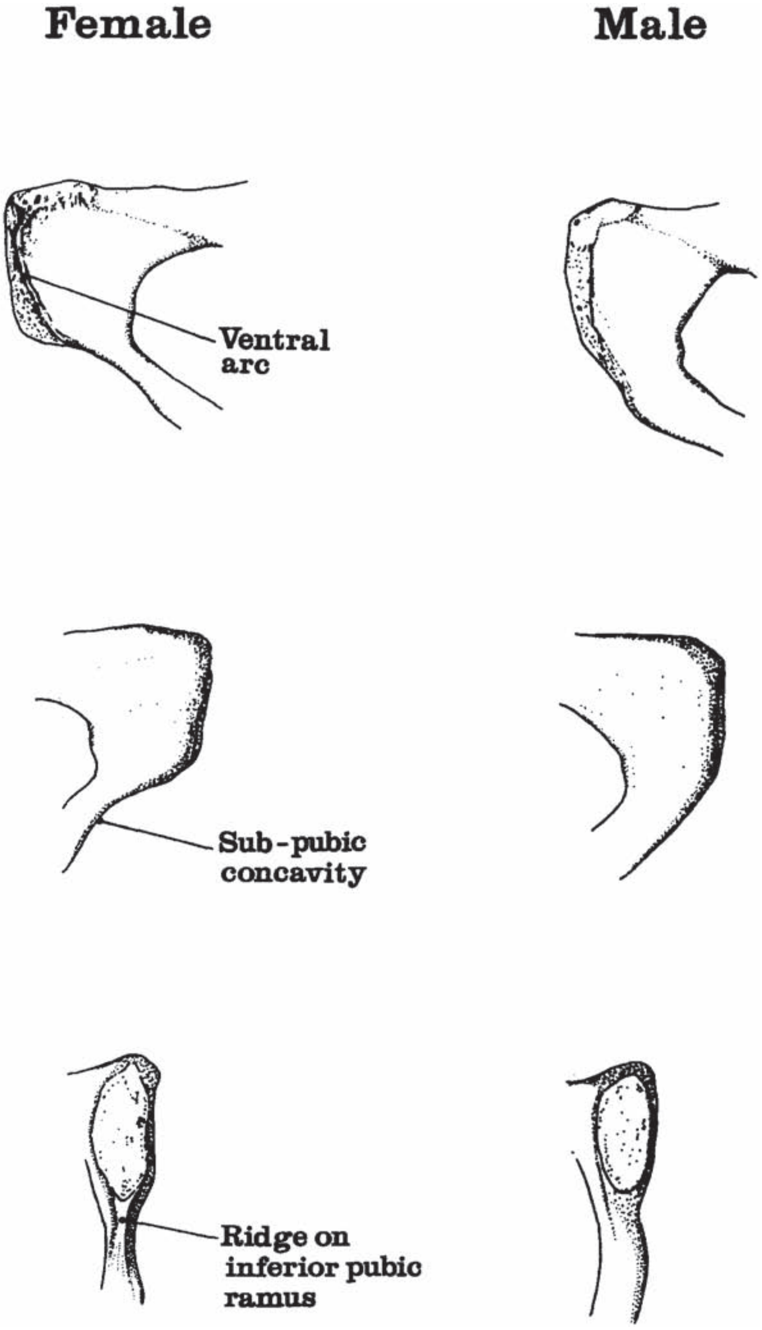
*Figure 3.2* Sex differences in the adult pubic bone. The anterior surface of the female pubic bone generally shows development of the ventral arc; this is usually lacking in the male, although slight ridging may occur. Seen from the dorsal aspect, the female pubic bone often shows a concavity in the inferior pubic ramus. The female pubic bone often shows a ridge on the medial surface of the inferior pubic ramus; in the male this area is generally rather flatter

*Source*: Redrawn from Phenice (1969).


Female
Male
Ventral arc
Sub-pubic concavity
Ridge on inferior pubic ramus

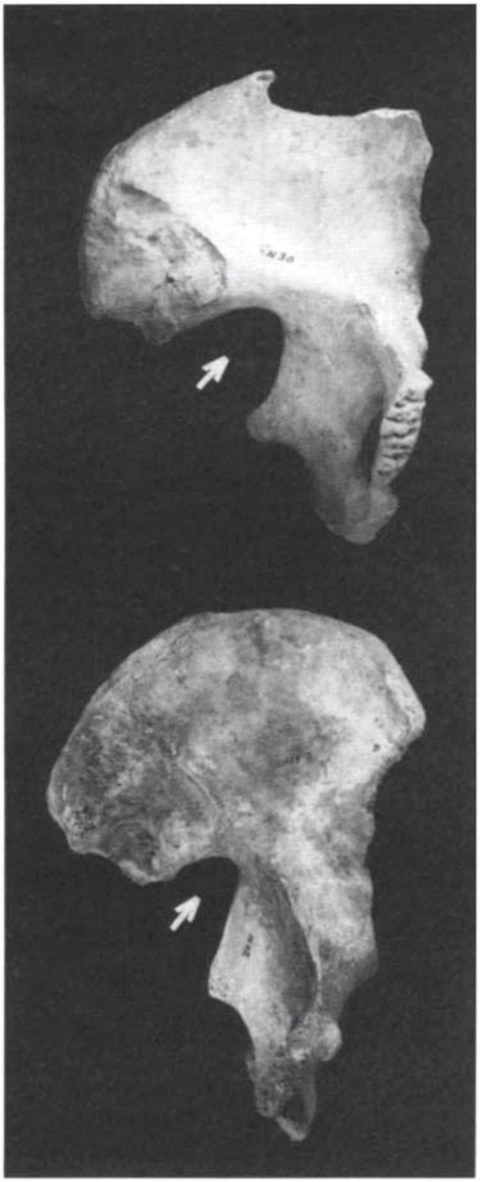


*Figure 3.3* Left pelvic bones of an adult female (above) and an adult male (below). The sciatic notch is indicated on each bone by the arrows

greater robusticity of the male skeleton is related to the generally greater muscle mass of the male. Most of the important dimorphic features of the skull are a manifestation of the greater robusticity of male bones. Specific aspects of the cranium useful for sex determination include the brow ridge, the nuchal crest and the mastoid processes; all are more pronounced in the male (Figure 3.4).

The general size and robusticity of the post-cranial skeleton can be used as an auxiliary sex indicator. However these aspects are more heavily influenced by activity patterns and nutrition, and so are less reliable than pelvic and cranial features.

## The Origins of Skeletal Sexual Dimorphism

The origins of sex differences in the skeleton lie in the hormonal differences between males and females. The sex of an individual is established in the chromosomes from the moment of conception, a female having two X chromosomes, a male an X and a Y. The foetus develops ovaries or testes depending upon the chromosomal sex. It is the hormones secreted by the testes that elicit the development of the bodily features which characterise males. In mammals, ovaries are not necessary for the development of most female characters—work with animals has shown that foetuses of either sex in which the gonads have been removed develop female physical characteristics. Thus the female can be considered as the 'basic' sex into which a foetus will develop unless redirected by male hormones (Wilson *et al.* 1981).

Testosterone is the hormone largely responsible for the development of male physical characteristics, and hence a large part of mammalian sexual dimorphism is due to the action of this hormone in the developing male. This appears to apply no less to the skeleton than to other bodily tissues. Experiments involving the castration and administration of sex hormones in mice (Crelin 1969; Uesugi *et al.* 1992) and sheep (Gardner and Pfeiffer 1943) indicate that male sex hormones are required for the development of male pelvic characters. In the absence of male hormones, the

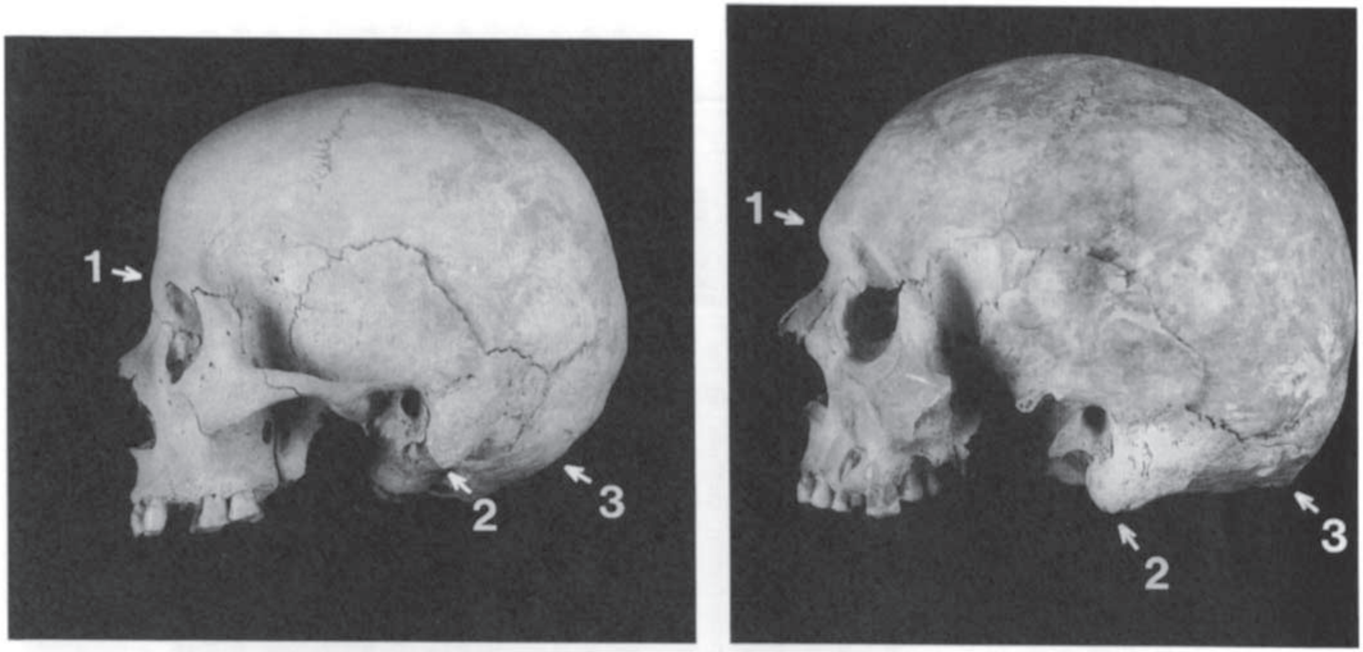


*Figure 3.4* Adult skulls, female on left, male on right. The brow ridge (1) is more developed in the male and the forehead is more sloping. In the female the brow ridge is smaller and the forehead more vertical. The mastoid processes (2) and the nuchal crest (3) are more developed in the male

pelvic bones were mainly female in character, oestrogens did not appear to be necessary for the development of most charac-teristics of female pelvic form, the exception being the pubic bone, which appears to be influenced by oestrogens as well as by male hormones. Work with rats (Dahinten and Pucciarelli 1986) has shown that sexual dimorphism in skull form arises as a result of the action of testicular hormones on the bones of the male skull. Although it would be surprising if these observations were not broadly applicable to man, data on the hormonal influence on human skeletal sexual dimorphism are sparse and, it must be said, somewhat equivocal. Testosterone also has a general effect on growth, both of the musculo-skeletal system and other tissues (Tanner 1989), and so is a reason for the greater size and robusticity characteristic of the male skeleton.

### Reliability of Sex Determination

Sex is generally determined in adult burials from a simple visual inspection of the bones. Although some schemes based on measurements of the skull (Giles and Elliot 1963) and pelvis (Stewart 1954) have been devised, measurement methods do not generally offer improvements in reliability over visual inspection.

For the experienced osteoarchaeologist, sex determination from simple visual examination of adult skeletons is quite reliable, providing that the skull and, particularly, the pelvic bones are available for examination. For example, work by Meindl *et al.* (1985), using modern skeletons of documented sex, found that 97 per cent could be correctly sexed if both pelvis and skull were available. Looking at the skull alone sex was correctly inferred in 92 per cent of cases; for the pelvis the figure was 96 per cent.

Substantial collections of skeletons from archaeological sites, where sex and other data, such as age at death, are known for individual skeletons from gravestones or coffin plates are few. This limits the opportunities for directly testing methods of ageing and sexing on archaeological material. However, one important known age and sex archaeological collection was excavated from the crypt of Christchurch, Spitalfields, London. The crypt needed to be cleared due to building work, and this provided the opportunity for study of the skeletons which were interred there. Almost a thousand burials were excavated. About one-third of them had legible coffin plates which gave the name (and hence the sex), age and date of death of the occupant. The burials are of people who died in the eighteenth and early nin-teenth centuries AD. Although they are quite recent compared with most archaeological material, they do provide a population with living conditions very different to those of today upon which to study the reliability of ageing and sexing methods. Much of the work on this collection has been co-ordinated by Theya Molleson of the Natural History Museum in London. The reliability of sex determination was tested using this collection—Molleson and Cox (1993:206) report that they were able correctly to identify sex in 98 per cent of adult skeletons.

## Sex Determination in the Immature Skeleton

It is much less easy to determine sex in child remains than it is in adults. This is because testosterone levels are much lower before puberty, so skeletal sexual dimorphism is slight. The testosterone level in pre-pubertal males, although always low compared with levels at puberty, does vary during development. In the male foetus, the testosterone level starts to rise at about eight weeks of gestation and maintains a relatively high level until birth (Wilson *et al.* 1981: Figure 1). Soon after birth the testosterone level falls, and it remains low until puberty. The testosterone level in the male foetus means that slight sex differences do exist in perinatal (foetal and new-born) skeletons, so, in theory at least, it should be possible to determine their sex. The small sex differences in foetal skeletons soon become blurred during postnatal growth, so it is not generally possible to determine the sex of children from their bones.

## Determination of Sex in Perinatal Remains

A number of studies (e.g. Fazekas and Kosa 1978; Boucher 1957) have demonstrated sexual dimorphism in pelvic bones of perinatal skeletons. As in adults, males tend to have narrower sciatic notches than females. Differences are however usually so slight that it is very difficult to sex perinatal pelvic bones with the naked eye. Measurement of the bones is required to show up sex differences. One approach to sexing archaeological remains might be to measure pelvic bones of modern perinatal infants and then to determine whether archaeological specimens group with the modern males or the modern females. However, this strategy is not likely to be very reliable. As will be seen in Chapter 4, different human populations differ somewhat in the size and shape of their bones. This applies to the pelvic bones as well as to the rest of the skeleton. Populations also differ in degrees of skeletal sexual dimorphism. For these reasons it is difficult to apply formulae based on measurements of the bones of recent perinatal material to determine sex in archaelogical remains. A better approach, provided the assemblage under study contains enough well-preserved infant skeletons, is to take measurements on a promising area, such as the sciatic notch, and plot them onto a graph. If two separate clusters are present they probably represent pelvic bones of male and female babies. Often though, there is only one peak in the frequency, which implies that the degree of dimorphism in that population happens to be too low for discrete male and female clusters to appear; another, less likely explanation would be that all perinatal deaths were of one sex.

I tried this sexing method on perinatal remains from the churchyard at medieval Wharram Percy. There were 66 skeletons from this site of babies who died at or around birth. Of these, 36 had pelvic bones with measurable sciatic notches. I measured the width and depth of the sciatic notches of these small bones under a low-power microscope. The results for each bone were expressed as an index

$$100 \times \frac{\text{sciatic notch depth}}{\text{sciatic notch width}}$$

The results are shown in Figure 3.5a. There is possible bimodality in the distribution of the index — two peaks are apparent, one centred on an index of about 15, one on an index of 18–19. These peaks probably correspond to males and females, the males being represented by that at the higher index value.

As discussed, the hormonal factors underlying mammalian skeletal sexual dimorphism suggest sex differences in older infants and children should be even less pronounced than in perinatal infants. This expectation was borne out in the work of Reynolds (1947). He looked at X-rays of the pelvic bones of living infants and children and found a tendency for sex differences to grow progressively less with age, only to reappear at puberty. At Wharram Percy I also measured the sciatic notches of pelvic bones of older infants, up to the age of 2 years. The bimodality visible in the perinatal material was not apparent, only a single peak in the distribution was visible (Figure 3.5b). This suggests that any pelvic sex differences which were present at birth had already become obscured by the growth process.

## Sex Determination in Children

Although it is not generally feasible to determine the sex of children from their bones, in some populations at least it is possible using the teeth.

Teeth of males tend to be slightly larger than those of females. The size difference is generally too small to be visible to the naked eye, measurements are needed for differences to become apparent. Unlike the bones, the teeth cannot change their shape or size once formed. Therefore, sexual dimorphism in the permanent dentition of children should be similar to that present in adults from the same population. Dental measurements thus offer a way of sex determination in children who have developed at least some of their permanent teeth.

The most sexually dimorphic tooth is generally the lower canine (Perzigian 1976). The degree of dimorphism varies between populations, but occasionally the size difference in lower canines is large enough to allow sexing simply by plotting out crown widths for male and female adult skeletons, and then measuring

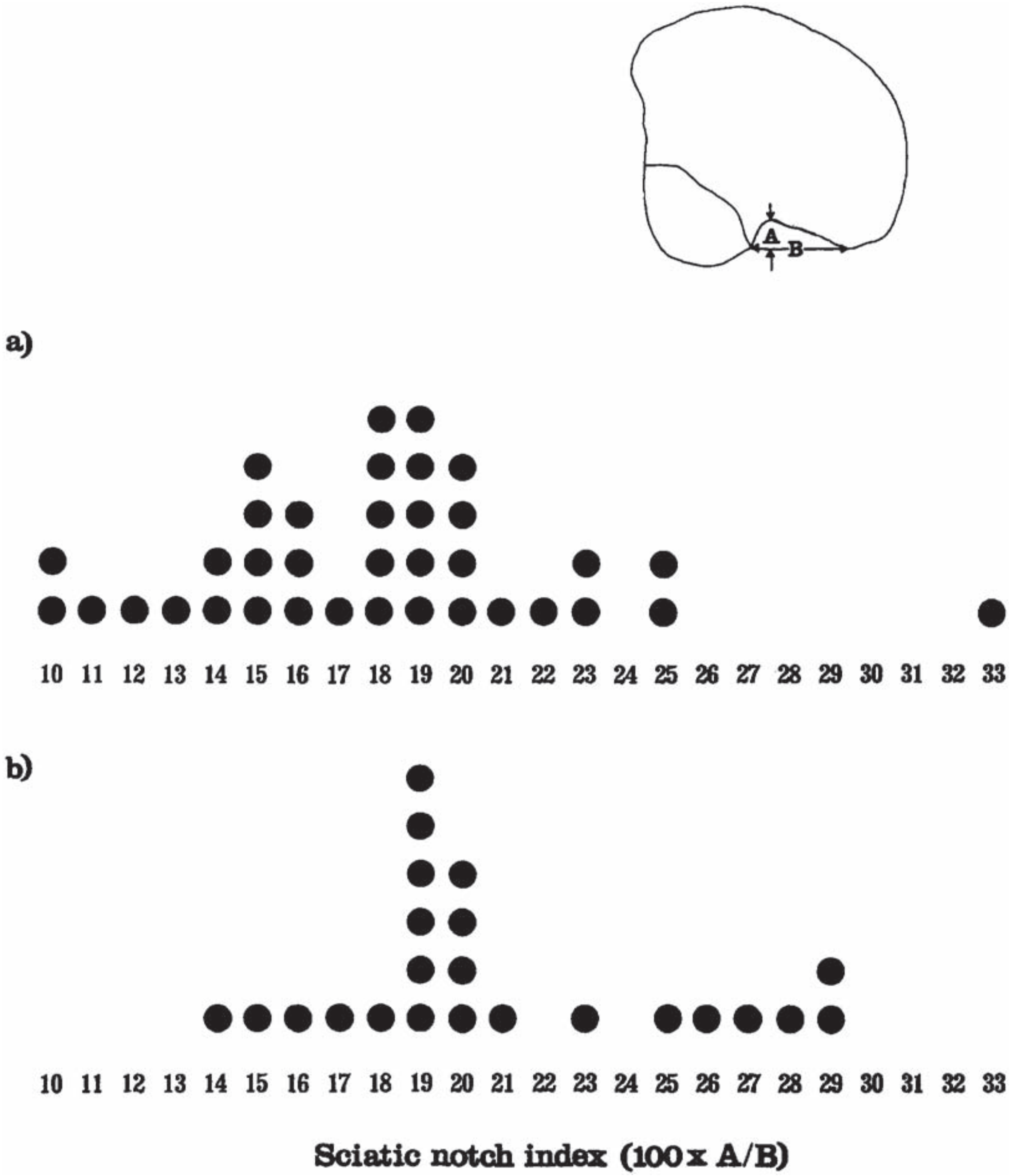


*Figure 3.5* (a) Distribution of sciatic notch index for the Wharram Percy perinatal infants; (b) distribution of sciatic notch index for Wharram Percy infants up to 2 years old (excluding the perinatal material)

the permanent canines of children to determine whether they lie in the male or female ranges. This was the strategy used by Molleson (1993) at the Romano-British (third-fourth century AD) cemetery at Poundbury, Dorset (Figure 3.6). This enabled the sex of children of about 6 years (the age at which the crown of the mandibular permanent canine is formed) and over to be determined.

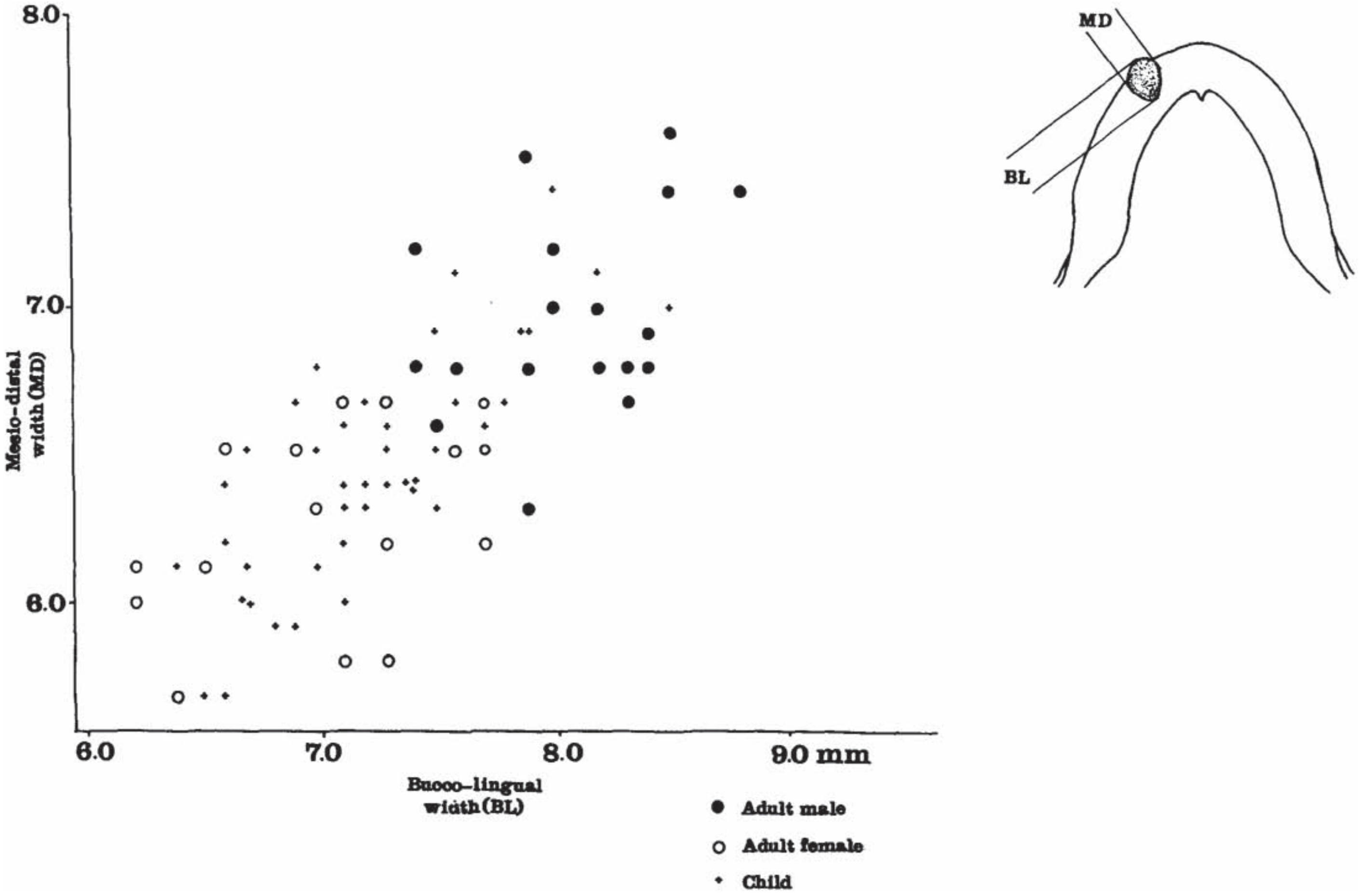


*Figure 3.6* Bivariate plot of lower canine dimensions for burials from Poundbury. Since there is little overlap between the adult male and female clusters, the sex of most juveniles with measurable permanent canines can be inferred simply by plotting them onto the graph. The reliability of this method is discussed in the text

*Source*: After Molleson (1993: Figure 114).

Poundbury is, however, exceptional—in most skeletal assemblages the degree of sexual dimorphism in the dentition is insufficient to enable sex to be identified from a simple bivariate scatterplot of the dimensions of a single tooth. In such instances, sex of children can often be inferred from a combination of several measurements using the multivariate technique, discriminant function analysis. This procedure combines a number of measurements in such a way as to maximise the separation between groups (males and females in the present context). The resulting formula can be used to group unknown cases—in the present instance to infer sex of juveniles. The reliability of sexing using a discriminant function analysis of dental measurements can be estimated by determining the percentage of cases in the base population (i.e. the adults of known sex used to generate the discriminant function) correctly classified. This procedure suggests that in many archaeological assemblages the percentage correctly classified may be as high as 80–90 per cent. (This is not quite as impressive as it sounds—remember we could expect to get 50 per cent right by guessing!)

An assumption when sexing children from teeth in this way is that the tooth size in children is similar to that in adults of the same sex. There is evidence that sometimes this assumption may be problematic. Experiments with mice (Searle 1954), rats (Bunyard 1972) and pigs (Tonge and McCance 1965) suggest that tooth crown size may be reduced by poor nutrition during development, and in man there is evidence (Garn *et al.* 1979) that maternal health may affect the crown dimensions of teeth developing whilst the baby is in the womb.

There is potentially a problem of mortality bias here. Those suffering most from poor nutrition and health during growth may tend to die early, hence there is the potential for those who die in childhood to have smaller teeth than those who survived to become adults. It is difficult to know how pervasive this, problem might be in archaeological material, but it has the potential to cause too many females to be identified. Gugliardo (1982) and Simpson *et al.* (1990) have claimed to have found this phenomenon in archaeological assemblages. Looking at Figure 3.6, the canine dimensions of most children from Poundbury seem to fall into the female range. It is tempting to interpret this as indicating higher childhood mortality in females, perhaps relating to a lower value placed on female children in this community. However, it may be that this bias is simply an artifact of the sexing method if those dying in childhood at this site had smaller teeth than those who survived to adulthood. This illustrates the point that before making archaeological inferences we must first consider the effects of biasing factors on our assemblage and possible shortcomings in our methodologies.

## AGE DETERMINATION

In immature remains, age at death can be estimated using aspects of skeletal growth and development. Once skeletal maturity is attained in the adult, age at death can be inferred from the progress of degen-erative conditions and from wear on the teeth.

### Age Determination in the Immature Skeleton

Methods used to estimate age at death in immature remains generally involve the use of growth standards derived from recent data relating to children of known age. The assumption here is that growth and development in the ancient skeletons under study follow a similar chronological schedule to that seen in recent children. For some methods this assumption may be broadly valid, for others it is problematic. The general aim of osteoarchaeologists should be to minimise problems by selecting those aspects of growth and development which are least subject to influence by extraneous factors such as disease and under-nutrition.

#### Age Determination in the Perinatal Skeleton

In perinatal skeletons, bone size is a good indicator of age. Bone growth in the foetus may be influenced by extrinisic factors such as poor maternal nutrition, but it is much less easily influenced than it is after birth, Maternal malnutrition has to be quite severe to retard growth in the developing foetus (Bagchi and Bose 1962), as in this situation the foetus is protected at the expense of the mother.

Scheuer *et al.* (1980) studied the relationship between long-bone length and age using foetal material from medical collections in England. The gestational ages of the foetal skeletons ranged from 27–46 weeks (the average gestational age at birth is 38–41 weeks—Tanner

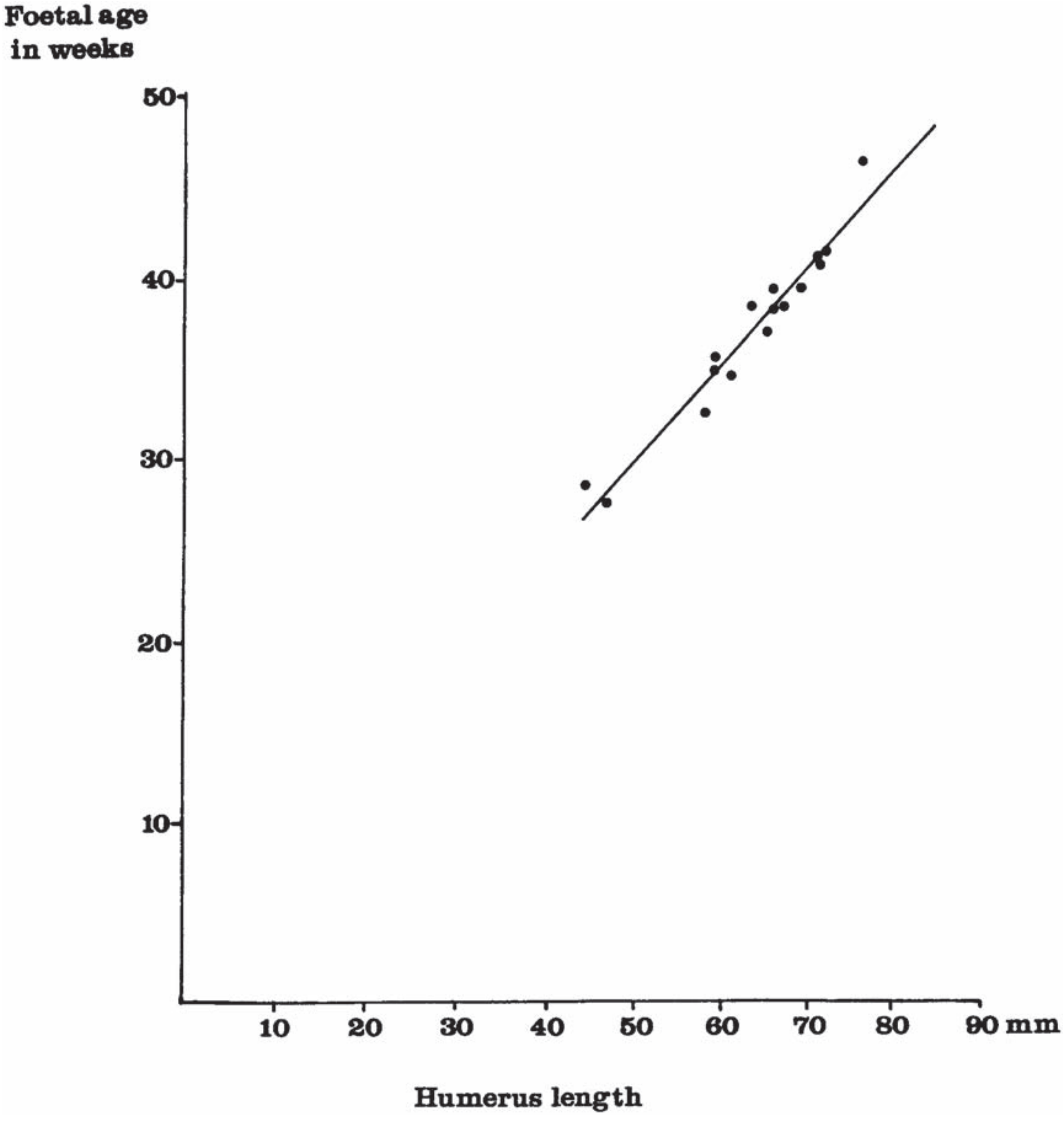


*Figure 3.7* Linear regression of foetal age against humerus length

*Source*: Redrawn from Scheuer *et al.* (1980: Figure 1).

1989:43). They measured the length of the limb bones and found that bone length bore a close relationship to age (Figure 3.7). The closeness of the relationship between age at death and long-bone length in foetal remains means that we can use it to estimate age at death to within about two weeks.

## Age Estimation in the Child Skeleton: The Teeth

After birth, bone growth is heavily affected by extrinsic factors such as nutrition and disease; by comparison growth of the teeth is relatively little affected (Lewis and Garn 1960). Dental development is therefore the method of choice for age determination in child skeletons.

Tooth formation begins near the tip of the crown, and the crown and a substantial portion of the root are completed whilst the tooth is still hidden within the jaw bone. The lower parts of the root are completed once the tooth has emerged through the gum into the mouth. There are thus two components to dental development, the formation of the teeth and their eruption into the mouth. For age determination the former is preferable, as it is less affected by extrinisic factors (Demirjian 1978). The deciduous teeth start to form whilst the baby is still in the womb, and are complete by the time the child is between 3 and 4 years old. The permanent dentition starts to form at around time of birth. Growth of most of the permanent teeth is complete by about 15 years of age, although the third molar, or wisdom tooth (which is not present in all individuals) may not be completely formed until about 20 years. Dental development therefore provides a potential method of age estimation throughout childhood.

Our knowledge of the chronology of tooth formation comes principally from radiographic (X-ray) studies of the jaws of living children, and also from what few studies there are of teeth dissected from child corpses of known age at death (Smith 1991).

Two researchers working in Sweden, Gosta Gustafson and Goran Koch, conducted a survey of the literature on dental development in populations of European descent (Gustafson and Koch 1974). They combined data from different studies to produce a scheme showing the chronology of the development of the dentition. They then tested the value of their scheme for determining age by using it to estimate age from dental radiographs in 41 children, aged 3 to 13 years. They found a close correspondence between age as estimated using their scheme and actual age (Figure 3.8). The mean error in age estimation was only two months.

Because it is little affected by extrinsic factors, one might expect modern chronologies of dental development to be broadly applicable to ancient remains. Work on the Spitalfields material seems to bear this out. Sixty-three child skeletons from Spitalfields with ages at death up to 5.4 years were aged using a number of dental development standards (Liversage 1994), including that of Gustafson and Koch. All performed well: for example, the mean difference between actual age and the age estimates produced using the chart of Gustafson and Koch (1974) was 0.1 years. However, it is worth noting that despite the high accuracy of age estimation using dental development, all the standards tested were found slightly to under age. The reason for this was uncertain, but it may well reflect slight slowing of dental development due to the significantly poorer nutrition likely for the eighteenth/nineteenth century children compared with the modern children from which the dental standards were derived. This serves to emphasise that even dental calcification is not invulnerable to extrinsic influences, even though the degree of retardation may be fairly minor.

A chronology for the development of the permanent teeth is shown in Figure. 3.9. This chart is drawn up from data given by Gustafson and Koch (1974), except for the third molar, where the data are from Anderson *et al.* (1976), Levesque *et al.* (1981), and Garn *et al.* (1962). Formation of the third molar is somewhat more variable in absolute terms (but not in proportion to individual age) than that of the other teeth, but it is still a useful age indicator. For example, Thorson and Hägg (1991) found that the mean difference between age estimated from mandibular third molar development and actual age in individuals aged 14.5–20.5 years old was eight months.

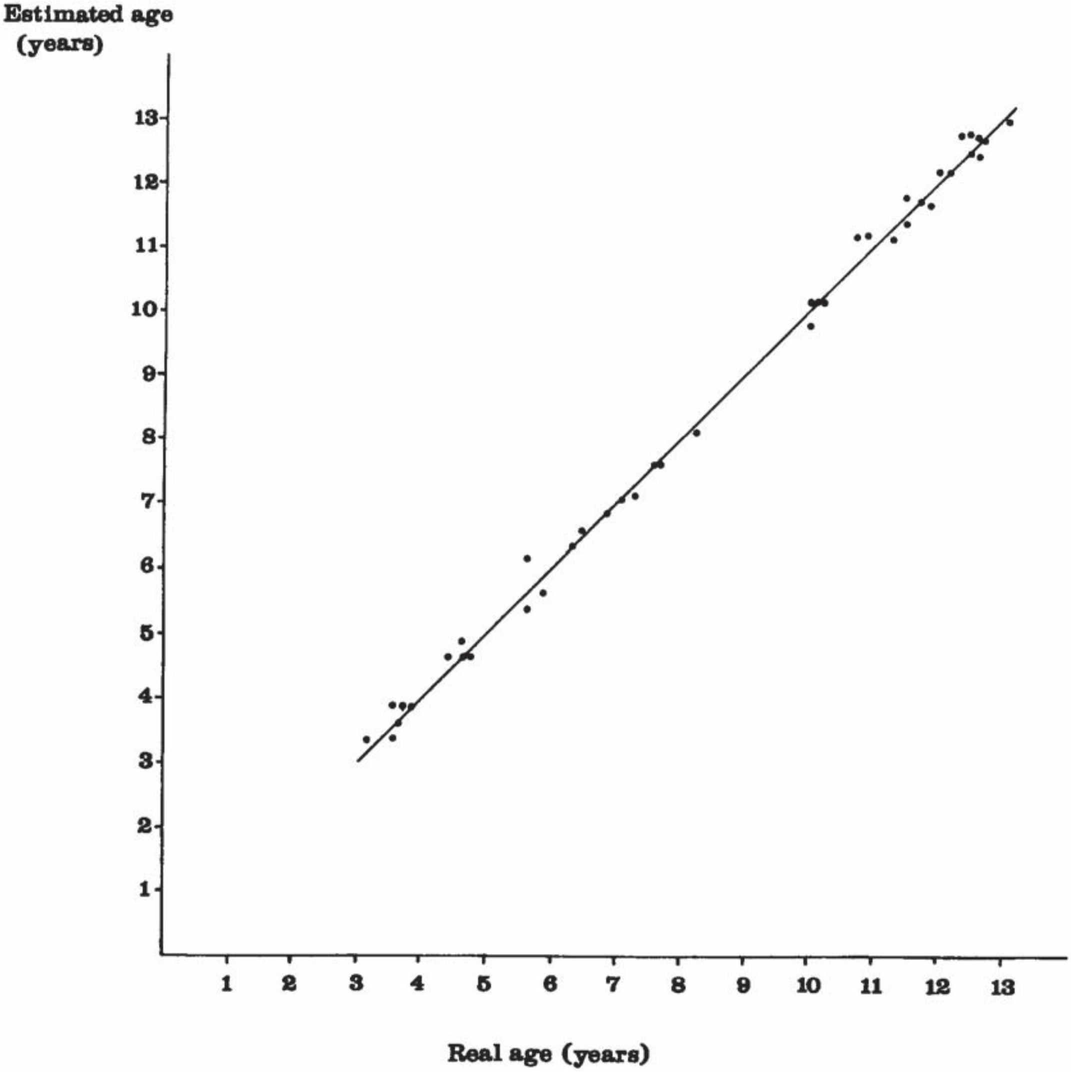


*Figure 3.8* Actual age plotted against age estimated from dental X-rays using Gustafson and Koch's dental development scheme. Data for recent Swedish children

*Source*: Redrawn from Gustafson and Koch (1974: Figure 5).

In fragmentary archaeological material, it is often possible to record the state of dental calcification visually. Teeth which have erupted into the mouth by time of death are often loose in their sockets and can easily be removed for examination of their roots. However, in many cases, particularly in well-pre-served material, the jaw bones are intact with the incompletely formed teeth still hidden inside. In such cases, radiography of the jaws is necessary in order to determine the state of dental development.

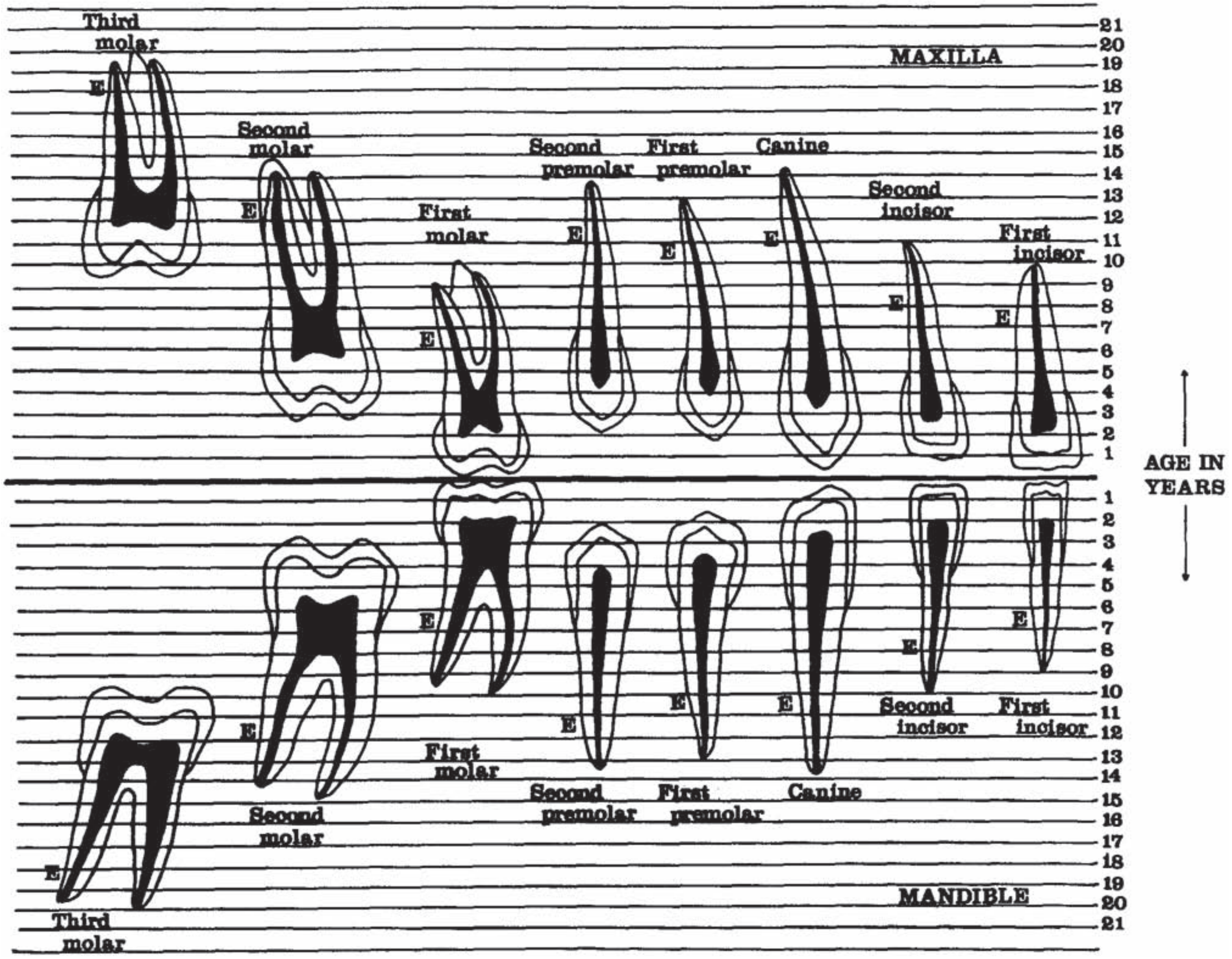


*Figure 3.9* Chronology of the development of the permanent teeth. E denotes approximate age at eruption.

*Source*: Modified from Stermer Beyer-Olsen and Risnes (1994: Figure 2).

*Note*: For data sources see text.

## Age Estimation in the Child Skeleton: The Bones

It may be recalled from Chapter 1 that the extremities of a long-bone are usually formed from secondary ossification centres (epiphyses), united with the diaphysis (shaft) of the growing bone by the growth cartilages. Most other bones, save those in the skull and the ankle and wrist, also possess epiphyses. When bones cease growing the growth cartilage ossifies, fusing the epiphyses with the diaphysis (Figure 3.10). Epiphysial

*Figure 3.10* The femur on the right is an immature bone with an unfused distal epiphysis. That on the left is a mature bone for comparison

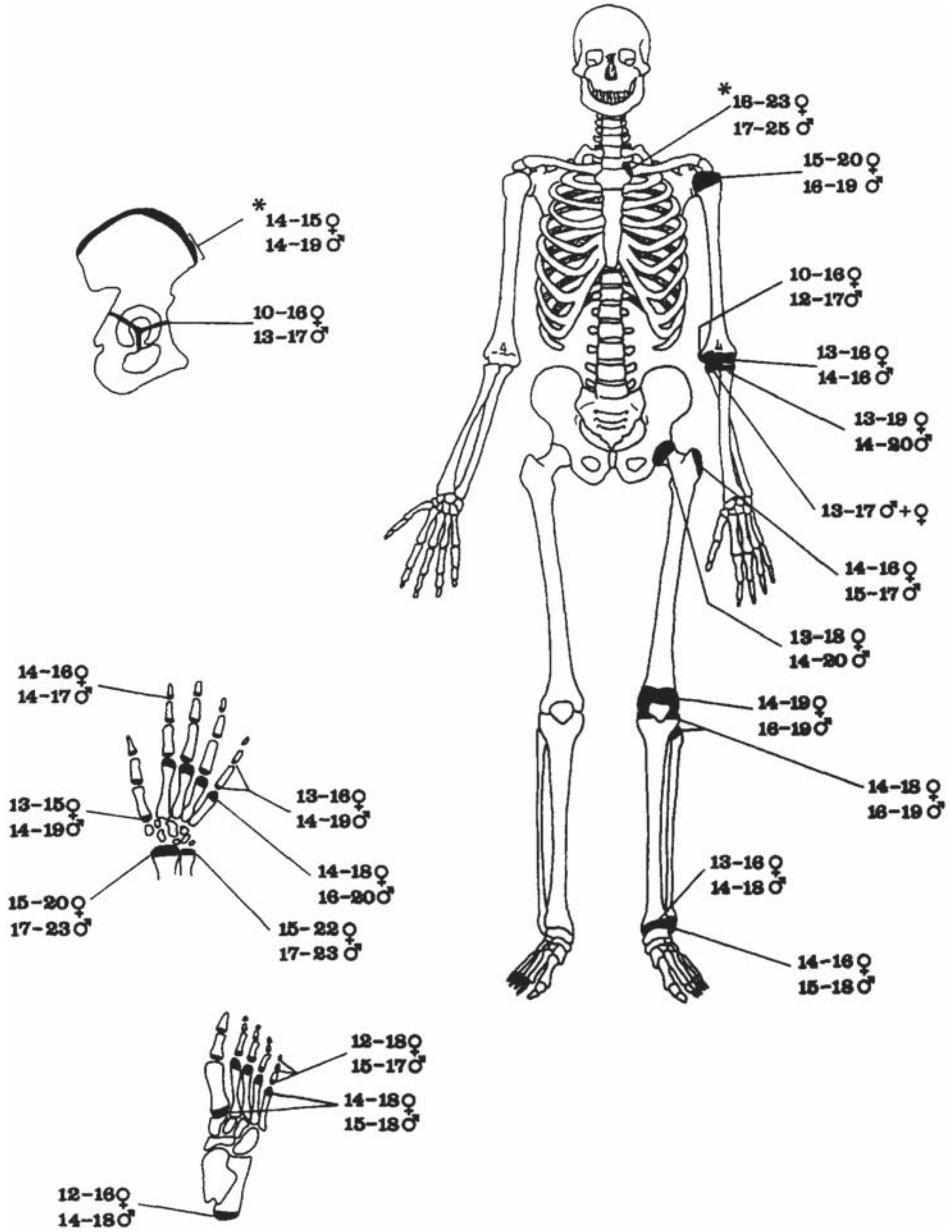


*Figure 3.11* Epiphysial fusion. Data are from Flecker (1942), except those marked * which are from Webb and Suchey (1985). The lower ends of the age-ranges are the ages at which fusion of epiphysis to diaphysis was first noted, the upper ends those at which completely unfused epiphyses were last noted

fusion proceeds in an orderly manner during adolescence and early adulthood. Although, like other aspects of bone maturation, it is more affected by extrinsic factors than dental calcification or eruption (Lewis and Garn 1960), it is usual to use epiphysial fusion as a method of estimating age at death in skeletons of adolescents or young adults where dental development is complete or for which dental remains were not recovered.

The chronology of epiphysial fusion has been studied both by radiography of living subjects and by examining bones from collections of recent skeletons of known age at death. Much of this work was undertaken some time ago. Studies investigating union at a range of epiphyses include the radiographic surveys of Flecker (1942) and Borovansky and Hnevkovsky (1929), and the dry bone studies of Stevenson (1924) and McKern and Stewart (1957). Studies concentrating on observations at specific sites or regions of the skeleton include dry bone studies of the iliac crest and clavicle (Webb and Suchey 1985), and the radiographic studies of Greulich and Pyle (1950) on the hand, and of Pyle and Hoerr (1955) on the knee.

Most standard anatomical textbooks, such as *Gray's Anatomy,* also give ages for epiphysial fusion. The precise origin of much of this data is obscure, but in most cases it appears to have been based on unpublished nineteenth-century observations, as figures given in recent texts have generally been copied faithfully from early editions of these works.

Since no single study is truly comprehensive in including all epiphyses and both sexes, many texts intended for use by osteoarchaeologists present diagrams combining data from various sources. This has the disadvantage that it conflates data from studies using different methodologies and types and sizes of samples. Other writers content themselves by presenting results from a single study even though this may omit many epiphyses.

Figure 3.11 presents data for the timing of epiphysial fusion. Most of the data come from a study done in Australia by Flecker (1942). This work was conducted using X-rays of a large number of hospi-tal patients of European ancestry, ranging in age up to 29 years old. These data are supplemented by those for the clavicle and the anterior part of the iliac crest from a more recent dry bone study by Webb and Suchey (1985).

Unfortunately, no adequate collections of adolescent individuals of known age at death exist from archaeological contexts to test the reliability of epiphysial fusion as an ageing method for ancient skeletons. It is also difficult to compare age estimates from epiphysial fusion with those from dental development in archaeological material as assemblages are generally short of adolescent skeletons (in most populations mortality in this age group is low), and in any event the formation of most of the dentition is complete before most of the major epiphyses start to fuse. There is indirect evidence which indicates that there may be some problems in apply-ing modern fusion data to archaeological remains. Nutritional deficits delay epiphysial fusion in man. Dreizen *et al.* (1957) studied subjects from Alabama, USA, with and without histories of malnourish-ment. They used X-rays to study hand and wrist epiphyses. They found that those who had a history of poor nutrition showed later epiphysial closure than their better-nourished counterparts. Dreizen and colleagues concluded that poor nutrition extends the growth period by delaying epiphysial closure. One might thus expect available standards of epiphysial fusion to tend to under-age when applied to ancient material. In the latter part of this chapter we shall see that in nineteenth-century populations growth was prolonged, by as much as ten years in the poorer social classes, compared with modern Western populations. This illustrates the potential for significant delay in epiphysial closure in earlier human populations. Although this suggests that epiphysial union may have the propensity to under-age when applied to archaeological material, it is, provided this is borne in mind, still a useful, if rather approximate, age indicator.

## Determination of Age at Death in the Adult Skeleton

Many methods have been used for estimating age at death in adult skeletons from archaeological sites. As with the techniques discussed for immature ske-letons, almost all rely on standards generated from modern material of known age. Thus far no method has been devised for adults which bears as close a relationship with age as the growth-based methods do for immature individuals. Rates of skeletal ageing and degeneration vary much more between individuals and populations than do rates of dental development. We have only recently begun to realise the extent of the problems with our methods for estimating adult age at death. At present, the lack of a wholly satisfactory technique for estimating age at death in adult skeletons from archaeological sites is one of the most thorny problems facing human osteoarchaeology.

The following section briefly describes some of the methods customarily used for estimating age at death in adult skeletons (Figure 3.12). The methods may be considered in three groups: those which rely on morphological changes at some joints in the body where movement between bones is limited or non-existent (methods 1–4 in Figure 3.12), those which look at bone structure (numbers 5 and 6) and techniques which use the teeth rather than the bones (numbers 7–9).

1 Cranial suture closure. Most of the separate bones which make up the cranium interlock at fibrous, non-movable joints called sutures. As an adult individual grows older it appears that the skull vault sutures progressively fuse and become obliterated. Over the years many schemes have been published which purport to show the relationship between this process and age in human populations. However any association between age and suture closure appears fairly weak (Masset 1989).

2 Rib-end morphology. This technique was devised by Yassar Iscan and his US colleagues in the mid-1980s using autopsy material (Iscan *et al.* 1984, 1985). The ribs are united with the sternum by lengths of cartilage. Initially, the rib ends, where they join the cartilage, are fairly flat, but subsequently there is the formation of a progressively deeper pit here, the rim of which becomes increasingly ragged and irregular. Iscan and colleagues classified these changes into discrete phases and found that they related to age at death in their sample.

3 Auricular surface morphology. The auricular surface of the ilium is the joint by which this part of the pelvis articulates with the sacrum. In young adults, its surface is undulating, but later becomes progressively smoother. Eventually this smooth surface becomes porous with bony lipping at its edges. Lovejoy *et al.* (1985a) developed this method using a collection of US anatomical skeletons.

4 Pubic symphysial morphology. This is a widely used method and will be discussed in more detail below.

5 Investigation of bone microstructure. This involves grinding slices of bone into thin sections and examining osteon frequency and various other features under a microscope (Stout 1992).

6 The ‘Complex Method’. This involves studying age-related loss of trabecular bone in the femoral and humeral heads, either by X-ray or by sectioning the bones. Results here are used, in conjunction with pubic symphysis morphology and closure of the skull sutures to provide an estimate of age at death. The method was devised by Nemeskeri and co-workers (Nemeskeri *et al.* 1960; Acsadi and Nemeskeri 1970) in Hungary, mainly using autopsy specimens. This ageing method is widely used in Continental Europe.

7 Tooth wear. This will be discussed below.

8 Cementum incremental layers. Cementum, the material which coats the tooth roots and helps anchor them in the jaw, appears to increase in thickness throughout life. Microscopic examination of cut sections of human teeth shows that cementum is deposited in layers which may correspond to annual increments. Cementum deposition was developed as an ageing method for humans using corpses of known age at death and teeth extracted from dental patients (Charles *et al.* 1989).

9 Dental microstructure. This involves sectioning tooth roots and assessing their transparency when viewed under a microscope. A number of other, related, parameters are also taken into account, including deposition of secondary den-tine in the

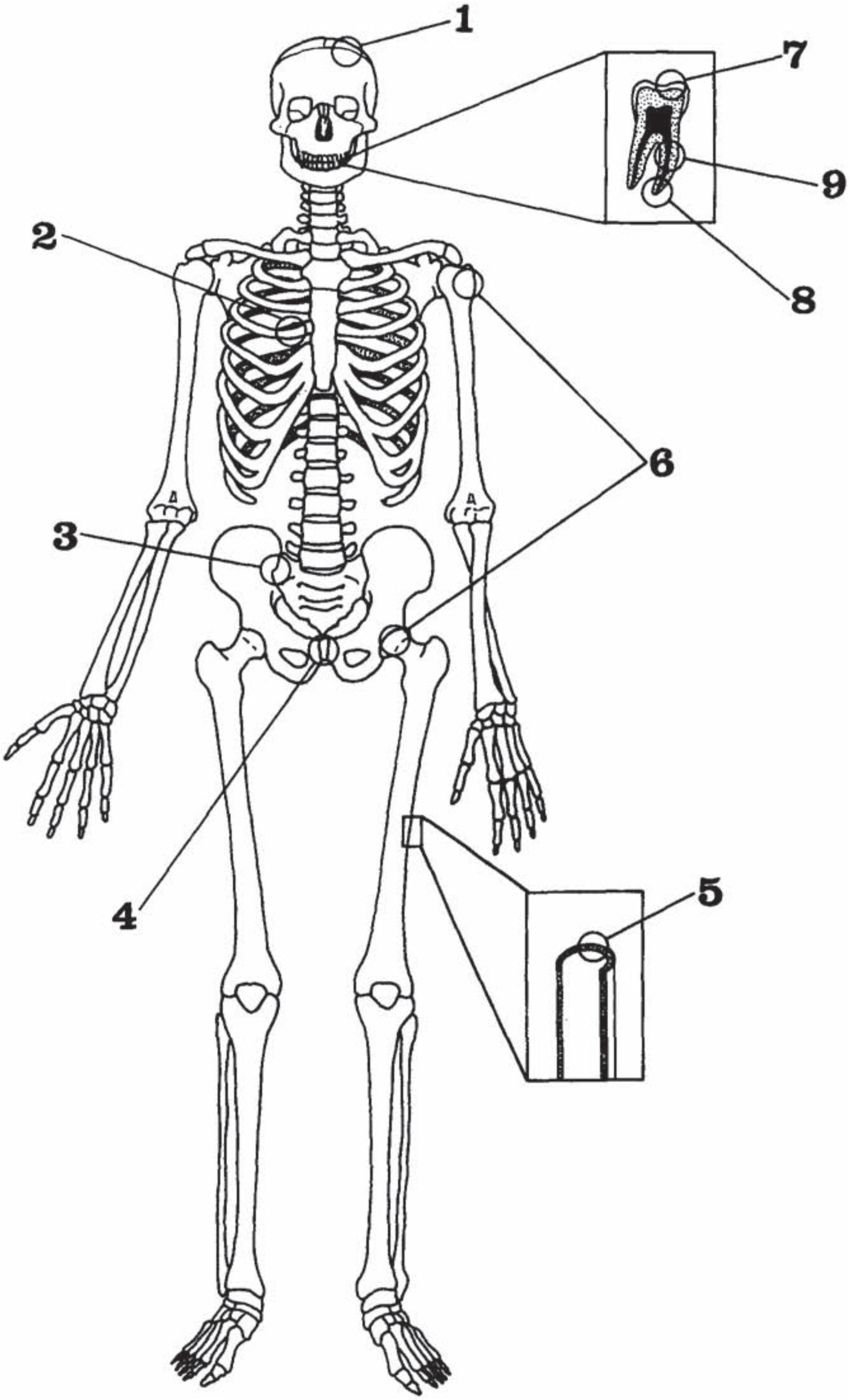


*Figure 3.12* Some methods which have been used to estimate age at death in adult skeletons from archaeological sites (for key, see text)

pulp chamber and the amount of cementum (Lucy *et al.* 1995).

Two methods, pubic symphysial morphology and dental wear, will now be discussed in detail. Pubic symphysial morphology has long been regarded as a mainstay in ageing archaeological material, particularly in North America. The technique will be described and some of the problems discussed. Problems with this technique are illustrative of the sorts of difficulties which often attend attempts to derive ageing standards from recent material and to apply them to ageing archaeological specimens. Ageing using dental wear will also be described. This technique does not rely on the generation of modern ageing standards but rather attempts to estimate the rate of wear in the population under study.

## Pubic Symphysial Ageing

The left and right pubic bones at the front of the pelvis are not fused together in the midline—rather, they are separated by a fibro-cartilagenous disc. This joint is known as the pubic symphysis. The bone surfaces underlying this joint appear to show age-related changes in the adult. Initially the symphysial surface displays ridges and furrows, but these are progressively

*Figure 3.13* The symphysial faces of three adult male pubic bones to show some of the age-related aspects of morphology. In the young adult (left), the symphysial surface displays traces of a ridge and furrow pattern. These ridges and furrows are progressively bliterated so that the surface becomes smoother, and a rim of bone forms around it (centre). In the older adult, the rim breaks down and the symphysial surface may become pitted and porous

obliterated and bone builds up around the joint margins. The bony deposits around the margins eventually unite to form a continuous rim. Finally, this rim breaks down and the symphysial surface may become porous and pitted. The three pubic bones in Figure 3.13 illustrate some of these changes.

Over the years, a number of schemes have been put forward classifying the changes seen at the pubic symphysis and showing the purported relationship of these phases with age at death (Todd 1920; McKern and Stewart 1957; Gilbert and McKern 1973; Katz and Suchey 1986; Suchey *et al.* 1988). Important recent studies have been published by the American forensic anthropologist Judy Myers Suchey and her co-workers. They examined pubic bones dissected during autopsy from 1,225 corpses of known age at death. They classified the age-related changes in morphology into six phases. The earlier studies, referred to above, had shown that male and female pubic bones differ in their morphology, but Suchey and her co-workers were, by concentrating on key features, able to produce a classification of morphological phases applicable to both sexes, although the age-spans corresponding to these phases were different in males and females (Table 3.1).

The age-spans in Table 3.1 are in general very broad. In some instances the age-ranges are so large that there is almost complete overlap between those of adjacent phases (e.g. stages IV and V in females). It would seem from the study of Suchey and colleagues that the relationship between pubic morphology and age in all but the youngest of adult age groups is too poor to be of very much use for palaeodemography. Earlier work however, had suggested that it was a much better age indicator; it was the false confidence engendered by such work that lead to the popularity of pubic symphysial ageing for skeletal material. The first study, by T.Wingate Todd (1920), had suggested that individuals could be aged to within five years or less up to the age of 50 and that there was minimal overlap between different phases (Table 3.2).

*Table 3.1* Relationship Found Between Pubic Symphysial Phases and Chronological Age in the Material Studied by Suchey and Co-workers

| | *Age (years)* | |
|---|---|---|
| *Phase* | *Females* | *Males* |
| I | 15–24 | 15–23 |
| II | 19–40 | 19–34 |
| III | 21–53 | 21–46 |
| IV | 26–70 | 23–57 |
| V | 25–83 | 27–66 |
| VI | 42–87 | 34–86 |

*Source*: Data from Brooks and Suchey (1990: Table 1).
*Note*: The age-ranges are those into which 95 per cent of the individuals displaying each particular phase fell.

In a subsequent study, McKern and Stewart (1957) found that for the collection of male skeletons they worked on, Todd's ageing scheme was unsatisfactory. They found a more elaborate component scores method was required to describe accurately pubic morphology in their sample. Their scheme had broader age-ranges for each stage than Todd's and there was more overlap between age-spans (Table 3.3). Todd did not have access to sufficient female skeletons to generate a pubic ageing scheme for females. However Gilbert and McKern (1973) produced standards for females, again using a component scores method (Table 3.4).

It is clear then that since Todd's study nearly eighty years ago pubic ageing schemes have undergone heavy revision, with a progressive broadening of age-ranges corresponding to particular morphological phases and an increase in age overlap between phases. That such drastic revision should have taken place is perhaps surprising, and the reasons why are worth considering.

Firstly, there were problems associated with the reference collections used by earlier workers. Todd used the collection of skeletons from Cleveland, Ohio, which was later to bear his name. The skeletons in the Todd Collection came from corpses gathered in the earlier part of the twentieth century from local hospitals and medical schools. There are problems with the reliability of the documented ages for these skeletons.

*Table 3.2* Relationship Found Between Age at Death (in years) and Pubic Symphysis Phases in the Todd Collection. Males Only

| Phase | I | II | III | IV | V | VI | VII | VIII | IX | X |
|---|---|---|---|---|---|---|---|---|---|---|
| Age | 18–19 | 20–21 | 22–24 | 25–26 | 27–30 | 30–35 | 35–39 | 39–44 | 45–50 | 50+ |

*Source*: Data from Todd (1920).

*Table 3.3* Relationship Found Between Age at Death (in years) and Pubic Symphysis Scores in the Material Studied by McKern and Stewart. Males Only

| Score | 0 | 1–2 | 3 | 4–5 | 6–7 | 8–9 | 10 | 11–13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|
| Age | Under 17 | 17–20 | 18–21 | 18–23 | 20–24 | 22–28 | 23–28 | 23–39 | 29+ | 36+ |

*Source*: Data form McKern and Stewart (1957).

*Table 3.4* Relationship Found Between Age at Death (in years) and Pubic Symphysis Scores in the Material Examined by Gilbert and McKern. Females Only

| Score | 0 | 1 | 2 | 3 | 4–5 | 6 | 7–8 | 9 | 10–11 | 12 | 13 | 14–15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age | 14–18 | 13–24 | 16–25 | 18–25 | 22–29 | 25–36 | 23–39 | 22–40 | 30–47 | 32–52 | 44–54 | 52–59 |

*Source*: Data from Gilbert and McKern (1973).

In some cases age appears to have been estimated by anatomists on the basis of the external appearance of the corpse, rather than known exactly. Furthermore, skeletons in which documented age seemed incompatible with the then existing standards for skeletal development were eliminated from Todd's (1920) study. This is a key omission, as it will have the effect of falsely reducing sample variability—if these individuals had been included, then the age-spans on Todd's pubic phases would doubtless have been broader.

McKern and Stewart, in their 1957 study, used bones of US Korean War dead. Age at death for these individuals was known accurately, but this sample suffered from other problems. The chief drawback, as McKern and Stewart recognised, was the restricted age range of the material: there were very few individuals over 30 years old. This must have produced a false truncation of the age-spans of many phases, and if more older individuals had been present they may have shown some phases not seen at all in the material under study.

Age for the female sample studied by Gilbert and McKern (1973) seems to have been reliably documented, and their sample contained a reasonable spread of ages. However, their numbers were rather small (103 individuals spread over 12 age groups).

These problems have significance beyond their implications for pubic ageing. The problems with the reliability of age documentation with the Todd Collection have a direct effect on other ageing methods because much work on skeletal ageing standards has been conducted using this material. For example Lovejoy *et al.* (1985a), whilst acknowledging the potential problems, used the Todd Collection to generate the standards for their auricular surface method. On a more general note, some other dissection-room collections of skeletons of 'known' age share the problems of the Todd Collection in terms of reliability of age documentation. Worldwide there are few large collections of skeletal material of reliably documented age at death, with good spreads of ages and adequate representation of both sexes. This naturally hinders the development and testing of skeletal ageing schemes; it is likely that most future work, will, like that of Suchey and colleagues, rely on dissecting out specific bones from autopsied corpses.

Problems with the reference samples used by the earlier studies are not likely to be the whole explanation for the heavy revision of pubic ageing standards which has taken place over the years. There may have been genuine differences in pubic morphology, and its relationship to chronological age, between populations.

A major problem is that it is not well understood why the morphological phases which have been observed on the pubic bones take the form they do, let alone what extrinsic factors might affect the relationship of these phases to chronological age. This means that we simply don't know whether ageing standards for the pubic symphysis derived from modern bones can be applied to archaeological remains, where diet, health and general way of life were very different. This conclusion also applies to most other methods for ageing adult skeletons. For example, cranial suture closure is one of the oldest ageing methods, yet in a recent publication Key *et al.* (1994) were still able to state that little was known of the function of suture closure or the determinants of its rate; they remark that more understanding of such aspects is needed if we are to be able to use it accurately to age ancient skeletons.

### Testing Pubic Ageing and Other Methods on Archaeological Material

What little evidence we do have from archaeological collections of skeletons of known age at death seems to confirm suspicions that standards derived from modern populations may not be applicable to such material. For example, excavations at Belleville, Ontario, Canada produced some nineteenth-century skeletons of documented age at death. Saunders *et al.* (1992) tested a variety of ageing methods, including pubic symphysial morphology. Of the 23 males, in eight actual age fell outside the range suggested by the pubic symphysis using Suchey and colleagues' standards. This was surprising, particularly considering the very broad age categories of the Suchey scheme. All but one of the actual ages of the females fell within the predicted ranges, but the sample was very small (12 individuals) and the female age-spans of the Suchey system are often even wider than those of the males. The poor performance in ageing was not restricted to the pubic morphology method; Saunders *et al.* also tested the rib-end technique, auricular surface ageing and cranial suture closure. All showed very much weaker associations with individual age than the work with the modern reference samples suggested. Some workers (e.g. Bedford *et al.* 1993) have recommended the combining of several age indicators in a 'multifactorial approach' in order to improve results. However Saunders *et al.* (1992) found that this strategy did not produce improved age estimates for their material.

Saunders and co-workers' results have been reinforced by work on the much larger archaeological collection of individuals of known age at death from Spitalfields, London. Here pubic symphysis morphology, the rib-end technique, cranial suture closure and bone microstructure methods were applied; all performed poorly, showing only very weak associations with individual age (Molleson and Cox 1993; Aiello and Molleson 1993; Key *et al.* 1994). Molleson and her collaborators also investigated the utility of the 'Complex Method' of age estimation, which a working party of European anthropologists had recommended as the best method to use in an influential paper published in 1980 (Workshop of European Anthropologists 1980). The originators of the method claimed that its reliability was such that estimated age should fall within five years of actual age in 80–85 per cent of cases. When tested on the adult skeletons of known age at death from Spitalfields (Molleson and Cox 1993:167–172) it was found to perform much less well. Less than 30 per cent of individuals were aged correctly to within five years. Molleson and Cox also found a systematic error, those over about 70 years of age tended to be under-aged, those under 70 tended to be over-aged, the degree of over-ageing being greatest for the younger end of the age range (Figure 3.14). This may suggest that rates of

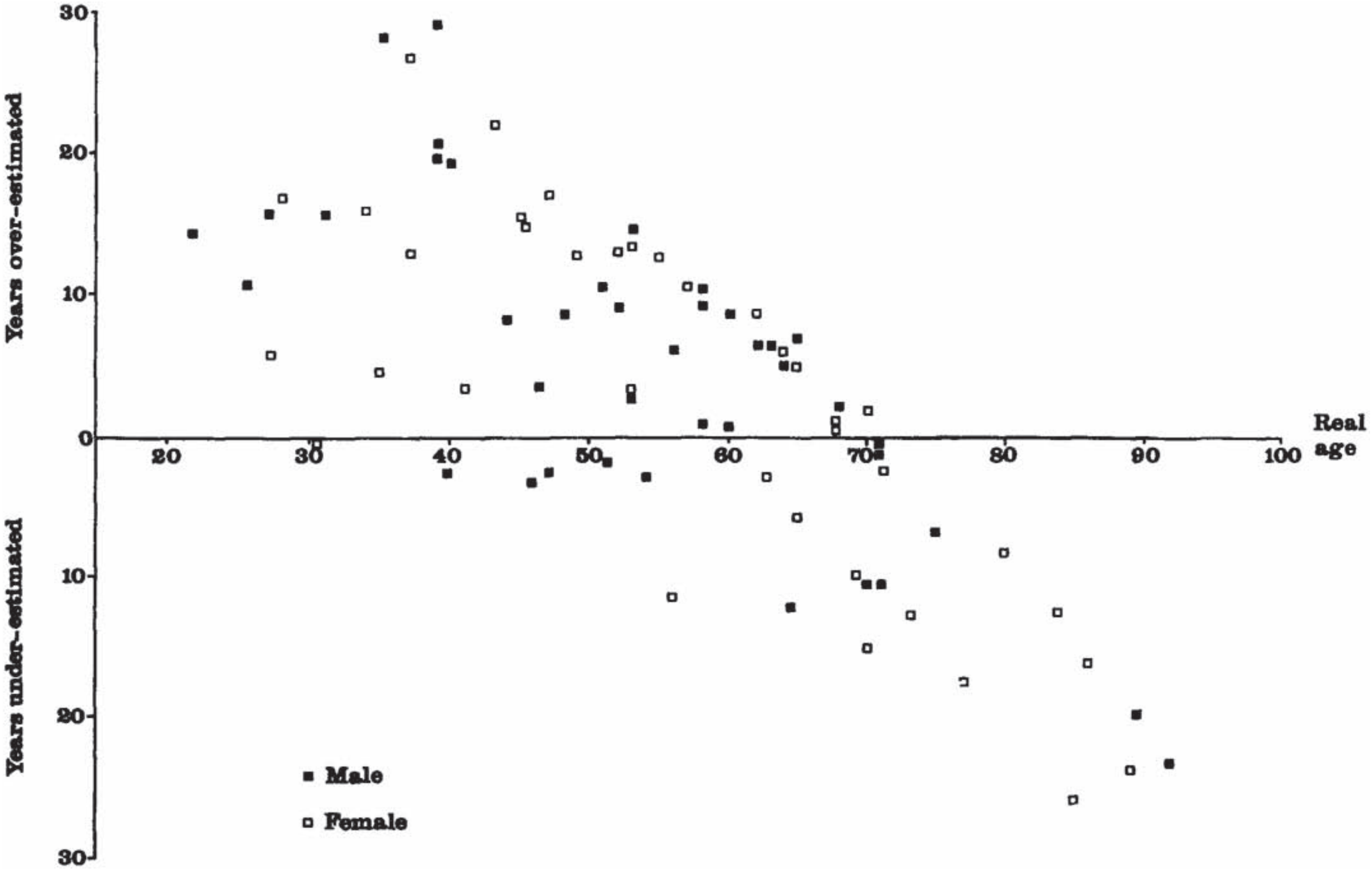


*Figure 3.14* Deviation of age estimated using the four criteria of the Complex Method from real age in the Spitalfields adult skeletons
*Source*: After Molleson and Cox (1993: Figure 12.4).

ageing were different in the Spitalfields group than in the reference sample used to develop the method. A mortality bias may also be playing a part here: Molleson (1995) interprets the pattern as indicating that those who died young tended to have prema-turely aged bones, whereas those who survived to older ages tended to retain relatively young bones.

## Dental Wear

The soft, processed diets consumed by modern Western peoples mean that wear on our teeth is slight. However this was not the case in the past; prior to recent times all human groups consumed a coarse, tough diet which caused considerable dental wear (see Chapter 7). We would thus expect older individuals to show greater tooth wear than younger ones in archaeological groups. Wear is generally most regular on the molar teeth, so it is these which are most often emphasised in ageing studies.

Initially there is wear on the enamel only, but soon the underlying dentine is exposed. Eventually the entire enamel crown may be worn away, although secondary dentine formation by the odontoblasts which line the pulp cavity generally pre-vents exposure of the dental pulp (Figure 3.15). Patterns of dentine exposure have been used as a means of recording dental wear. A number of schemes for recording wear have been proposed; that developed by Brothwell for the molar teeth is shown in Figure 3.16.

An advantage of tooth wear over most other ageing methods is that it is easily studied in living individuals. Many non-Western groups still show heavy dental wear and so are suitable study populations. For example Tomenchuk and Mayhall (1979) and Richards and Miller (1991) studied dental wear in living Eskimos and Australian Aboriginals respectively. Both groups experienced a higher rate of wear than modern Western populations. Correlation coefficients between individual age and dental wear were found to be about 0.8–0.9 for the first molar (a value of 1.0 would indicate perfect correlation, a value of zero no correlation at all). Correlation coefficients for the second molar were slightly lower, those for the third molar lower still, between 0.32 and 0.65. The poorer performance of the third molar as an age indicator probably stems from the fact that it is quite variable in form and often does not attain full occlusion (contact with opposing teeth).

Lovejoy *et al.* (1985b) compared the performance of several age indicators (dental wear, pubic symphysis morphology, loss of trabecular bone in the proximal femur, auricular surface metamorphosis and cranial suture closure) using the Todd Collection. Dental wear was rated as the best one. Its correlation with documented age was 0.70, with a slight tendency to under-age. The good performance of dental wear was despite the fact that many aspects of the Todd Collection militated against its success. Wear rates were low compared with archaeological groups, making wear more difficult to measure and meaning that idiosyncratic individual habits such as tooth-grinding (bruxism) made a greater contribution to individual wear rates. The collection is also highly heterogeneous, so marked inter-individual variation in diets was likely.

As we have seen, a major problem with most ageing techniques for archaeological skeletons is that we are reliant on chronological standards derived from modern material. We do not know why the morphological changes take the form they do and hence what extrinsic factors might influence their relationship with individual age. We therefore do not know whether these standards are applicable to archaeological material. Dental wear to a large extent circumvents these problems. The coarse nature of the diet is largely responsible for the tooth wear customarily seen in archaeological assemblages. The appearance of the phases of dental wear (Figure 3.16) is a result of the nature of tooth structure and the mechanics of human mastication. We understand, therefore, why dental wear occurs and why the morphological phases into which it can be scored take the form they do. We can therefore also predict what factors are likely to cause differences in wear rates between populations. The chief factor is probably food

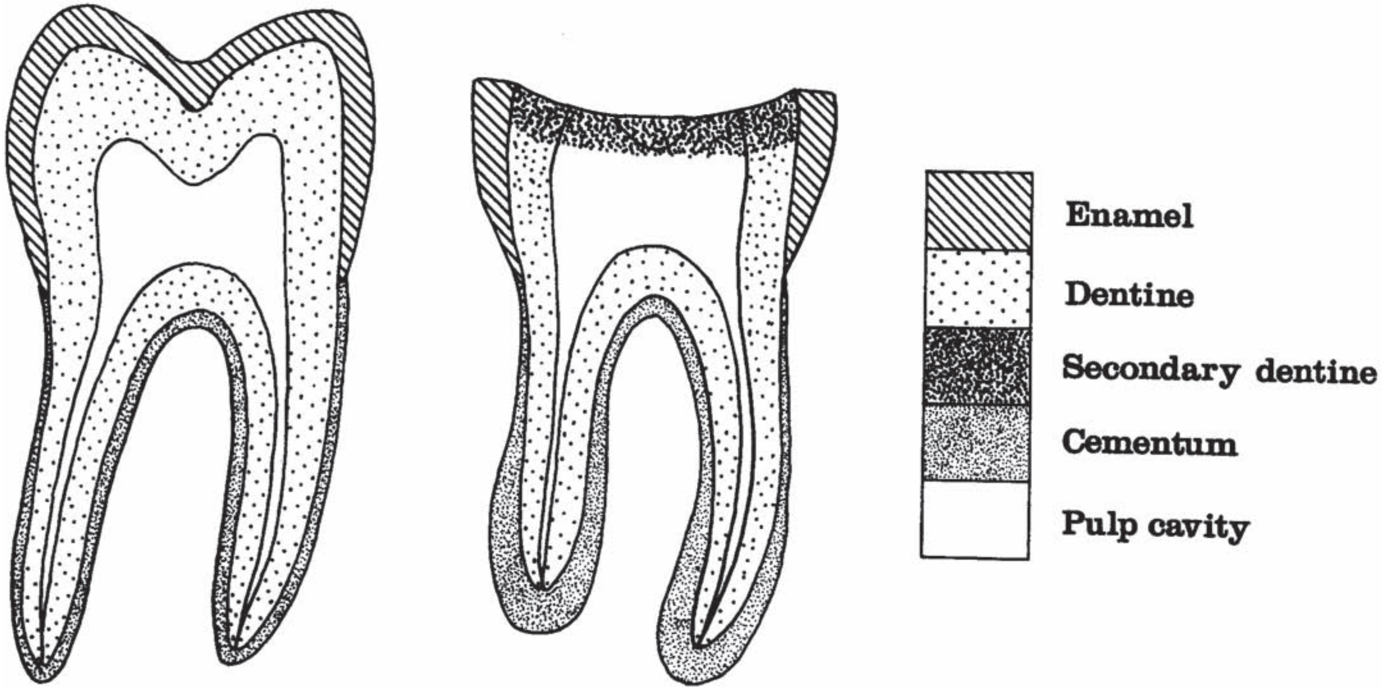


*Figure 3.15* Diagrammatic sections through an unworn and a heavily worn molar

*Source*: After Brothwell (1981: Figure 2.32).

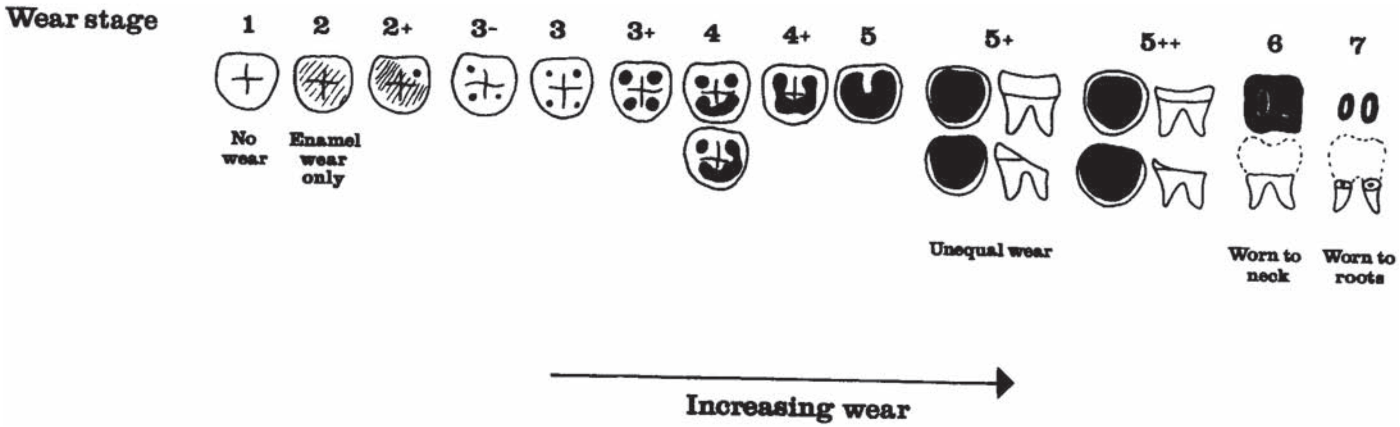


*Figure 3.16* A classification of molar wear. White denotes enamel, black exposed dentine

*Source*: Adapted from Brothwell (1981: Figure 3.9).

preparation techniques (see Chapter 7), but differences in types of food consumed are also important. This shows us that it would be futile to try to use modern rates of wear to try to age archaeological populations. However, unlike the other methods in Figure 3.12, we can estimate the rate of dental wear in the particular archaeological population under study.

Estimation of the rate of molar wear in an archaeological population is achieved through the study of the dentitions of immature individuals who can be accurately aged using dental development. The methodology to do this was developed by A.E.W. Miles (1963). The first molar erupts at about 6 years, the second at about 12 and the third molar at approximately 18 years old (Figure 3.9). The amount of wear on the first molar when the second molar erupts gives an indication of the amount of wear expected on a tooth which has been functioning for about six years; when the third molar erupts the first will have 12 years of wear, while the second molar will have about six years. This difference between the eruption times of the molars creates a sort of clock against which wear can be calibrated. So, if, say a second molar in an individual shows a functional age of 12 years, and a third molar a functional age of 6 years, the individual is probably about 24 years old. By looking at the wear on the first molars of such individuals we can gauge the amount of wear which represents about 18 years of tooth function. Those with second molars with functional ages of 18 years will be aged about 30. In this fashion we can estimate age through the entire adult part of an assemblage, starting with the youngest and working our way through to those individuals showing the hea-viest wear. An assumption in this method is that the molars wear at similar rates. Miles, looking at a British Anglo-Saxon population, found that there was a slight wear gradient, the first molars wearing fastest, the third molars slowest. As an approxima-tion, Miles felt that it took a second molar about 6.5 years to reach the same state of wear as a first molar showed after six. A third molar seemed to take about seven years to reach a similar wear state. This correction factor was incorporated into Miles's diagram showing wear against age (Figure 3.17).

There are a number of possible problems with dental wear as an ageing method. One is that it assumes that individuals in an archaeological group all experienced similar rates of wear. Research by Don Brothwell, using child skeletons from British sites from various archaeological periods (see below), suggests that until recently wear rates were stable over extended periods of time. Given this result, it would be surprising if great differences in wear rates often existed in the past between individuals within a single community. Work using tooth crown height measurements provides some support for this supposition. For example, at the Romano-British site at Poundbury, analysis of the relationship between crown height and age in child skeletons aged accurately using dental development showed no evidence for marked inter-individual differences in wear rates (Mays *et al.* 1995).

An assumption in Miles's calibration method is that the rate of wear in children is a useful guide to that in adults. In children, fewer teeth are erupted into the mouth than is the case in adulthood. This might be expected to result in an increased rate of wear as the chewing load is shared between fewer teeth. In adults, the jaw muscles are stronger, so this factor would tend to increase wear in adults compared with children. Miles felt that such factors probably tend to cancel one another out, so that his method should work fairly well.

Despite the potential problems discussed above, a test of the Miles method conducted by Kieser *et al.* (1983) on living Lengua Indians from Paraguay has shown that the method appears to work well. The Lengua show heavy dental wear, and the ages of those in Keiser and co-workers' study were known from missionary records. It was found that at the population level the Miles method provided a good estimate of true age (Table 3.5).

A reasonable number (about 20 or more—Nowell 1978) of child dentitions with erupted permanent molars are needed to calibrate dental wear. Since in most human populations mortality in later childhood and adolescence is low, many archaeological assemblages contain too few individuals of this age. Research by Don Brothwell (Brothwell 1963a) has helped circumvent this problem, at least for British material. He studied children's teeth from various British sites and found that wear rates did not alter

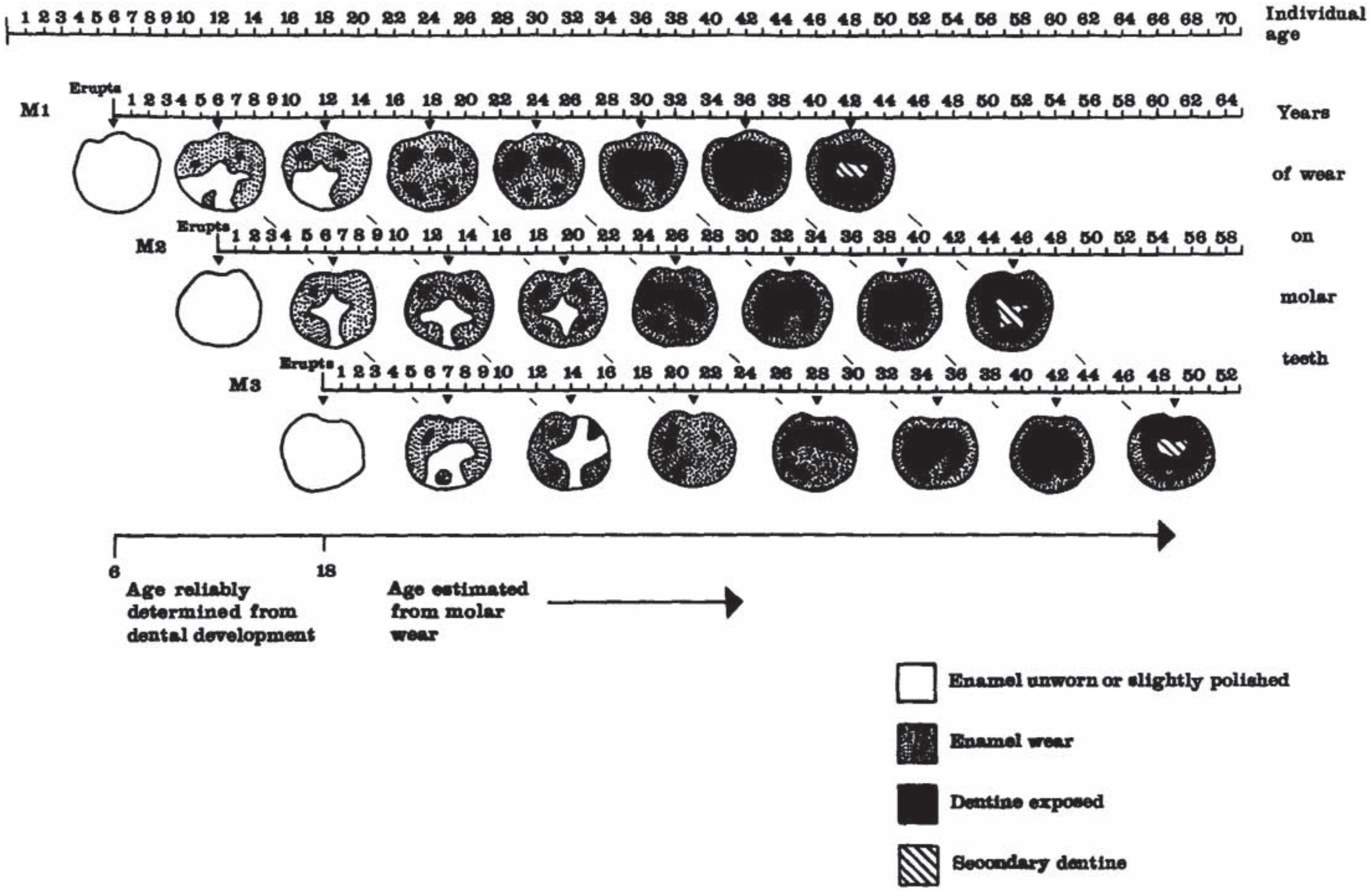


*Figure 3.17* Illustration of the Miles method for estimating the rate of dental wear in a skeletal collection, and hence for determining adult age at death
*Source*: Redrawn from Miles (1963: Figure 10).

*Table 3.5* Comparison Between Mean Real Ages and Mean Age as Estimated from Dental Wear Using the Miles Method in Paraguayan Lengua Indians

| *True age range* | *No.* | *Mean true age* | *Mean estimated age* |
|---|---|---|---|
| 20–22 | 18 | 20.38 | 20.55 |
| 23–24 | 9 | 23.50 | 23.70 |
| 25–26 | 19 | 25.10 | 24.89 |
| 27–30 | 11 | 28.72 | 29.00 |
| 31–36 | 24 | 33.60 | 33.50 |
| 37–46 | 23 | 40.78 | 41.56 |
| 47–56 | 23 | 50.82 | 53.17 |

*Source*: Data from Kieser *et al*. (1983).

greatly from Neolithic (*c*. 4000 BC) to medieval times (up to the sixteenth century AD). This allowed him to produce a chart (Figure 3.18) showing the estimated correspondence between actual age and molar wear stages which should be generally applicable to British material from the Neolithic to the medieval period. If insufficient child skeletons are available in an assemblage to determine the rate of molar wear, this chart can be used to estimate age in British material.

## Tooth Loss: A Problem for Age Determination Using Dental Wear

Tooth loss during life is common in most archaeological populations (see Chapter 7). If all molar teeth are missing then we clearly cannot record wear, but even if only some have been lost in life it still presents problems in interpreting the wear on those that remain—for instance when a tooth is lost the wear on its occlusal partner effectively ceases.

As we shall see in Chapter 7, loss of teeth can stem from a variety of causes, including tooth decay (caries), gum disease or, indeed, from heavy dental wear. When wear is heavy, teeth continue to erupt form their sockets to maintain occlusion. When wear is advanced, this continued eruption of teeth may proceed to the point at which they are only held in their sockets by the root tips. This weakening of the support for the tooth may precipitate its loss (Clarke and Hirsch 1991). This raises the possibility that many molars may be lost before they reach the more extreme wear grades. Consistent with this, in British assemblages it is quite rare to observe the highest grades of molar wear, even though ante-mortem molar-loss is common (Mays *et al.* 1995).

The frequency of conditions such as caries and gum disease increases with age. This, together with the observation that advanced wear may precipitate tooth loss, might lead one to suspect that tooth loss would be strongly correlated with individual age, and indeed this has been a finding in both recent and ancient populations (references in Mays *et al.* 1995). Work on populations who did not consume modern Western diets suggests that those over about 50–60 years have generally lost more than 50 per cent of their teeth. On this basis, those showing substantial ante-mortem loss of teeth in archaeological populations are likely predominantly to be past middle age. It is difficult precisely to know what age to assign these individuals, but they cannot simply be omitted from analysis, as to do so would truncate demographic profiles, giving the false impression that few survived past middle age in antiquity. One strategy is simply to assign them to a broad 50+ age group, on the basis that studies of populations consuming non-Western diets show that individuals showing substantial tooth loss are generally over about 50 years.

It is a general pattern that methods of skeletal age estimation perform better in younger age groups, because idiosyncratic differences between individuals tend to accumulate with age. In most of the bone methods mentioned above, morphological changes are

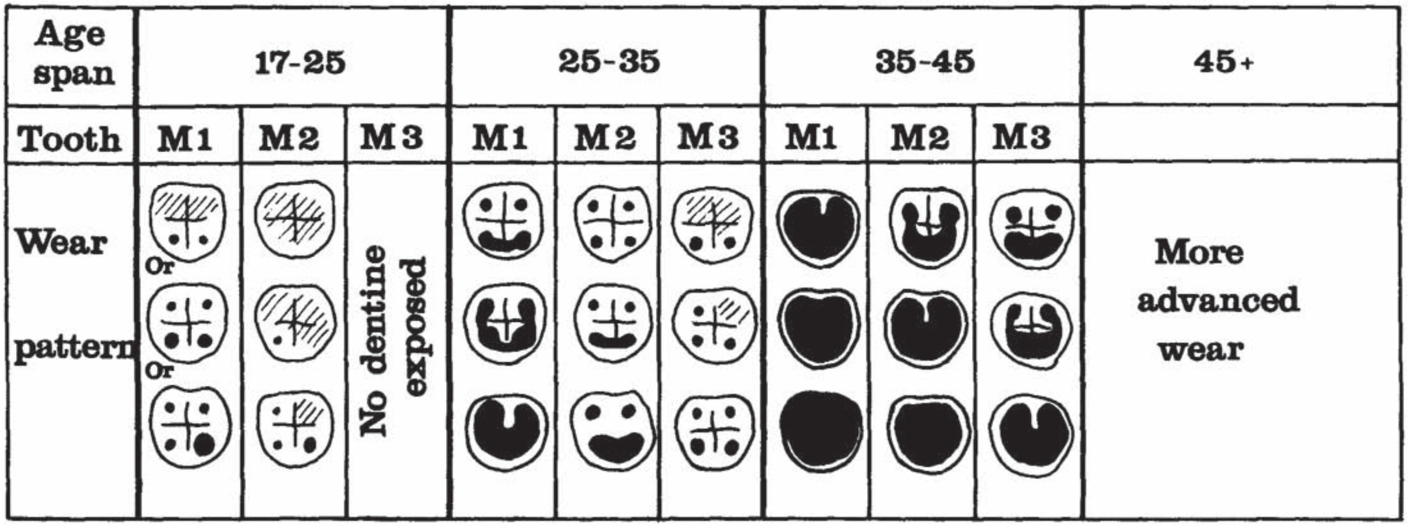
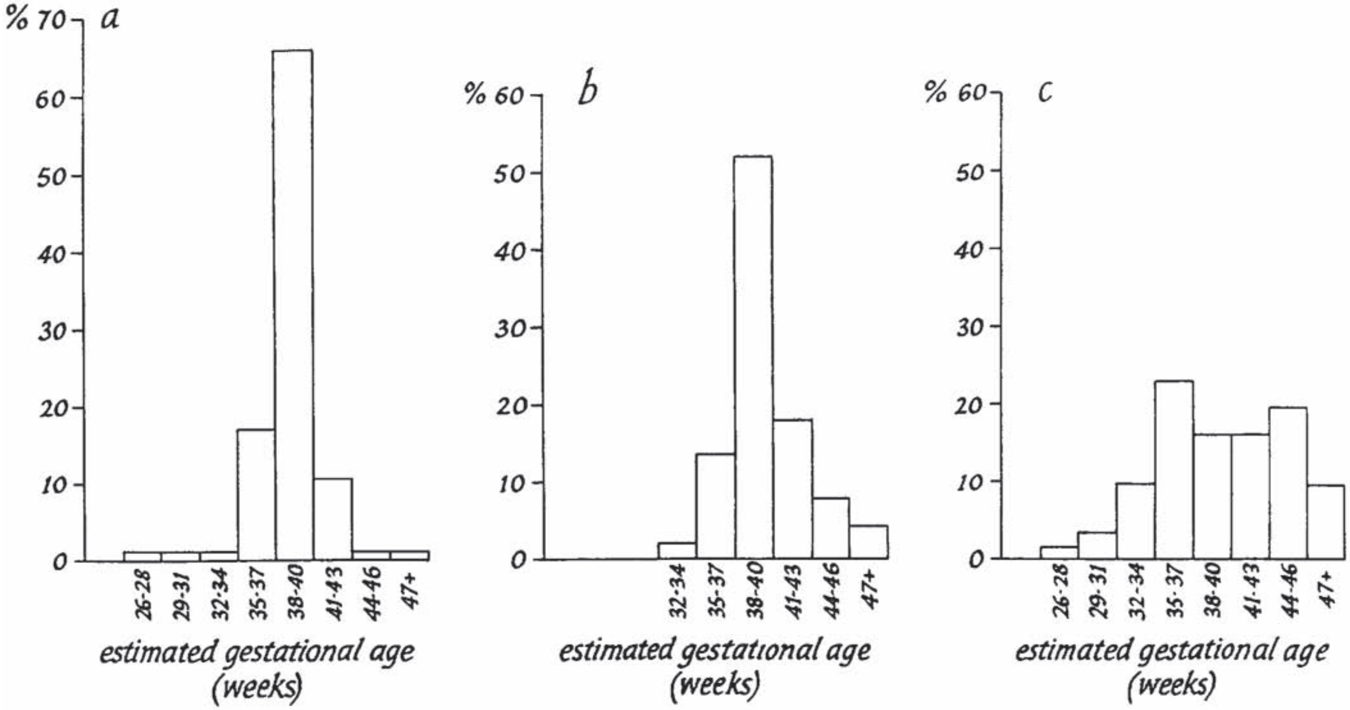


*Figure 3.18* Estimated correspondence between adult age at death and molar wear phases for British material from Neolithic to medieval periods

*Source*: After Brothwell (1981: Figure 3.9).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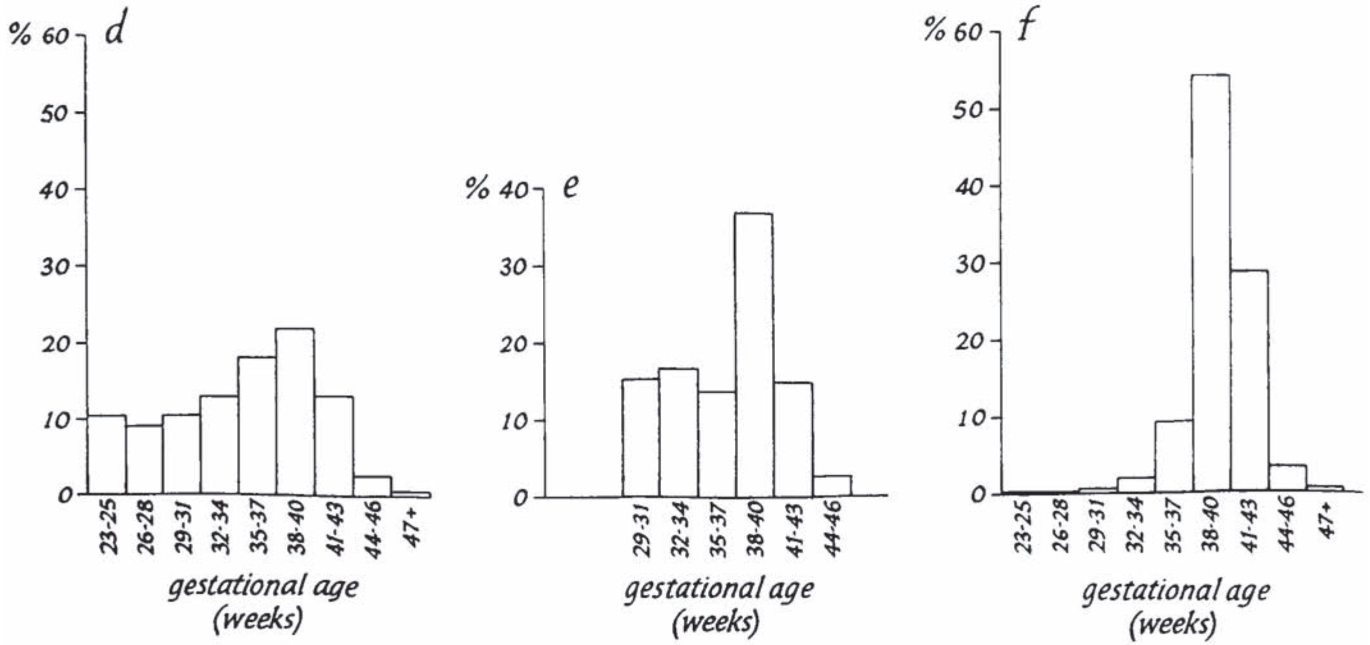


*Figure 3.19* Distributions of ages of archaeological and modern perinatal infants: (a) Romano-British settlements (N = 78); (b) Romano-British cemeteries (N = 86); (c) Wharram Percy (N = 61); (d) modern stillbirths (N = 16,702); (e) modern livebirths dying within seven days of birth (N = 196, no data given below 29 weeks); (f) total modern live births (N = 802,532)

*Source*: After Mays (1993a: Figure 1), where details of the sources for the data may be found.

essentially complete before the indivi-dual is much past middle age, meaning that it is impossible to age older adults with any accuracy. The shortcomings of dental wear with older adults are shared by most methods of age estimation.

## The Value of Determining Sex and Age at Death in Skeletons in Archaeological Assemblages

Age and sex of skeletons are clearly key components of cemetery data—for example for investigating whether certain grave goods are associated with one sex or other or with particular age groups. As will become apparent in later chapters, age and sex also form the background against which other bone data can be interpreted.

By analysing age and sex data from reasonably large numbers of skeletons we may be able to gain insights into past mortality patterns and demographic compositions of earlier human communities. By combining age data with aspects of bone size in child skeletons we can investigate growth rates in the past. What follows are three archaeological examples of the use of demographic data in studies of skeletal assemblages. The first discusses evidence for the practice of infanticide. The second looks at child growth and the third is a study of demographic aspects of adult individuals, particularly age at death, in a British rural medieval community.

### Evidence for Infanticide

Our ability to estimate age with some precision in perinatal skeletons has provided evidence concerning the practise of infanticide. Infanticide is the killing of unwanted infants, and until recently was a widely practised and tolerated means of population control (Mays 1995a).

I studied ages at death of perinatal burials from the Roman period in Britain and from medieval Wharram Percy (Mays 1993a). There was a difference in age at death distributions between the Roman and medieval data. The data from the Roman perinatal infants showed a strong peak at about 38–40 weeks (Figure 3.19a, b), the age corresponding to about a full-term baby. The medieval distribution was much flatter, with no strong peak at full term (Figure 3.19c). I argued that the difference between the Roman and medieval data might reflect differences in the major causes of death. Perinatal burials may be stillbirths, natural deaths in the immediate postnatal period or victims of infanticide. Age distributions of modern stillbirths and natural deaths soon after birth are shown in Figure 3.19d and e. The Wharram Percy distribution resembles these fairly flat distributions, suggesting that these medieval data represent a ‘natural’ pattern of perinatal deaths, consisting of some combination of stillbirths and natural deaths in the immediate postnatal period. Since infanticide is generally carried out immediately after birth, the age distribution of victims of this practice would be expected to mimic the gestational age of all live births. Figure 3.19f shows the age distribution for total live births for modern infants. The similarity between this and the age distributions for Romano-British perinatal infants suggest that the Roman assemblages contain substantial numbers of infanticide victims. Documentary evidence (Langer 1974) shows that infanticide was practised in early Roman society as a means of population control; the archaeological evidence, above, suggests that it was also practised in Britain when it was a province of the Roman Empire. The fact that the same perinatal age at death pattern holds for Roman cemetery as well as non-cemetery sites (Figure 3.19a, b) indicates that victims of infanticide in Roman times in Britain were not always denied regular burial.

### Child Growth in Antiquity

The first large-scale measurement studies of living children were undertaken about one hundred and fifty years ago. These and subsequent data show that there has been a trend for increased height in children (and to a lesser extent in adults) in the developed world. Most of this trend appears to have occurred in the last one hundred years, and in most instances seems now to be slowing or stopping (Tanner 1989:156ff.). Since long-bone length bears a predictable relationship to standing height, mea-surement of bone lengths allows stature to be estimated. Plotting this against age, inferred from the calcification of the teeth, allows the relationship between age and standing height to be estimated from skeletal evidence. Analysis of archaeological human remains therefore permits the study of growth to be extended back into the more remote past, before the first height surveys of living children.

I have studied growth in the children from medieval Wharram Percy. Before describing the analysis, a few words about the site are probably in order. Wharram Percy is a deserted medieval village situated in North Yorkshire, England (Figure 3.20). The only medieval building left standing now is the church, and this is in ruined state, but the remains of earthworks show where peasant houses once stood. A long-running archaeological excavation (Beresford and Hurst 1990) has taken place here, and as a result nearly seven hundred skeletons have been recovered from the churchyard. These burials date from the tenth to the nineteenth century AD, but the bulk are medieval (eleventh to sixteenth century). The burials are mainly of ordin-ary peasants who lived at Wharram Percy itself and elsewhere in the parish.

The first step in the study of child growth in the Wharram Percy material was to estimate standing height from the child skeletons. The US anthropologist Marc Feldesman has shown that femur length bears a predictable relationship to stature using data from published X-ray studies of living subjects (US children of European ancestry) aged 8–18 years (Feldesman 1992). For example, for 10-year-olds he found that the average femur:stature ratio for females was 0.2691 and for males 0.2675, with little variation between different populations, producing a mid-sex mean of 0.2683 (we need the midsex mean to estimate stature in skeletal material because of the difficulties in determining the sex of child skeletons). Feldesman's (1992) figures for femur:stature ratio in children refer to total bone length, including epiphyses. In archaeological material the epiphyses are present as separate pieces of bone (Figure 3.10). Even when they are recovered undamaged, it is often difficult to refit them accurately to the diaphyses, particularly in younger individuals. Long-bone length in archaeological material is therefore usually taken on the diaphyses alone. For the Wharram Percy children, however, some femur epiphyses *were* present and undamaged, and could be refitted accurately to the diaphysis. This indicated that the diaphysis made up about 91 per cent of total femur length. This figure closely matches that obtained from a modern radiographic study (Maresh 1955). For Wharram Percy 10-year-olds, average diaphysial length of the femur is 28.5 cm, so the estimated mean total length is 31.3 cm. Using Feldesman's femur:stature ratio, the estimated mean height for 10-year-olds at Wharram Percy is 116.7 cm, or about 3 feet 10 inches. In this fashion, stature for Wharram Percy children aged between 8 and 17 years old was estimated. These figures are plotted against age, estimated from dental calcification, in Figure 3.21. Also plotted for comparison are data from two measurement studies of living subjects, one of recent (Tanner *et at.* 1966) and one of nineteenth-century British children. The nineteenth century data come from a survey done in 1833 in north-west England on children employed in fac-tories (figures reproduced in Tanner 1981).

Before comparing the archaeological data with those from living subjects, a few words of caution are necessary. In the archaeological material, both age and height were estimated, whereas in the nine-teenth-century and modern studies these were known exactly. Mortality bias in the archaeological data may prejudice comparisons with data from living subjects. For growth studies this is because in archaeological material we are looking at growth in those who died in childhood. It might be suggested that this is not representative of growth of healthier children who survived into adult life. However, a recent literature survey on this problem (Saunders and Hoppa 1993) shows that the biasing effect on skeletal growth studies is probably minor.

Although these potential problems should be kept in mind, some interesting comparisons can be drawn. The most striking thing about Figure 3.21 is the height difference between the modern and the medieval

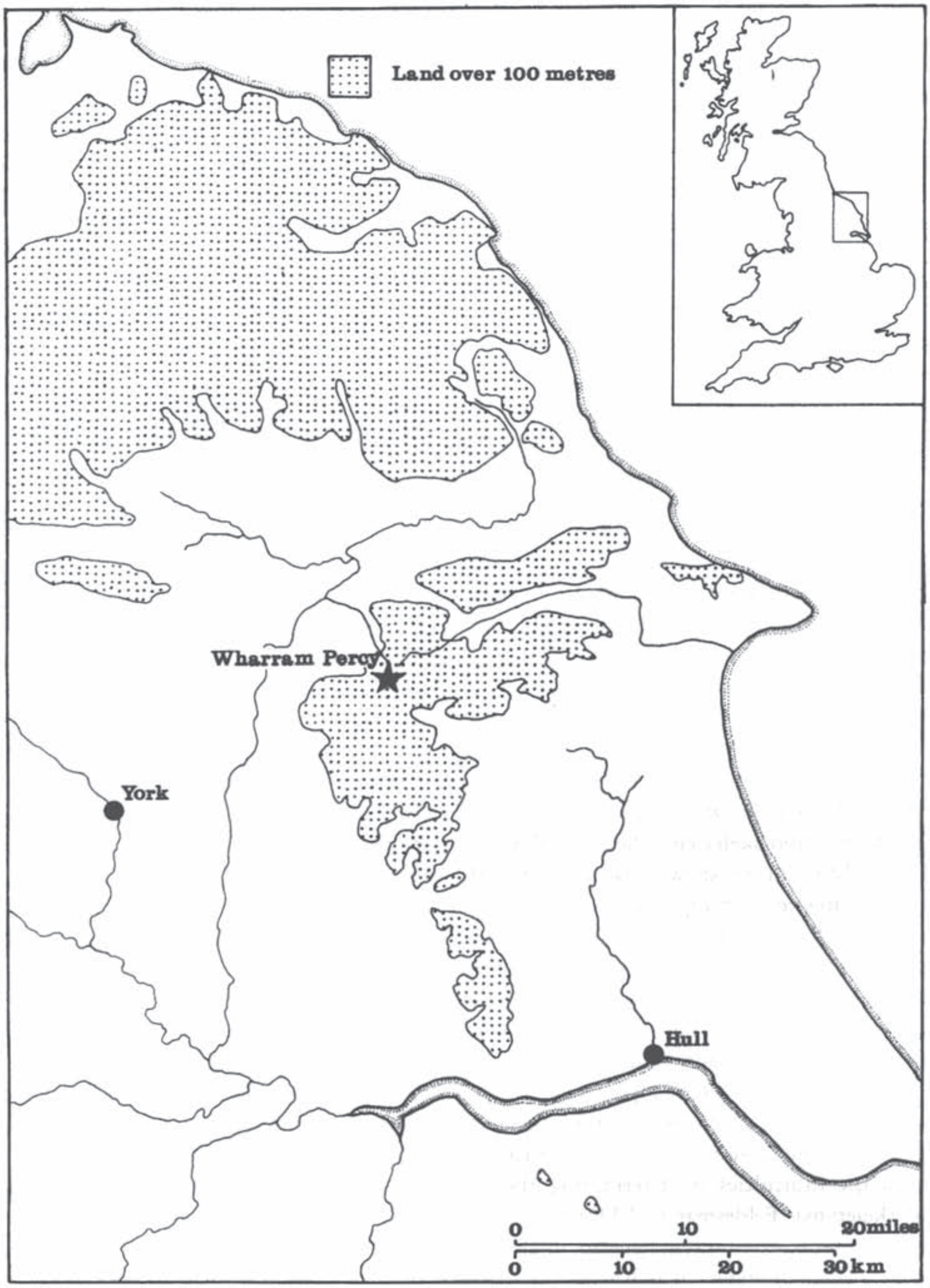


*Figure 3.20* Map showing location of the deserted medieval village of Wharram Percy
*Source*: After Beresford and Hurst (1990: Figure 1).

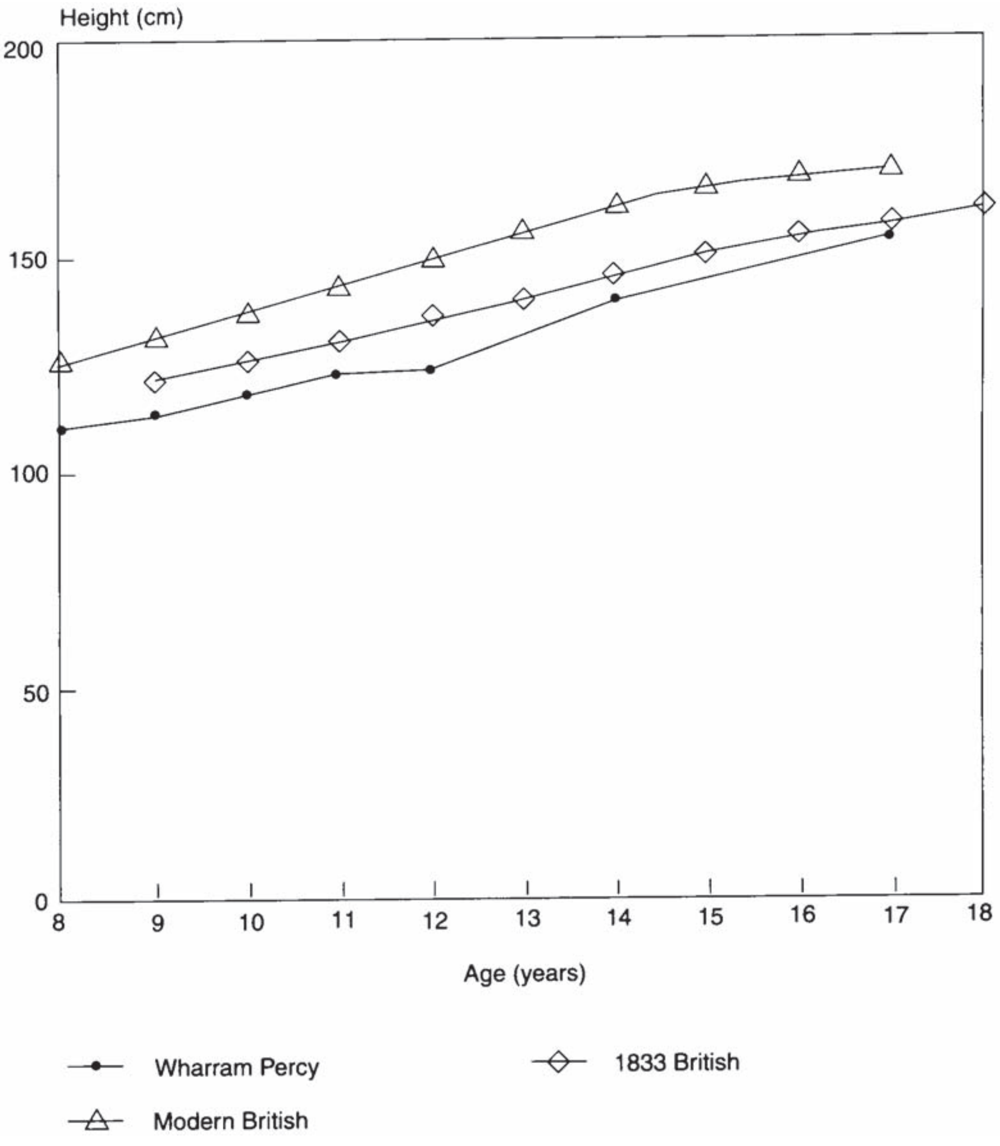


*Figure 3.21* Stature plotted against age for the Wharram Percy children. Figures for recent and nineteenth-century British children are also included for comparison

*Notes*: Stature figures are mid-sex means. For data sources see text. For the nineteenth-century data adjustment has been made to take account of footwear (see Tanner 1981: note 7.5).

children. For example, the estimated average height for a Wharram Percy 10-year-old, at about 117 cm, is fully 20 cm shorter than the modern figure (137 cm). Or, to put it another way, the height of 14-year-olds at Wharram Percy was only about the same as that of modern 10-year-olds.

The difference between nineteenth-century children and Wharram Percy children is less pronounced, but the medieval children do seem to be somewhat shorter, lagging behind in growth by about 1–2 years at most ages.

Growth in children is strongly dependent upon nutrition and disease experience (Eveleth and Tanner 1990), so much so that height has been used as a proxy for health when making comparisons on a population level (Tanner 1989:163). In this light, the present results suggest that, not surprisingly, the medieval group had poorer nutrition and suffered a greater disease load than modern children. If the present figures are anything to go by, the health of the Wharram Percy children was perhaps even worse than that of the urban poor during the Industrial Revolution.

In instances of long-term sub-optimal nutrition, growth is retarded, so that children are short for their ages. However, under such circumstances the growing period is extended, so that final adult stature may be unaffected (or at least affected less than height for age in childhood), although it will be reached at a later age (Eveleth and Tanner 1990). As might be anticipated from this, concomitant with the recent trend for increased childhood (and adult) stature, there has also been a trend for final adult stature to be reached earlier.

In modern populations in the developed world, growth in height is virtually complete by about 18 years (Tanner 1989: Figure 4). However, records show that in the nineteenth century growth was not completed until somewhat later. For example, Morant (1950) studied surveys of growth in nine-teenth-century England, splitting the data by social class. In the period 1857–1883, final adult stature was not attained until about 29 years in the lowest social class. The age of attainment was earlier among the more privileged, but still later than in recent populations—for example it was about 21 years in the 'professional' classes.

At Wharram Percy the bone data provide some evidence that growth was more prolonged than in modern children. The estimated mean height for 10-year-olds at Wharram Percy is 116.7 cm. Mean stature for adults, estimated from long-bone lengths (using formulae derived by Trotter and Gleser 1952, 1958) is 168.9 cm for males and 157.9 cm for females, giving a mid-sex mean of 163.4 cm. Thus height at 10 years was about 71 per cent of final adult height. This compares with a figure of 81 per cent for recent 10-year-olds (Tanner *et al.* 1966). Consistent with this, the difference in height between the medieval and modern adults is less than that during childhood. For example at 10 years old, the height of medieval children was 85 per cent of that reported for recent children in Tanner and co-workers' survey, but the medieval adult height was about 97 per cent of that quoted by Tanner *et al.* (1966). These observations are consistent with the hypothesis of prolonged growth in the medieval group.

## Adult Age at Death in a Medieval Community

A question one is often asked by members of the public interested in archaeology is 'how long did people live in the past?' Indeed, this sort of basic issue forms a fundamental area of academic enquiry in the demography of past populations. For most of the human past this is a question which can only be investigated by the study of skeletal remains. One way of studying length of life would be to look at the average age of death in the archaeological assemblage of interest. This would not be a very informative exercise, however, as the figure produced would be heavily influenced by the number of infant burials recovered; a large number of infant burials would of course greatly reduce the mean age at death. As we saw in Chapter 2, infants are often under-represented in archaeological assemblages, mainly as a result of burial practices, and therefore the degree to which this was so in the assemblage under study will greatly influence the mean age at death figure. What we often mean when thinking about length of life in the past is length of adult life —for example it has been said that, prior to recent times, it was fairly rare for people to survive beyond middle age. In order to study this sort of issue for the medieval period I conducted an analysis of the adult skeletons from Wharram Percy.

To estimate age at death in the Wharram Percy adults I used dental wear. Although there are, as we have seen, problems associated with it, I felt that it was less problematic than other methods where we are forced to rely completely on standards developed on recent material without knowing whether they are applicable to ancient populations. I also resisted the temptation to use several age indicators, as recommended by some workers. I felt that this would simply risk contaminating data which there is reason to suppose are reasonably reliable (dental wear ages) with those which, as far as archaeological populations are concerned, are of completely unknown reliability. At Wharram Percy there were sufficient child skeletons to calibrate the rate of dental wear using Miles's method. The sex of the adult skeletons was determined using the criteria described earlier in this chapter.

For this analysis I classified the adults into three broad age categories. It has already been explained that older adults cannot be aged any more precisely than that they are over about 50 years. With some dental wear recording methods it is probably possible to age younger adults into narrower age-spans— 10-year age-ranges are used by many workers—but for the present purposes the three age groups shown in Table 3.6 were deemed adequate.

Table 3.6 would seem to indicate that there were reasonable numbers of older adults in the peasant community at Wharram Percy. The data suggest that a person on the threshold of adulthood had about a 4 in 10 chance of surviving to at least 50 years of age. However, there are a number of complications to be borne in mind before this interpretation can be accepted.

Firstly, the assemblage represents an aggregate over the period for which the burial ground was used. Longevity may have varied markedly over this period, variations reflecting such factors as climate (and hence success or otherwise of harvests), disease load, etc. Therefore at different times adult longevity may have been greater or less than that for the whole assemblage.

The impression given of expectation of life from an assemblage of skeletons is also influenced by whether the population of the community was growing or declining.

Emigration may be an important point to consider for Wharram Percy. Russell (1948) offers historical evidence that in medieval times populations of urban centres were maintained by immigration from surrounding rural communities. Wharram Percy lies some 20 miles from York, a major urban centre. Russell shows, using documentary data, that many probably emigrated this sort of distance to become resident in York.

Goldberg (1986) shows that in the later medieval period, many urban centres in northern England had imbalanced adult sex ratios. For example in Hull, East Yorkshire, it was 0.86, in York 0.91, both in favour of females. Goldberg argued that these skewed sex ratios resulted from female-led migration into towns and cities from surrounding rural areas. Migrant female labour was absorbed into domestic service and into the emergent craft indus-tries such as weaving (Goldberg 1986).

At Wharram Percy, the adult sex ratio is 1.58:1 in favour of *males*. Not all the churchyard was excavated,

*Table 3.6* Age Distribution of Wharram Percy Adult Burials

| | *Total** | | *Males* | | *Females* | | *Male:Female ratio* |
|---|---|---|---|---|---|---|---|
| *Estimated age* | *Number* | *%* | *Number* | *%* | *Number* | *%* | |
| 18–29 | 65 | 21 | 36 | 20 | 28 | 23 | 1.30 |
| 30–49 | 116 | 39 | 64 | 37 | 50 | 41 | 1.28 |
| 50+ | 119 | 40 | 75 | 43 | 44 | 36 | 1.70 |
| Total | 300 | | 175 | | 122 | | 1.58† |

*Notes*: * Includes a few adults for which, due to the state of the skeleton, sex could not be determined,
† Includes some adults in which age at death could not be determined.

but in those parts which were, there is no evidence of anything other than a random intermixing of male and female burials, so it is unlikely that the 'missing' females are lurking in a cluster in some unexcavated area. A better explanation would seem to be that at Wharram Percy we are seeing the other side of the coin concerning medieval migration patterns, with a depletion of adult females due to female-led migration to urban centres like York or Hull.

The effect, if any, of this postulated migration upon the adult age structure of the Wharram Percy burials depends upon the age at which migrants generally left the parish. If most left in adolescence or early adulthood then the effect on the adult age at death distribution should be minimal—those that remained could either die young or live to grow old. If, however, most migrants tended to leave in middle age, this would have the effect of skewing the adult age at death distribution towards the younger ages. Logically, one might expect most migrants to leave in late adolescence or early adulthood. Indeed, the data discussed by Goldberg (1986) for immigrants to York appear to support this, and the observation that the sex ratios in the three adult age groups at Wharram Percy do not differ from one another in any statistically valid manner is also consistent with this. The effect, therefore, on the Wharram Percy adult age at death distribution may be small.

Whether a community grows or dwindles depends also on the birth and death rates within that population. If birth rate exceeds death rate then, other factors being equal, the population will grow. If the converse is the case, it will decline. If the birth rate exceeds the death rate, the age structure of the excavated skeletons will tend to underestimate the true life expectancy, as at any particular time the younger deaths will be derived from a larger population than that which produced the older deaths (Boddington 1987a). The opposite is true if death rate exceeds birth rate.

In the Wharram Percy case, use of the burial area covers both a period of growth of population and, from the mid-fourteenth century onwards, a period of population decline (due to the effects of the Black Death and changing agricultural practices), as well as doubtless many short-term fluctuations and periods of stasis. It may be, then, that the effect of this factor on the overall age structure of the assemblage is fairly minimal.

From the above discussion it may be that the adult age distribution from the skeletons gives a reasonable, though time-averaged impression of adult length of life at Wharram Percy.

In order to help put the Wharram Percy results in context it is helpful to compare them with documentary data on medieval longevity. Reliable documentary data are sparse and do not relate directly to the peasant classes. For example, Russell (1937) studied age at death in the period 1250–1348 using the Inquisitions Post-Mortem. These are reports of evidence taken by Royal officials regarding the property and heirs of deceased persons who held land directly from the Crown. The inquests give the age of the heir, not of the deceased, this must be calculated from his age at the death of his predecessor. Data relating to 582 deaths were collected by Russell. They refer solely to males aged 21 years and over (Table 3.7).

Russell's data are not too dissimilar to the Wharram Percy results, but they are in general somewhat older (for example, 50 per cent of individuals seem to have died aged 50 or over, compared with 40 per cent at Wharram Percy). There may be a number of reasons for this.

Russell's ages were calculated from the age of an individual when his predecessor died. Therefore individuals who pre-deceased their father would not, even if they had died aged over 21, be included in the data. This would tend to make Russell's figures exaggerate age at death somewhat. We would expect particularly deaths in the 21–30 age group to be under-represented.

*Table 3.7* Age Distribution in Russell's (1937) Demographic Study

| *Age range* | *Number* | *Percentage* |
|---|---|---|
| 21–29 | 58 | 10 |
| 30–49 | 232 | 40 |
| 50+ | 292 | 50 |

Secondly, Russell's figures refer solely to wealthy landowners. The Wharram Percy peasants represent some of the poorest members of what was a very hierarchical society. It can be assumed that their living conditions were much harsher than those of the wealthiest classes, so if anything we would expect that their longevity would be less.

Thirdly, Russell deliberately excluded the great Black Death years of 1348–1350 from his data, whilst the Wharram Percy burials cover the entire medieval period, plagues and all. This factor too would tend to skew Russell's data towards the older ages.

Another factor is that we are comparing ages estimated from dental wear with ages which were known fairly reliably from documents. Although dental wear is arguably the best method available for determining age at death in adult skeletons from archaeological sites, it is, as we have seen, hardly free of potential problems. Nevertheless, the Wharram Percy results are not too dissimilar from those obtained from medieval documents, and the discrepancies which do exist are understandable in the light of differences between the two datasets. The archaeological data would seem to suggest that once adulthood was attained, the medieval peasants of Wharram Percy had quite a reasonable chance of surviving to beyond 50 years. However, due to the limitations on skeletal ageing techniques it is impossible, using archaeological evidence, to com-ment on what proportion of adults survived into their seventies, eighties or even greater old age in medieval times. For this we are currently forced to rely on documentary evidence such as Russell's. This indicates that, despite the good representation of those in their fifties and sixties, only 8 per cent of those featuring in the Inquisitions Post-Mortem survived to 70 years of age or over, although one individual did live to be 100.

# 4

# METRIC VARIATION

No two skeletons are the same. Firstly, bones and teeth differ in *size* and shape between individuals. This type of variability, the subject of the present chapter, lends itself to recording by measurement, and so is called metric variation. Skeletons also differ in ways which are much more difficult to measure. This type of variability takes the form of minor anomalies of the bones and teeth. These sorts of variants, termed non-metric traits, are discussed in the next chapter.

Measurement studies of the post-cranial bones play an important role in the analysis of normal skeletal variation. For example, we saw in the last chapter that long-bone lengths could be used to study growth and stature. Another important focus of metric studies is, and has been, skull measurements (craniometry), particularly for investigating relationships between populations and for discern-ing evidence for migrations of peoples in the past.

Craniometry is the focus of the present chapter. It starts with a brief discussion of how cranial measurements are taken. There then follows a consideration of some of the factors which influence cranial form. Later parts of this chapter discuss theoretical and methodological aspects of craniometry, and two archaeological examples are used to illustrate the potential value of craniometric data in the investigation of ancient migrations.

## MEASURING SKULLS

Bones are highly irregular in shape. This immediately poses problems for the osteoarchaeologist—given the lack of flat surfaces and right-angles, from what points should one measure? On the skull this problem has been tackled by defining certain internationally accepted anatomical points, termed 'cranial landmarks', and taking measurements between them. In this way aspects of skull size and shape may be assessed, and data from different workers compared.

Many measurements are taken as straight lines between cranial landmarks. These measurements are termed 'chords', and are generally taken using sliding or spreading callipers (Figure 4.1a, b). These comprise the majority of measurements used by most workers. Less often, dimensions may be taken using a tape measure, measuring along the surface of the bone between two landmarks. These are called arcs. There are also measurements which quantify the relative projection of different parts of the skull. These are called subtenses, and are taken using a co-ordinate calliper (Figure 4.1c).

Cranial landmarks each have their own technical name. Landmark definitions may vary slightly between different textbooks. The classic text in this respect is that of Rudolf Martin (Martin 1928). More recent texts (e.g. Brothwell 1981; Howells 1973) often base their definitions on those of Martin. Because definitions do differ slightly between authors, it is important to state whose landmark and measurement definitions one is following. The ones discussed below are those of Brothwell (1981).

Landmarks may be defined according to a variety of anatomical criteria. Some are defined in terms of

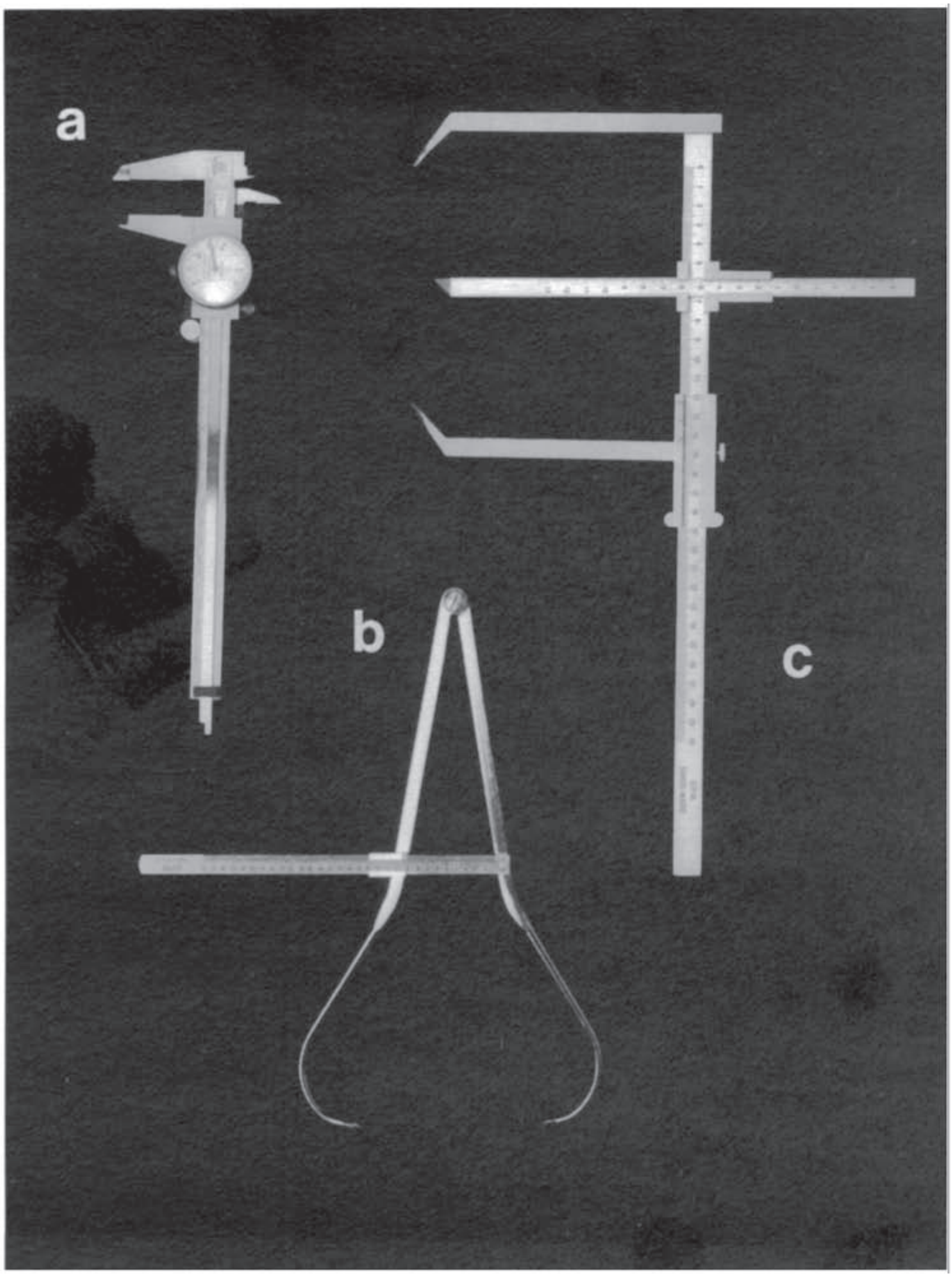


*Figure 4.1* Instruments for measuring skulls: (a) sliding calliper; (b) spreading calliper; (c) co-ordinate calliper

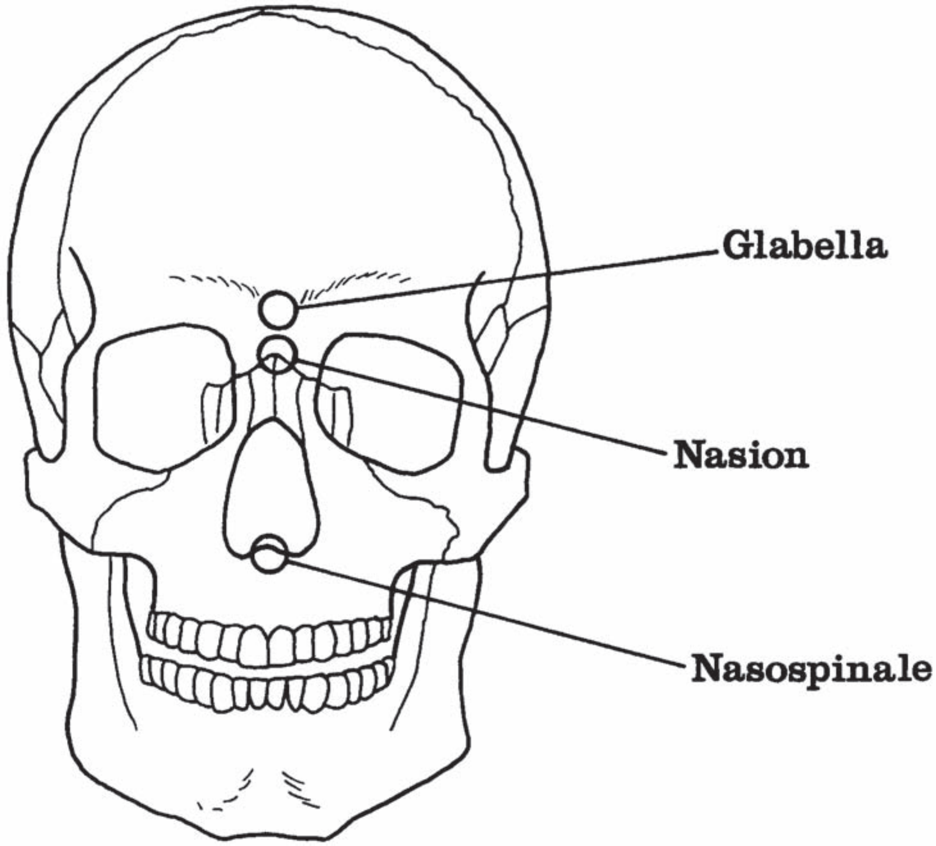


*Figure 4.2* Anterior view of skull, showing glabella, nasion and nasospinale

maximum projection of the skull in certain directions. For example, the glabella is the most promi-nent point between the supra-orbital (brow) ridges at the midline (Figure 4.2). Many landmarks, particularly on the skull vault, are defined according to the points at which certain cranial sutures meet. For example, the bregma is defined as the intersection of the coronal and sagittal sutures (Figure 4.3); the nasion is defined as the midpoint of the suture between the frontal and the two nasal bones (Figure 4.2). Other landmarks are defined on the basis of the locations of anatomical features, such as bony crests for muscle attachment, or with respect to lines projected from them. For example, the nasospinale is the point at the midline lying on a line projected between the lowest parts of the pyriform (nasal) aperture (Figure 4.2).

As we saw in the last chapter, tooth measurements can be useful in sexing, particularly for immature skeletons; as will become clear they are also useful for population studies. Most measurements of the teeth are not defined in terms of anatomical landmarks. The two most commonly used dental dimensions are simply the widths of the crown in the bucco-lingual and the mesio-distal directions (see Chapter 3).

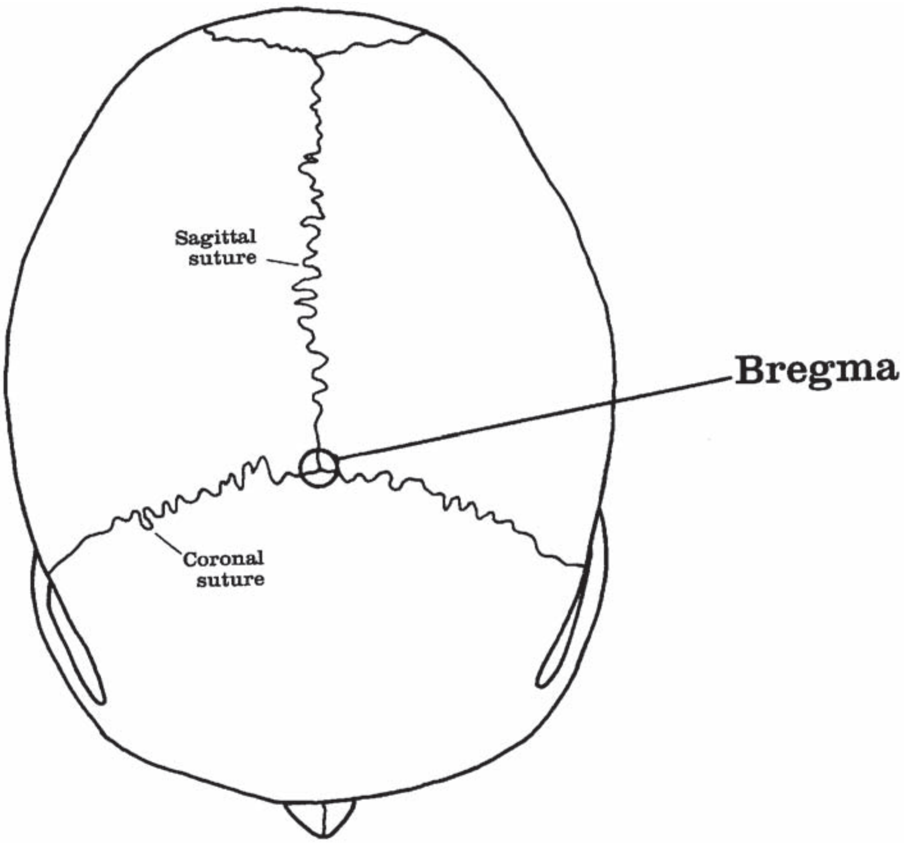


*Figure 4.3* Superior view of skull, showing position of bregma

## CAUSES OF VARIATION IN CRANIAL FORM

In order for us to interpret patterning in measurement data from ancient skulls, we clearly need to know something of what the causes of variation in cranial morphology are. We have already seen in Chapter 3 that age and sex are important determinants of skull form. In the growing child, the skull has yet to assume its final form, hence most population studies of craniometric data confine themselves to adult material. The differences between the sexes mean that craniometric data for males and females need to be analysed separately.

As will be shown below, genetic factors play a large part in determining cranial form, but non-genetic factors also have an influence.

### Non-Genetic Influences on Skull Form

Direct mechanical pressure on the growing skull may influence skull form. Some populations practise deliberate artificial cranial deformation by binding the heads of infants (Dingwall 1931). Some diseases may affect cranial form. For example, hydrocephalus (water on the brain) results in an enlarged, globular skull.

Diseased or artificially deformed skulls can simply be excluded from population studies of cranial morphology. However, there are other, more subtle, influences which need to be borne in mind when interpreting craniometric data. Major non-genetic influences on skull form include diet, nutrition and climate.

## Diet and Nutrition

Diet may be defined simply as what is eaten; nutrition is the value of that food to the body. Both may potentially influence skeletal form.

### Nutrition

As we saw in the last chapter, poor nutrition during development can affect the growth and final dimensions of the bones. Larry Angel (1982) formulated the hypothesis that the degree of flattening of the base of the skull in the adult might be an index of growth efficiency, which would in turn be influenced by health and nutrition during childhood. His reasoning was that this part of the skull supports the weight of the brain and head, therefore weakening of the growth of the bone in this area should result in a flattening of the skull base by compression. He investigated this idea by measuring cranial base height in skulls of recent origin, comparing data from a collection of skeletons of socio-economically deprived classes in the US, with those from skeletons of middle-class Americans. He found that the lower social group did indeed show greater cranial base flattening than the middle-class skulls.

Angel also measured cranial base height in ancient skeletons (Angel and Olney 1981), including those from Bronze Age Greece. He found that skulls from the Royal tombs at Mycenae showed a greater mean cranial base height than did those of their counterparts of lower social status. This suggests that, as one might anticipate in such a hierarchical society, the privileged elite enjoyed rather better childhood nutrition than did those further down the social scale.

The teeth are less vulnerable to environmental insults than the bones. However, as we saw in Chapter 3, poor nutrition during the growth period may influence dental dimensions.

### Diet

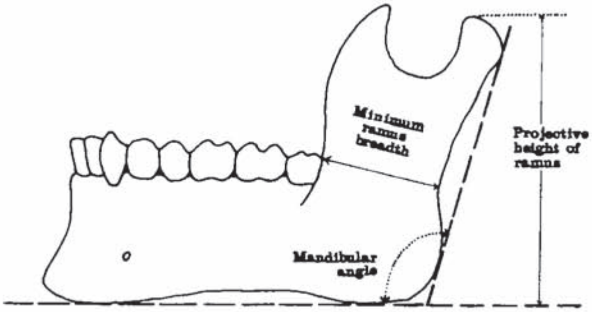
Wolff's Law tells us that bone mineral tends to be built up where it is needed and lost where it is not. This means that mechanical factors may influence the shape as well as the size or thickness of a bone. These observations apply to the skull no less than to any other part of the skeleton.

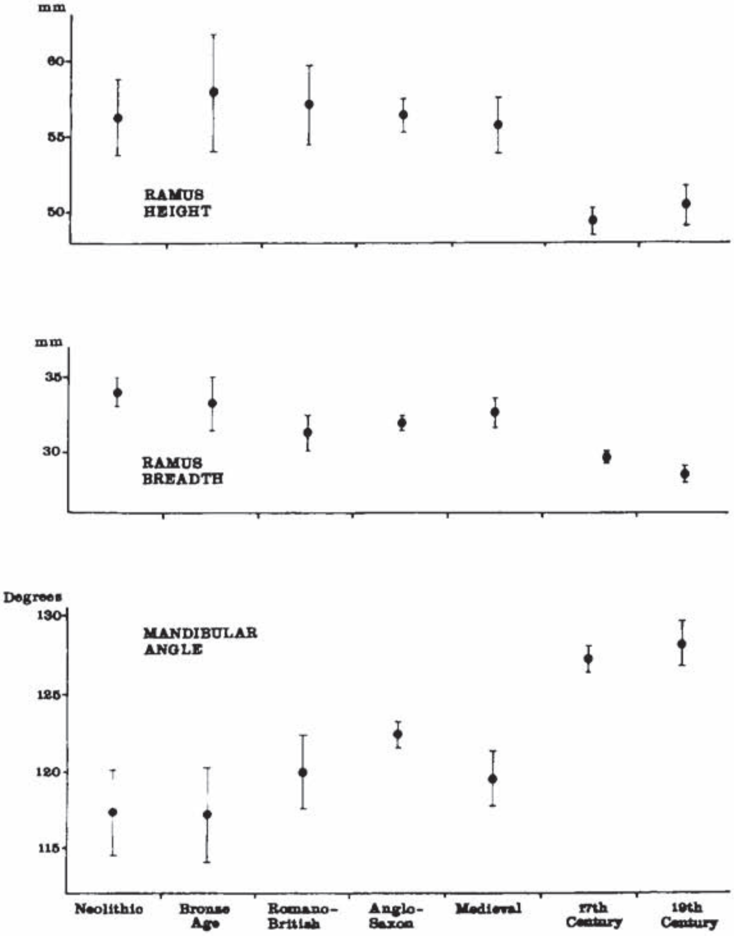
A major part of the mechanical forces acting on the skull arises from the action of the strong muscles involved in mastication (chewing). The tougher the consistency of the diet, the greater the bite forces required. This leads to greater development of the muscles involved in chewing, and thus to greater development of the bones of the facial skeleton associated with these muscles. This has been shown to be the case in scientific work using non-human primates which involved feeding them diets of different consistency (Corruccini and Beecher 1982).

Secular trends in craniometric data have also been understood from this perspective. For example, Moore *et al.* (1968) studied changes in the form of the human mandible in British populations from Neolithic *(c.* 3000 BC) to recent times. They found a general reduction in the size of the mandible over time, the greater part of this change occurring between the end of the medieval

*Figure 4.4* Three mandibular measurements, showing trends in British material from the Neolithic to the nineteenth century AD. The reduction in ramus dimensions is indicative of a reduction in the chewing muscles associated with this part of the jaw. The increase in the mandibular angle is probably partly associated with the reduction in the mandibular ramus, but also reflects a reduction in the development of the angular region itself where the powerful masseter muscle attaches

*Source*: After Moore *et al.* (1968: Figures 1, 3 and 4).


Minimum ramus breadth
Projective height of ramus
Mandibular angle


mm
60
55
50
RAMUS HEIGHT
mm
35
30
RAMUS BREADTH
Degrees
130
125
120
115
MANDIBULAR ANGLE
Neolithic
Bronze Age
Romano-British
Anglo-Saxon
Medieval
17th Century
19th Century

period and the seventeenth century. The trend was particularly pro-nounced for ramus breadth and height, and mandibular angle (Figure 4.4). These measurements relate to parts of the mandible where powerful chewing muscles attach. Goose (1962), studying the maxilla (upper jaw), likewise noted a reduction in dimensions between medieval times and the seventeenth century. The skeletal evidence therefore suggests a transition to a softer diet after the medieval period; this interpretation is supported by his-torical data. From the fifteenth

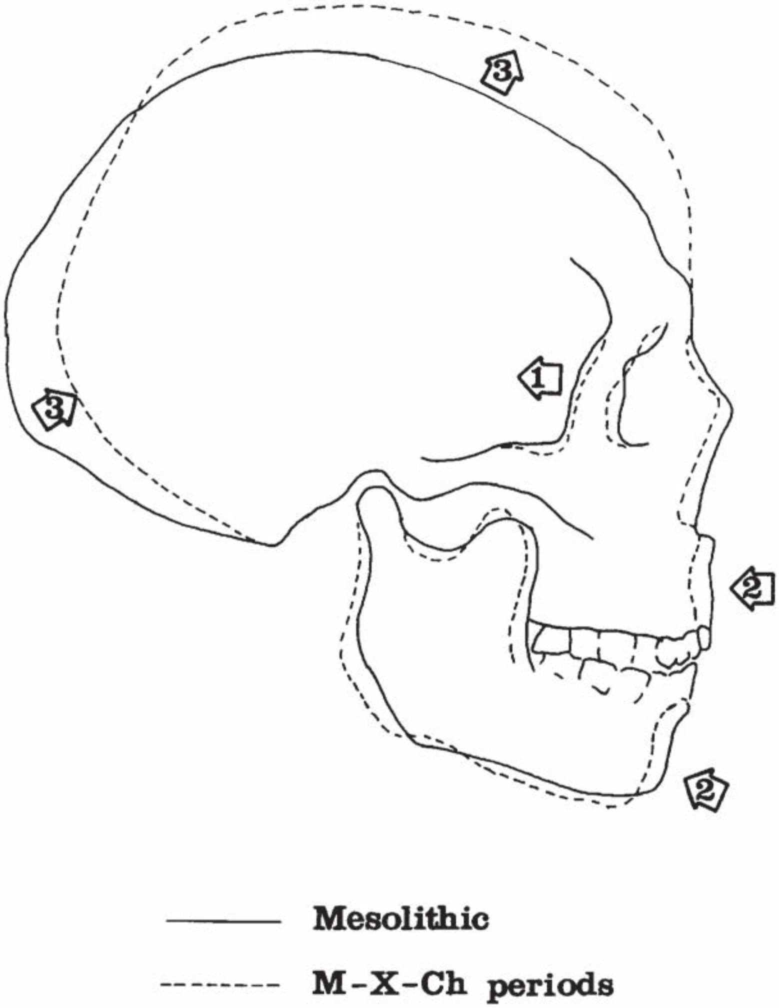


*Figure 4.5* Summary of cranial changes from Mesolithic to Meroitic/X-group/ Christian periods in ancient Nubia: (1) reduction in general robusticity, particularly in those areas associated with the muscles of mastication; (2) lower parts of the face become reduced in size, less robust and more 'tucked under' the cranial vault; (3) reduction in cranial length and increase in height
*Source*: After Armelagos *et al.* (1981: Figure 1A).

century AD onwards in Britain, an increasing proportion of the flour used in bread-making was prepared with the use of fine cloth sieves to remove coarse particles after grinding, By the seventeenth century it is likely that urban groups were generally consuming bread made from finely milled flour, in contrast to the coarse bran and rye breads which formed the staples for earlier populations. Seventeenth-century diets, at least in urban areas, were softer than previously, and this trend continued in following centuries (Moore and Corbett 1975; Corbett and Moore 1976).

Carlson and van Gerven (1977, 1979) studied crania from Nubia (northern Sudan and southern Egypt). They compared skulls of Mesolithic (*c.* 10,000 BC) hunter-gatherers with those of later groups who practised agriculture. The skulls from the post-Mesolithic periods showed differences in form from the earlier material, including an increase in the height and a decrease in the length of the cranial vault, together with a general decrease in robusticity, particularly of the areas such as the jaws and other facial bones directly associated with mastication (Figure 4.5). Carlson and van Gerven suggested that the reduction in robusticity could be understood in terms of a reduction in chewing forces, reflecting changes in diet and food-prepara-tion techniques associated with the advent of agriculture. The increase in height and decrease in length of the skull vault were viewed as compensa-tory changes to those in the jaws and other facial bones.

As was discussed in Chapter 1, tooth enamel, in contrast to bone, is not living tissue. Therefore, unlike bone, teeth cannot re-shape themselves to adjust to increased or decreased functional demands during an individual's lifetime. Nevertheless, tooth dimensions might be expected to change in populations over periods of time in response to selection pressures.

Tooth measurements taken from skeletal collections show that there has been a reduction in human tooth size world-wide during the course of human evolution, and that this reduction has been particularly rapid since the late Pleistocene (i.e. over the last 100,000 years or so). This may be a result of a progressive softening of the diet.

With a tough, coarse diet, wear on the teeth will be heavy. In these circumstances natural selection may tend to favour larger teeth, as these will wear down more slowly than small teeth. The mechanism of tooth reduction is still debated. Calcagno and Gibson (1988) maintain that a softer (and more cariogenic) diet may actively select for smaller teeth as, they argue, these may be somewhat less vulnerable to caries than are larger teeth. However, the American anthropologist C. Loring Brace considers that simple relaxation of selection pressure favouring larger teeth is sufficient explanation for reduction in tooth size (Brace 1964).

Brace has argued that the softening of the diet since the late Pleistocene may have been mainly due to changes in food preparation techniques rather than in the foodstuffs themselves (Brace *et al.* 1987, 1991). Over 200,000 years ago man learnt the use of fire. During the later Pleistocene, fire was used not only for warmth as the climate cooled and the ice sheets advanced, but also for cooking. Archaeological evidence shows that earth ovens, pits filled with hot stones, were used in Europe during this period for cooking food. Cooking ren-ders food more tender, meaning that less chewing was necessary. Brace suggests that the use of fire for cooking may mark the start of the process of dental reduction which is visible in the late Pleistocene, from about 100,000 to 10,000 years ago. European evidence suggests an average rate of reduction of about 5 $mm^2$ every 1,000 years during this period (Figure 4.6).

Brace suggests that the introduction of pottery may be an even more important milestone on the road to smaller teeth. Pottery vessels, which often appear in the archaeological record at the same time as the adoption of agriculture, meant that food could if desired, be converted to a drinkable consistency. In parts of the world where the use of pottery has a long history, the rate of tooth reduction since its introduction is approximately double that of the pre-pottery era. In Europe, pottery vessels have been used for about 8,000 years. Figure 4.6 confirms that the rate of dental reduction in Europe during this period is approximately double that in earlier times.

Brace points out that his theory is also consistent

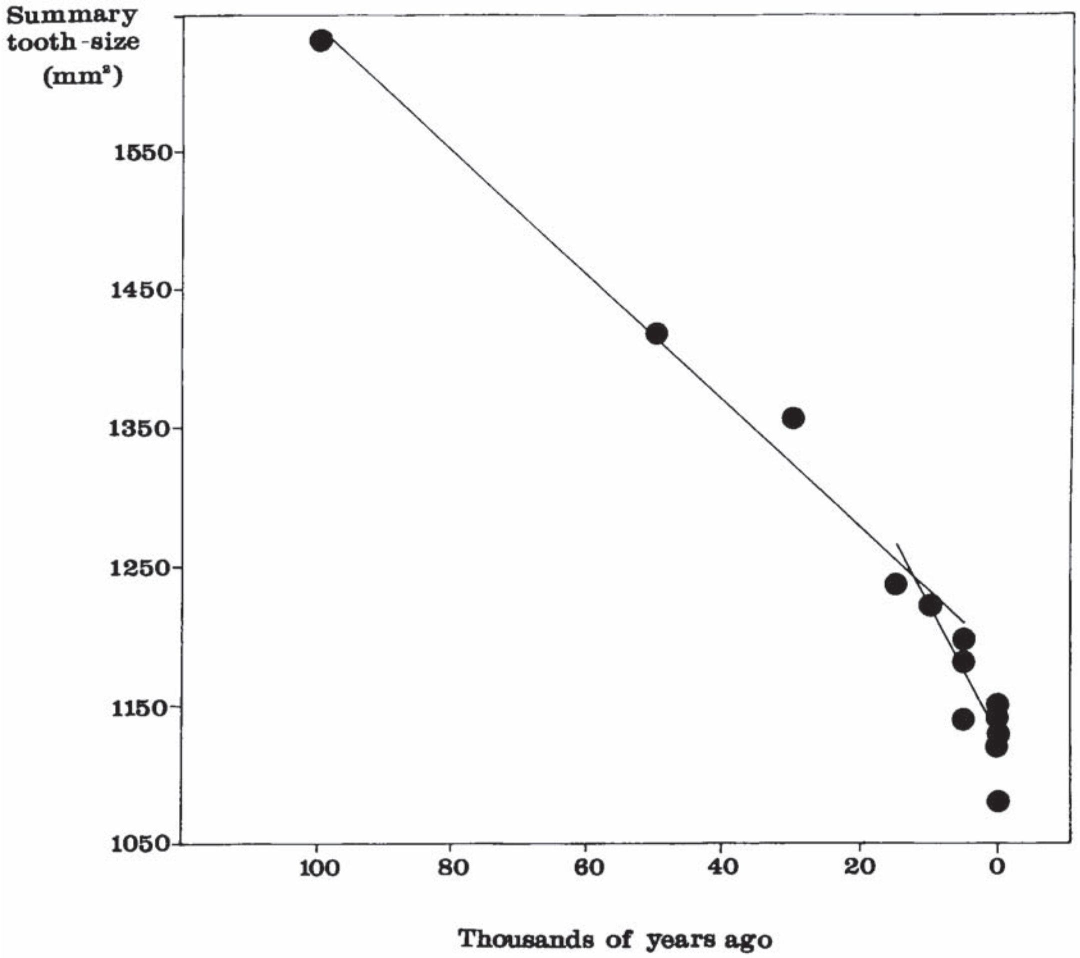


*Figure 4.6* Trends of dental reduction in Europe from the late Pleistocene to recent times. Summary tooth size is the product of bucco-lingual and mesio-distal tooth dimensions summed over the eight tooth types
*Source*: After Brace *et al.* (1987: Figure 2).

with some geographical patterns observed in tooth size. For example, Australian aboriginals have the largestteeth of any living population. The earth oven was adopted in Australia later than in most other areas of the world (about 30,000 years ago), and prior to European contact, pottery was unknown. The earliest pottery culture in the world is that of the Jomon people of Japan, who adopted it more than 12,000 years ago. Their likely modern-day descendants, the Ainu, show the greatest dental reduction of any world population.

## THE INFLUENCE OF CLIMATE ON SKULL FORM

Many of the physical differences between human populations around the world represent adaptations to regional climatic regimes. Skin colour is one obvious example, but some differences in cranial form can also be understood in terms of climate. In particular, it has long been argued that global variation in aspects of the shape of the human nose can be viewed as an adaptive response to regional climatic conditions.

An important function of the nose is to warm and moisten inspired air. When air is exhaled, some heat and moisture is lost to the surroundings. The longer the nasal passage, the more efficient the nose is for warming and moistening incoming air, and also the less heat and moisture are lost on exhalation. A narrow, high nose gives a longer nasal passage than a low, broad nose. Therefore, in cold or dry conditions, a high, narrow nose is preferable for warming and moistening air before it reaches the lungs, and for reducing loss of heat and moisture in expired air. In hot, humid conditions a low, broad nose better serves to dissipate heat (Wolpoff 1968; Franciscus and Long 1991).

Davies (1932) studied the nasal index in living groups around the world. In the living person, the nasal index is the ratio (expressed as a percentage) of the width across the nostrils, to the length measured between the root of the nose at the nasal bridge and the angle made by the nose and the upper lip. In other words, it is a measure of the width of the nose relative to its height. The results of Davies's study are mapped in Figure 4.7. The pattern of variation in nasal index corresponds very broadly to that expected if nasal form is indeed an adaptation to regional climate. The highest nasal index values, representing the broad, low noses, tend to be those of populations in the humid tropical regions of Africa and SE Asia. Populations with low mean nasal indices (high, narrow noses) tend to be found in the cold, northern latitudes, and also in arid regions, such as the desert areas of East Africa and the Arabian peninsula.

When measuring the nasal index in skeletons, the width of the nose is represented by the width of the pyriform aperture and the height by the chord between the nasion and the nasospinale (Figure 4.8). Davies found that the nasal index taken on the living was closely correlated with skeletal nasal index. This suggests that there should likewise be an association between skeletal nasal index and climatic zone, and indeed other workers have found this to be the case. For example, Newman (1953) studied nasal index in skeletal collections from the Americas. He found that populations with the greatest mean skeletal nasal index came from the humid tropics of Central America, with values decreasing with increasing latitude north and south, reaching a minimum in the Arctic.

## GENETIC FACTORS AND CRANIAL FORM

Despite the influences on cranial form of extraneous factors such as climate and diet, the most common use to which craniometric data have been put is to study population history. For this to be a valid strategy there must be a reasonable genetic contribution to population variation in cranial morphology. Evidence for a genetic component in cranial variability comes from family studies and from studies of human populations whose genetic relationships with one another are known or can reasonably be inferred.

### Family Studies

It is a commonplace observation that members of the same family tend to resemble one another in facial features. It should therefore come as no surprise to learn that the form of the skull bones, the architecture which underlies, and to a large extent determines the features and shape of the face and head, does indeed have a strong inherited component.

Family studies of skull form have been done by measuring the heads of volunteers, or by X-raying people's heads and taking measurements from the radiographs. Reviewing the literature, Kohn (1991) indicates that a high degree of inheritance in skull measurements has been a consistent finding. This would seem to indicate that there is a firm founda-tion, at least, for using craniometry to investigate biological relationships between human groups.

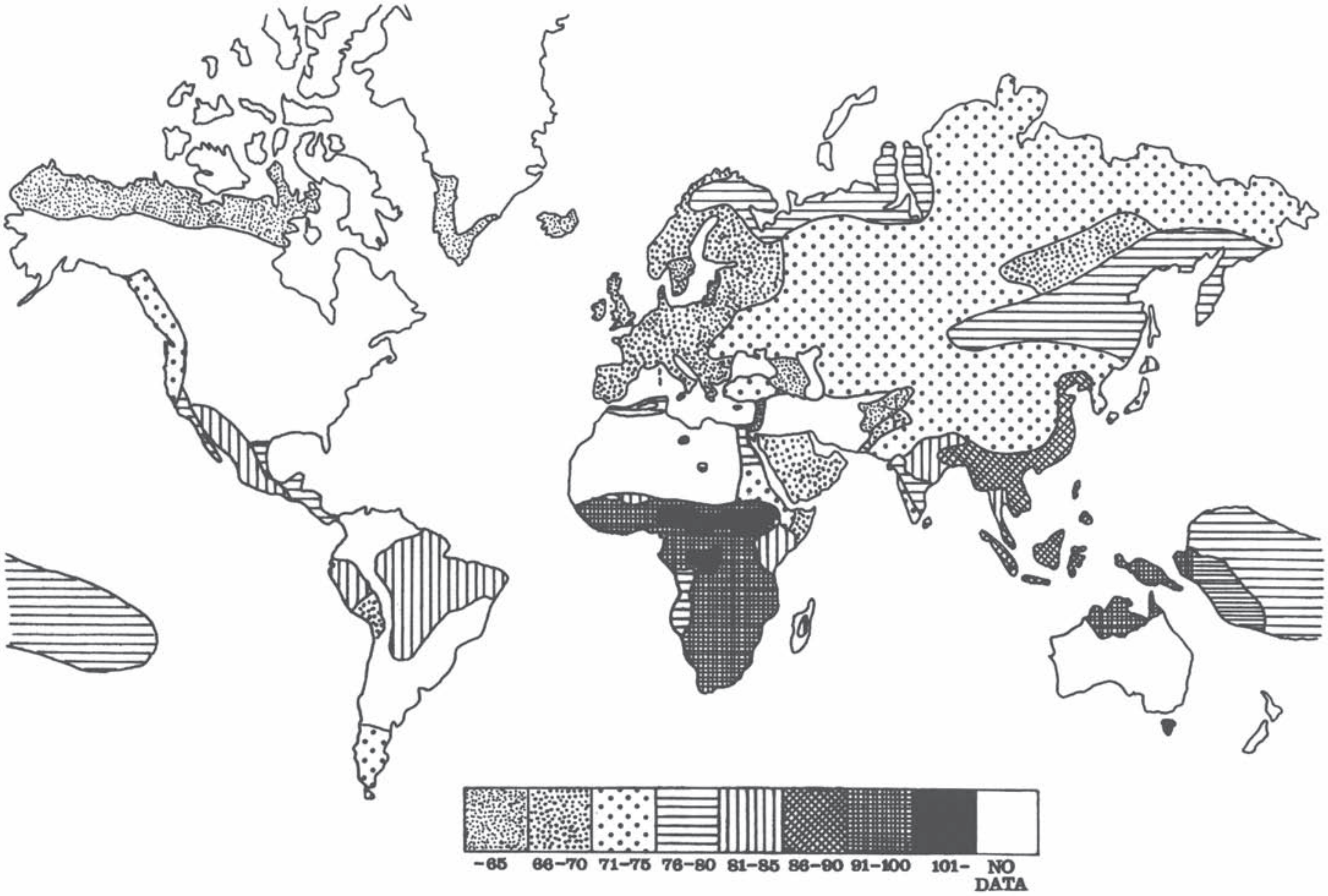


*Figure 4.7* Nasal index taken on living populations around the world

*Source*: After Davies (1932: Map 1).

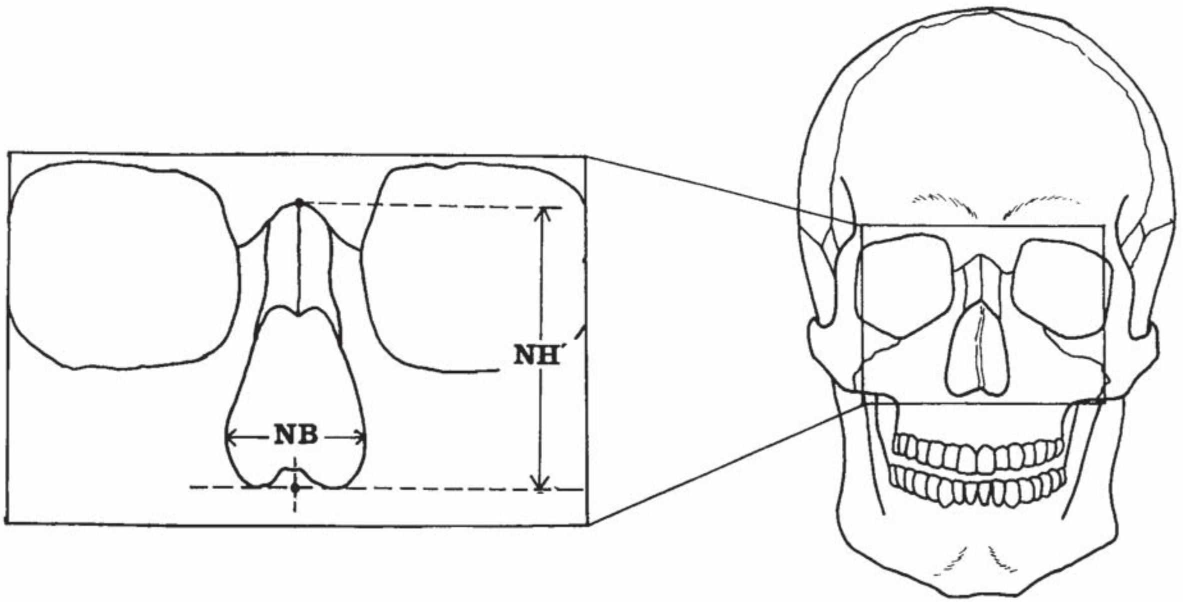


*Figure 4.8* Anterior view of skull, showing nasal area and method of taking nasal index. Nasal index is 100 × (NB/NH′)

## Population Studies

Richard Spielman and Peter Smouse, two American geneticists, studied nine head and three other measurements in living Yanomama Indians from southern Venezuela and northern Brazil (Spielman and Smouse 1976). The study populations lived in a number of different villages, scattered over an area of about 200 by 300 kilometres. The geneticists classified these settlements into nine clusters. These clusters were geographical or were of villages known to have been the product of recent settlement fission. It was found that individuals from different village clusters were distinct from one another in terms of measurements. This difference between clusters was great enough that an individual could be assigned to the correct village cluster on the basis of the measurements taken in nearly 60 per cent of cases. Had it been possible to study bone measurements instead of ones which included soft tissue, it is likely that this figure might have been improved upon, as soft tissue thicknesses are likely to show more random idiosyncratic variation between individuals.

Salzano *et al.* (1980), studying groups of indigenous peoples from another part of South America, found a strong correlation between biological relationships between groups revealed by biochemical genetic markers, and ones based on anthropological measurement data. Vecci *et al.* (1987) conducted a similar study on groups from southern Mexico, and came up with similar results.

Rightmire (1976) studied data from a rather wider geographic area. He looked at skulls from six different human groups from southern and eastern Africa. Historical, linguistic and other non-osteological data suggested that these populations were related to one another in the manner shown in Figure 4.9. He used 15 cranial measurements to generate the results reproduced in Table 4.1. The numbers in the table are a measure of how similar the crania from the different groups are over the whole suite of measurements, the lower the number the more similar the skulls.

The skull measurements show a close affinity between the two east African groups (i.e. the value of the distance statistic between Rundi and Rwanda is low), and these two groups are more distant from the Zulu, Xosa and Sotho skulls than from the Venda. Among the southern African populations, the closest relationship is between the Xosa and the Zulu. These findings tally closely with the relationships inferred from the linguistic and other non-osteological data depicted in Figure 4.9.

*Table 4.1* Values for Distance Statistics (Mahalanobis $D^2$) Between Six African Populations Derived from 15 Cranial Measurements

| | *Rundi* | *Zulu* | *Xosa* | *Sotho* | *Venda* |
|---|---|---|---|---|---|
| Rwanda | 2.16 | 8.23 | 6.10 | 6.71 | 3.80 |
| Rundi | — | 6.91 | 8.64 | 11.35 | 3.45 |
| Zulu | — | — | 1.96 | 2.16 | 3.96 |
| Xosa | — | — | — | 2.46 | 3.42 |
| Sotho | — | — | — | — | 5.38 |

*Note*: Figures from Rightmire 1976: Table 2. The Rwanda and the Rundi are from East Africa, the other groups are from South Africa.

The results of studies like these confirm the potential value of cranial measurements for investigating relationships between ancient populations.

## The Use of Measurements of Skulls from Archaeological Sites to Investigate Ancient Migrations

### Theoretical Aspects

The study of change in prehistory has long been central to archaeology. Archaeologists have employed a variety of theoretical models in order to try and explain important changes in the archaeological record in aspects such as subsistence strategy, material culture or burial practices.

Until the 1960s, the tendency was to ascribe innovation in these spheres to the influence of more ‘advanced’ peoples. In Europe, most innovations were thought to owe their origins to influences from the civilisations of the Near East. Often the nature of these ‘influences’ was not specified, but in many cases

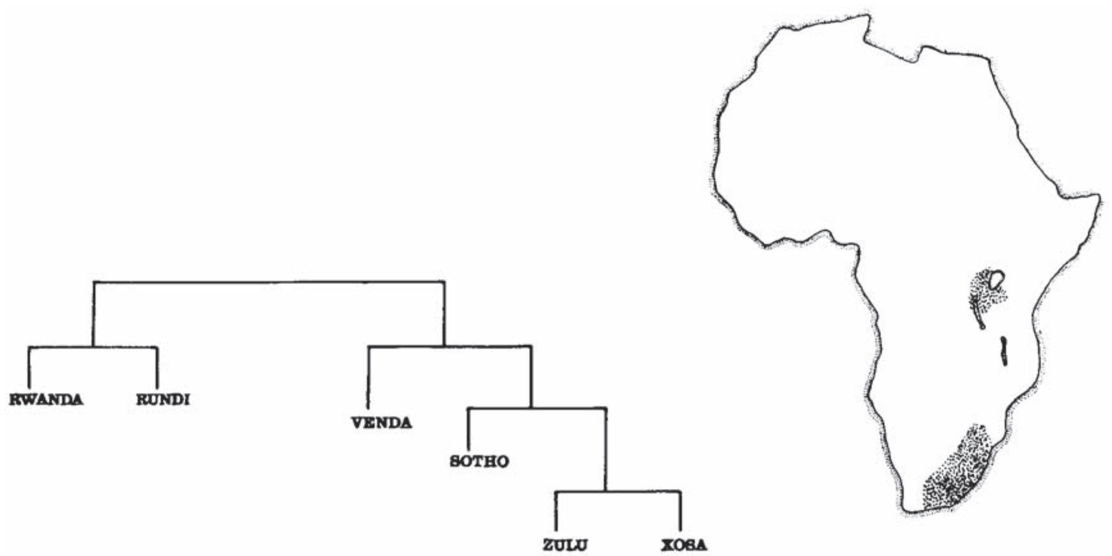


*Figure 4.9* Schematic representation of relationships between six African populations as suggested by linguistic, historical and other non-osteological data. Rwanda and Rundi are from the Lake Victoria region of east Africa, the other populations are from southern Africa, as indicated on the map
*Source*: From Rightmire (1976: Figure 1).

changes were ascribed to invasion or immigration of foreign peoples. Large-scale movements of peoples might be expected to leave some trace in the skeletal record, so during this period physical anthropology made a central contribution to archaeology, as skulls were measured in an effort to find evidence for ancient migrations.

Since the 1960s, migrationism as a general explanatory framework has been in retreat in archaeology as practised in many areas of the world (Adams *et al.* 1978), and there has been a concomitant decrease in interest in craniometric studies aiming to investigate past population movements. The reasons are to a large extent related to changes in archaeological theory.

The changes in archaeological theory were sparked by a revolution in archaeological science—the development of radiocarbon dating in the 1950s and 1960s. This provided, for the first time, a reliable method of absolute dating for prehistoric remains. In Europe, this showed that many of the innovations traditionally ascribed to the influence of Near Eastern civilisations, such as the building of megalithic communal tombs in areas bordering the Atlantic and North Sea, in fact predated their supposed prototypes in the eastern Mediterranean (Renfrew 1973).

Radiocarbon dating did much more than provide empirical evidence against some specific instances where migrations or other 'influences' were invoked as explanations for culture change. The 'radiocarbon revolution' also prompted archaeologists to re-think their whole approach to understanding change in prehistory. There was a general realisation that explanations for culture change were likely to be very much more complex than simple migrations and replacements of peoples. This was part of a growing movement, influenced by the American 'New Archaeology', away from particularistic approaches to the past, which ascribed changes to unique historical events (such as migrations), to per-spectives which placed an emphasis on attempting to understand process. These processes might be external to the population under study, such as exchange of goods with neighbouring or distant groups, environmental change or population pressure. On the other hand, they might arise from within ancient societies, for example tensions between the rulers and the ruled. In this new theoretical environment, the possibility that migration of peoples might sometimes account for changes observed in the archaeological record was not so much refuted as simply ignored (Adams *et al.* 1978). Nevertheless, ancient migrations and population history in general are important areas of academic enquiry, and, as we shall see, form a core part of archaeology in many countries. Because genetic factors make a major contribution to skull form, craniometry is a good way of studying these aspects.

## Methodological Considerations

If we only wish to study one particular part of the skull, and how it differs among assemblages, then perhaps only a few or even a single measurement need be taken on each specimen—for example as we saw above, informative results were obtained by Moore *et al.* (1968) on the British mandibles using only a few measurements. However, if the aim is to investigate population history using craniometry, a more exploratory approach is generally used, in which a number of skull measurements are taken in order to gain a general impression of cranial morphology. In theory, the more measurements one takes, the better the description of skull form. Indeed, this sort of reasoning prompted von Török, at the end of the nineteenth century, to suggest that over 5,000 measurements should be taken on each skull! (Howells 1969). However, skull measurements tend, to a greater or lesser extent, to be correlated with one another. The correlations between measurements mean that there is a certain degree of redundancy of information between them. A 'law of diminishing returns' tends to set in as one measures more and more cranial dimensions. It has been shown (e.g. Hanihara 1993) that when comparing ancient skeletal series, a relatively restricted number of dimensions (about 10–30) often gives results very similar to those obtained from much larger batteries of measurements.

## Statistical Techniques

The number of measurements taken on each skull clearly affects the statistical methods needed to analyse the results most effectively. When dealing with a single measurement or index (one measurement divided by another), univariate statistics, such as means and standard deviations, can be used to sum-marise the data. Early work on cranial form in ancient populations, even when the writers took large numbers of measurements, tended to compare populations on each measurement in turn using univariate statistics. In the early twentieth century, multivariate statistical techniques, which can deal with more than one variable at a time, were developed. Calculating multivariate statistics by hand is extremely tedious and time-consuming, so it was only when computers became more widely available in the 1960s and 1970s that multivariate analyses began to make a widespread impact on craniometry.

A variety of multivariate techniques have been used in craniometric studies. Among the more common ones are principal components, discriminant function and cluster analyses.

As has already been mentioned, many skull measurements are correlated with one another. Principal components analysis uses this correlation between measurements to produce a new set of variables (or axes) which are uncorrelated with one another. These axes are composites of the original variables, and to a certain extent are interpretable in terms of combinations of the raw measurements. The first new axis accounts for the most original variance, the second the second most, and so on. There are as many new axes as there were original variables, but in many cases the first few axes account for most of the original variance, and hence should provide a simplified, but still valid summary of the data. In this way the visualisation of any groupings or patterning in the data may be facilitated.

Unlike principal components analysis, discriminant function analysis requires that groupings exist within the data, and that which skulls or assemblages belong to which groups be known before-hand. Discriminant function analysis produces a new set of independent variables from the original measurements but, unlike principle components, these new variables are constructed from the raw measurements in such a way as to maximise the separation between the groups.

Cluster analysis is a generic term for an array of techniques which aim to find groupings in a collection of objects. In the type of cluster analysis most often used in craniometry, a similarity coefficient, which measures the similarity between skulls or assemblages across the whole battery of measurements taken, is calculated. Alternatively, the inverse of a similarity coefficient, a distance statistic, may be used (see Table 4.1). Similarity data may then be displayed as a dendrogram, a sort of family tree representing the similarities between the skulls or assemblages.

### Choice of Measurements

The question now arises as to how one chooses what skull measurements to record if one's purpose is to reconstruct biological relationships between ancient human populations. There are several principles to bear in mind. Firstly, it would clearly be preferable to use a suite of measurements which cover the various different regions of the skull, rather than to concentrate on one particular area to the exclusion of others. Spreading one's measurements over the different areas of the skull enables one to derive a better overall picture of cranial form. This helps us to understand which cranial areas differ between populations under study and which are similar.

For some assemblages, the range of measurements which can be taken is restricted by preservation factors. For example, in poorly preserved collections the facial bones, being generally more fragile than those of the cranial vault, may not survive, forcing one to concentrate on measurements of the skull vault.

It is helpful to concentrate mainly on dimensions which have little functional or adaptive significance. If one studies aspects of skull form which *do* have important adaptive value, then populations would tend to group into those which had similar environments or diets, etc. By contrast, if we concentrate on traits which have little adaptive significance, we might expect that the similarity between the two groups will be proportional to the time elapsed since they shared a common ancestor—i.e. the similarity on these measurements will be a measure of the genetic relationship between the groups (discussion in Brace and Hunt 1990).

In reality, bone measurements cannot be neatly divided into those which are of adaptive significance and those which are not. Rather, they grade in a continuum from those which are clearly functionally and adaptively important, to those which have no demonstrable value. However, this does give some basis upon which to make decisions concerning choice of variables, and it also needs to be kept in mind when interpreting the results of craniometric studies. For example, to study biological relationships between world populations it would not be desirable to concentrate on measurements of the mandible or nasal area, since the form of these areas appears to be heavily influenced by diet and climate respectively. By contrast, some upper facial dimensions may be relatively little affected by environmental factors, and so be better for population historical studies. It may be useful, though, to include some diet- or climate-influenced traits, as these can act as markers, helping to flag up instances where climate or diet may be playing a part in general cranial differences or similarities between populations.

What follows now are two examples of the application of craniometric studies to investigate ancient migrations. These studies, taken from Japanese and British archaeology, are followed by a discussion of the value and limitations of the bone data in each

## The Yayoi Culture of Japan

During the Jomon period (*c.* 10,000–300 BC), the Japanese archipelago was populated by human groups with a mainly hunter-gatherer life-style. Although some agriculture does seem to have been practised in Jomon times (Anderson 1987), it was not until the Yayoi period (300 BC-AD 300) that the transition to a fully agricultural subsistence strategy was made (Higuchi 1986). During the Yayoi period, intensive rice agriculture was practised. In addition, there is evidence for a number of important technological innovations, such as metal-working, wheel-made pottery and weaving (Higuchi 1986). There is also evidence of increased social differentiation at around this time. Rice is not native to the Japanese islands and so must have been introduced from mainland Asia where it was cultivated before its appearence in Japan (Kagawa 1973). Against this background, the question arises as to whether intensive rice agriculture and other aspects of the Yayoi cultural package were introduced to Japan by immigrants from the Asian mainland, or whether they were simply adopted by the indigenous peoples of the Japanese islands without significant ingress of population. The study of human skeletal remains has made a significant contribution to this problem, as well as to more general questions concerning Japanese population history.

Craniometric studies (e.g. Brace *et al.* 1989) have shown that, compared with the Yayoi, Jomon skulls tend to have lower, broader faces, narrower noses, and they tend to be generally more robust, with pronounced brow ridges (Figure 4.10). Although these differences are well established, there has been much debate over their interpretation and meaning for Japanese population history. Some (e.g. Kanaseki 1986) have interpreted the change in cranial form as supporting the hypothesis of Yayoi immigrants. Others (e.g. Suzuki 1969) have attributed it primarily to cultural factors acting on the indigenous population. For example, the greater robusticity of the Jomon crania might be because these (primarily) hunter-gatherers ate a coarser diet than the rice-agriculturalists of later periods. Given the generally coarser diet of hunter-gatherers compared to farmers (see the Nubian example, p. 80–81) this is not an unreasonable argument. Other aspects of the changes observed (for example in the morphology of the nasal area) might be interpreted in climatic terms.

Recent work by Takahiro Nakahashi of the University of Kyushu has provided support for the immigration hypothesis (Nakahashi 1993). He studied Japanese crania dating from the Jomon period to recent times. The skulls came from an area of south-western Japan comprising northern Kyushu and the western tip of Honshu (Figure 4.11). These areas are important for the present purposes, as they are the parts of Japan which lie closest to the rice growing areas of China and Korea, and hence are the logical places to start looking for evidence of rice-farming immigrants from the mainland. Using the south-western Japanese material, Nakahashi confirmed the differences between Jomon and Yayoi skulls discussed above. He compared his results with data previously published (Suzuki 1969) for crania from the Kanto region of eastern Honshu (Figure 4.11). The Kanto material did not show the marked change in skull morphology between the Jomon and Yayoi periods which characterised the south-western crania. During the Jomon period cranial form is similar in the two regions, but the marked change in morphology in the south-west means that the Yayoi skulls here are very different from those excavated from the Kanto area. This pattern is illustrated for upper facial index in Figure 4.12. Nakahashi states that evidence for rice agriculture, a major feature of the Yayoi cultural package, is not confined to Kyushu and western Honshu but seems to have spread quite rapidly though Honshu during the Yayoi era. He thus argues that if cultural factors (i.e. diet) were important causes of the changes in skull morphology, similar morphological changes might be expected in the Kanto region. That these were not found suggests that immigration of peoples from mainland Asia to SW Japan is a better explanation of the osteological data. Nakahashi's study would also seem to suggest that Yayoi culture may have spread from the western part to other regions of Honshu without any great additional movement of peoples, at least initially.

Work conducted using crania from other countries in the region also appears consistent with Yayoi immigration into Japan. Brace *et al.* (1989) conducted a craniometric study of various groups of skulls from east

*Figure 4.10* Japanese Jomon (top) and Yayoi (bottom) skulls
*Source*: After Brace and Nagai (1982: Figures 1 and 2).

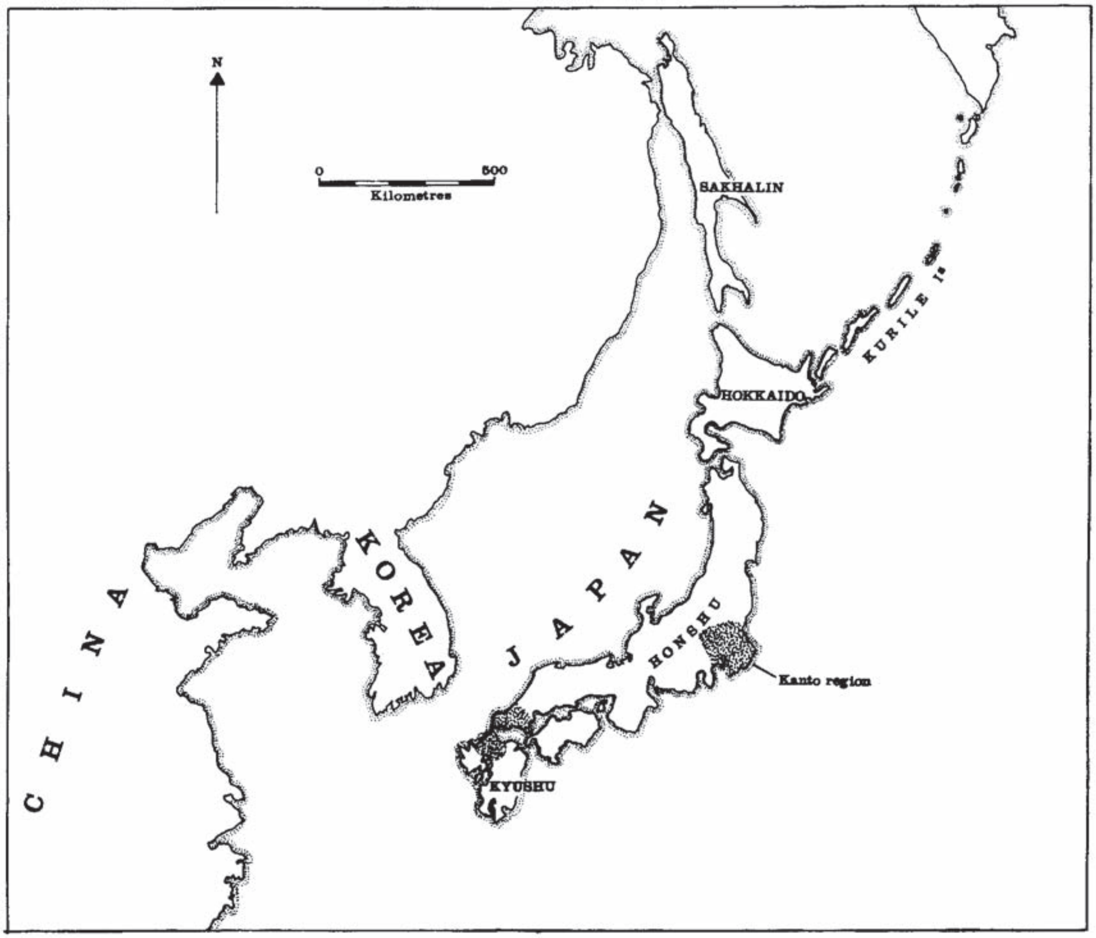
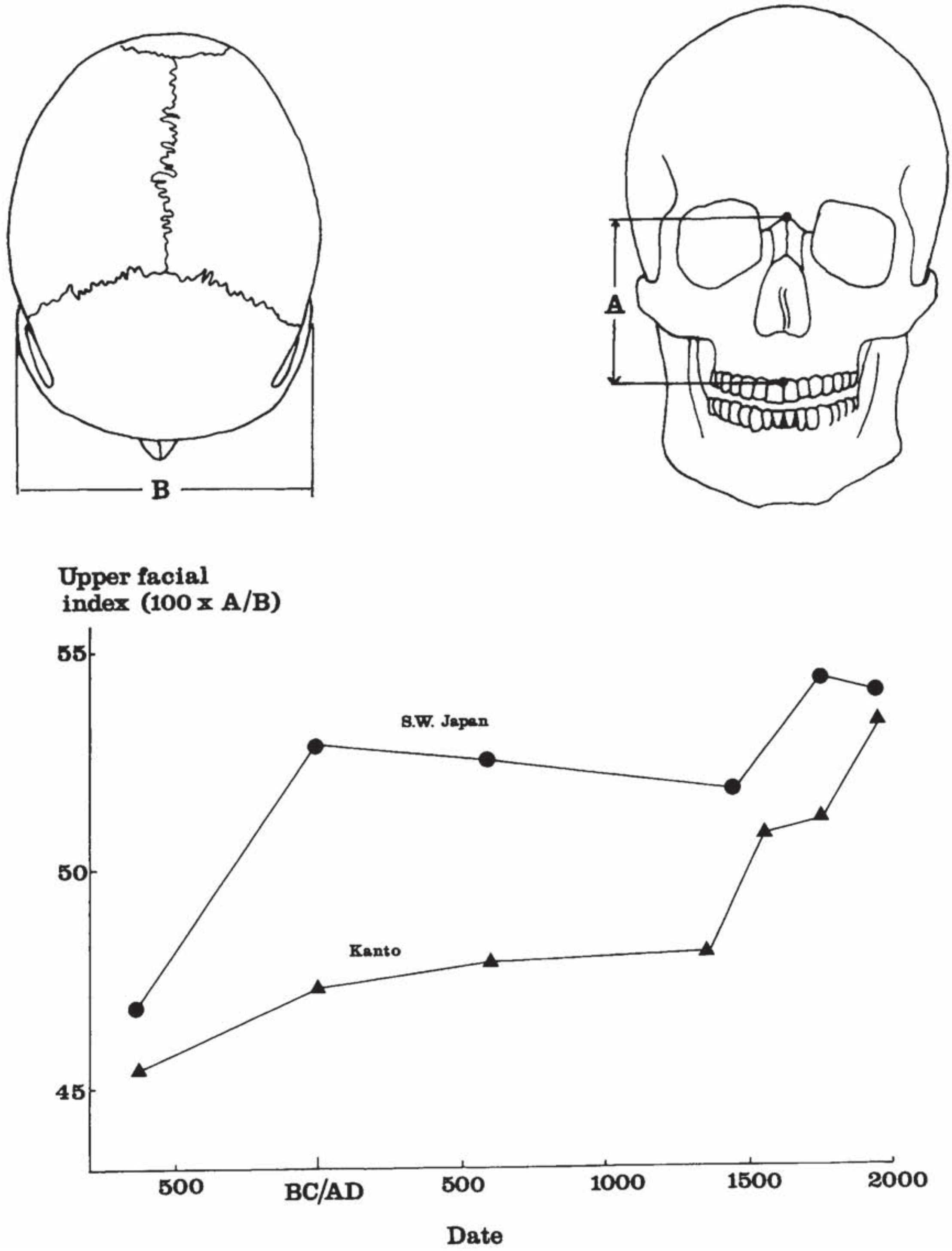


*Figure 4.11* Map of Japan. Stippling indicates the area of south-western Japan where the crania studied by Nakahashi (1993) came from, and the Kanto region where the material studied by Suzuki (1969) was found

Asia and the Pacific. Japanese material examined included that from the Jomon and Yayoi periods as well as from modern ethnic Japanese. They also studied Ainu crania. The Ainu are a distinct ethnic group, presently concentrated on the northern Japanese island of Hokkaido, as well as in the former Japanese territories of Sakhalin and the Kurile Islands. The Ainu are the aboriginal inhabitants of Hokkaido and perhaps of other parts of the Japanese archipelago. In their study, Brace *et al.* (1989) used 18 measurements of the face and skull

*Figure 4.12* Temporal changes in upper facial index for south-western Japanese material and skulls from the Kanto region from Jomon to modern times. Note the marked change in the Yayoi period in the south-western skulls which is lacking in the Kanto material

*Source*: Drawn from figures presented by Nakahashi (1993) and Suzuki (1969).


B
A
Upper facial index (100 x A/B)
55
50
45
S.W. Japan
Kanto
500
BC/AD
500
1000
1500
2000
Date

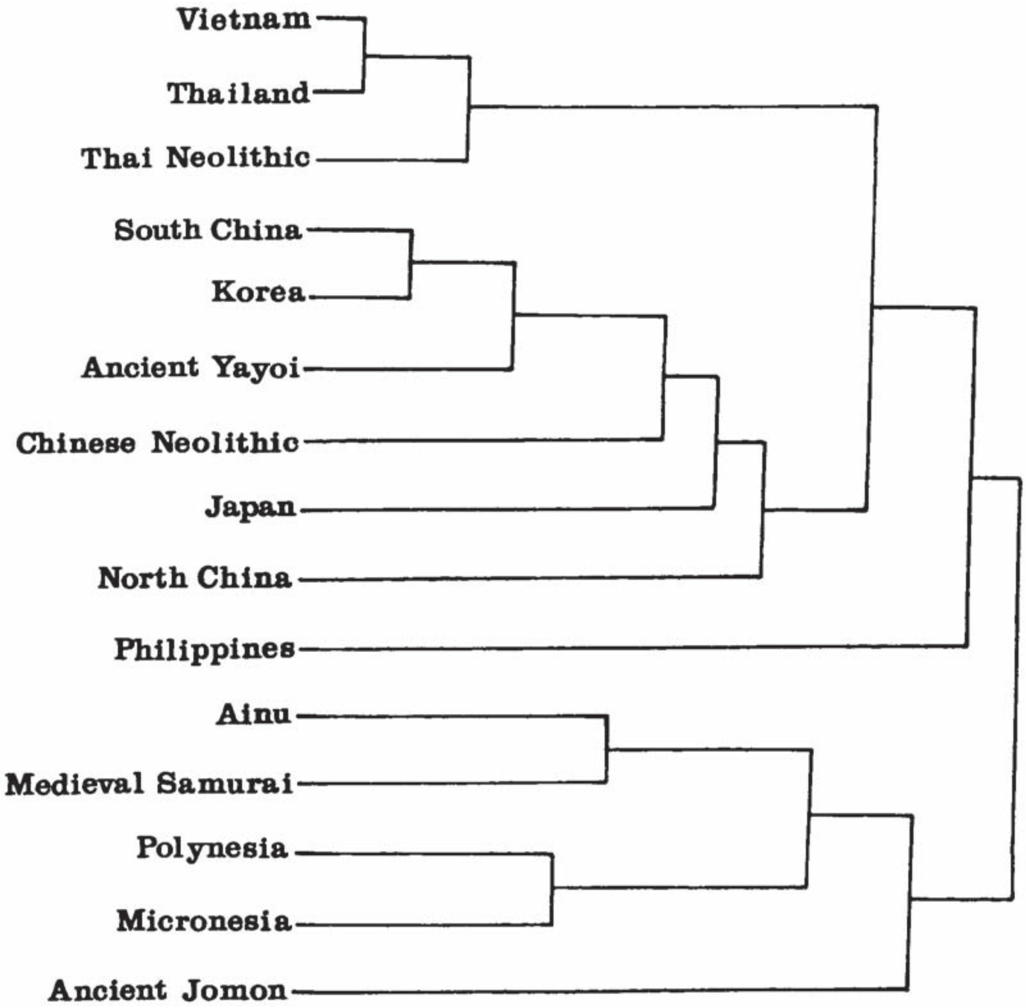


*Figure 4.13* Dendrogram from cluster analysis of measurements from Far Eastern and Pacific skulls. All material is of recent origin unless stated
*Source*: After Brace *et al.* (1989: Figure 3).

vault. Using a cluster analysis, they showed that the Yayoi grouped with skulls from modern Japan and with Chinese and Korean material. The Jomon and Ainu crania were separated from this material in a different cluster (Figure 4.13). This would appear to support the hypothesis that the Yayoi represent immigrants from the Asian mainland. The Ainu are traditionally thought to be descendants of the Jomon people. The craniometric data are consistent with this.

Brace and Nagai (1982) conducted a study of dental dimensions of Far Eastern populations. They measured teeth from Yayoi skulls from south-western Japan, and teeth of Jomon and recent ethnic Japanese, as well as some from mainland Asian populations. Some of the results are shown in Figure 4.14. As was disscused earlier

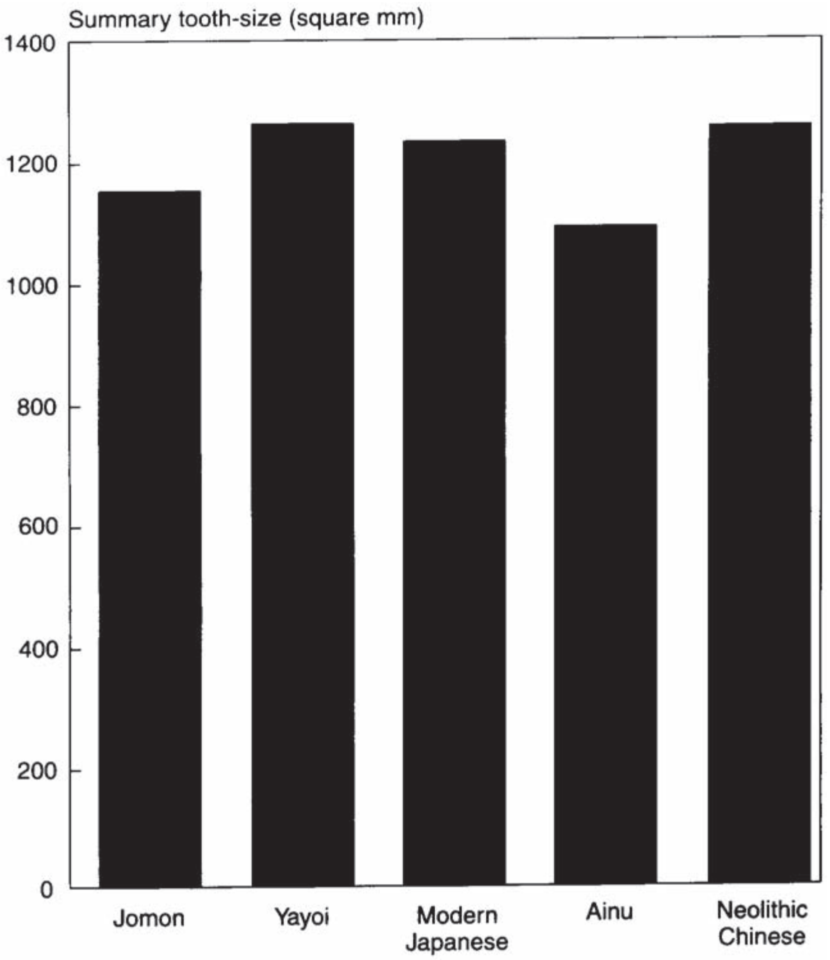


*Figure 4.14* Summary tooth size from Japanese and Chinese samples
*Source*: Based on figures given in Brace and Nagai (1982).

in this chapter, Brace has argued that reduction in tooth size is a fairly universal trend in human history. However Figure 4.14 shows that this does not seem to hold for Japan. The ancient Jomon have smaller teeth than do groups from the succeeding Yayoi period, and are also smaller than those of modern Japanese. Brace and Nagai suggest that on this basis it is unlikely that the Yayoi or more recent Japanese are descended from the Jomon; the pattern would be much more consistent with the Yayoi being immigrants. The reduction in tooth size between the Yayoi period and recent times is in line with that which might be expected as a secular trend within a single population, although there might equally be a contribution to the reduction by admixing with the smaller-toothed Jomon people. Brace and Nagai note that the Yayoi teeth were similar in size to those from the Chinese Neolithic, supporting the idea that the Yayoi folk might be immigrants from the Asian mainland. The data are also consistent with the idea that the Ainu are descendants of the Jomon people.

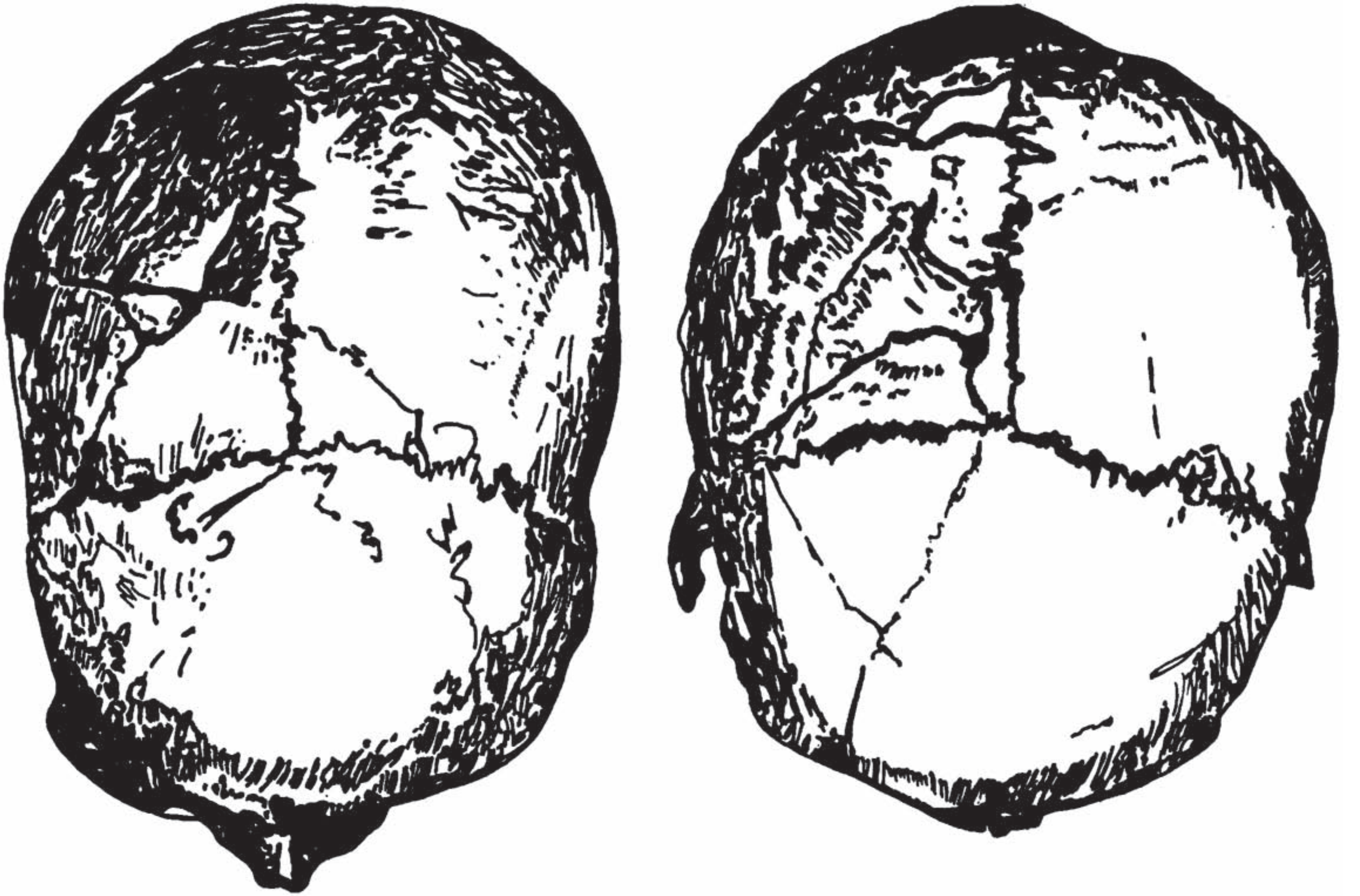


*Figure 4.15* Superior view of typical long-headed Neolithic skull (left) and round-headed Beaker skull (right). Both specimens are from Britain
*Source*: After Harrison (1980: Figure 105).

As we shall see in the next chapter, non-metric cranial and dental variants are under a significant degree of genetic control. Studies of non-metric skeletal variation support the craniometric data in suggesting immigration to the Japanese islands of people from mainland Asia at about 300 BC. Yayoi and more recent Japanese cluster together on the basis of cranial non-metric traits, and are distinct from the Jomon and Ainu (Dodo and Ishida 1990). There is an abrupt change in cranial non-metrical features in the skulls of the Yayoi period in south-west Japan, and the Yayoi skulls resemble those from the Chinese mainland in terms of their non-metric traits (Kozintsev 1990). Similar patterns have been reported for dental non-metric variants (Hanihara 1992).

## The Neolithic-Bronze Age Transition and the Problem of the 'Beaker Folk' in Britain

As we saw in Chapter 2, the predominant archaeologically visible burial rite in the southern British Neolithic involved collective burial in long barrows. However, there was a change in the third millen-nium BC, during the transition to the Bronze Age, as collective burial was replaced by individual burials beneath round barrows. Unlike the Neolithic burials, those of the early Bronze Age were generally accompanied by grave goods. A number of other changes are observable in the archaeological record at around this time, including the introduction of metalwork, and the advent of a new pottery style: finely made, elaborately decorated beakers.

In the traditional explanatory framework which dominated British archaeology until the 1960s, the changes observed in the archaeological record at the Neolithic—Bronze Age transition were ascribed to invaders or immigrants. This interpretation seemed to be supported by observations made of differences in cranial form between the skulls interred in the Neolithic communal tombs, and those of individuals buried beneath round barrows with Beaker pottery and other grave goods. As long ago as the mid-nineteenth century, the general pattern: 'Long barrows, long skulls; round barrows, round or short skulls' (Thurnam 1863:158) was noted. Indeed, the difference between Neolithic and Beaker period British skulls is visually striking (Figure 4.15).

In the 1960s and 1970s, migration or invasion hypotheses for the Beaker phenomenon rather fell from favour. New explanations, involving movements of goods rather than people, were offered. For example, it was suggested that Beakers represented 'prestige' or valued items, and that they may have been exchanged between elite social groups in Europe (Thorpe and Richards 1984; Thomas 1987). It has also been argued (Burgess and Shennan 1976) that the popularity of the Beakers may have been more to do with what they contained than with the vessels themselves. Burgess and Shennan argued that Beakers may have contained some sort of alcoholic beverage, such as beer or mead. This suggestion receives some support from findings from the study of pollen grains in residues from a Beaker which accompanied a burial from Ashgrove, Scotland (Dickson 1978). The pollen evidence was interpreted as indicating that the vessel contained a honey-based mead. Burgess and Shennan suggested that the Beaker phenomenon might be the material evidence for the spread of a drinking-cult in early Bronze Age Europe, analogous in some ways to the spread of the Peyote drug cult among North American Indians in the nineteenth century.

Explanations for the Beaker phenomenon advanced since the 1960s have tended to be mainly or entirely built around the artifactual data. Osteo-logical evidence is rarely discussed on an equal foot-ing with the other archaeological data—it is generally dismissed on the basis that environment may influence skull form, so cranial shape may change even in the absence of migrations. The specific non-genetic factors which might be responsible for the discontinuity in the craniometric data, and their merits as explanations of the data relative to migration hypotheses, are rarely considered.

The visual difference in skull shape between the long-headed Neolithic folk and the rounder-headed Beaker burials, noted since the nineteenth century, has been confirmed metrically, using the cranial index (the skull width divided by its length, multiplied by 100) (Table 4.2).

*Table 4.2* The Cranial Indices of British Neolithic and Bronze Age Skulls

| | | *Mean index* | *Number of skulls measured* |
|---|---|---|---|
| **Neolithic** | **Males** | 70.4 | 53 |
| | **Females** | 71.3 | 28 |
| | **Total** | 70.7 | 81 |
| **Bronze Age** | **Males** | 78.1 | 109 |
| | **Females** | 78.8 | 48 |
| | **Total** | 78.3 | 157 |

*Source*: Figures calculated from Brodie (1994: Table 8.4).

Multivariate analyses of the crania have also been attempted. Brothwell and Krzanowski (1974) studied 11 cranial measurements of Neolithic, Bronze Age and later burials. The measurements they used were all of the cranial vault, because in the material available to them few of the more delicate facial bones survived. They used a discriminant function analysis, and did indeed find a good separation between Neolithic and Bronze Age skulls (Figure 4.16).

Little further was done on the British Beaker phenomenon in the way of craniometric analysis until Brodie (1994) published a reconsideration of the problem. Unlike the case for Brothwell and Krzanowski 20 years earlier, enough skulls were available with intact facial bones for Brodie to take measurements here as well as on the cranial vault. He employed a battery of 20 measurements. Using principal components analysis, he corrobo-rated Brothwell and Krzanowski's finding of a distinction between Neolithic and Bronze Age skulls. He also noted that the differences between the Neolithic and Bronze Age skulls were essentially restricted to differences in vault length and breadth. It now remains to consider what the best interpretation of this change in skull form might be.

Many writers (e.g. Burgess and Shennan 1976) who have argued against migration as playing a significant role in the Beaker phenomenon in Britain, have emphasised that most British Neolithic bones come from early and middle Neolithic contexts. Several centuries separate them from the Beaker period. Plenty of time, they suggest, for change in skull form to occur in the absence of population movements. Brodie (1994) did have access to 11 late Neolithic crania. These gave a mean cranial index of 71.5, close to that for the other Neolithic skulls. On the face of it, this would appear to suggest that change in cranial index did indeed occur at or around the transition to the Bronze Age, but with so few late Neolithic skulls it is difficult to be certain.

It is true that changes in cranial form may occur in response to non-genetic factors over the sort of time-span which separates the bulk of the Neolithic skulls from the Beaker period. Indeed, studies of cephalic index (the analogue of cranial index taken on living individuals) in immigrants have shown that significant changes in this index can occur over one or two generations (Kobyliansky 1983). Work on skulls excavated from archaeological sites has shown that there was an increase in cranial index in Britain between the Saxon and medieval periods, despite little evidence of large-scale population ingress (Tattersall 1968; Brothwell 1972:92). There is also some evidence from other parts of western Europe for an increase in cranial breadth at about this time (Rösing and Schwidetzky 1984).

As has already been discussed, changes in the consistency of the diet may cause changes in cranial form. For example, Carlson and van Gerven (1977) observed a reduction in cranial length in their ancient Nubian material (see Figure 4.5), which seemed to be associated with reduced chewing forces as a consequence of a softer diet. Could a dietary change be responsible for the shorter skulls of the British Beaker period?

If a change to a softer diet did occur around the time of the Neolithic-Bronze Age transition, then we might also expect changes in the jaws and other areas directly associated with the chewing appara-tus (as was also found in the case of ancient Nubia). However Brodie (1994) found no changes in the maxillary and palate area, and when Moore *et al.* (1968) measured mandibles of Neolithic and Bronze Age date they found little difference between them (Figure 4.4). Although the other, non-osteological evidence for diet is scanty,

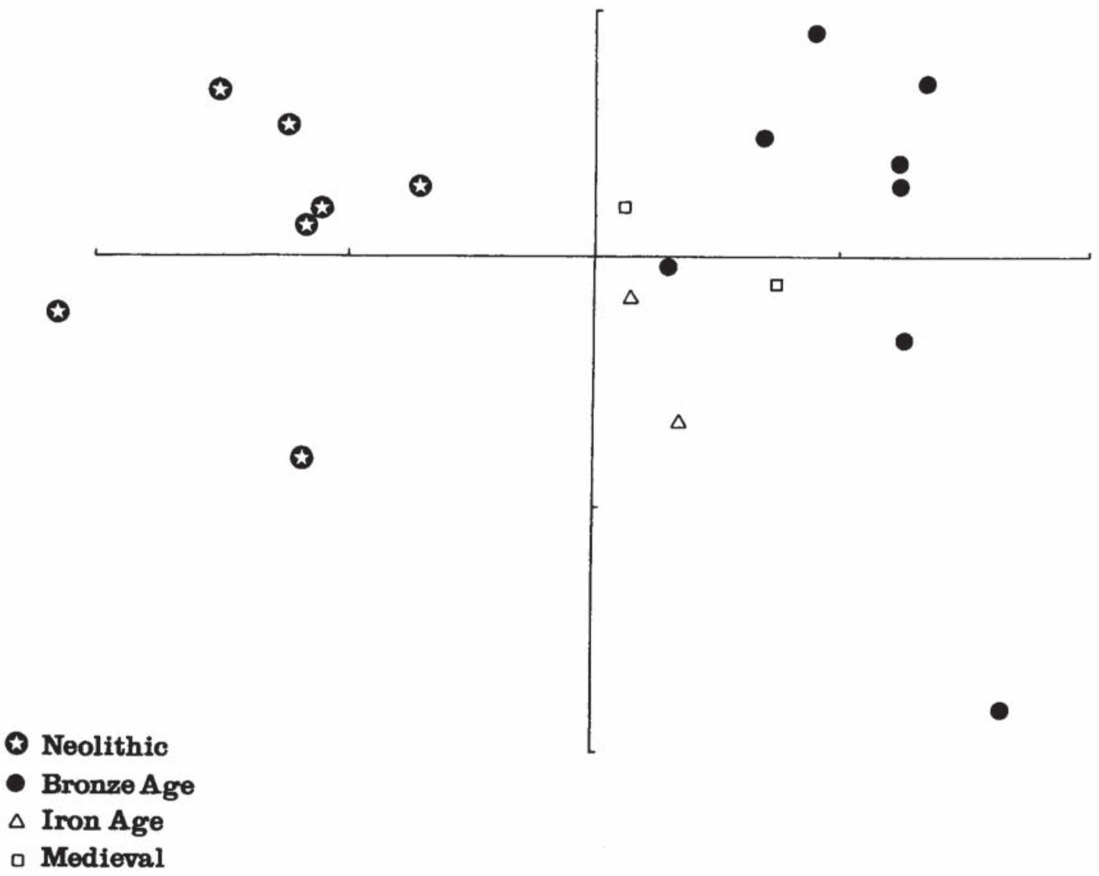


*Figure 4.16* First two axes of Brothwell and Krzanowski's discriminant function analysis of British skulls, showing results for Neolithic and Bronze Age skulls, and also for some later material
*Source*: After Brothwell and Krzanowski (1974: Figure 2).

there is little suggestion of an important change in foodstuffs or food preparation techniques between the Neolithic and the Bronze Age. A change in the consistency of the diet seems an unlikely explanation for the craniometric data.

Climate is an important variable affecting craniometric parameters. The example of nasal form has already been discussed, but climate can also influence cranial index.

The most efficient shape from the point of view of conserving heat is a sphere, as this has the lowest surface area:volume ratio of any geometric form. The more rounded the head shape (i.e. the closer the cranial index is to 100), the greater the heat con-servation efficiency. Although no skulls actually attain an index of 100, a high cranial index would be expected to be more advantageous (and hence occur more frequently) under cold conditions, particularly as much heat loss from the human body occurs through the head. Beals *et al.* (1983) studied cephalic index in populations around the world. They found the index did indeed vary with climate. The most important climatic influence seemed to be temperature, particularly winter temperature. For example, those groups living in areas experiencing winter frosts showed a mean cephalic index significantly higher than those from the frost-free tropics. The explanation for the changes in the cephalic index of immigrants in the study referred to above is probably that it is mainly a response to climate (Kobyliansky 1983). Climatic factors may also be implicated in the change in cranial index in Britain between the Saxon and medieval periods, although more work is needed to help clarify this.

Traditionally, the Beaker period has been thought to coincide with a trend towards a somewhat more continental and slightly cooler climate (Tinsley 1981:210; Evans 1975:143–144). Since a climatic regime with increased cold stress is associated with an increased cranial index, one could argue that this climatic change might account for the alteration in cranial form. However, any change in climate which occurred around the time of the Beaker period in Britain was probably a fairly slight long-term trend subject to shorter-term oscillations, rather than an abrupt change from one stable climatic regime to another. The change in cranial index at the Neolithic—Bronze Age transition would seem to be more closely correlated with changes in material culture occurring at this time than with climate change. Furthermore, if cranial morphology were responding to climate change, then we might also expect to see changes in other parts of the skull, such as the nasal area, which we know to be climate-sensitive. However, Brodie's (1994) figures show no evidence of a decrease in nasal index at the Neolithic-Bronze Age transition. It seems highly unlikely that response to climatic change can explain the craniometric results.

Regarding the migration hypothesis, it would be useful to compare the British crania with their counterparts from continental Europe. If the British Beaker skulls are indeed those of immigrants, we would expect them to resemble contemporary skulls from north-western parts of the European mainland, the area from which the Beaker culture is traditionally supposed to have entered Britain. Suitable skeletal assemblages from this region are few, but some do exist from north-east France and Denmark. These do indeed show strong similarities to contemporary material from Britain; however, they were not associated with Beaker artifacts (Brodie 1994).

## Discussion of the British Beaker and Japanese Yayoi Examples

There are a number of parallels between the problem of the British 'Beaker Folk' and the 'Yayoi Folk' of Japan. Both Japan and Britain are islands situated close to large continental land masses. In both the Beaker and the Yayoi cases marked, and seemingly abrupt, changes were observed in a number of aspects of the archaeological record, including craniometric data. In both cases the role, if any, that immigration of peoples from the nearby continental mainland may have played has been the subject of debate.

In the British case, the specific differences observed between the Neolithic and later skulls were difficult to explain in terms of extraneous factors known to influence cranial form such as climate or diet. Although one could argue that some, as yet unidentified, environmental factor(s) might be responsible for the change in cranial form, migration does seem the most parsimonious explanation for the discontinuities observed in the archaeological record as a whole at the Neolithic-Bronze Age transition in Britain. If one subscribes to a 'prestige goods' or 'drinking cult' model to account for the appearance of the Beaker pottery, one is driven to explain the other changes seen in the archaeological record in piecemeal fashion. The migration hypothesis would also be consistent with the similarity in cranial index between the Beaker period British skulls and contemporaneous material from Denmark and northern France. Although the cranial evidence does not provide us with a definitive solution to the problem of the Beaker Folk (like most archaeological evidence it is open to more than one interpretation), proper consideration of it is necessary to form a balanced view of the archaeological evidence from this period.

In the case of the Japanese Yayoi, the skeletal evidence seems to point much more clearly towards at least limited immigration into the Japanese islands. There are several reasons why the skeletal evidence was less equivocal in this case than for the British one. Firstly, good series of crania from locations on the Asian mainland have been studied for comparison with the

Japanese skeletons, and rigorous multivariate analyses have been carried out on the data. Secondly, the pattern of regional differences in Japanese crania was important in arguing against an environmental or cultural hypothesis for the changes noted in the Yayoi crania from south-western Japan. Thirdly, the patterns seen in the cranial measurement data were echoed by other studies of bones and teeth—dental metrics, and both bone and dental non-metric traits support the migration model.

When looking at the literature, one cannot help but be struck by the relative profusion of craniological and other skeletal studies aimed at investigating ancient migrations in Japan and the Far East. By contrast, such studies in Britain are few, and those which have been done seem to have made little impact on mainstream archaeological thought. The main reason for this disparity appears to be a difference in theoretical orientation between Japanese and British archaeology. Developments such as the American 'New Archaeology', which wrought such changes in archaeological thought in Britain, made little impression on theoretical aspects of Japanese archaeology (Pearson 1986). Culture history remains the predominant theme in archaeology in Japan (Tsude 1995; Campbell 1986). Japanese archaeology aims to trace a continuous link between the modern Japanese nation and its remote cultural past. Population history is a strong component within this tradition. Human skeletal remains make a central contribution to this, and to Japanese archaeology in general; craniometry has not become marginalised, as it has in Britain. This difference in theoretical outlook is probably the major reason why a more complete picture of ancient migrations, and population history in general, is available for Japan than for Britain.

Recently in British archaeology there have been some signs of a revival of interest in ancient migrations. This is due, at least in part, to the interest of some archaeologists in linguistics and modern population genetics and what they can tell us about the past. Past population movements will have left traces in modern-day gene frequencies and language distributions, so by studying such aspects in living populations clues to ancient migrations may be gleaned. For example Colin Renfrew of the University of Cambridge and his co-workers (Renfrew 1992; Barbujani *et al.* 1994) have argued from this sort of evidence that agriculture spread through most of Europe in the Neolithic by movement of farming peoples from a centre in the Near East northwards and westwards into territories previously occupied by Mesolithic hunter-gatherers (although this is controversial—Richards *et al.* 1996). Perhaps a renewed interest in ancient migrations, stimulated by this kind of work, will lead to a revival of craniometry in British archaeology.

# 5

# NON-METRIC VARIATION

The term 'non-metric variation' is generally taken to encompass any minor anomaly of skeletal anatomy not normally recorded by measurement. Non-metric traits are usually recorded as being either present or absent, or less often, scored according to the degree of development of the feature. As one might expect, given this definition, non-metric traits are a rather heterogeneous bunch, but one thing the variants discussed in this chapter do have in common is that none can be considered a sign of disease. Their presence in the skeleton causes no symptoms—you or I may have many of the non-metric traits discussed below in our own skeletons and be quite unaware of them.

More than four hundred non-metric variants have been described for the human skeleton in the anatomical and anthropological literature (Saunders 1989). They vary in frequency from those which are rarely found in most populations, to those where, in some groups, the 'abnormal' form is almost as common as the 'normal' form. As they are so heterogeneous, classifying them can be problematic. In order to try and illustrate the range of variants which may be encountered in human skeletal material, a seven-point classification is used here.

## A CLASSIFICATION OF NON-METRIC SKELETAL VARIANTS

1 *Variations in the numbers of bones or teeth*. The adult skeleton normally consists of 206 bones and 32 teeth. However, fewer or extra elements may be present.

Extra, or supernumerary, bones may be normal in form (e.g. in the spine an extra vertebra may be present), but more often they are small and irregular in morphology, and are known as ossicles. A particularly common site for supernumerary ossicles is within the skull sutures, where they may occur singly or in numbers. The lambdoid suture, which separates the occipital bone from the parietal bones at the back of the skull, is a particularly frequent location (Figure 5.1). Small supernumerary bones are also common in the ankles and wrists (O'Rahilly 1953). Missing bones are a much less common variant than extra bones.

The total number of teeth may also vary, but here missing elements are more usual than extra teeth. The tooth which most often fails to form is the third molar, or wisdom tooth, but other teeth may also be absent.

2 *Anomalies of bone fusion*. Component parts of a bone may fail to fuse together, or normally discrete skeletal structures may instead be fused. An example of the former is metopism—the retention of the metopic suture in the skull. In the foetus, the frontal bone in the skull is formed via intra-membranous ossification from two halves which make up the left and right sides of the bone. These two parts generally fuse in the first few years of life to form a single bone. On occasion, however, they fail to unite, so that the division persists. In such cases, the two parts meet at

*Figure 5.1* Posterior view of a skull showing an ossicle at the lambda (light arrow) and a lambdoid ossicle (dark arrow)

the midline in a suture of similar form to those between the other bones of the skull vault. This suture is called the metopic suture (Figure 5.2).

3 *Variation in bony foramina.* A foramen (pl. foramina) is a small, natural hole in a bone. Foramina usually convey blood vessels and/or nerves through the bone. Variants may consist of the presence of a foramen where none is normally found, or a foramen may be missing where it is usual to find one. The positions of foramina may also vary with respect to features such as cranial sutures etc.

Traits of this type are the skeletal manifestations of variations in the degree and location of branching in blood vessels and peripheral nerves. An example of this sort of trait is the presence of parietal foramina. The parietal foramen takes the form of a small hole piercing the parietal bone of the skull vault, near the midline (Figure 5.3). It transmits a small vein.

4 *Articular facet variations.* In a human skeleton, the part of the bone at a joint which bore the articular cartilage in life may be recognised, since, as long as it is not diseased, it is of smoother appearance than non-

*Figure 5.2* The skull on the left shows retention of the metopic suture. The skull on the right is of normal form for comparison

articular bone. Variation in the form of these joint surfaces may occur. Variants may consist of simple extensions or elongations to normal joint surfaces, or else a joint surface may be split into two separate facets. Alternatively all or part of a joint surface may be in an anomalous position, or small extra articulations may be present. Examples of this type of non-metric trait are the so-called squatting facets which may be present on the distal (lower) end of the tibia. Here, the distal joint surface of the tibia extends onto the anterior surface of the bone (Figure 5.4).

5 *Hyperostoses: traits characterised by a localised excess of bone formation.* Hyperostoses may take the form of bony spurs or protuberances at sites in the skeleton which do not normally have them. An example is the posterior bridge on the atlas vertebra, the uppermost cervical vertebra, which articulates with the skull base. On each side of the superior surface of the posterior arch of the atlas is a groove, within which runs an artery and a nerve. Occasionally, a spur of bone running between the articular facet and the posterior arch transforms this groove into a foramen, through which the nerve and artery pass (Figure 5.5a). This trait is classed here as a hyperostosis rather than a foraminal variant, as the bony variant is not accompanied by alteration in the anatomy of the nerve or blood vessel.

Some broader bony overgrowths are called tori (singular, torus). Frequent sites for tori are the upper and lower jaws. For example, the palatine torus is a low bony ridge along the midline of the lower surface of the bones which form the hard palate in the roof of the mouth (Figure 5.5b).

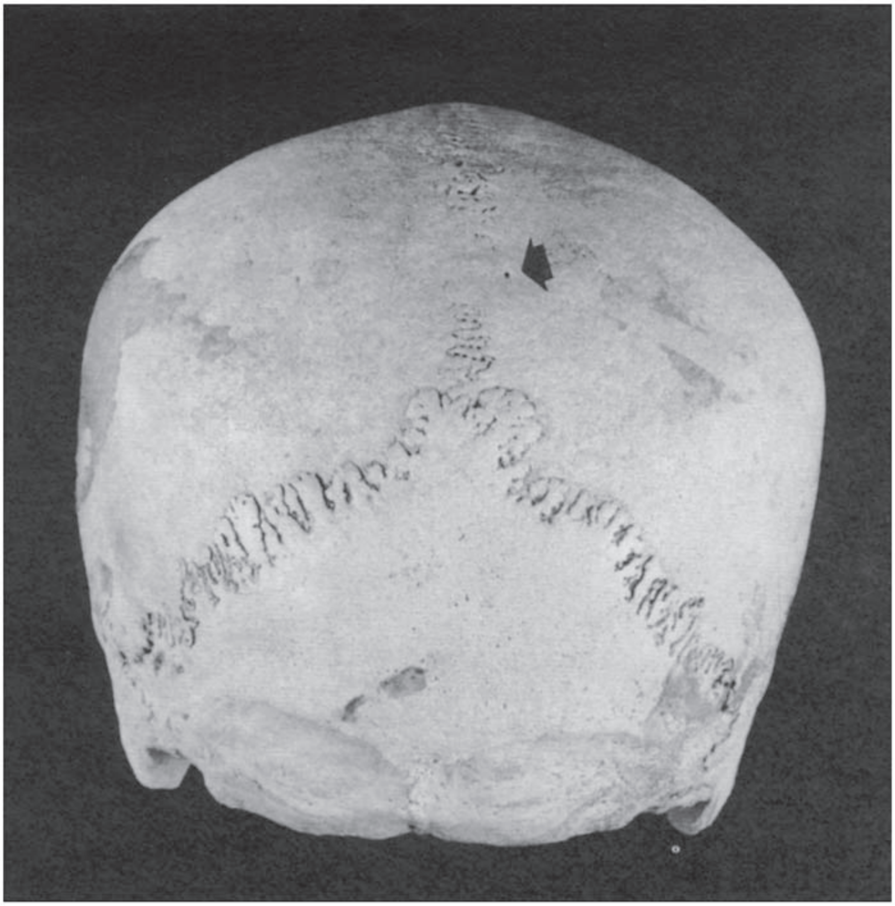


*Figure 5.3* A parietal foramen (arrow) is present on the right parietal bone; the trait is absent on the left parietal

6 *Hypo-ostoses: traits characterised by a localised deficiency of bone.* Hypo-ostoses are perforations or depressions in bones which do not normally bear them. An example of a hypo-ostosis is the vastus notch, a depression on the lateral/superior surface of the patella (Figure 5.6).

7 *Variations in the form of the tooth crowns.* These range from minor differences in the patterns of the pits and fissures which make up the normal anatomy of the occlusal surfaces of the teeth, to major variations in crown shape. An example of the latter is the so-called shovel-shaped incisor. This trait (which is generally restricted to the maxillary incisors) takes the form of ridges near the margins of the lingual (inner) surface of the incisor crown, which transform the normally fairly flat lingual surface into a concavity (Figure 5.7).

Although non-metric traits have long been noted by anthropologists (e.g. Russell 1900), and recognised as normal variants rather than signs of disease or injury, their causation remained obscure for a long time. Scientific studies from the 1950s onwards on

*Figure 5.4* The tibia on the right shows a squatting facet (arrow); that on the left is normal for comparison

laboratory animals, and work on man, has aided our understanding of their causes. Much of this work has been directed at determining the degree to which they are under genetic control.

## EVIDENCE FOR GENETIC INFLUENCE ON NON-METRIC SKELETAL VARIATION

### Studies in Mice

Much of the animal work on the genetic basis of non-metric skeletal variation was carried out on laboratory mice. The first trait to be studied in this way was the absence of the third molar (Grüneberg 1951). From breeding experiments it seemed that, in the mouse, this trait was under a degree of genetic control. Grüneberg proposed a model to account for the patterning in its occurrence. He found that whether or not the third molar develops is dependent upon the size of the tooth germ; if it falls below a certain critical size it fails to develop, leading to absence of the third molar. The size of the tooth germ is dependent upon genes determining tooth size and overall body size, and also upon non-genetic, environmental factors. Thus the presence or absence of the third molar is not in itself inherited, but the size of the tooth germ to some extent is. There is a continuous variable (tooth germ size in this case) upon which there is imposed a threshold—tooth germs below a certain size fail to develop. Thus from an underlying continuous variable two distinct physical types are produced: those with and those without third molars. This property led Grüneberg to term this sort of variant a quasi-continuous trait.

In the mouse, the third molar fails to develop if the tooth germ falls below a certain size at about 5– 6 days after birth—its development is arrested at this age and it regresses (Grewel 1962). Environmental factors acting while the baby mouse grows in the womb and during the first five days after it is born, have the potential to affect whether the missing third molar trait manifests itself or not. Poor maternal diet led to a reduction in the size of teeth in the offspring (Searle 1954), making it more likely that their third molars would fail to develop. Analysis of results showed that this was a reflection of deficiencies experienced both by the foetus as it developed in the womb, and during the first few days of life of the young mouse as a result of poor lactational performance of the mother (Searle 1954). Frequencies of other non-metric traits in offspring are also affected by maternal diet (Searle 1954; Deol and Truslove 1957; Dahinten and Pucciarelli 1983).

The patterns of occurrence of many other non-metric traits of the mouse skeleton are consistent with the threshold model described above (Berry and Searle 1963; Grüneberg 1952, 1963).

In the mouse, the extent of genetic control was found to vary quite markedly between traits, but was often fairly low (Berry and Searle 1963; Self and Leamy 1978). Nevertheless, analyses of non-metric traits in wild-living mice and other mammals (refs in Berry 1979) have been successful in distinguishing different populations, showing that useful genetic information can be obtained from these variants.

The skeletal variants studied in the mouse are broadly analogous to those which are present at birth, or develop during the postnatal growth period in the human skeleton. Some studies have been conducted to investigate patterns of inheritance of non-metric traits in man.

## Studies in Man

Some traits can be recorded on living subjects, and this clearly facilitates study of their inheritance patterns. Tooth crown variants can be recorded either by peering into the mouths of volunteers or by studying casts of their teeth. A British researcher, Caroline Berry, conducted a study of dental variants (Berry 1978) using casts of the teeth of more than a hundred families from Liverpool, England, and of the dentitions of more than a hundred pairs of twins from Germany. She found that the traits in her study were under a degree of genetic control and this seemed stronger for the major variants, such as shovelling of the incisors, than for finer variations in the form of the tooth crowns. For shovel-shaped maxillary incisors 69 per cent of offspring showed the trait if both their parents did, 57 per cent when only one parent showed it. When neither parent showed it the frequency was only 29 per cent.

A few variants can be palpated (felt beneath the skin) in living people. For example Suzuki and Sakai (1960) used this method to study the occurrence of palatine torus in some Japanese families. They found that if both parents showed the trait, then so did 64 per cent of their offspring. If one parent showed the trait then the figure for their children was 52 per cent. In children for whom neither parent showed the trait, the torus was present in only 8 per cent of cases. This provides strong evidence of an inherited component in the causation of this trait.

The great majority of variants cannot be seen directly on living subjects. Some are, however, visible on X-ray. The missing third molar trait has been studied this way. In man the third molars often fail to erupt, but are present in the jaws. X-rays are used to study the missing third molar trait so that instances where third molars are truly absent can be distinguished from cases of simple non-eruption. A number of studies have been done on this trait using

*(a)*

living subjects, and, discussing them, Berry (1968) concludes that the frequency of missing third molars in first degree relatives (i.e. offspring, parents or siblings) of those who themselves lack third molars is about five or six times higher than in the general population.

Some bone traits have also been studied by radiography. Saunders and Popovich (1978) recorded posterior atlas bridging using head/neck X-rays of 598 subjects from 147 families from Ontario, Canada. They found that the frequency of bridging in first degree relatives of those who showed the trait was 42 per cent, compared with 29 per cent in the study group as a whole.

Torgersen (1951a) studied the metopic suture in Norwegian families using head X-rays. He showed that this variant was under a degree of genetic control—it tended to 'run in families'. He found similar results for the occurrence of ossicles in the lambdoid suture (Torgersen 1951b, 1954).

Many variants are, however, difficult to record in the living, even using radiography. Studies investigating their genetic transmission have to be undertaken on dry bones. In order to study patterns of inheritance of traits in this way, we need a fairly large collection of skeletons for which the individual identities are known and for which known familial relationships exist between individuals. Needless to say, collections meeting such criteria are very rare, but a few do exist. One such is in Austria.

In many parts of Europe, bones were exhumed from burial grounds when they became full in order to make way for new burials. The exhumed bones were stored in charnel houses or ossuaries. In the eighteenth and nineteenth centuries, in Alpine regions of Austria and Germany, a tradition existed whereby exhumed skulls were painted with the name of the deceased and also often decorated with painted designs of leaves and flowers. Unfortunately most collections of these painted skulls were re-buried in the early years of the twentieth century, but one collection which survives is that from Hallstatt, Austria (the place better known archaeologically for the large Iron Age cemetery found there).

The Hallstatt collection contains about seven hundred decorated skulls. This collection has been

*Figure 5.5* Hyperostotic traits: (a) an atlas vertebra shows the posterior atlas bridging trait on the right side (arrowed); the trait is absent on the left side; (b) the palatine bones show development of a bony torus along the midline (arrows)

studied by the Swedish anthropologist Torstein Sjøvold (Sjøvold 1984, 1987) and, as part of his work, he investigated patterns of inheritance of some non-metric cranial traits. He used the church records of births, marriages and deaths to reconstruct family trees for this material. Of the 700 skulls, 346 fell into 91 families for which at least two members could be identified. Working in the charnel house where the skulls were stored, Sjøvold recorded an array of non-metric traits on the material. He recorded a list of 30 traits for which definitions had been published by Berry and Berry (1967). He selected these variants because they are often routinely recorded in archaeological skeletons. Of these, some had to be excluded from analysis because they were very rare in the Hallstatt skulls. This left 25 traits whose heritabilities could be studied. Of these 25, 13 were found to show clustering in families, although in all cases the degree of genetic control appeared fairly low. Among those traits which were found to be under significant genetic control in the Hallstatt material were metopic suture, lambdoid ossicles and ossicle at lambda (confirming Torgersen's results on living subjects for these three traits), together with

*Figure 5.6* The patella on the left shows a vastus notch (arrow); that on the right is normal for comparison

palatine torus and a group of foraminal variants, including parietal foramina.

The scientific work has shown that, for some non-metric traits at least, there is a significant genetic component in their causation. This has led to the widespread use of non-metric variants to study genetic relationships in archaeological material. However, as we have seen from the mouse work, the frequency of many traits can be significantly influenced by nutrition and other factors operating during the growth period. Furthermore, as we shall see, some traits, particularly those involving variations in joint surfaces, are a reflection of mechanical factors operating on the bones. Some variants have thus been used to investigate nutrition or activity patterns in earlier human populations. Despite the scientific work which has been conducted on non-metric traits, the causes of most are still unknown. The value of recording these in archaeological material is fairly limited because until their causes have been elucidated, the meaning of any patterns in their occurrence in bone assemblages will be unclear.

## Recording Non-Metric Traits

Traits may be scored according to degree of expression. For example, palatine tori can be scored according to their length, width or elevation above the surface of the bones of the hard palate. These parameters may be taken into account in a subjective way, such as classifying the torus as small, medium or large, or measurements of its dimensions may be taken (discussion in Hauser and de Stefano 1989:177). However, most workers score traits simply as present or absent; indeed, most of the research work on the genetic basis of non-metric traits scored them on this basis.

As with cranial measurements, the precise definitions of non-metric traits vary somewhat between writers, so that it is important to state whose trait definitions one is following. As already mentioned Berry and Berry (1967) published a list of 30 cranial variants, and Finnegan (1978) has given definitions of 30 traits of the post-cranial skeleton. Many workers, myself included, follow these definitions when scoring

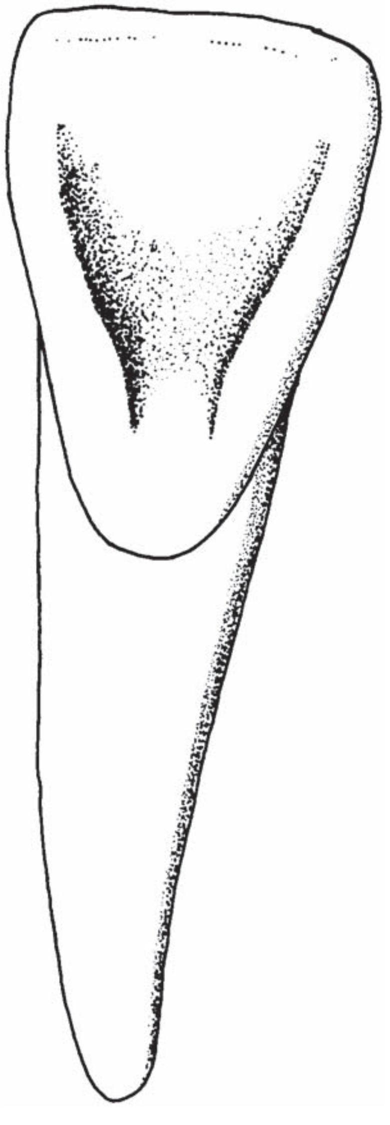


*Figure 5.7* A shovel-shaped maxillary central incisor. Normally the lingual surface of the incisor crown is fairly flat, but in this example ridges at its margins create a shovel shape

non-metric variants in ancient skeletons. Turner *et al.* (1991) have published standards for scoring dental non-metric variants. These mostly involve scales expressing the degree of development of a trait—for example they classify shovelling of the incisors on an eight-point scale from no trace of shovelling at all, through to extreme development of the trait. If required, their stages could be combined in order to dichotomise trait scores.

As may have become apparent in earlier sections of this chapter, most traits can occur on either side of the body, for example a parietal foramen may occur on the left and/or right parietal bones (Figure 5.3). In general there is marked correlation between left and right sides of the body in the manifestation of non-metric traits—most variants tend to occur on both sides of the body if they occur at all (Perizonius 1979). When traits do occur unilaterally (i.e. on one side of the body and not the other) the trait does not usually systematically favour one side over the other (McGrath *et al.* 1984). This sort of random asymmetry is called fluctuating asymmetry. Fluctuating asymmetry in the skeleton is generally a reflection of environmental disruption during development, so asymmetry in the occurrence of non-metric traits is probably best interpreted as an effect of environmental rather than genetic factors. Consistent with this, McGrath *et al.* (1984) found that asymmetry in the expression of non-metric variants was not inherited even when the presence or absence of a trait was. Therefore, when traits are recorded with the purpose of elucidating genetic relationships, cases of unilateral trait presence are often combined with cases where it is present on both sides to produce a single ‘trait present’ category.

In children some non-metric traits cannot be recorded. For example, metopic suture cannot be scored in infants and young children, as it is only after the first few years of life that it becomes apparent whether the suture will fuse in the normal way or will be retained. Joint surface variants, such as squatting facets, are also difficult to score, as in the child skeleton joint surfaces are incompletely mineralised. Even for traits which can be reliably scored in immature skeletons, their frequency may vary with age at death. Hyperostotic traits may increase in frequency with age—they involve progressive ossification which may continue during the growth period (Buikstra 1972). For example, the frequency of mandibular torus seems to increase with age in children (Axelsson and Hedegard 1981). For adults, the age effect on non-metric traits generally seems minor (Berry 1975).

Most archaeological studies of bony non-metric traits exclude child skeletons from the analysis. This is not the case for dental traits. It will be recalled that, unlike bone, dental enamel is not living tissue, so tooth crowns, once formed, cannot grow or otherwise change in morphology. Thus, as long as their tooth crowns have formed, children can be included in analyses of dental non-metrics. Problems in scoring dental traits occur at the other end of the age range in archaeological populations. In middle aged and older adults the relevant areas of the crowns have often been worn away by dental attrition.

Although a few workers have found sex differences in the frequencies of some variants (e.g. Corruccini 1974), most writers have concluded that sex differences in traits are trivial (e.g. Berry 1975; Rösing 1982). Thus, if desired, the sexes can be lumped together for analytical purposes.

## Application of Non-Metric Traits to Archaeological Problems

### Investigation of Genetic Relationships

Non-metric traits have been used to study relationships between earlier human populations. In the last chapter we saw that studies in non-metric variation in Far Eastern skeletal material provided important support for craniometric data in showing the likely immigration of farming peoples from mainland Asia into the Japanese Islands at about 300 BC. Non-metric traits have also been used to investigate population history in other parts of the world (Ossenberg 1976; Pitrusewsky 1972).

Other workers have concentrated on elucidating genetic relationships between individuals in a single cemetery. Much of this work has been directed toward the detection of 'family groups' within burial areas. For example, Ullrich (1972) studied burials from an early Bronze Age (*c.* 2000 BC) cemetery at Grossbrembach near Sömmerda, eastern Germany. He recorded various non-metric traits, including metopism and sutural ossicles, together with missing third molar and several other dental variants. The distribution of burials with metopism is shown in Figure 5.8. There appear to be three concentrations, in the central, southern and eastern parts of the site, perhaps corresponding to different families. Other traits also showed some evidence of non-random spatial patterning, enabling Ullrich to argue for the existence of several kin groupings buried at different locations within the cemetery.

As discussed, the genetic control over variants is generally thought to be fairly weak—in the studies referred to above on human subjects, first degree relatives of individuals showing a particular trait showed a frequency of the trait that was at most about six times greater than in the general population. The burial of genetically related individuals near one another in a cemetery would have had to have been rigidly adhered to for any spatial patterning in skeletal non-metric traits to be apparent archaeologically. Most cemeteries excavated by archaeologists appear to have had no permanent grave markers and were in use for extended periods of time, sometimes several centuries or more. The insertion of new burials among those whose identities would have been long forgotten would tend to blur any spatial patterning in traits which might have existed. An additional problem is that although there are statistical methods for determining whether a spatial pattern is non-random, they are often not well suited to cemetery analyses (Goldstein 1981). It is perhaps not surprising then that instances where convincing clusters of traits emerge when variants are simply plotted on a cemetery plan are few. If we can partition a cemetery on the basis of a spatial or other discontinuity, then this facilitates investigations concerning whether genetic relationships between individuals were a factor in determining the location of burials. Once we have created sub-populations in this way, we can test

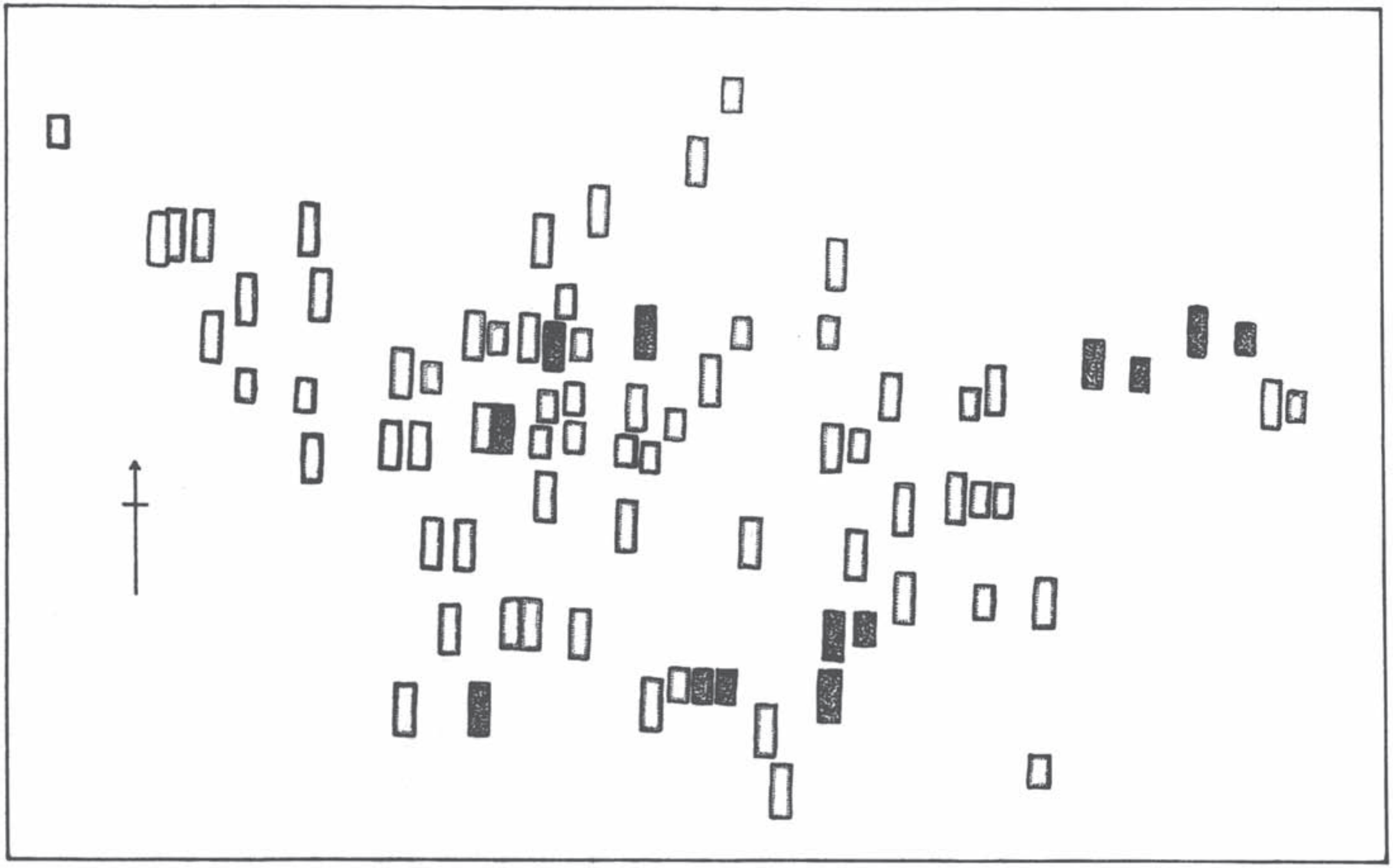


*Figure 5.8* A schematic diagram of the layout of burials in the cemetery at Grossbrembach, Germany. The shaded burials are those showing metopism
*Source*: After Ullrich (1972: Figure 9).

for differences in trait frequencies between them. It is thus possible to investigate a specific hypothesis (that the sub-groups correspond to kin groupings), rather than looking for an unspecified number of groupings which could appear anywhere in a cemetery. This strategy of first partitioning the data was used by Bondioli and colleagues when investigating kin groupings in an Italian Iron Age burial ground (Bondioli *et al.* 1986).

The cemetery at Alfedena, central Italy, was in use *c.* 500–400 BC. The graves were laid out in groups around what appear to be circular or semicircular structures (Figure 5.9). When the first excavations were undertaken at the site in the nineteenth century it was speculated that perhaps these grave clusters might correspond to kin groupings. Using better documented skeletal material, from more recent excavations (Parise Badoni and Ruggeri Giove 1980), Bondioli and co-workers conducted a study of some aspects of skeletal variation, including non-metric traits, in an attempt to investigate this suggestion. They studied 89 adult skeletons from three grave groupings (Figure 5.9). Of the 27 non-metric features scored, five showed significantly different frequencies between the three grave groups for male skeletons. Given that the occurrence of non-metric traits tends to be independent of one another (i.e. the presence of any one trait generally does not affect the chances of another being present), this number is more than would be expected on the basis of chance alone. For the females, however, only one trait showed any significant difference in frequency between the three groups. Bondioli and colleagues also took a wide range of measurements on the cranial and post-cranial bones. The results from the measurements resembled those from the non-metric variants in showing greater between-group differences for males.

Bondioli *et al.* (1986) argued that their results suggest that, for the males at least, the three burial groups at Alfedena do indeed represent separate kin groupings. The lack of significant non-metric trait segregation between the groups for females, and the weaker patterning in the females than the males in this respect for the measurement data, was interpreted as suggesting that the three groups of graves might represent patrilocal kin groupings. In patrilocal groups, men tend to spend their lives in the community where they were born, but the women move to their husbands' dwelling places on marriage. Under such circumstances, closer genetic ties would exist between the men in a particular community than between the women. The skeletal data are thus consistent with the burial clusters at Alfedena being patrilocal kin groups.

## Investigation of Non-Genetic Aspects of Ancient Populations

The French anthropologist, Jean-Pierre Bocquet-Appel (1984) studied a collection of nineteenth-and early twentieth-century crania kept at the University of Coimbra, Portugal. These skulls come from local graveyards and represent bones disinterred as burial rights expired. Bocquet-Appel's aim was to try and discern the effect of nutrition upon the expression of non-metric traits in this group of skulls. He used as his index of nutrition the price of wheat. Wheat was the staple crop during the period in question in Portugal. High wheat prices would have coincided with periods of food shortage and hence poor nutrition, low prices with more plentiful supply and hence better nutrition. He split the assemblage of nearly two thousand adult skulls into five chronological groups, comprising those born in 20-year spans from AD 1810– 1909. He conducted statistical analyses to determine whether there were significant differences in trait frequencies between these chronological groups and, if there were, whether they corresponded to fluctuations in the price of wheat, and hence by implication to nutrition, during the growth period.

He found that frequencies of some non-metrics, including several foraminal traits and sutural ossicles at various locations in the skull, did indeed correlate with the price of wheat (Figure 5.10). Bocquet-Appel rightly cautions that changes in the price of foodstuffs will affect not only nutrition but also other factors such

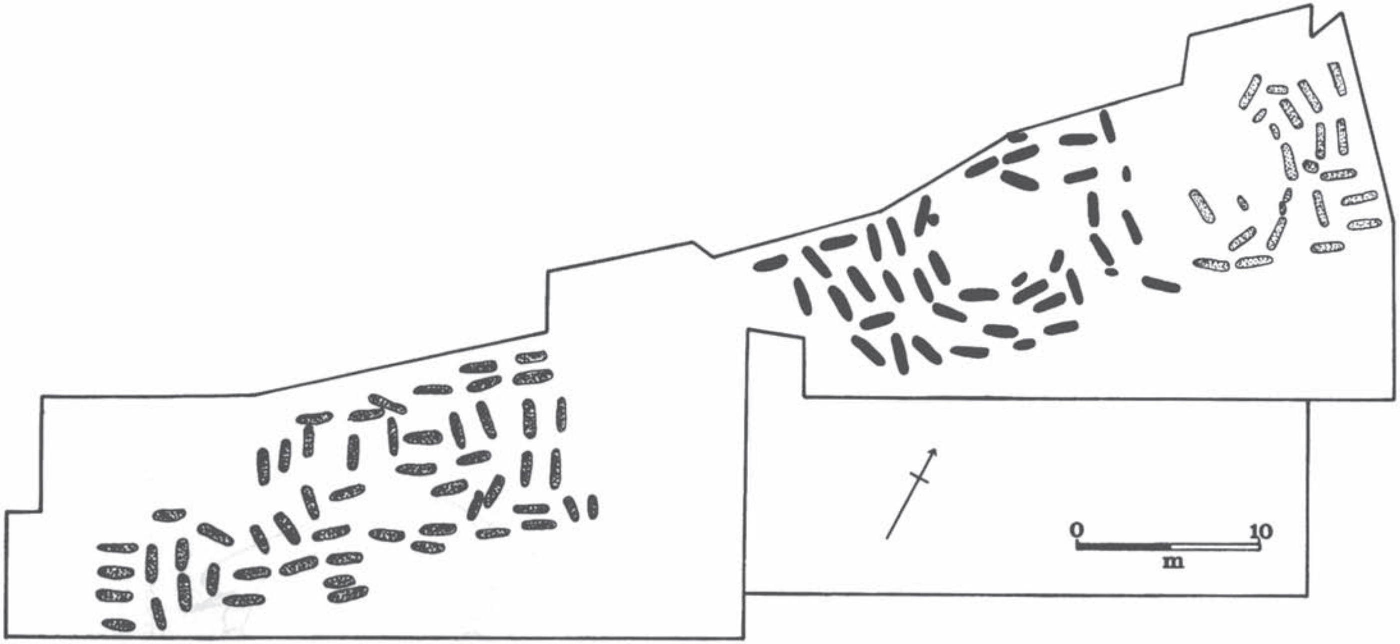


*Figure 5.9* Part of the cemetery at Alfedena, Italy, showing the three grave groupings discerned by the excavation team

*Source*: Adapted from Parise Badoni and Ruggeri Giove (1980: Figure D).

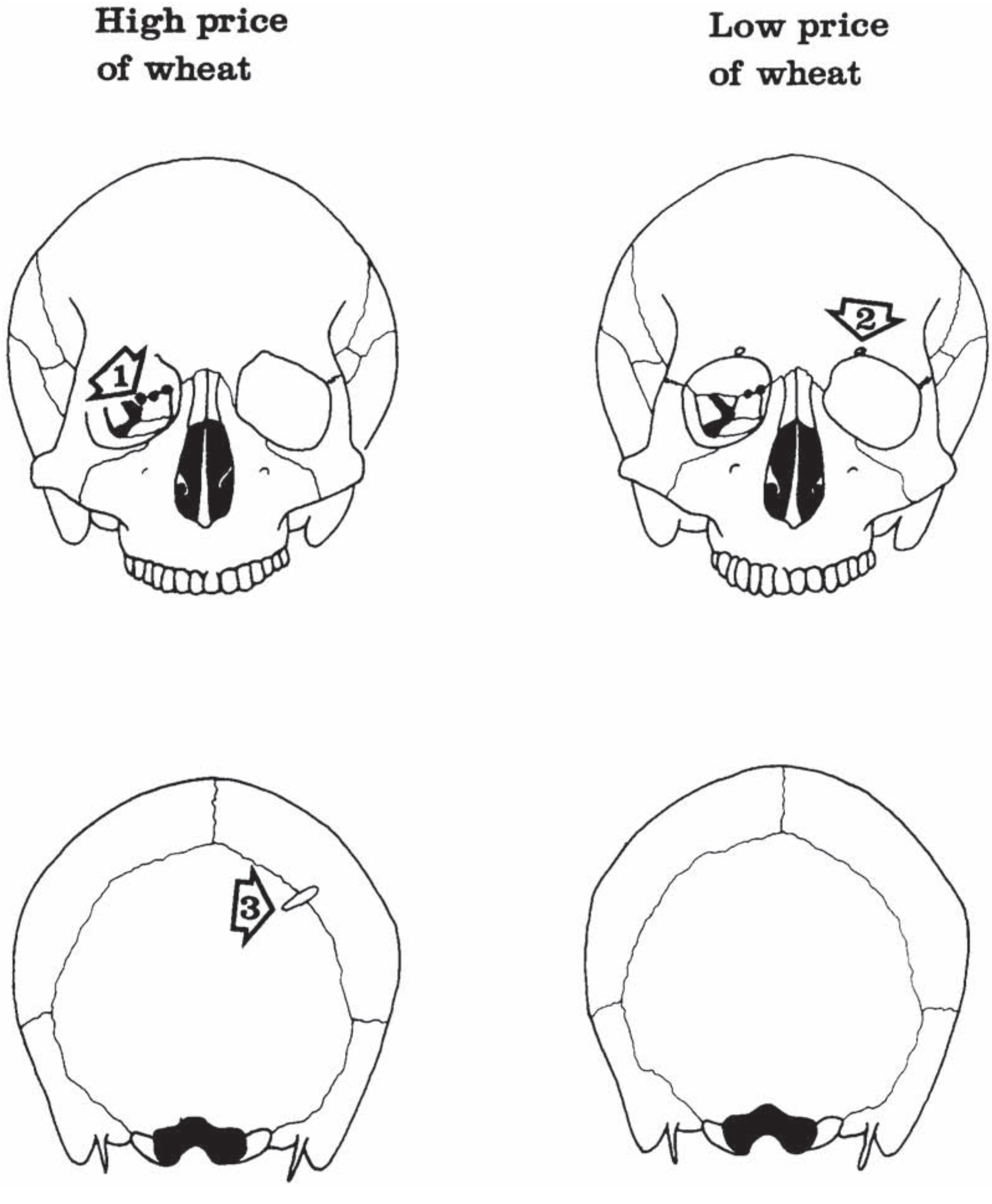


*Figure 5.10* A schematic representation of the distribution of some non-metric traits in the skulls from Coimbra, Portugal, according to the price of wheat: (1) accessory ethmoid foramen; (2) supra-orbital foramen; (3) lambdoid ossicle

*Source*: Data from Bocquet-Appel (1984).

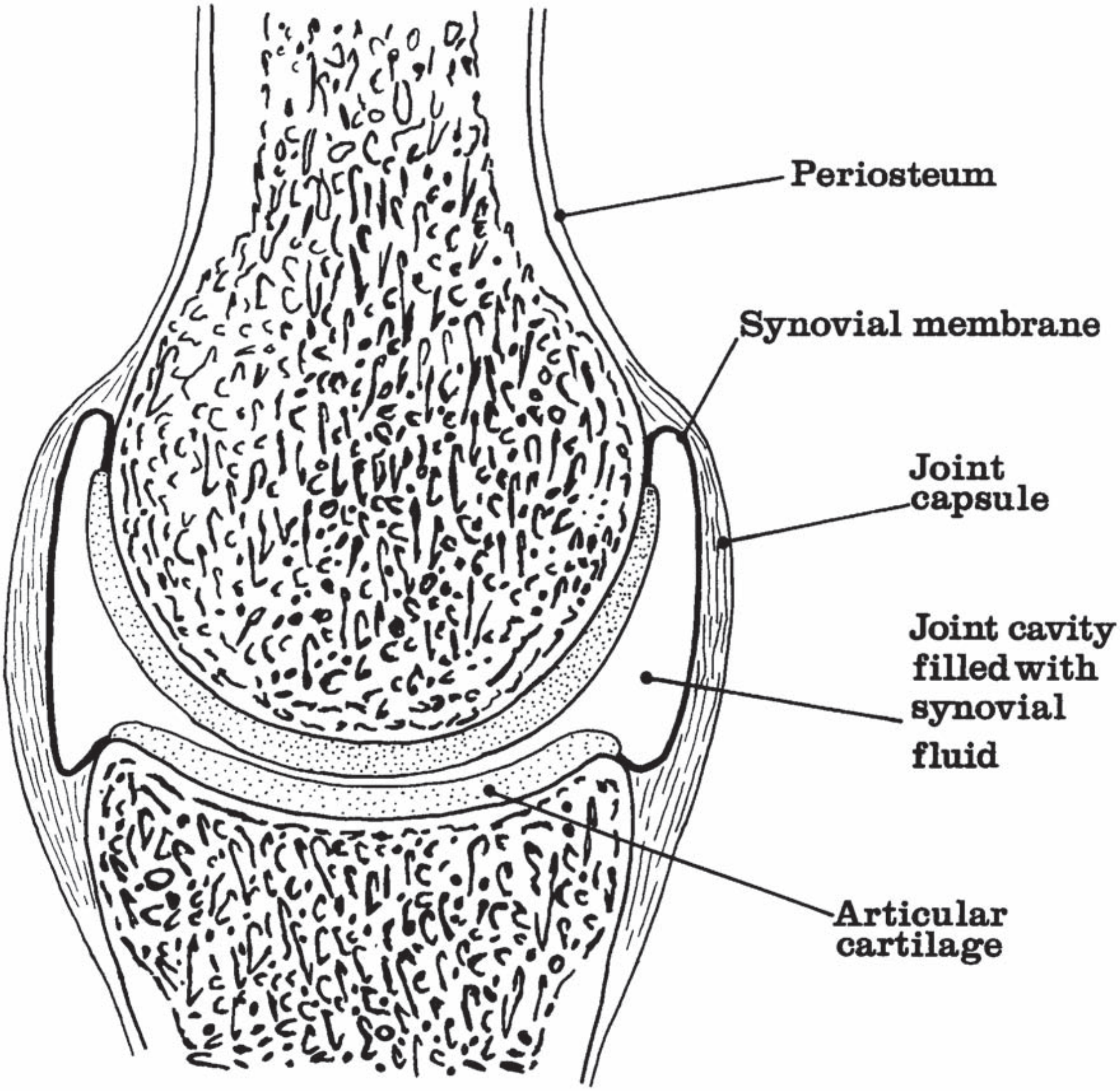


*Figure 5.11* A generalised joint

as general living conditions, and may also induce local or regional migrations which may influence the genetic structure of the population. Nevertheless, his results do recall those of the mouse work, which indicated that nutrition during development can affect the expression of non-metric variants.

A group of non-metric traits which in general appear to be caused by non-genetic factors are extensions to joint surfaces, such as the so-called squatting facets of the ankle region (Figure 5.4).

The structure of a generalised joint, of the type which exists at most of the movable articulations between the bones of the human body, is shown in Figure 5.11. The bone-ends are enclosed by a joint capsule, and are held in position by ligaments (not shown in Figure 5.11). The bone ends are covered by articular cartilage. The synovial membrane lines the joint capsule, and produces and contains the synovial fluid.

Habitual extreme movement at a joint promotes extension of the joint capsule and articular cartilage along the bone. This maintains the cushioning effect of the cartilage at the joint, preventing destructive bone-on-bone contact (discussion in Trinkaus 1975). The skeletal manifestation of this process is an extension to the smooth articular bone surface.

Many human groups who do not use furniture to sit on adopt the squatting posture (Figure 5.12) in repose or whilst working on tasks low to the ground. In this

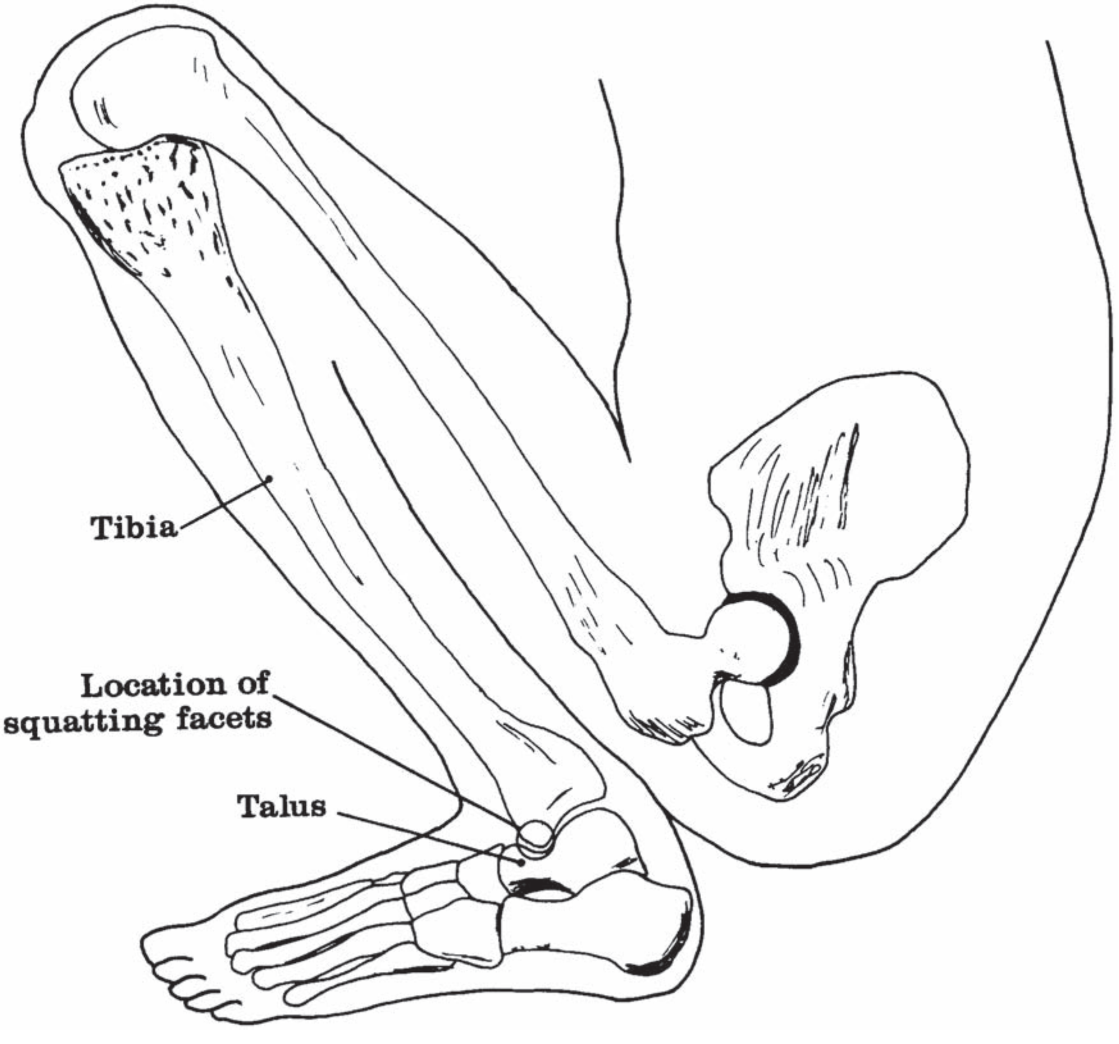


*Figure 5.12* The position of the leg in the squatting posture
*Source*: After Huard and Montagne (1950).

posture the body weight is supported with minimal muscular activity; it is a comfortable rest-ing position for those used to it. In the squatting position there is extreme dorsiflexion of the feet—in other words, the feet are fully bent upwards at the ankles. Prolonged, passive dorsiflexion of the feet puts continuous pressure on the ankle ligaments which tends to elongate them, permitting greater dorsiflexion of the joint between the tibia and the talus (Trinkaus 1975). Habitual extreme dorsiflexion of the ankle joints, as occurs in those who squat, might be expected to lead to the formation of anterior extensions to the joint surfaces on the talus and the lower end of the tibia—squatting facets. Consistent with this, squatting facets have been found to be common in the bones of groups known habitually to rest in the squatting posture—for example Indians and Australian Aboriginals, but are rare in those who generally do not, for example recent Europeans (Singh 1959; Rao 1966). It is worth noting that dynamic activities, such as walking or running, are not likely to lead to the formation of squatting facets. In walking or running the foot is rarely dorsiflexed to the limit of ankle joint movement, and in any case extreme joint excursions during these sorts of activities are prevented by the ankle ligaments (Trinkaus 1975).

Squatting facets have been studied in archaeological populations in order to investigate past activity patterns. Among the burials from the eighteenth/ nineteenth-century crypt at Spitalfields, London, squatting facets are rare (Molleson n.d.), but they are frequent among the medieval (eleventh to sixteenth century AD) peasants from Wharram Percy (Table 5.1).

*Table 5.1* Squatting Facets at Two British Sites

| | Spitalfields | Wharram Percy |
|---|---|---|
| Skeletons with squatting facets | 9 (2%) | 102 (55%) |
| Skeletons without squatting facets | 455 (98%) | 85 (45%) |

*Source*: Data from Spitalfields supplied by The/a Molleson.

The frequency of squatting facets in the Spitalfields group is similar to figures quoted for modern Europeans, whereas that from Wharram Percy is much higher, approaching the levels of 70–80 per cent seen in recent populations known to squat.

Those buried in the Spitalfields crypt were the monied middle classes of Georgian and Victorian London. They would certainly have used chairs rather than reposed in the squatting position. By contrast, chairs were a rarity for the medieval peasant (Field 1965), although benches and low stools were known. The bone evidence suggests that at Wharram Percy the inhabitants habitually adopted postures involving extreme dorsiflexion of the feet. The habitual adoption of squatting or a similar posture, perhaps to tend a fire or to attend to other tasks low to the ground, would be the sort of routine activity which might lead to the production of these facets.

Among the Wharram Percy people there is a difference in the frequency of squatting facets between males and females—71 per cent of the women show facets but only 44 per cent of the men. It would seem, therefore, that the women at Wharram Percy adopted the squatting posture more frequently than the men.

In rural medieval England there was no rigid sexual division of labour, although many tasks were loosely associated with one sex or other. Both men and women did agricultural labour, women joining the men in the fields when additional labour was needed. However, women more often worked around the dwelling, caring for infants, watching children, cleaning, preparing meals, baking, spinning and weaving cloth, etc. (discussion in Bennett 1987). These tasks might be expected to have involved more working in a squatting or similar posture than was the case for male activities.

Another non-metric variant which has been used to give clues to ancient activity patterns is the auditory torus. This is a hyperostosis which manifests itself as a small, bony protuberance on the inner wall of the ear canal (Figure 5.13). The origin of this little bony projection has been discussed in detail by Kennedy (1986). She indicates that auditory tori are probably caused by cold water in the ear canal. The skin in the

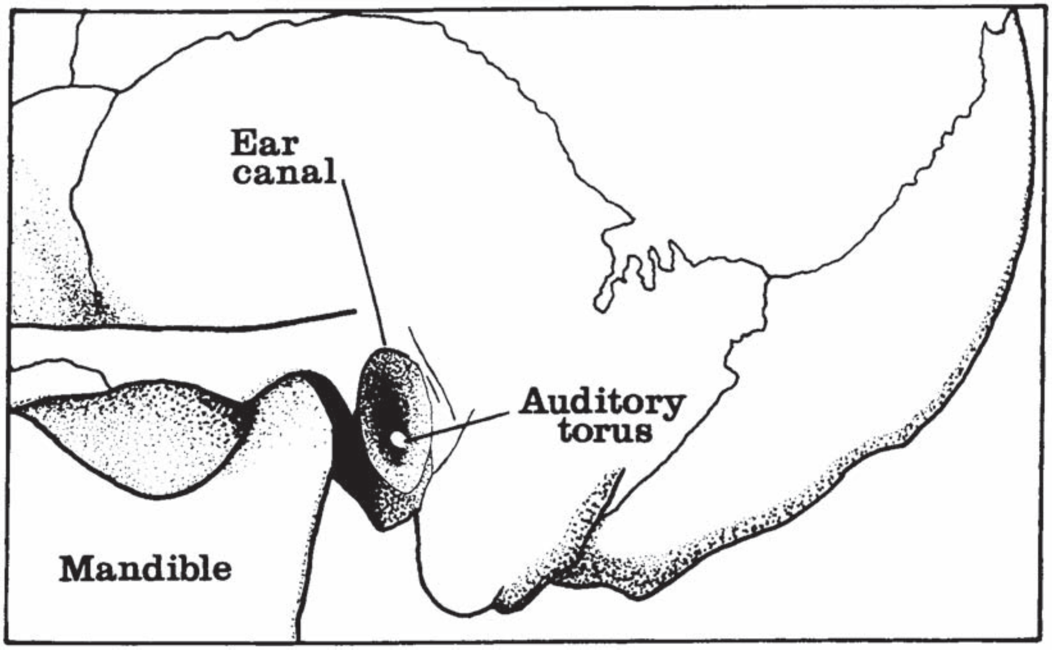


*Figure 5.13* Part of the left side of the skull. The posterior wall of the ear canal shows an auditory torus

ear canal is very thin, so the periosteum here is very near the surface. Irrigation of the ear canal with cold (below about 19°C) water has been shown to cause prolonged local redness and blood congestion which may traumatise the periosteum, stimulating it to lay down new bone. In this way auditory tori may be produced. Consistent with this, cases of auditory tori in man are generally associated with a history of cold water exposure over a long period of time, and auditory tori have been produced experimentally in guinea pigs by irrigating their ears with cold water (discussion taken from Kennedy 1986).

In order to test whether the cold-water-in-the-ears hypothesis might explain patterns in occurrence of auditory tori in archaeological skeletons, Kennedy investigated the way in which frequencies vary on a world-wide basis with respect to latitude. She hypothesised that at low latitudes (30°S–30°N), where sea surface temperatures are rarely below about 21°C, the frequency of tori should be low, as the water would generally be insufficiently cold to produce them. At high latitudes (above about 45°N), water should be too cold for prolonged full body immersion so here too tori should be rare. However, between 30 and 45 degrees of latitude, water temperatures should be cold enough to have the potential to produce tori, but not so cold as rapidly to produce lethal hypothermia. At middle latitudes we might expect auditory tori to be more frequent than at high or low latitudes if the cold-water-in-the-ears hypothesis is valid.

Broadly speaking Kennedy found that this expectation was confirmed. For example in Australia, where data on tori are particularly plentiful, skeletons from the northern parts, which lie in the tropics, show very low frequencies, as do those from inland, desert areas. In south-eastern Australia, surface water temperatures are low enough potentially to produce tori. In the river valleys and coastal areas in this region it was found that frequencies of tori in male skulls were high, but frequencies in females were low. There is considerable ethnographic evidence that in this area freshwater fish were an important food resource for the aboriginal inhabitants. They were caught by casting a net into the water, whereupon the men would dive in, pinning the fish to the river bed. This would seem to be consistent with the difference in frequency of tori between the sexes. By contrast, in Tasmania ethnographic evidence shows that diving into the cold waters surrounding the island for shellfish was a female activity. In skulls from Tasmania, Kennedy found tori only in females.

Building upon Kennedy's work, David Frayer, of the University of Kansas, studied auditory tori in a group of Mesolithic skeletons from Vlasac, Serbia (Frayer 1988). Vlasac lies on a terrace overlooking the river Danube. The skeletons from this site showed a high frequency of tori (34 per cent)—similar to that observed by Kennedy in her Australian groups known to dive for aquatic resources. There was no difference between the sexes in terms of frequencies of exostoses, but the tori tended to be larger in males, perhaps indicating greater exposure to cold water.

Examination of the animal bones excavated from Vlasac (Bökönyi 1978), showed that 60 per cent of the vertebrate fauna were fish. Although a few fish spears were found among the artifacts from the site, there was no evidence for fish-hooks or other fishing equipment. Frayer suggests that the high prevalence of auditory tori may indicate that the fish were obtained by diving into the Danube, where the water would easily have been cold enough to elicit their formation. Another possible explanation for the tori is bathing, but Frayer points out that if bathing were a general cause of tori then they would be expected to occur regularly in European prehistoric skeletons, whereas in fact in most European collections they are rare.

# 6

# BONE DISEASE

When excavating a burial on an archaeological site, a question one is often asked by visiting members of the public is 'How did he die?' Generally speaking, the answer that one has to give is that we don't know. Evidence for lethal injury is rarely found in archaeological skeletons, and in any case most deaths in the past were doubtless due to disease, and, unfortunately from the osteoarchaeologist's point of view, most diseases leave no traces on the skeleton. This is certainly true for the acute infectious diseases which were the great killers in antiquity. The response of bone tissue to disease is relatively slow, so that in general only the more long-lasting conditions even have the potential to affect it. Even for those life-threatening infections which do have the potential to spread to the skeleton, the absence of effective treatment in antiquity would have meant that few individuals would have survived long enough for them to do so. This would have been particularly so if the individual's resistance was lowered as a result of having had no previous exposure to the disease or through poor nutrition. Most skeletons excavated from archaeological sites therefore show no signs of cause of death.

Only a sub-set of the more chronic diseases to which mankind is heir affect the skeleton, so by studying disease in archaeological remains we are in fact seeing some of the diseases which individuals must have endured for some time—often years or even decades. Many of these conditions are not life-threatening and many are found in a healed state, indicating that the individual made a full recovery. Most of the diseases we see in archaeological skeletons have little to do with the cause of death of the individuals concerned, but may well have affected the individual's life-style, at least for some part of their life. Furthermore, on a population level, the diseases which afflict a human group are to an extent a reflection of that group's life-style and the general environment in which they lived. It might be said, then, that studying disease in ancient skeletons generally tells us more about how people lived than how they died.

The study of disease and injury in ancient skeletons is termed palaeopathology, and it is to palaeopathology that the next three chapters are devoted. The present chapter deals with diseases of bone, the following one with dental disease, and Chapter 8 with traces of injury on the skeleton.

## A CLASSIFICATION OF DISEASE OF BONE

Each disease is unique, but in order to provide a framework for discussion it is useful to classify in some way those which affect the skeleton. A classification which is useful for the present purposes is given in Figure 6.1. It is based on the cause of the disease and the pathological changes in the bones.

### Congenital Abnormalities

These are present from birth, either as a result of genetic defects or due to problems during pregnancy. They

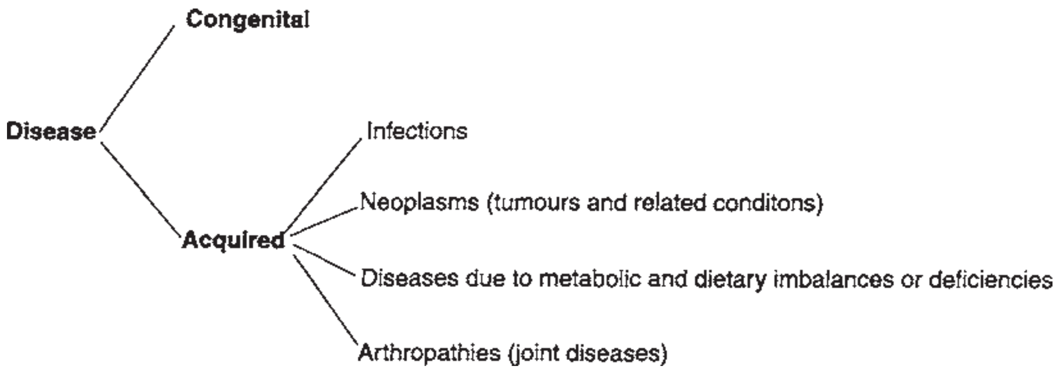


*Figure 6.1* A classification of the diseases of bone
*Source*: Based on Manchester (1983a).

range in severity from those which are incompatible with life and hence would have resulted in the infant being stillborn, through those which would have resulted in disability, to those which would have caused no symptoms and of which the individual would have been unaware. Into the first category come gross malformations such as anencephaly, a condition in which there is almost complete absence of the skull vault and brain. Such a condition has been identified in an Egyptian mummy (Figure 6.2). The infant in question was found buried in catacombs along with sacred ape and ibis, and due to the severity of the deformities there was doubt for a time as to whether it was human. Ironically, the embalmer had attempted to extract the brain in the usual way through the nose, failing to realise the significance of the anomalies in the head and neck (Brothwell and Powers 1968). Abnormalities which would have resulted in disability rather than death include congenital hip dislocation, club foot and cleft palate, all conditions which have been recognised in ancient skeletons (Brothwell and Powers 1968).

## Infections

Infections are produced by pathogenic micro-organisms. Infection, be it of the soft tissues or of bone, results in inflammation. In the inflammatory process there is increased blood circulation, followed by migration of fluid and blood cells into the surrounding tissues. Bone inflammation is often divided into that which affects the outer surface (termed periostitis) and that which affects the compact bone, together with the marrow cavity or trabecular bone within, termed osteomyelitis. A case of osteomyelitis is shown in Figure 6.3. Inflammation may result in bone destruction, new bone formation or a combination of the two. Accumulation of pus and fluids raises the periosteum, stimulating new bone deposition beneath it. Increased blood supply also favours bone production. This new bone is initially laid down as woven bone, but is progressively remodelled to lamellar bone. On the other hand, pressure from pus in the internal spaces of bone leads to blockage of blood vessels, and consequent localised necrosis (death) of bone which is then resorbed by osteoclasts (discussion in Steinbock 1976:60ff.).

For lesions showing new bone deposition it is important to record whether deposits are of woven bone, lamellar bone or both. The presence of woven bone denotes a lesion which was active at time of death, and hence, depending upon its nature, the disease that caused it might be implicated as cause of death. Woven bone alone indicates that the individual died shortly after contracting the condition; a mixture of woven and lamellar bone indicates that the individual survived for rather longer. The presence of remodelled bone only indicates a healed (or at least quiescent) lesion.

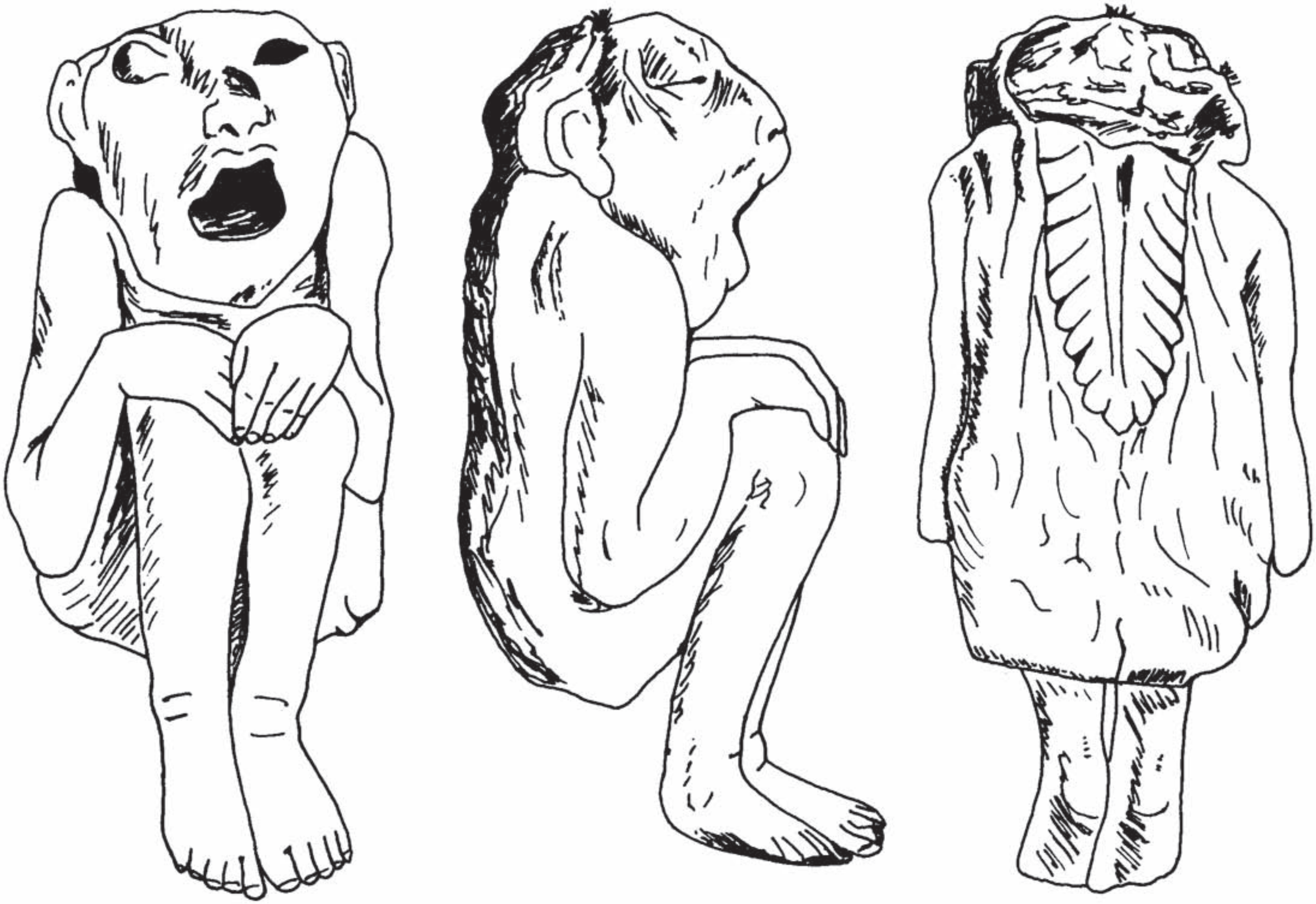


*Figure 6.2* Three views of an anencephalic infant from Hermopolis, Egypt

*Source*: Redrawn from Brothwell and Powers (1968: Figure 3).

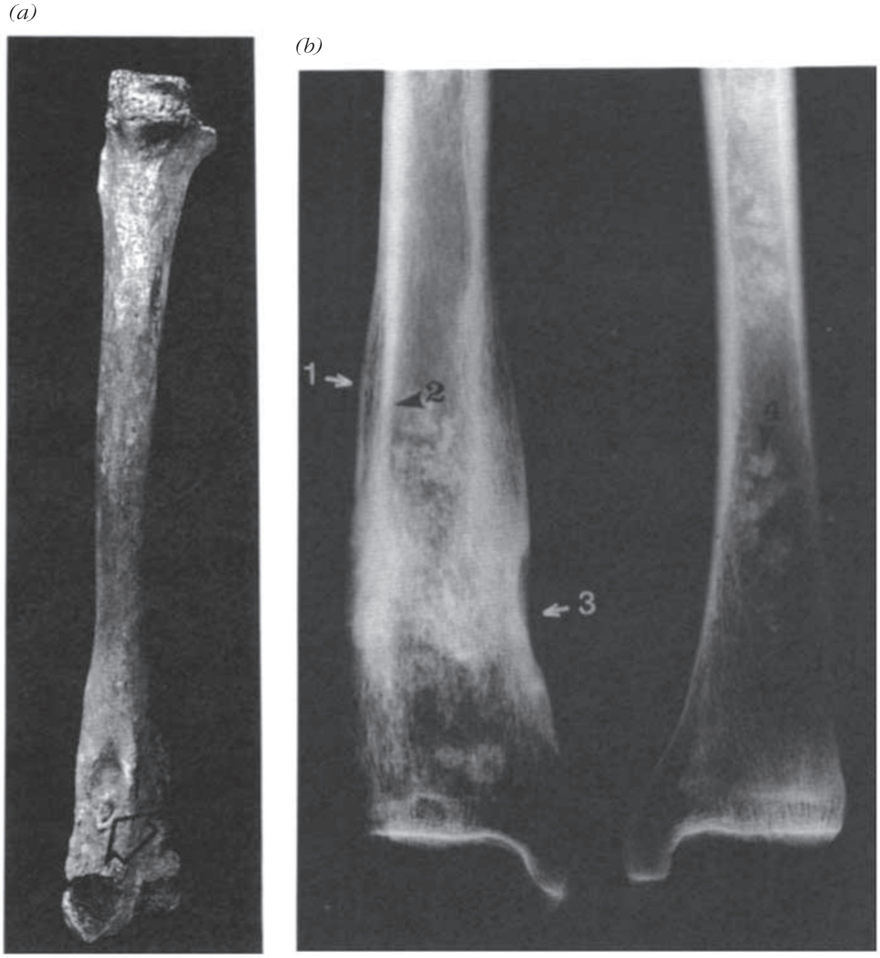


*Figure 6.3* Osteomyelitis, (a) There is marked swelling near the distal (lower) end of the tibia. On the medial aspect there is an oval depression (arrowed) which probably represents a healed cloaca, a channel formed through the bone cortex as a result of pressure from pus within the bone, and through which pus and dead bone fragments are discharged, (b) The radiograph (anterior view) shows that the outer surface of the bone at the site of the lesion (1) is a shell around the original cortex (2). This new shell of bone forms as a result of elevation of the periosteum and infection beneath it. The original cortex underneath dies as a result of pressure blockage of blood vessels, and in this case has been partly resorbed. (3) indicates the site of the healed cloaca. On the right in the X-ray is the normal left tibia from this burial for comparison. The radiographs of both tibiae show 'blotches' (4) due to ingress of earth into the bones as they lay in the soil. This case of osteomyelitis has the appearance of a healed, or at least quiescent infection rather than one which was active at time of death

It is often difficult to determine which micro-organism might have caused lesions seen in an ancient skeleton (i.e. to determine which disease is may be similar to those caused by another. In such responsible), the changes wrought by one infection cases, the only diagnosis which can be made is non-specific periostitis or osteomyelitis. However some micro-organisms do produce lesions which are distinctive in their appearance

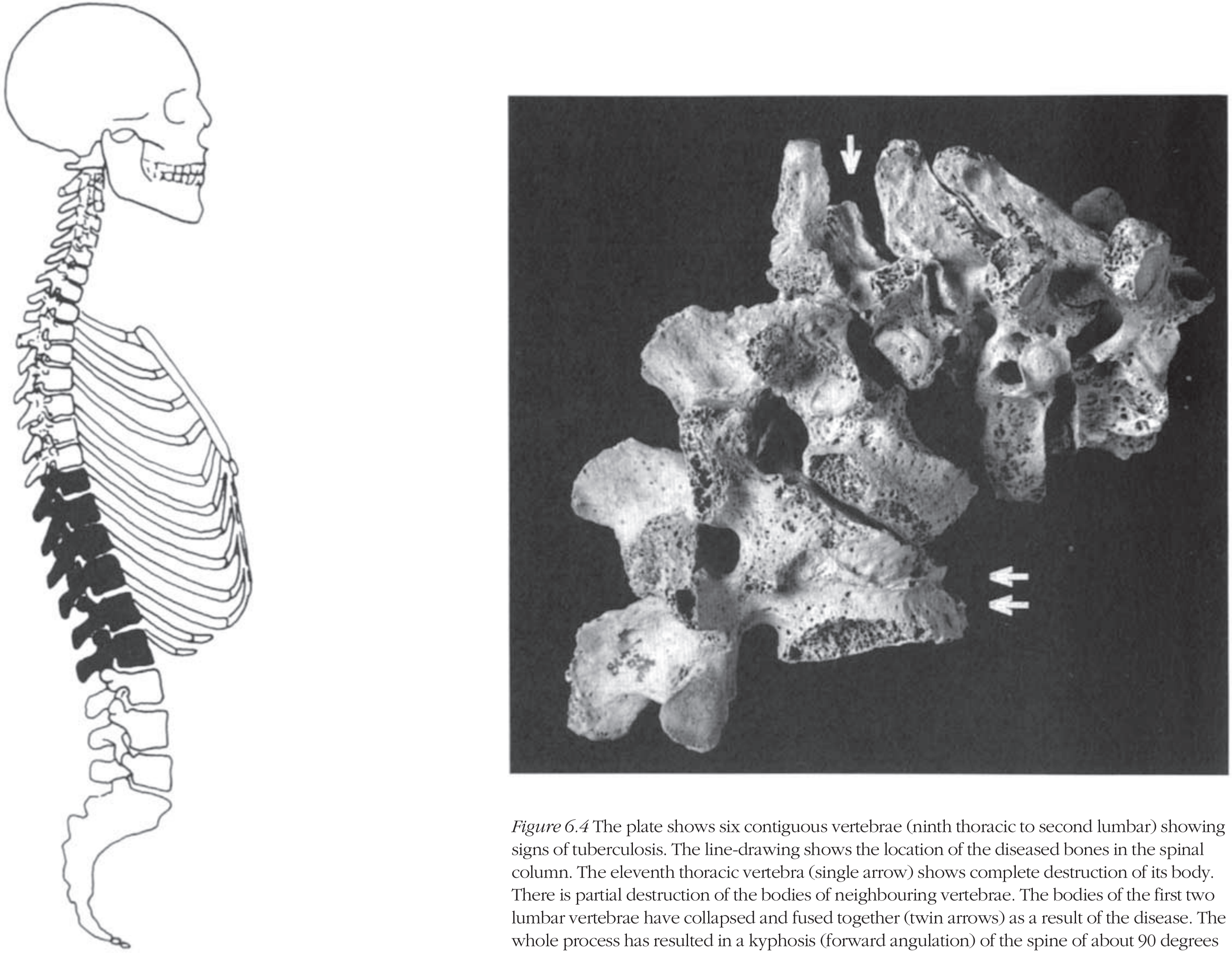


*Figure 6.4* The plate shows six contiguous vertebrae (ninth thoracic to second lumbar) showing signs of tuberculosis. The line-drawing shows the location of the diseased bones in the spinal column. The eleventh thoracic vertebra (single arrow) shows complete destruction of its body. There is partial destruction of the bodies of neighbouring vertebrae. The bodies of the first two lumbar vertebrae have collapsed and fused together (twin arrows) as a result of the disease. The whole process has resulted in a kyphosis (forward angulation) of the spine of about 90 degrees

or distribution in the skeleton. This may enable the identification of particular infections. Infectious diseases which have been identified on ancient skeletons include tuberculosis, syphilis and leprosy. A probable example of skeletal tuberculosis is shown in Figure 6.4.

### Neoplasms

A neoplasm, or tumour, is an uncontrolled growth of cells. Tumours may be benign or malignant. In the former case they tend to be slow-growing and remain localised. In the latter they may be faster growing and spread to other parts of the body via the bloodstream or lymphatic system. Tumours in the skeleton may originate in the bone, but more often they are carried to the skeleton from another tissue. Malignant neoplasms ('cancers') are generally life-threatening. Neoplasms may be bone forming or they may result in bone destruction; in many cases a combination of both processes occurs. About forty different types of tumour may affect bone (Steinbock 1976:316), but it is often very difficult to distinguish one from another in skeletal material. An example of one type of malignant neoplasm is shown in Figure 6.5. This is a probable case of metastatic carcinoma, the skull perforations (arrowed) have occurred as a result of detached fragments of a soft tissue cancer spreading to the skeleton (Manchester 1983b).

### Diseases Due to Metabolic or Dietary Deficiency or Imbalance

These are disorders which either result in inadequate or excessive bone production, or in excessive deossification of existing bone. They may be caused by deficiency or excess of one or more components in the diet, or they may occur when diet is adequate if, for some reason, the body cannot maintain normal bone metabolism.

Rickets is an example of a metabolic bone disease which has been recognised in skeletal remains (Stuart-Macadam 1989a: 206–212). Rickets is a disease of childhood; it is a failure of proper mineralisation of growing bone due to inadequate availability of vitamin D. Most vitamin D in man is not dietary but is synthesised in the body by the action of sunlight on a substance in the skin. Thus most rickets is caused by inadequate exposure of the skin to sunlight (Resnick and Niwayama 1988:2100– 2101). The bones become bent and distorted, particularly those of the legs (Figure 6.6).

Other nutritional/metabolic diseases which have been recognised in skeletal remains include scurvy and iron deficiency anaemia (Stuart-Macadam 1989a).

### Arthropathies

There are more than two hundred and fifty arthropathies (joint diseases) currently defined (Rogers 1989). They have many different causes. Not all leave diagnostic traces on the bones—less than ten specific arthropathies have been identified with any frequency in skeletons from archaeological sites (Rogers *et al.* 1987; Dieppe and Rogers 1989).

When they leave traces on the skeleton, arthropathies generally result in both bone formation and bone destruction, but they may be classified as proliferative or erosive depending upon which process predominates.

Osteoarthritis and vertebral osteophytosis are proliferative arthropathies, and are the two most common joint diseases seen on bones from archaeological sites. Vertebral osteophytosis results from degeneration of the intervertebral disc, which leads to osteophytes (bony outgrowths) at the margins of the vertebral body, the weight-bearing part of the vertebra. Osteoarthritis is degeneration of the cartilage at a joint. The bony signs are osteophytes at the joint margins coupled with pitting and/or polishing of the joint surface (Figure 6.7). The causes of these conditions are multiple, but mechanical strain on the joints seems to play an important role (Hadler *et al.* 1978; Croft *et al.* 1992; Radin *et al.* 1980).

Another proliferative arthropathy which has been identified in ancient bones is diffuse idiopathic skeletal hyperostosis, or DISH for short. This disease is characterised by large amounts of new bone formation,

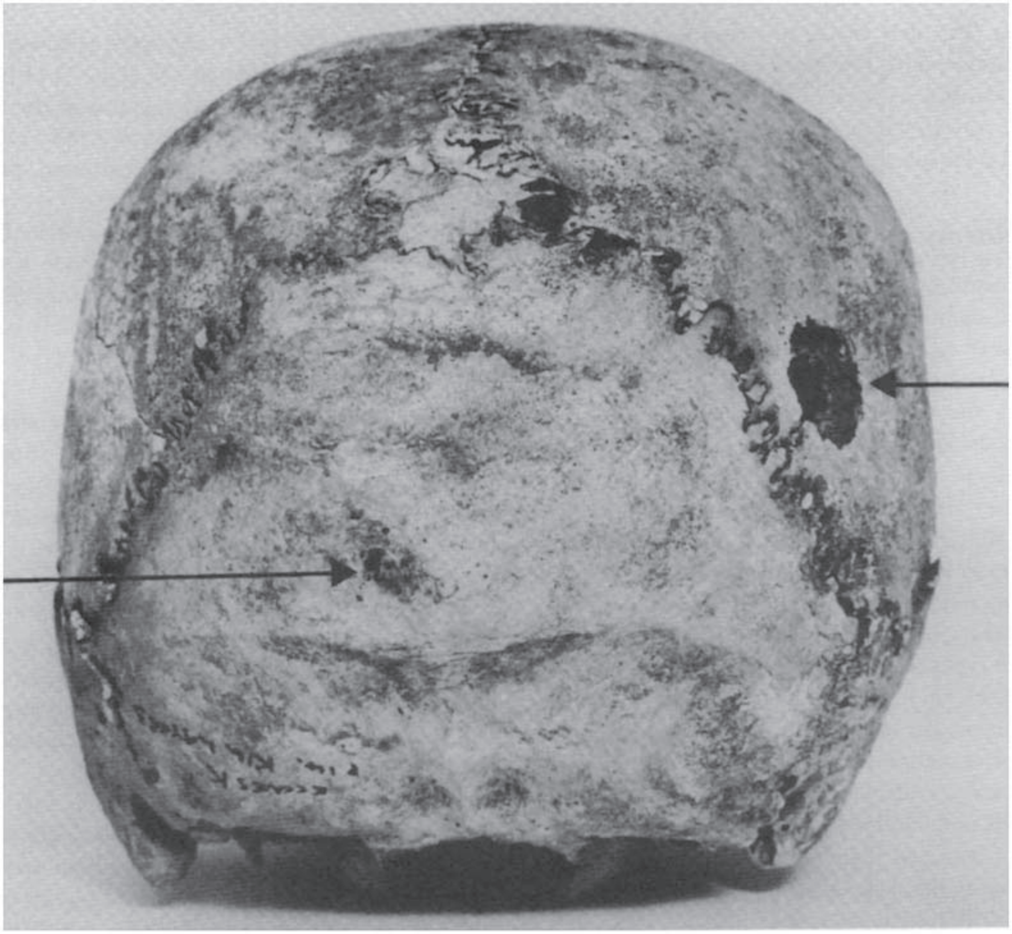


*Figure 6.5* Metastatic carcinoma: this skull shows perforations (arrowed) in the bones of the vault due to the disease
*Source*: Reproduced from Manchester (1983b).

particularly in the spine where large flowing osteophytes may unite several vertebral bodies. Although its precise cause is uncertain it may be associated with diabetes and with obesity (Julkunen *et al*. 1971).

Arthropathies where erosive changes predominate are generally rarer in-palaeopathology. They include gout, rheumatoid arthritis, ankylosing spondylitis and a group of joint diseases which may occur as reactions to venereal, skin or gut infections.

## THE DIAGNOSIS OF DISEASE IN SKELETAL REMAINS

When confronted with an apparently abnormal bone, the first task is to determine whether the changes

*Figure 6.6* The lower leg bones of an adult bowed as a result of childhood rickets
*Source*: Reproduced from Molleson and Cox (1993: Figure 3.9).

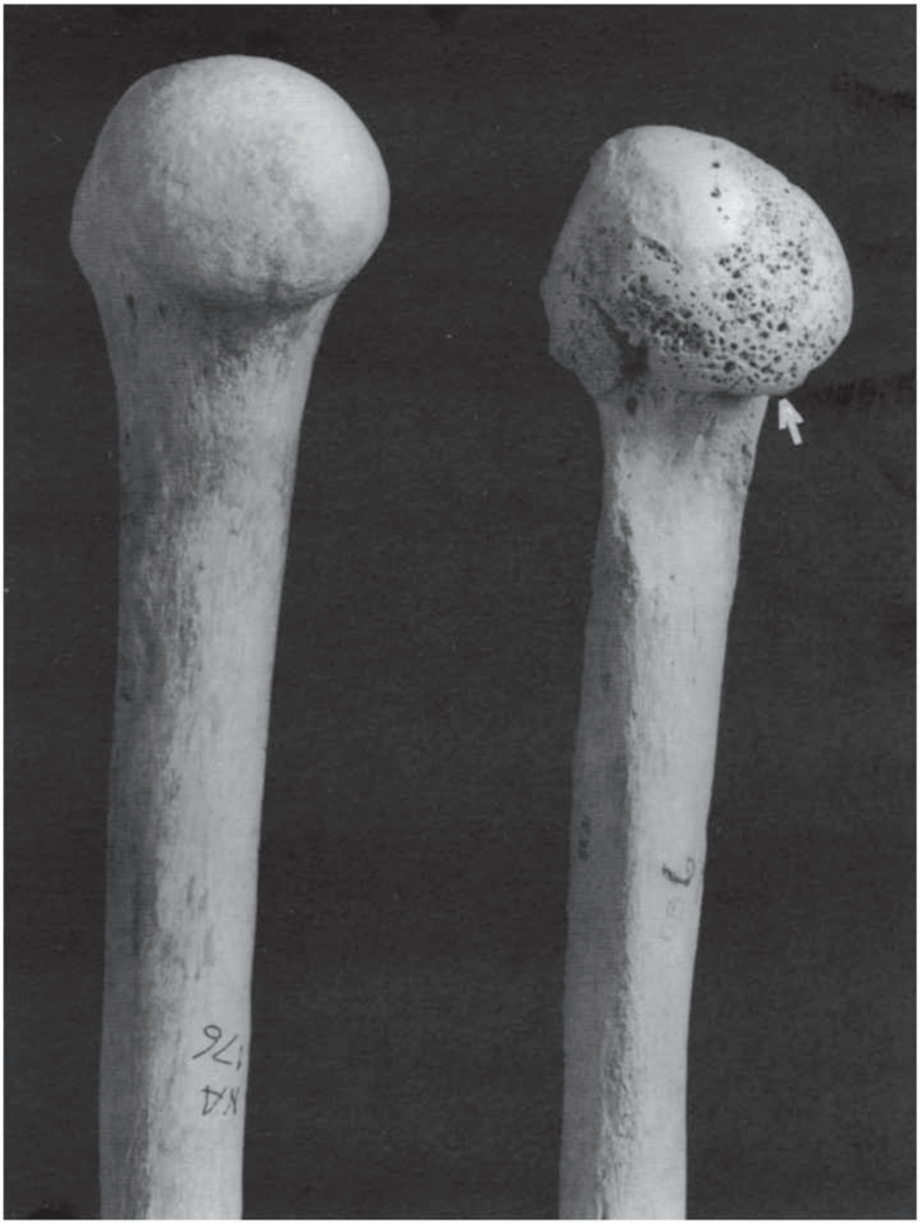


*Figure 6.7* The humerus on the right shows severe osteoarthritis of its proximal (upper) joint surface. Marginal osteophytes (arrowed) are present, accompanied by pitting and polishing of the joint surface. On the left is a normal humerus for comparison

*Figure 6.8* An illustration of the distinction between bone destruction caused by a disease process and that due to post-depositional damage. Post-depositional damage is illustrated in the lower vertebra of the three. The trabecular structure of the bone is exposed. The edges of this damaged area are ragged and the trabeculae are fine and unremodelled. The vertebra in the middle of the photograph also shows an area of superficial destruction with exposure of the underlying trabecular bone. However, there is evidence of remodelling of the trabeculae in the form of coarsening and thickening of the honeycomb structure, and the surfaces of the destroyed area are smoother and less ragged. This remodelling indicates that the bone destruction is due to a disease process and not to post-depositional damage. A normal, undamaged vertebra is shown at the top of the photograph for comparison

occurred during life or simply result from damage to the bone as it lay in the soil. Although diseased bones present a myriad variety of appearances, ultimately the only way in which the skeleton can respond to disease is by removal of bone or formation of bone. Clearly, processes occurring in the soil after burial cannot result in new bone formation, but they can destroy bone. The problem, then, is distinguishing cavities or holes in bone which result from disease from those caused by post-depositional damage.

When a cavity in bone is caused by post-depositional factors, such as soil erosion, it tends to have rather ragged edges. With a cavity due to disease, the trabeculae at its edges are, to a greater or lesser extent, remodelled, a process which is evident as thickening of the bony trabeculae and smoothing of the walls of the lesion (Figure 6.8). This effect is greatest in slow-growing lesions and is least when bone destruction is rapid (Ortner and Putschar 1985: Figure 28). In most cases the experienced osteoarchaeologist can distinguish genuine instances of disease from post-depositional damage.

Familiarity with normal skeletal anatomy generally allows one to distinguish features due to disease from those due to normal variation in bone form (Figure 6.9).

Having established that changes observed in an ancient skeleton are not due to post-depositional damage or normal skeletal variation, the next step towards a diagnosis is to describe the changes.

As well as being able to talk to the patient, the modern physician has at his or her disposal a wide array of diagnostic techniques, but the great majority of these are not applicable to the study of ancient

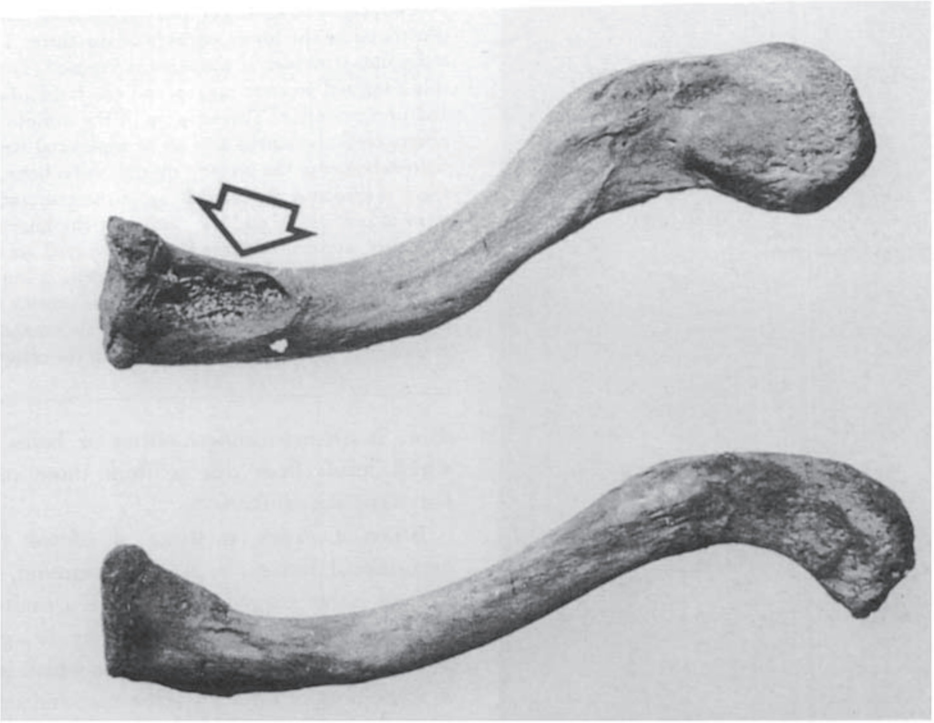


*Figure 6.9* Inferior (lower) view of two clavicles. The top one shows a deep cavity towards its sternal end. This is not an abscess cavity but a normal anatomical variant at the point of attachment of the costo-clavicular ligament. Sometimes this pit is absent, as in the bone in bottom of the picture

bones. However, osteoarchaeologists do have one great advantage, they can actually see the bones. Thus careful visual examination of the bones and careful recording of the findings, in the form of written descriptions augmented as appropriate with photographs and diagrams, are most important in osteoarchaeology.

Osteoarchaeological diagnoses are made from the nature of the lesions themselves and their distribution in the skeleton. Diagnoses are made with reference to bone changes produced by known diseases in modern or recent cases. If the lesions caused in the skeleton by a particular disease are characteristic and are distinct from those caused by other diseases, then if similar changes are seen in an ancient skeleton the suggestion is that they were caused by the same disease. Assumptions here include that the disease has not changed sufficiently since ancient times to preclude its recognition, and that no other disease process existed that had a similar appearance but no longer exists (Rothschild 1992).

A detailed knowledge of the range of bone changes likely to be caused by the various diseases which may affect the skeleton is needed in order to form the baseline for interpretation of archaeological specimens. There are a number of textbooks (e.g. Steinbock 1976; Ortner and Putschar 1985; Zimmerman and Kelley 1982; Mann and Murphy 1990) which detail the bone changes wrought by various diseases with the aim of providing diagnostic criteria for archaeological cases.

A potential problem when comparing changes in ancient bones with those in modern cases is that the manifestations of many diseases have been changed in recent times by the advent of effective drug and other therapies. This is particularly so for bacterial infectious diseases, whose courses have been radically altered by antibiotics. By contrast, in antiquity the disease process would, in most cases, have proceeded essentially unchecked, except by the body's natural defences, until the individual either succumbed or recovered. Textbooks aimed at establishing palaeopathological criteria thus tend to use documented specimens pre-dating the era of effective antibiotic and other treatments. For example in their textbook, Ortner and Putschar (1985) use specimens from medical and other museums dating to between about AD 1750 and 1930. They argue that material from this period is likely to provide the best general baseline for interpreting lesions seen in archaeological skeletons, as it is late enough for the medical diagnosis for the specimens to be reasonably secure, and early enough for the patterns of bone involvement to be unaltered by antibiotics and other modern treatments. However, some diseases have only recently been recognised as distinct entities. In such instances we are forced to use bone changes in modern cases as our baseline for interpreting archaeological material. This is so, for example, for many of the arthropathies (Rogers *et al.* 1987).

Examination of recent dry bone specimens where the disease history is known provides a direct link with disease seen in archaeological bones. However, the number of reliably documented specimens is relatively few. In addition, many were only kept as isolated bones rather than as complete skeletons and this means that it is difficult to determine general patterns of skeletal involvement from these collections. Typical frequencies of skeletal involvement and distributions of lesions amongst the various bones of the skeleton can best be estimated with reference to statistical data gathered by physicians prior to the introduction of effective drug and other therapies. Where such data are available (as they are, for example, for tuberculosis and syphilis), palaeopathological textbooks use them to help infer the likely distribution of lesions among the different bones of the skeleton in archaeological cases.

Several techniques are available to the osteoarchaeologist which may assist diagnosis of disease in ancient bones. These include microscopic examination (Aaron *et al.* 1992; Roberts and Wakely 1992) and, to some extent, chemical analyses (Fornaciari *et al.* 1981; von Endt and Ortner 1982). In future it may be possible reliably to identify diseases in ancient skeletons by immunological techniques (Ortner *et al.* 1992; Childe and Pollard 1992) or by detection of minute traces of DNA from infecting micro-organisms left in the bones (see Chapter 10). However, the technique which is currently the most important aid to visual examination is radiography of ancient bones (Mays, forthcoming).

By X-raying ancient bones, the appearance of lesions seen in archaeological skeletons can be directly compared with those in X-rays of modern patients. Thus radiography provides a direct link between the changes seen in palaeopathological specimens and those in living people with known diseases. In addition, modern radiographic data have the advantage that they are much more numerous than are reliably documented cases of disease in recent dry bone specimens. Provided that it is borne in mind that advanced, untreated forms of disease, and quiescent, healed lesions are likely to be rare amongst them, modern X-ray data can help strengthen our baseline for the diagnosis of disease in ancient bones.

It must be emphasised that radiography of archaeological specimens should be used in addition to careful visual examination of the bones, not as a substitute for it. Post-depositional effects such as soil erosion, breaks in the bone or ingress of soil particles to the bone interior cause changes in the X-ray appearance (see Figure 6.3b) which might be mistaken for those due to disease. Radiographs should always be examined in conjunction with the specimen itself (Wells 1967).

A change in bone density of about 40 per cent is required before any change is visible on conventional X-ray films (Ortner 1991). This means that many of the more subtle changes are invisible on X-ray, even though they may be clearly seen on the specimen itself. For example, examination of recent skeletons of individuals known to have died from tuberculosis (Kelley and Micozzi 1984) revealed that many ribs showed periostitis on their inner surfaces. The frequency of rib lesions was much greater than that reported in modern medical surveys of tuberculosis. This is probably because the rib changes were generally rather slight and would probably not have been visible in an X-ray of a living patient, even though they were obvious to the naked eye in the dry bone.

Conversely, lesions which are confined to the interior of the bone will not be visible to the naked eye on the dry bone specimen, whereas they may be revealed by X-ray. Radiography may thus reveal additional lesions in a skeleton recognised as diseased from visual inspection, or X-ray of apparently normal specimens for other reasons may occasionally reveal unsuspected pathological changes.

The use of radiography as an aid to description and diagnosis is more valuable for some diseases than for others. Its value has been stressed in the palaeopathological study of arthropathies (Rogers *et al.* 1987), whereas for other conditions radiographic appearances have been less emphasised. Diseases such as osteoporosis, which involve loss of bone mineral without changes to the external form of the bones, cannot be adequately studied by visual examination of the dry bone specimen. Radiography or related techniques are thus particularly important for study of this type of disease in archaeological remains.

Despite the work which has been directed at enabling palaeopathological diagnosis, diagnosis of disease from the bony changes alone remains very difficult. The limited way in which bone can respond to disease means that different diseases may appear alike on the skeleton. Furthermore, in a particular disease, bony manifestations may differ according to, among other things, whether the lesions were healed or active at time of death, the degree of resistance of the individual to the disease and the length of time the condition was present. These difficulties are compounded in archaeological cases as skeletons are often incomplete, and the bones which do remain may be damaged by post-depositional processes. Careful study of the lesions and their distribution in the skeleton may suggest a diagnosis, but in many cases, particularly where the only change is an isolated lump, bump or cavity on a bone, a firm diagnosis may be elusive.

## THE CONTRIBUTION OF PALAEOPATHOLOGY TO ARCHAEOLOGY

Once we have arrived at a possible diagnosis for as many cases of disease as we can in the skeletal assemblage under study, it remains for us to try and understand what the results mean both at an individual and, more importantly, at a broader level.

Most of us have experienced the pain of toothache or a dental abscess. Even if we have not been so unfortunate as to suffer from them ourselves, the symptoms of diseases such as gout or rheumatoid arthritis are well known. When examining a carious tooth or an arthritic bone we are able to empathise, and indeed, sympathise, with the pain and discomfort the individual must have endured, and this in an era where there was little prospect of alleviating the person's suffering, let alone curing the disease.

However, as archaeologists it is important for us to progress beyond the case study of the individual skeleton in order to tackle meaningful archaeological questions, and hence make more general inferences about the past. By utilising the great time depth provided by archaeological remains, the study of ancient skeletons may allow us to extend our knowledge of the occurrence, frequency and severity of some diseases back beyond the point at which the first reliable written descriptions occur. By relating disease frequencies to aspects such as changes in subsistence strategy, climate and urbanisation we can increase our knowledge of these important transformations and their effects on earlier human populations. On the intra-population level, we can examine disease prevalence with respect to social rank or gender in order to understand better the nature of past social inequalities. However, because many diseases which may potentially affect the skeleton actually do so only in a minority of cases, care is needed in interpreting frequency figures. For example, tuberculosis may affect the skeleton by spead of infection from the soft tissues—often the lungs. From a survey of some of the literature, Steinbock (1976:175) suggests that on average it may do so in only about 5–7 per cent of cases. However, it must be emphasised that this is an average figure. If, for example, tuberculosis spread to a population which had little resistance to it, we would expect few to survive the disease long enough to show bone changes, so less than Steinbock's figure of 5–7 per cent would show skeletal signs. However, in the case of a population which had built up some resistance to tuberculosis, as a result of long association with the bacterium which causes it, we might expect longer survival before succumbing to, or recovering from the disease, and hence a somewhat higher frequency of bone changes. It is worth bearing in mind, then, that differences in frequencies of infectious diseases, such as tuberculosis, in archaeological assemblages may reflect not only differences in the prevalence of a disease in the populations from which the assemblages are drawn, but also, to some extent, the resistance of those populations to the disease.

What follows are two examples of the contribution osteoarchaeology has made to the study of the history of particular diseases. A third example discusses the way in which frequencies of pathological lesions in an ancient population varied between those living in different ecological zones within a fairly small geographical area, and what this may tell us about diet, population densities and general living conditions.

## THE HISTORY OF SYPHILIS IN EUROPE

Syphilis is one of four related infections caused by bacteria of the genus *treponema,* the others being treponarid (also called endemic, or non-venereal syphilis), yaws and pinta. Collectively they are termed the treponemal diseases. All except pinta may affect the skeleton. Yaws is a disease of the humid tropics, and is spread by skin contact. Treponarid, like yaws, is spread via skin contact or may also be communicated via shared eating and drinking vessels. It is mainly found in warm, dry climates, although in the past it seems to have occurred in temperate Europe. Syphilis is the only one of the treponemal diseases which is sexually transmitted, and it may also be passed from an infected mother to the developing foetus so that the child is born with the disease. The distribution of syphilis shows no climatic restrictions.

### The Bone Changes in Syphilis

The course of syphilis is generally protracted and may be divided into three stages (Sparling 1990). The primary stage lasts about three weeks and involves the appearance of a sore at the point of infection (usually the genitals). Secondary syphilis marks the spread of the disease through the body via the bloodstream and lymphatic system, and is characterised by fever and a transient skin eruption. Features of the tertiary stage, which commences some 1–20 years after initial infection (Musher 1990:209), include spread of syphilitic damage to different organs, such as the circulatory system, which may result in syphilitic aneurysms, and the central nervous system, which may result in blindness, deafness, paralysis and insanity (Sparling 1990; Swartz 1990). Untreated syphilis may cause death, but generally only after the sufferer has had the disease for a long period of time, often several decades (Sparling 1990).

Diagnostic bone changes are confined to the tertiary stage of the disease (Hackett 1976; Ortner and Putschar 1985). Formation of gummata may occur. A gumma is a firm swelling which may form within various tissues, including bone. Skeletal changes in syphilis may be due to the formation of gummata in or adjacent to the bones (gummatous lesions) or simply to chronic inflammation not associated with gumma formation (non-gummatous lesions). Formation of gummata leads to cavities within the bone or on its surface. Chronic inflammation leads to periostitis with marked bone thickening.

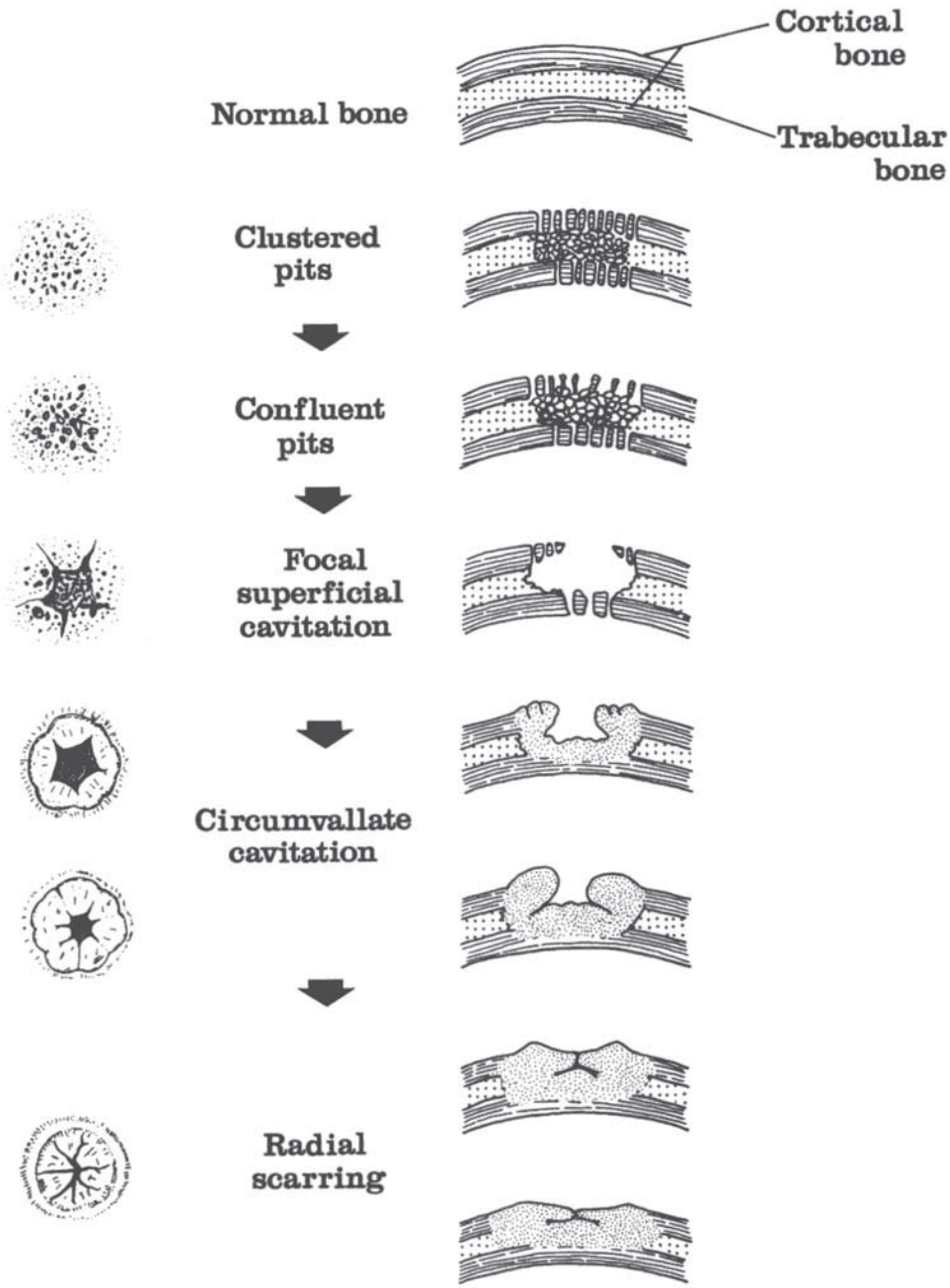


*Figure 6.10* Sequence of cranial vault changes in treponemal disease. The series on the left shows the superficial appearance of the lesions on the skull surface; that on the right shows them in cross-section

*Source*: Redrawn from Hackett (1983: Figure 2).

*Figure 6.11* Syphilis: four views of a tibia thickened due to non-gummatous periostitis
*Source*: Reproduced from Hackett (1976: Figure 21).

In syphilis, the bones most commonly affected are those of the cranial vault (particularly the frontal bone) and the tibia (Figures. 6.10 and 6.11); involvement of the other tubular bones is also frequent, as are changes in the ribs and sternum (Ortner and Putschar 1985: Table 10). The lesions in the other treponemal diseases which may affect bone, treponarid and yaws, are very similar to those in venereal syphilis (Steinbock 1976; Anderson *et al.* 1986; Reichs 1989), so it is difficult to distinguish these three from one another in the skeleton.

Controversy has long existed over the origin and geographical spread of the treponemal diseases, particularly syphilis. Specifically, much discussion has centred over the introduction of syphilis into Europe. One theory, termed the Columbian hypothesis, maintains that it originated in the Americas and was brought back to Europe by Columbus and his crew when they returned in 1493 from their first voyage to the New World. Other theories hold that it was already present in Europe prior to this.

## Historical Evidence for the Origin of Syphilis

Documentary evidence describes a disease which appears to be syphilis ravaging Europe in the closing years of the fifteenth century, an epidemic which appears to have coincided with Columbus's return from the New World. There is no unequivocal description of syphilis in any known pre-Columbian Old World literature and, almost without exception, sixteenth-century Old World writers considered it a new disease (Crosby 1969). In Europe it seems to have followed the classic course of a newly introduced disease of initial virulence followed by a decrease in its deadliness, and the various names initially given to it indicate that it was thought to be of foreign origin (Crosby 1969).

Several associates of Columbus felt that it had its origin in the New World. For example, the physician, Ruiz de Isla, claimed in a book published in 1539, but perhaps written as early as 1505, that the disease was seen in Columbus's men and that they contracted it on the Caribbean island of Hispaniola. He also described its rapid spread through Barcelona in 1493 after Columbus's return there from the Americas (Crosby 1969; Baker and Armelagos 1988). Historical sources suggest that syphilis was present in the Americas long before the arrival of Europeans. Bartolome de las Casas, who accompanied Columbus to the New World, learnt from the Native Americans that they had known the disease since time immemorial (Crosby 1969). Friar Ramon recorded the beliefs of the Arawak natives of Hispaniola in the mid-1490s. He tells of an Arawak folk hero, Guagagiona, who 'had great pleasure' with a woman but soon afterwards had to 'wash himself because he was full of those sores which we call the French disease' [i.e. syphilis] (Crosby 1969). Crosby indicates that this myth is likely to have originated long before the arrival of Columbus.

Those who have attacked the Columbian theory on the basis of the documentary evidence suggest that syphilis was present in Europe prior to 1493 but that it was not distinguished from other diseases, particularly leprosy. This is supported by medieval documents which refer to 'venereal' or 'hereditary leprosy'. True leprosy is not sexually transmitted and does not occur congenitally. It is thus suggested that the 'syphilis epidemic' in late fifteenth-century Europe may merely have been the recognition of syphilis as a distinct disease entity rather than it being a truly new disease.

Other criticisms of the Columbian hypothesis have been made on the basis of the historical evidence. With the possible exception of Ruiz de Isla, a New World origin for syphilis was not mentioned until at least thirty years after Columbus's first voyage, whereas if a relationship existed one might have expected it to be mentioned sooner (Holcomb 1935). In particular no mention of the disease is made in the documents relating to Columbus's voyages written prior to its apparent outbreak in Europe (Crosby 1969). Furthermore, even if we accept that there were epidemics of syphilis in the closing years of the fifteenth century they may not be connected with the Columbus voyage (Holcomb 1935).

Thus whether syphilis was introduced to Europe from the Americas by Columbus and his crew or existed in Europe prior to 1493 is uncertain from the documentary data.

## The Contribution of Skeletal Evidence to the Debate

Over the years, an abundance of skeletal evidence has accumulated for treponemal disease of pre-Columbian date from the Americas (reviews in Baker and Armelagos 1988; Steinbock 1976:95– 97). The oldest New World skeletal material reported as showing signs of treponemal disease dates to about 4790–3380 BC (Snow 1948; radiocarbon date given in Libby 1955:94, calibrated according to Pearson *et al*. 1986).

Until recently, no good cases of treponemal disease which certainly pre-date 1493 were known from Europe. This was taken by many writers (discussion in Baker and Armelagos 1988; Crosby 1969) as supporting the Columbian hypothesis. However, recent discoveries in Europe have altered this picture.

In the 1970s, excavations of a medieval cemetery in York, England were undertaken (Dawes and Magilton 1980). An isolated skull, missing the mandible and facial bones, showed radial scarring on the frontal bone (Figure 6.12). This type of change strongly indicates a diagnosis of treponemal disease, the radial scars being indicative of healed superficial gummatous lesions (see Figure 6.10). A radiocarbon determination (HAR-6887) was later obtained, giving a date range of AD 1265–1389. The York skull indicates the existence of a treponemal disease in Europe more than a hundred years before Columbus.

Since yaws is a disease of the humid tropics, the treponemal infections to be considered with respect to the York find are treponarid and syphilis. As already mentioned, the bone changes in treponarid and syphilis are very similar, but the distributions of lesions in the skeleton do differ somewhat. For example, in treponarid the cranial vault is rarely affected, and when it is the lesions tend to be more localised and less destructive than in venereal syphilis (Steinbock 1976:139). Although on this basis the widespread

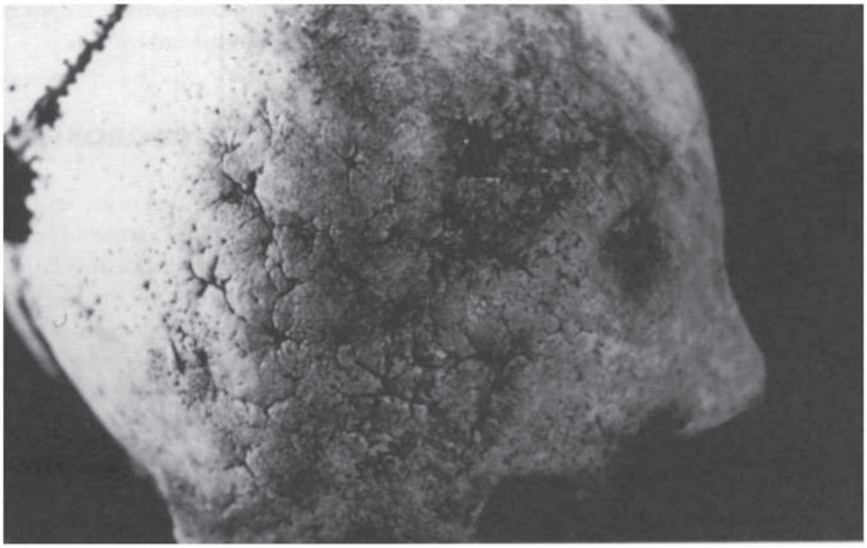


*Figure 6.12* Close-up of the frontal bone of the York skull showing radial scarring, a healed stage of cranial treponemal disease

*Source*: Reproduced from Dawes and Magilton (1980: Plate xi(d)).

lesions on the frontal bone of the York specimen might lead one to lean towards a diagnosis of venereal syphilis rather than treponarid, we cannot distinguish between the two conditions with certainty here.

Since the discovery of the York skull, several other skeletons showing both cranial and post-cranial signs of treponemal disease have been reported from pre-Columbian contexts in Britain (Mays 1991; Stirland 1994; Roberts 1994) and other parts of Europe (Blondiaux and Alduc le Bagousse 1994).

Traditionally, the debate on the history of the treponemal diseases has centred around the origin of venereal syphilis. Even if we can eliminate yaws as a diagnosis for European cases, it could still be argued that the pre-1493 European examples of treponemal disease *could* all represent treponarid and that syphilis *was* a Columbian import from the Americas. Indeed, some have maintained from documentary evidence that treponarid was common in Europe before Columbus (Willcox 1972). However, as evidence of pre-Columbian skeletons showing advanced cranial vault changes accumulates this argument becomes increasingly tenuous.

Another way of distinguishing syphilis from the other treponemal diseases would be if evidence was found of congenital disease—syphilis is the only treponemal disease which may be present congenitally. In this light a recent discovery from Costebelle, southern France, is interesting. Here, in an excavation of a cemetery dating to the third to fifth century AD, a skeleton of a woman was found who had died whilst pregnant, the bones of the foetus were found in her abdominal cavity. The foetus was of about 7 months' gestation and showed signs of disease, which have been described by Gyorgy Palfi and his colleagues (Palfi *et al.* 1992; Dutour *et al.* 1994). It showed periostitis of the skull and other bones, together with large bony plaques partially surrounding some of the long-bones. Some of the bones of the hands and feet were fused together by new bone formation, and, in addition, there were some localised areas of bone destruction. Palfi and colleagues state that the lesions indicate that some sort of infection was present, acquired via transmission across the placenta. After a consideration of some of the alternatives, they offer a diagnosis of congenital syphilis as consistent with the lesions seen on visual examination of the remains. In addition, the radiological appearance of some of the bones was found to be somewhat reminiscent of those seen in modern cases of congenital syphilis. They thus maintain that this case shows syphilis was present in Europe one thousand years before Columbus.

The great majority of work done on establishing diagnostic criteria for syphilis based on dry bone changes has been done using adult bones; such a baseline is lacking for foetal material. So although the lesions seen in the French case may be broadly compatible with congenital syphilis, we lack the necessary diagnostic criteria to exclude other congenital infections as the cause of the lesions. The Costebelle case shows some of the difficulties which often attend palaeopathological diagnosis, and the tantalising nature of some of the results.

In summary, the skeletal evidence has established that treponemal disease was not a Columbian import, but was present in Europe before 1493. In all probability this disease was syphilis, but finds of skeletons showing unequivocal lesions of congenital disease are needed to confirm this.

## MEDIEVAL OSTEOPOROSIS

Osteoarchaeology has also made an important contribution to the study of another disease, osteoporosis. This is a metabolic disease involving loss of bone mineral with advancing age. It results in decreased bone strength and increased vulnerability to fractures. It particularly affects older women. Unlike syphilis, documentary sources are largely silent on this disease—in order to study the history of osteoporosis we must study bones.

The prime cause of osteoporosis in women is the hormonal changes which accompany the menopause. However, a number of factors associated with modern Western life-styles also seem to play a part in exacerbating bone loss. Osteoporosis is a health risk for the elderly due to the fractures associated with it.

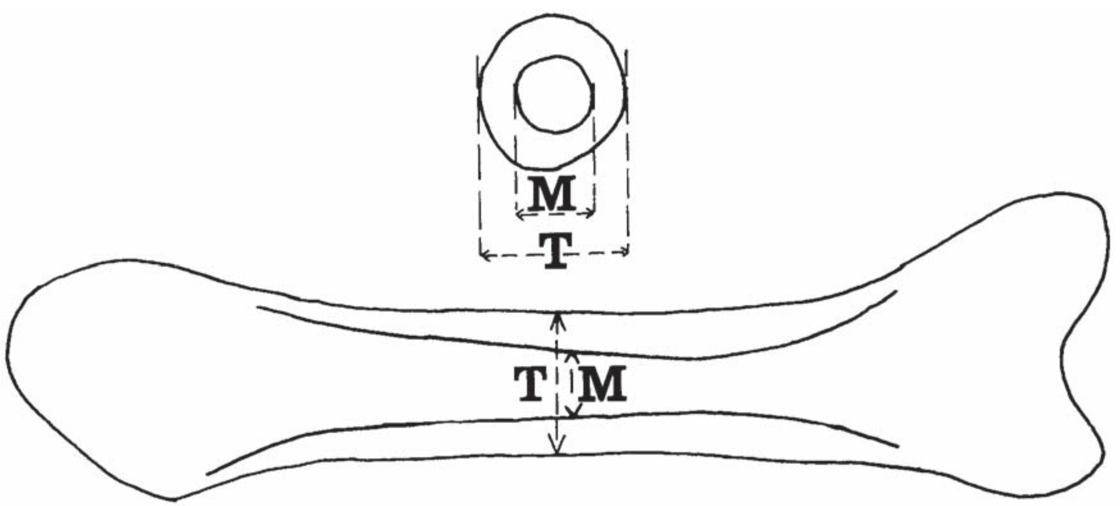


*Figure 6.13* Outline of a second metacarpal bone (dorsal view) to illustrate the method for calculating cortical index from a-p radiographs. T = total bone width, M = medullary cavity width. Measurements taken at the midshaft. A measurement of cortical thickness standardised for bone size was obtained using the cortical index. Cortical index = 100 × (T – M)/T
*Source*: After Dequeker (1976: Figure 1).

In most modern Western nations it is a major and growing cause of mortality and disability. It is clearly of interest from the point of view of our present-day understanding of this disease to study its history in earlier European populations with life-styles very different from our own. I have attempted one such study (Mays 1996), using skeletons of medieval women from Wharram Percy.

A variety of techniques are available for monitoring osteoporosis in living patients. Not all are well suited to the study of excavated bone, but one which is useful is measurement of the thickness of cortical bone in the second metacarpal from radiographs (Figure 6.13). Using this technique, I found that the extent of loss of bone substance among medieval women from Wharram Percy was very similar to that reported in a survey of modern European women (Virtama and Helela 1969); in each the mean value in those aged over 50 years was only about 80 per cent of that for young women (aged 18–30).

In modern women, osteoporosis leads to increased risk of fracture, particularly of the hip, wrist and the highly trabecular bone of the axial skeleton, principally the vertebral bodies but also the ribs (Aloia *et al.* 1983). At Wharram Percy, there were no hip or wrist fractures, but there were fractures of the ribs and compression fractures of the vertebral bodies. At Wharram Percy, women showing spinal or rib fractures had significantly less bone substance than those who did not (Table 6.1). There was no relationship between metacarpal cortical bone values and these fractures for males. This suggests that, for the medieval females, osteoporosis may have been a precipitating factor in fractures of the axial skeleton, just as it is for modern women.

Factors thought to exacerbate osteoporotic bone loss following the menopause include sedentary life-style, deficient calcium intake, cigarette smoking and perhaps vitamin D deficiency (refs in Mays 1996). Medieval peasants would have had a very physically

*Table 6.1* Metacarpal Cortical Index for those from Wharram Percy With and Without Healed Vertebral Compression and/or Rib Fractures (collectively denoted RV fractures)

| | *Individuals with RV fractures* | | | *Individuals without RV fractures* | | |
|---|---|---|---|---|---|---|
| | *No. of cases* | *Mean* | *Standard deviation* | *No. of cases* | *Mean* | *Standard deviation* |
| Females | 4 | 35.5 | 5.5 | 65 | 45.3 | 8.9 |
| Males | 16 | 40.9 | 6.7 | 65 | 43.7 | 8.4 |

*Source*: Figures from Mays (1996).

active life-style compared to their modern descendants. This is as true for women as for men. Wharram Percy lies on chalk geology, and many cow bones and fragments of pottery vessels used for dairy products were found there, so diet was unlikely to have been deficient in calcium. Given the outdoor life-style of medieval peasants, lack of exposure to sunlight sufficient to cause vitamin D deficiency is unlikely; the lack of any cases of healed rickets among the Wharram Percy adult skeletons supports this.

Given the perceived importance of life-style factors in influencing the severity of osteoporosis, the broad similarity in relative bone loss between the medieval and modern women was unexpected. The impression is that the life-style of medieval women would have been expected to lower their risk of osteoporosis compared with their modern counterparts. That the results indicate that they in fact suffered from similar bone loss may call into question the importance of life-style factors in the disease.

## ANAEMIA IN THE US SOUTH-WEST

Our third study looks at the frequency of a pathological condition, porotic hyperostosis, among ancient Native American groups in the US south-west, and discusses scenarios which have been put forward to account for the patterning observed in the data.

Porotic hyperostosis is a condition visible on skeletons as pitting on the bones of the skull, particularly the roofs of the orbits (Figure 6.14) and, sometimes, the external surfaces of the skull vault. These changes correspond to a thinning of the outer layer of cortical bone, together with an overgrowth of the underlying trabecular bone. It seems that porotic hyperostosis arises due to anaemia (Hengen 1971; Stuart-Macadam 1987, 1989b; Mensforth *et al.* 1978), in the majority of populations primarily iron deficiency anaemia. Iron deficiency anaemia is a reduction in the concentration of red blood cells due to inadequate levels of iron. The lesions characteristic of porotic hyperostosis appear to result from increased activity of the bone marrow as the body attempts to combat the anaemia by raising red blood cell production.

Iron deficiency may be due to lack of iron in the diet, but it may also result from disease, particularly gastro-intestinal infections or parasite infestations. Diarrhoea causes food to pass through the gut too quickly for nutrients, and minerals such as iron, to be absorbed, and parasite infestation may lead to anaemia through chronic blood loss (Kent *et al.* 1994; Kent and Dunn 1996; Stuart-Macadam 1992).

Mahmoud El Najjar and his co-workers (El Najjar *et al.* 1975, 1976) studied the frequency of porotic hyperostosis in 539 skulls from five Anasazi Indian sites in Arizona and New Mexico dating from the fifth century to the seventeenth AD. Three of the sites were situated at the bottom of canyons; the other two lay on the plains above (Table 6.2).

Lesions are more frequent in skeletons from canyon bottom sites than the plains, and are more frequent among children under 11 years than among adolescents and adults.

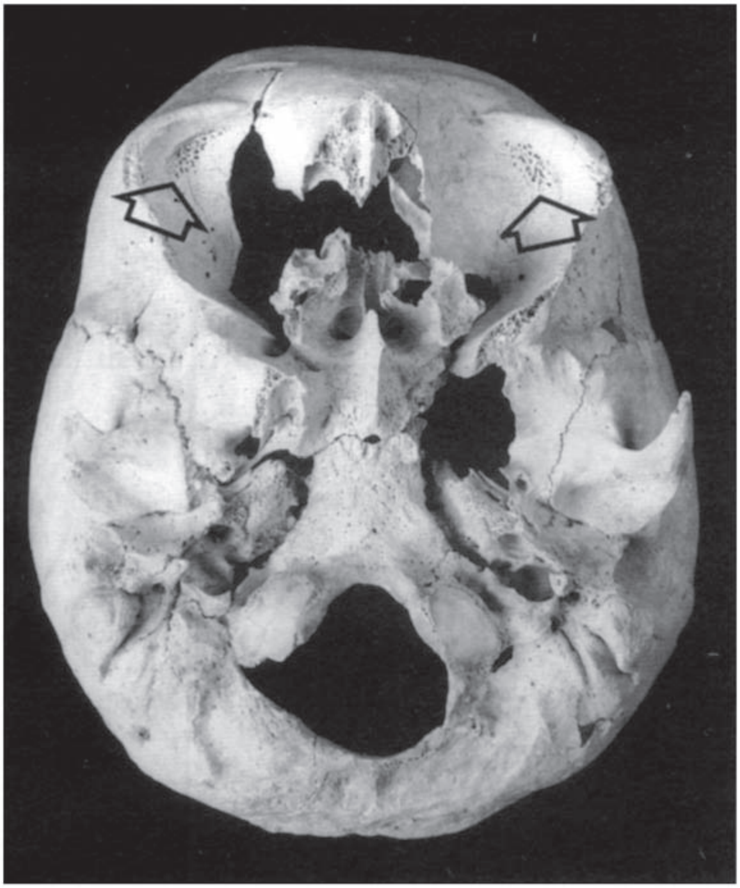


*Figure 6.14* Porotic hyperostosis of the orbital roofs (*cribra orbitalia*)

The pattern whereby porotic hyperostosis is more frequent in the bones of children is a general one. The reasons for this are that, even in normal infants and young children, every cubic centimetre of bone marrow is needed for red blood cell production, so in anaemic conditions the need for blood forming space greatly exceeds normal marrow volume. In adults there is much more 'spare capacity' in this respect, so they are less likely to develop the changes of porotic hyperostosis if they do suffer from anaemia (El Najjar *et al.* 1976; Stuart-Macadam 1985).

El Najjar and co-workers ascribed the difference in frequency of porotic hyperostosis between plains and canyon bottom sites to dietary factors. Both groups practised maize cultivation, and also hunted animals for meat and ate wild-gathered plant foods. Maize grows better in the canyon bottoms, but on the plains there is a greater variety of wild foods. Those at the canyon bottoms were thought to be more reliant on maize, whereas those living on the plains ate a more varied diet. Maize is low in iron and furthermore contains a substance, phytate, which inhibits absorption of iron from the gut. Most vegetable foods contain some phytate, reducing the availability of

*Table 6.2* Frequencies of Porotic Hyperostosis at Various Anasazi Burial Sites

| | | | | *Porotic hyperostosis* | | | |
|---|---|---|---|---|---|---|---|
| | | *Children (0–10 years)* | | *Adolescents/adults (11+ years)* | | *Total* | |
| *Site* | *Location* | *N* | *% with lesions* | *N* | *% with lesions* | *N* | *% with lesions* |
| Canyon de Chelly | Canyon bottom | 67 | 76.1 | 147 | 40.1 | 214 | 69.3 |
| Chaco Canyon | Canyon bottom | 12 | 83.3 | 20 | 65.0 | 32 | 71.8 |
| Inscription House | Canyon bottom | 11 | 63.6 | 13 | 46.2 | 24 | 54.2 |
| Navajo Reservoir | Sage plains | 44 | 15.9 | 48 | 10.4 | 92 | 13.0 |
| Gran Quivira | Sage plains | 66 | 18.2 | 111 | 13.5 | 177 | 15.3 |

*Source*: Data from El Najjar *et al.* (1976).

dietary iron, but by contrast meat, in addition to supplying relatively large quantities of iron, enhances the absorption of iron from other foods eaten with it. The greater prevalence of iron deficiency anaemia, as indicated by porotic hyperostosis, in the canyon bottom inhabitants was interpreted as due to low dietary iron and poor iron absorption as a consequence of heavy reliance on maize.

The above interpretation was challenged by Susan Kent, in a paper published in 1986. She pointed out that studies have shown that in man, low dietary iron is rarely the main cause of iron deficiency anaemia; it generally results from disease, particularly gastro-intestinal parasites or bacterial infections. There is a correlation among the ancient Anasazi between increasing reliance on maize agriculture and increasing settlement size and sedentism. The less agriculturally orientated Anasazi groups, who showed the lower rates of porotic hyperostosis, were also more mobile and lived in smaller groups than did those classed by El Najjar *et al.* (1975) as heavily maize dependent. Large aggregates of people living in close proximity favour the spread of disease. As well as offering increased opportunities for disease transmission directly between persons, sanitation and hygiene also tend to be poorer in large settlements, chiefly as a result of contamination of water supplies. Under such conditions, gut infections or parasites would be expected to be much more common than among the smaller, mobile bands of the plains dwellers. These factors, Kent suggested, may be more important than diet when it comes to interpreting the Anasazi porotic hyperostosis data.

Subsequent archaeological work appears to support Kent's interpretation. The study of coprolites has made an important contribution here. Coprolites are ancient faeces. Preserved due to the the arid climate these are frequent finds on archaeological sites in the US south-west. They yield information on foods consumed and on the presence of gut parasites. Karl Reinhard has analysed coprolites from a number of Anasazi sites (Reinhard 1988, 1992). Among Anasazi dependent on maize agriculture, he found no relationship between maize remains in coprolites and skeletal porotic hyperostosis, suggesting no causal relationship between maize consumption and anaemia. Few gut parasites were found in coprolites from sites of primarily hunter-gatherer Anasazi. By contrast, they were frequent among those from sites associated with maize agriculturalists, but the only species found with any frequency was pinworm. Reinhard found a strong correlation between the findings of pinworms in coprolites and skeletal porotic hyperostosis. However, this does not indicate that pinworm infestation was the cause of anaemia among the Anasazi agriculturalists for the simple reason that pinworms are largely harmless to man. Pinworms are parasites transmitted in conditions of poor hygiene and sanitation, so their presence indicates such conditions at Canyon bottom settlements. Under these circumstances diarrhoearal diseases are likely to be a significant health problem, particularly in young children; perhaps this is the most likely cause for the raised levels of porotic hyperostosis at these sites.

# 7

# DENTAL DISEASE

Most of the dental diseases observed in archaeological skeletons arise as a result of the exposure of the teeth to foodstuffs and associated material taken into the mouth. The most common of these conditions are dental caries ('tooth decay'), tooth loss, dental abscesses and periodontal disease (an infection of the gums and other tissues which support the teeth).

The development of the teeth within the jaws during childhood may be disturbed by episodes of disease or poor nutrition. These growth perturbations may manifest themselves on the tooth crowns as bands of thinned enamel, termed enamel hypoplasias. Thus the teeth may bear scars which give clues concerning the earlier general health of the individual.

Much work on dental disease in ancient skeletons has focused on the investigation of ancient diets using diseases which originate from attacks on the teeth from substances in the oral environment. Dental caries in particular, has been extensively studied. Likewise, much archaeological work has been undertaken on dental enamel hypoplasias, with the aim of assessing child health. This chapter will, therefore, concentrate principally on these two aspects.

## DENTAL CARIES

### Diagnosis of Dental Caries in Archaeological Remains

As was discussed in Chapter 1, bone is a dynamic tissue—it is continually being renewed. That this is not the case for the dental hard tissues has important consequences as far as dental caries and other diseases which may affect the teeth are concerned. Disease in a bone may result in an increase or a decrease in bone substance. Whichever occurs, it is the result of a dynamic response of the bone to the disease process. By contrast, dental caries can only result in destruction of tooth substance, hence the characteristic cavities produced by the disease. The destruction in dental caries is a passive process (chemical dissolution by acids released by bacteria), rather than active resorbtion. Once formed, caries cavities cannot heal.

As we saw in Chapter 6, initial steps in diagnosing disease in ancient skeletons involve distinguishing changes which result from disease from those arising from post-depositional erosion and from features which represent normal anatomical variants. The next stage is to describe the changes and attempt a diagnosis on the basis of comparison with changes produced in recent material by known diseases. In bone disease, this last step is often very difficult as many conditions are alike in the ways in which they affect the skeleton. However, there are no dental diseases which an experienced worker is likely to confuse with caries, so the main thing in establishing a diagnosis is to ensure that cavities observed are not confused with post-depositional erosions or anatomical variants.

Unlike erosions produced by post-depositional factors, caries cavities generally have sharp, well-defined edges (Figure 7.1). In addition, the diameter of caries

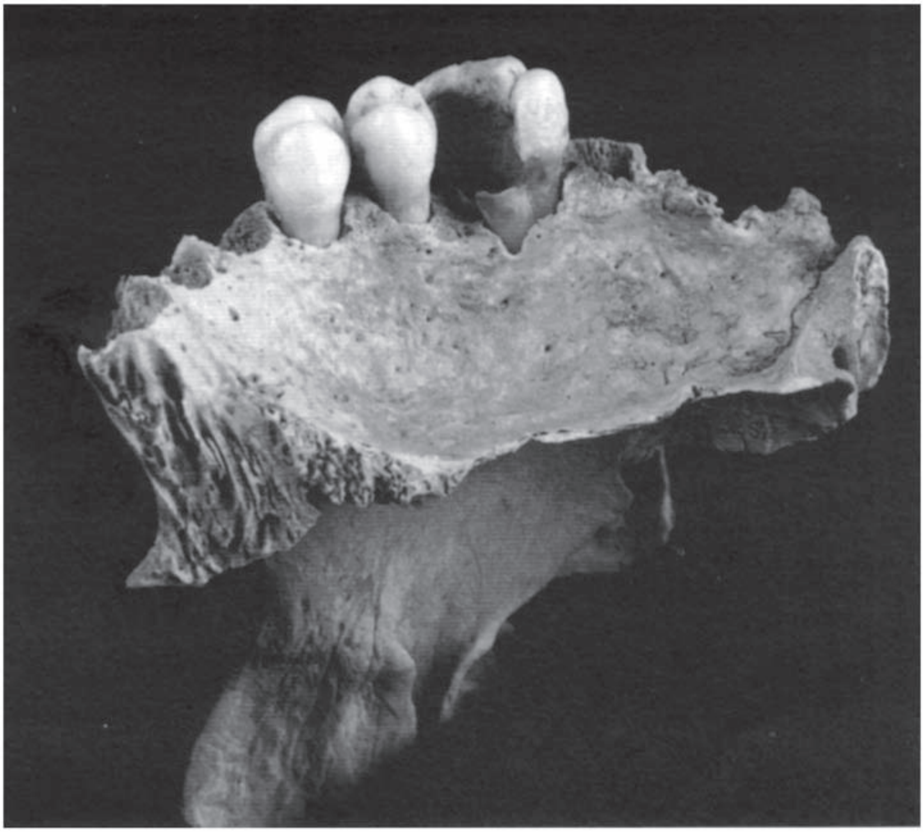


*Figure 7.1* A large caries cavity in a molar tooth. The cavity has sharp, well-defined edges and its dimensions are larger within the tooth than where it breaches the tooth surface

cavities is often larger within the tooth than on the tooth surface. They also tend to be deeper in relation to their width than do post-depositional erosions, which are often broad and shallow.

Pits and fissures are present on many teeth, either as regular features or as anatomical variants. However, the seasoned observer is unlikely to confuse these with caries cavities.

## Quantifying Dental Diseases in Ancient Remains

The frequency of dental caries in a skeletal collection may be expressed in a number of ways. One would be simply to score caries as present or absent in individual skeletons. The number of individuals suffering from caries can then be expressed as a proportion of the total number of skeletons examined. A problem arises here concerning what to do about individuals with incomplete dentitions. Teeth often fall out of their sockets as a body decays, and these loose teeth may not all be recovered if sieving of the soil from the grave is not carried out. Dental elements may also be deficient through the vagaries of skeletal survival in the burial environment. If a skeleton with an incomplete dentition shows one or more carious teeth then there is clearly no problem in deciding that caries was present in that individual. However the situation is less straightforward if a skeleton with some teeth missing does not show caries in any remaining teeth. In this case we could not say for certain that caries was absent as one of the missing teeth might have shown a cavity. One way to get around this problem over the reliability of negative evidence would be to include in our study only those skeletons with the full complement of teeth. In reality this is not a viable strategy given the incomplete nature of most archaeological material—we would be left with very few skeletons to work with. We have to include skeletons with incomplete dentitions but bear in mind that we will be underestimating the proportion of individuals suffering from caries and that this underestimate is greater the fewer teeth are present for observation.

An alternative to using the individual as our unit of analysis is to score caries frequencies with respect to total teeth in an assemblage available for observation. This eliminates the problem over the reliability of negative evidence but, unlike frequencies expressed with respect to individuals, the results are not amenable to analysis using standard statistical tests. This is because teeth in an individual mouth cannot be considered as independent observations for statistical purposes.

Similar considerations to the above apply for scoring other dental pathologies such as tooth loss or dental abscesses, where the options are to quantify affected individuals or affected tooth sockets. Perhaps the best solution is to quantify both by individuals, so that statistical tests can be carried out, and also by teeth/tooth positions, to see whether a consistent picture is obtained comparing assemblages using both methods.

The older an individual, the longer his or her teeth have been exposed to the agents causing caries. This, together with the fact that caries cavities do not heal once formed, means that assemblages with older mean ages at death should tend to show higher frequencies of carious teeth than do younger ones (Brabant 1967; Larsen *et al.* 1991). Bony pathologies also tend to accumulate with age, and lesions of the jaws are no exception to this. Indeed, until recently dental afflictions such as caries and tooth loss due to disease were primarily diseases of adulthood; child skeletons are rarely affected in archaeological collections. This age effect needs to be borne in mind when making comparisons between groups.

## The Carious Process

Dental plaque is a deposit on the teeth consisting of food debris, together with various components derived from the saliva. Within the plaque dwell bacteria. When these bacteria metabolise carbohydrates they produce acidic waste products. It is the dissolution of the dental hard tissues by these acids that causes caries cavities.

The initial lesion in dental caries consists of a softened area of enamel. This progresses so that a small cavity forms in the enamel surface. This cavity enlarges as the disease progresses. When it reaches the dentino-enamel junction it tends to spread laterally, due to the increased organic material in this area. This undermines the enamel crown, leaving a fragile shell which may collapse under the strain of mastication (Shafer *et al.* 1983:432). In this way, caries may lead to complete destruction of the tooth crown. Infection of the pulp may occur, either through direct exposure to the oral environment or via opened, exposed dentinal tubules (Hillson 1986: 316).

Infection of the pulp cavity may lead to the formation of a dental abscess at the tooth socket by extension of the infection along the root canal. An abscess is a collection of pus, and in archaeological material the manifestation of a dental abscess is a smooth-walled cavity at the base of a tooth socket. Pulp chamber infection and abscess formation generally culminate in the loss of the tooth, after which the abscess heals. Tooth loss occurring during life may be distinguished from instances where teeth have simply dropped out in the soil, since when a tooth is lost in life the socket becomes obliterated by bony remodelling (Figure 7.2).

Nowadays we tend to think of tooth decay as painful and inconvenient, but hardly life-threatening.

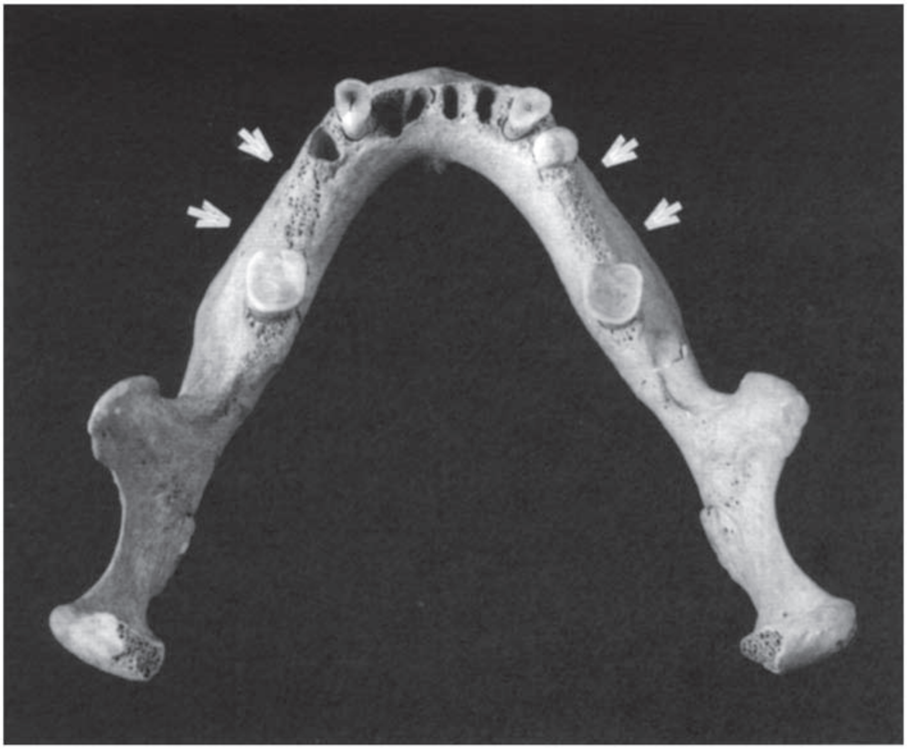


*Figure 7.2* The areas delimited by the arrows show where teeth have been lost in life; the sockets have been obliterated by bony remodelling. By contrast, the empty, unremodelled tooth sockets in the anterior part of this mandible show where teeth have fallen out after death

However, untreated caries can give rise to potentially lethal complications. Advanced caries of a maxillary tooth can lead to infections within the cranial cavity, such as meningitis or cavernous sinus thrombosis. Before the advent of antibiotics, death rates for these conditions were about 50–90 per cent (Calcagno and Gibson 1988:510). Advanced caries of the mandibular dentition may give rise to an infection in the lower jaw and throat, called Ludwig's angina. Prior to the antibiotic era the death rate from this was about 50 per cent (Shafer *et al.* 1983:516–517). Although the exact frequency in ancient times of these complications of advanced dental caries is not known, Calcagno and Gibson (1988) argue that clinical experience suggests that it may not have been insignificant. In antiquity, then, dental caries may have been anything but a trivial disease.

## Caries and Diet

Bacterial breakdown of carbohydrate food residues present in the mouth produces the acids responsible for caries cavities. Acidic by-products are not formed from the breakdown of non-carbohydrate food residues. Fats, oils and meats (including fish) are non-cariogenic (Shaw 1954), and protein residues in the mouth may actually inhibit the growth of the micro-organisms responsible for dental caries (Becks *et al.* 1944; Dreizen and Spies 1948). So, for example, dental caries rates were

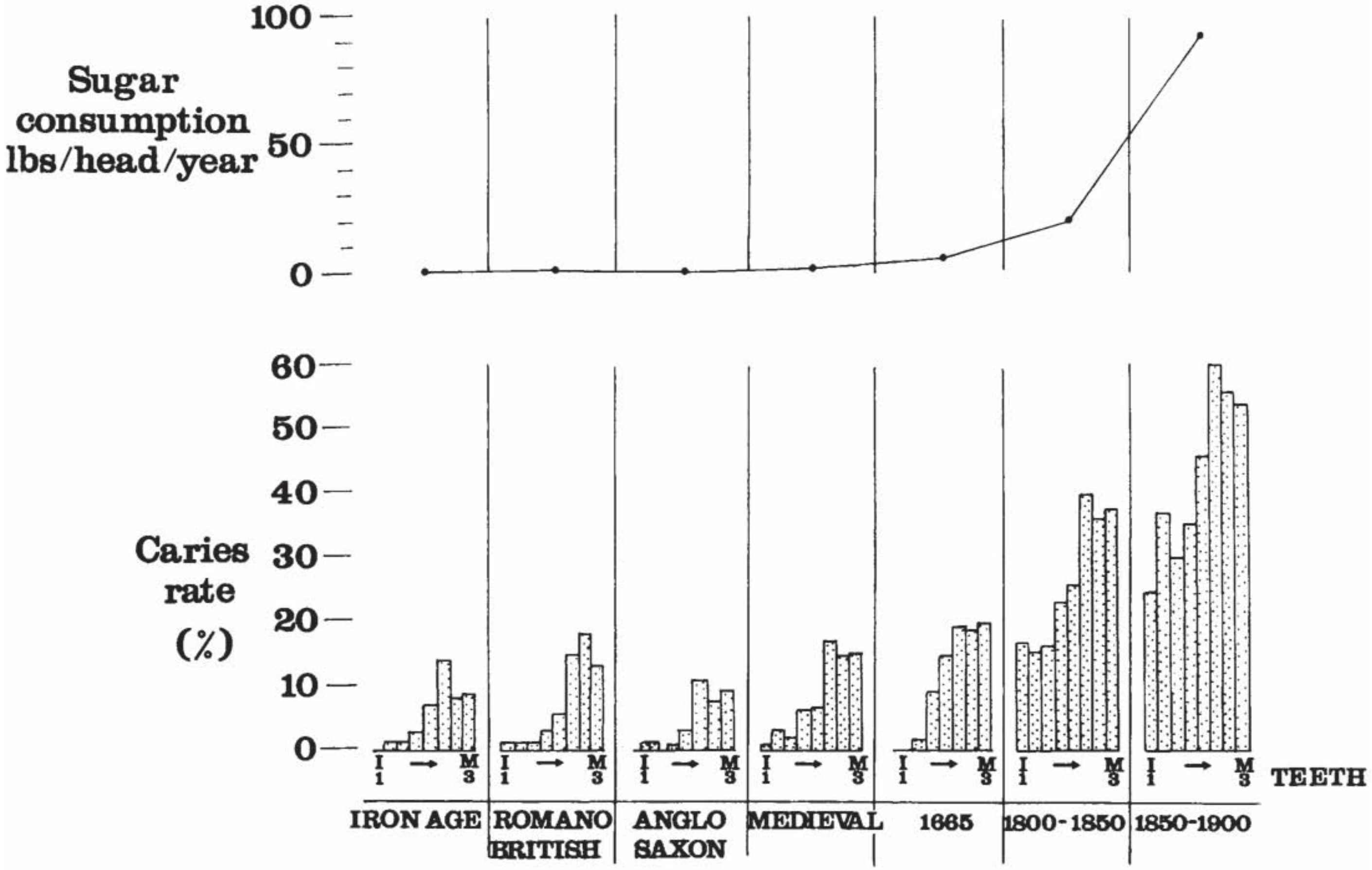


*Figure 7.3* Dental caries in relation to sugar consumption in Britain
*Source*: After Moore and Corbett (1978: Figure 8).

negligible in Greenland Eskimos prior to European contact, when they subsisted almost entirely on meat and fish. However, when these peoples included significant amounts of carbohydrate foods in their diets for the first time following contact with Europeans, caries became frequent (Pedersen 1947).

The most cariogenic carbohydrates are those of low molecular weight, such as sugars; these are very readily metabolised by bacteria to produce acidic by-products. Studies on recent populations show a close correspondence between the level of consumption of sweet, sugary foods and dental caries rates (Newbrunn 1982). This has also been shown for archaeological material. In Britain, small amounts of cane sugar began to be imported as early as the twelfth century AD, but significant amounts only started to arrive during the seventeenth century, with the establishment of sugar-cane plantations in the British colonies in the New World. From this time, sugar consumption increased in Britain. In the nineteenth century this trend was accelerated as import duty on sugar was progressively removed (Corbett and Moore 1976). Moore and Corbett (1978) studied dental caries in British skeletons dating from various periods up to about AD 1900. They showed that there was a marked rise in caries frequency in the nineteenth century, coinciding with the greatly increased sugar consumption which characterised that period (Figure 7.3).

Starches are a major dietary carbohydrate. Starches are high molecular weight carbohydrates, and are not directly metabolisable by plaquedwelling bacteria. However, if they are retained in the mouth long enough they are broken down into low molecular weight carbohydrates by ptyalin, an enzyme present in saliva (Mörmann and Mühlemann 1981). Consistent with this, Shaw (1954) found that when different diets were fed to laboratory rats, a diet in which starch was the sole carbohydrate did cause caries, although to a lesser extent than one high in sucrose. The potential for starches to be broken down in the mouth means that even before the introduction of refined sugars, diets rich in carbohydrate foods had the potential to lead to significant rates of dental caries. This is illustrated by a study by Frayer (1989), using archaeological material from Upper Palaeolithic and Mesolithic sites in Europe. He showed that there was a trend towards increasing dental caries through time (Table 7.1).

Frayer associated the increase in caries with changing environmental conditions. All the sites dating to the early Upper Palaeolithic were associated with periglacial environments inimical to most plant growth, so animal protein, which is non-cariogenic, probably formed the great majority of human diets. The late Upper Palaeolithic skeletons with caries mainly came from the terminal part of the period or from southern Europe. In either case the environmental conditions were generally warmer. Greater warmth would have allowed more plant foods to flourish, and the increased caries rate probably reflects an increased contribution from plant carbohydrates to human diets. The higher frequency of caries in the Mesolithic is consistent with further warming allowing greater availability of plant foods. Frayer also found that, for the Mesolithic material, there was a negative correlation between caries rates and latitude, skeletal assemblages from

*Table 7.1* Frequency of Dental Caries in Upper Palaeolithic and Mesolithic Skeletal Material from European Sites

| | *Early Upper Palaeolithic* | *Late Upper Palaeolithic* | *Mesolithic* |
|---|---|---|---|
| **Individuals with caries as a % of total individuals** | 0.0% (27) | 11.3% (62) | 19.1% (246) |
| **Teeth with caries as a % of total teeth** | 0.0% (371) | 1.5% (846) | 2.6% (4,664) |

*Source*: Figures from Frayer (1989).
*Note*: Figures in brackets are total numbers of individuals or total numbers of teeth examined. Early Upper Palaeolithic: prior to about 27,000 BP; Late Upper Palaeolithic: 27,000 BP to the start of the Mesolithic (about 10–11,000 BP).

northerly sites showing lower caries frequencies than those from more southerly climes. This would also seem to be explicable in environmental terms: in southern Europe the warm Mesolithic climate would have meant the availability of sweet, sticky, sub-tropical foods, such as dates and figs.

Although the type and quantity of carbohydrate in the diet is an important influence on the rate of dental caries in a population, a number of other factors also play a part. Certain trace-elements in foods and waters can inhibit caries; the role of fluoride in this respect is well known. Also important is the length of time foods remain in the mouth. The longer carbohydrate residues remain in the mouth, the greater their potential to cause caries, so sticky foods which adhere to the teeth are particularly cariogenic (Bibby and Mundorff 1975). Frequency of eating also influences caries rates—more frequent eating means that food and food residues are in contact with the teeth for longer (Cohen and Bowen 1966).

Coarse diets, as consumed by most human groups prior to recent times, tend to reduce caries by helping to scour the teeth clean of food debris and preventing excessive build-up of dental plaque. In addition to affecting the frequency of caries, the consistency of the diet also influences the location of cavities on the teeth. In modern Western populations, who consume a soft, processed diet, the most frequent sites for carious lesions are the occlusal (biting) surfaces of the posterior teeth. This is because the diet is insufficiently abrasive to ‘scour these surfaces clean or wear away the pits and, fissures which tend to act as foci for dental decay. As we saw in Chapter 4, there was a marked reduction in the coarseness of diets in Britain from about the seventeenth century AD onwards. Consistent with this, there is a change in the favoured site for carious attack on the teeth. In their study of ancient British skulls, Moore and Corbett (1978) found that before the seventeenth century the most frequent site for carious attack on the posterior dentition was at the cemento-enamel junction (Figure 7.4). As mentioned in Chapter 3, in a high attrition environment the teeth continue to erupt from their sockets, even in adulthood, in order to compensate for the wearing away of the crowns. This so-called super-eruption of the teeth helps expose the tooth neck to the oral environment, and also has the effect of increasing the inter-tooth space, permitting increased impaction of food debris between the teeth. When oral hygiene is poor, food residues may remain trapped between the teeth long enough for starchy foods to be broken down by enzymatic action, and the products fermented by plaque bacteria, leading to caries. From the seventeenth century onwards in Britain the proportion of cavities occurring on the occlusal surfaces (Figure 7.5) increases, until in the nineteenth century the distribution of carious lesions resembles the modern pattern.

## Prevention and Treatment of Dental Caries in Antiquity

Many recent tribal peoples practised elementary oral hygiene, using chewing sticks or tooth-picks (Enwonwu 1974; Oranje *et al.* 1935). There also seems to be some archaeological evidence for such practices among some earlier human populations. Grooves in the mesial and distal sides of teeth have often been noted in archaeological material. The interpretation of these ‘interproximal grooves’ is rather controversial (Willey and Hofman 1994), but some at least seem to have been made by toothpicks inserted between the teeth to dislodge stagnant food residues (ibid.). Bennike (1985) reports evidence for more dramatic dental intervention in a skeleton from Neolithic Denmark. The maxillary right second molar from this individual has a hole drilled in it just below the crown. There was a dental abscess at the socket of this tooth, which the drilling was presumably meant to treat.

Plant remedies to dull the pain of toothache were known to many recent tribal peoples (Willey and Hofman 1994) and were also used in the historical era (Bennion 1986). Historical evidence shows that extraction of painful teeth was known in Ancient Rome (Jackson 1988:119). Tooth extraction was likely practised before that, but we cannot be certain as in archaeological skeletons it is impossible to determine whether teeth lost in life were extracted or were diseased teeth shed

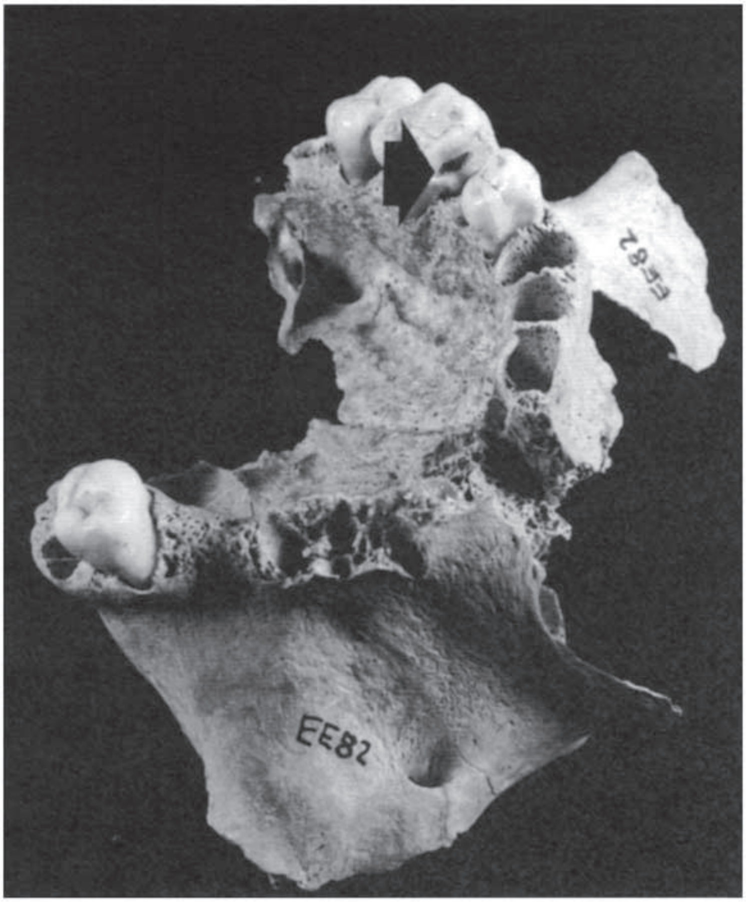


*Figure 7.4* A maxilla from a British medieval skeleton. A molar tooth shows a caries cavity at the cemento-enamel junction.

naturally without surgical intervention. Dentures to replace missing teeth have also occasionally been found on archaeological sites. Perhaps the earliest such example is the gold denture from central Italy dating to about 630 BC (Becker 1994).

## Caries Frequencies and Ancient Subsistence Strategies

Much work on dental caries in archaeological assemblages has been directed at investigating the way in which the frequency of the disease varies with different subsistence strategies. From a survey of literature relating to caries rates around the world, Turner (1979) found that hunter-gatherers showed an average caries frequency of 1.72 per cent of total teeth examined. The figure for those pursuing a mixed strategy involving both hunting/gathering and some plant cultivation was 4.37 per cent, and that for groups solely reliant on agriculture was 8.56 per cent. The increase in dental caries with the advent of plant domestication seems to reflect an increased reliance on carbohydrate-rich plant foods. Diets consumed by agriculturalists are also frequently less coarse than those

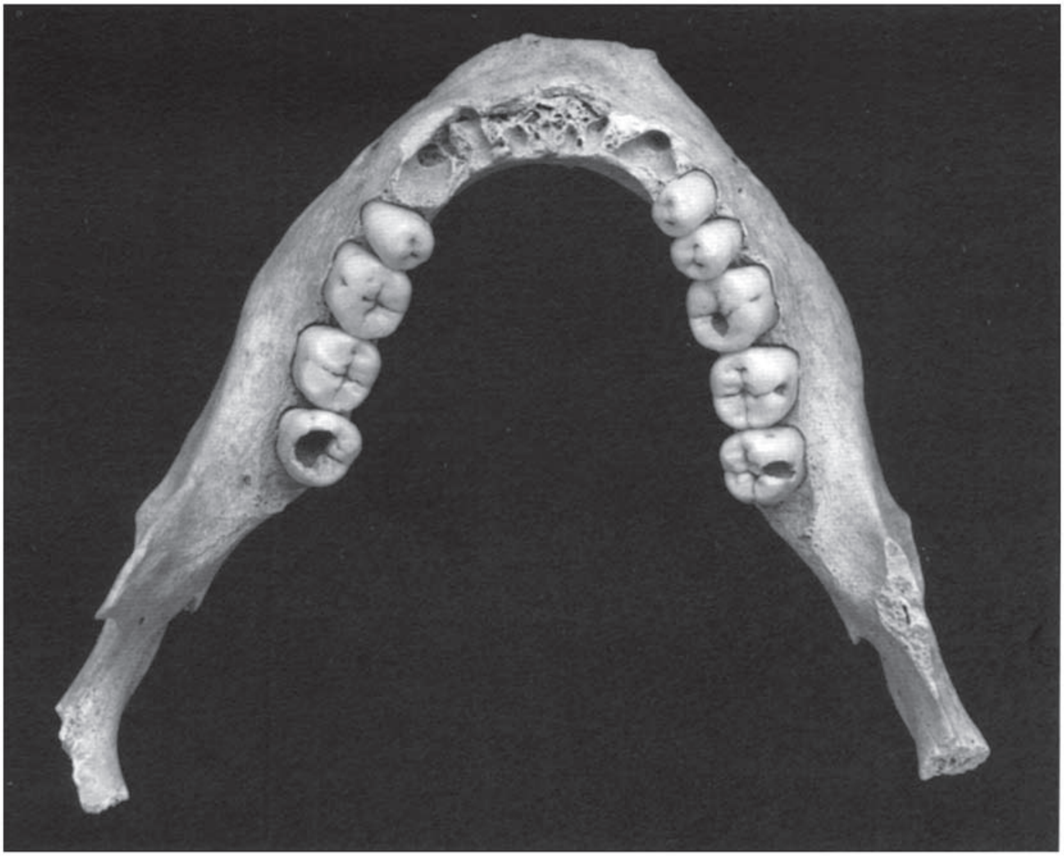


*Figure 7.5* A mandible from an eighteenth-century British skeleton. The left third molar and the right first molar show large caries cavities on their occlusal surfaces. The right third molar also shows a large caries cavity, but this probably originated on the side of the crown rather than on the occlusal surface

of hunter-gatherers (see discussion in Chapter 4): innovations in food preparation technologies, such as the use of pottery vessels, grinding stones, etc., which accompany the adoption of agriculture, generally tend to render the food softer and stickier, and hence more cariogenic.

Although an increase in caries with the adoption of agriculture seems to be a general finding, more detailed regional studies of caries patterns have proved useful in order to understand more fully the health implications of changes in diet and subsistence in particular environments or geographical areas. For example, Kelley *et al.* (1991) studied some dental diseases, including caries and tooth loss, in skeletal assemblages from several sites in northern Chile (Table 7.2).

Table 7.2 shows that the prevalence of caries increases through time, it being uncommon in those groups relying mainly or entirely on fishing, but showing a marked increase with the adoption of agriculture. This trend is apparent whether the data are expressed with the tooth or the individual as the unit of analysis. The pattern in terms of proportions of affected individuals is statistically significant.

*Table 7.2* Dental Caries and Tooth Loss in Four Burial Sites in Northern Chile

| | *Morro-1*<br>*3500–2000 BC*<br>*Fishing* | *El Laucho*<br>*2000–500 BC*<br>*Fishing/some cultivation* | *Alto Ramirez*<br>*1000 BC–AD 500*<br>*Incipient agriculture* | *Maitas*<br>*AD 800–1200*<br>*Intensive agriculture* |
|---|---|---|---|---|
| No. of skeletons examined | 41 | 45 | 41 | 55 |
| No. of teeth examined | 823 | 476 | 599 | 1,160 |
| Individuals with caries as % of total individuals | 4.9 | 15.5 | 71.7 | 76.4 |
| Teeth with caries as % of total teeth | 0.6 | 2.5 | 11.5 | 14.4 |
| Tooth loss as % of total teeth originally present | 4.3 | 4.6 | 10.1 | 16.2 |

*Source*: Data from Kelley *et al.* (1991).

In modern Western populations, extraction of carious teeth is the main cause of tooth loss. Therefore in studies of caries in living subjects in the developed world, numbers of missing teeth are generally combined with those which are carious or filled to produce the DMF (decayed, missing or filled) index. Although caries ultimately leads to the loss of the affected tooth even in the absence of surgical extraction, caries cannot simply be combined with tooth loss when studying archaeological skeletons as in earlier populations caries may not be the most important cause of tooth loss. When dental wear is heavy, super-eruption of teeth may proceed to the point where they are only held in their sockets by their root tips. This weakening of support for a tooth may precipitate its loss (Clarke and Hirsch 1991). In exceptional cases dental wear may be so rapid that deposition of secondary dentine by the odontoblasts which line the pulp cavity may be unable to keep pace, leading to exposure of the pulp with subsequent infection and tooth loss (Brothwell 1963b). Periodontal disease may also be an important cause of tooth loss (Walker and Hewlett 1990). Teeth may also be lost due to violence or intentional extraction for therapeutic, ritual or cosmetic purposes. The multiplicity of possible causes of tooth loss in ancient populations means that it is best treated separately from caries.

Kelley and co-workers attempted to elucidate possible causes of tooth loss at their Chilean sites. At the Morro-1 site, dental attrition was severe and caries rates were low, so they felt that supereruption or pulp cavity exposure probably accounted for most tooth loss at this site. At the other sites dental wear is less severe than at Morro-1, and the rise in tooth loss over time parallels that in dental caries. Kelley and colleagues suggest that caries may therefore be an important factor in tooth loss in these assemblages.

A diet based mainly on marine foods would not, as we have seen with the Eskimo example above, be expected to cause significant frequency of caries; the low caries rate observed at the Morro-1 site is consistent with this. Beginning at the El Laucho site, the reliance on cultivated plants, such as manioc, beans, squash and maize increases, whereas fishing decreased in importance. The patterning in dental caries would seem to reflect these changes in subsistence strategy. The decrease in the rate of dental wear at the later sites may also be playing a part in the deterioration of dental health.

## DENTAL ENAMEL HYPOPLASIAS

A dental enamel hypoplasia most often takes the form of a transverse line or band of depressed enamel on the sides of the tooth crown (Figure 7.6). Hypoplasias form as a result of disturbance to the growth of the dental enamel, or, more specifically, the organic matrix which is subsequently mineralised to form enamel. In general, disease and poor nutrition seem to be the main causes of dental enamel hypoplasias: during a period of disease or malnutrition less matrix is formed in the part of the crown which happens to be developing at the time, so the enamel is thinner in that area (Goodman and Rose 1990).

Dental enamel hypoplasias can only form during that part of childhood when the enamel of the tooth crown is developing, so they record episodes of disease or poor nutrition occurring during this period alone. In the permanent dentition, hypoplasias visible on the tooth surface record episodes of disease or nutritional stress occurring between about one and seven years of age (or up to about 13 years if the third molar is included) (Skinner and Goodman 1992: Figure 6). The fact that dental enamel is non-vital tissue means that, once formed, hypoplastic defects are not erased from the tooth unless the enamel is physically removed by dental wear. The tooth crowns therefore provide a ‘memory’ of biological disruptions which occurred during childhood.

Hypoplastic defects seem to represent one end of a continuum of growth disruptions which ranges down to perturbations of one or two enamel growth layers, which are visible only under the microscope (Hillson 1992). In living populations most studies have been of hypoplasias rather than microscopic defects, since the former can be recorded simply by looking into the mouths of volunteers, whereas the latter can only be studied by making thin-sections of extracted teeth. In archaeological material both hypoplasias and microscopic defects have been studied. Most work has been done on hypoplasias, so the present discussion will concentrate on these.

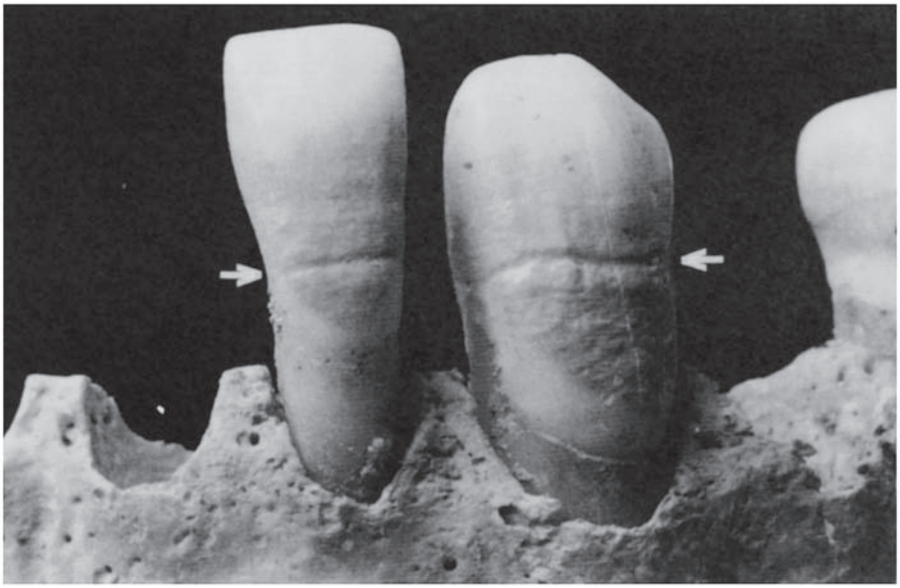


*Figure 7.6* Dental enamel hypoplasias (arrowed) on incisor and canine teeth

## Recording Hypoplasias

Many hypoplastic lines are quite faint, and this causes problems in scoring them. The enamel on the side of a tooth is never absolutely smooth, so the question arises as to how pronounced a groove has to be before it is classified as a hypoplasia. There is no simple answer to this question, the best that can be done is to ensure that one's results are repeatable—i.e. that identical (or at least similar) results are obtained when the same data are re-scored. It is good practice always to test the repeatability of one's results no matter what skeletal data one might be recording, be they measurements, non-metric traits or scores for pathological lesions, but the problems in scoring hypoplasias mean that tests of repeatability are particularly important here. In a brief test I conducted (Mays 1995b) for repeatability of hypoplasia scoring (recorded as presence/absence of lines in individual dentitions), I found that in 88 per cent of individuals my decision as to whether lines were present or absent was the same on a second inspection done under similar viewing conditions the next day. The best one can do is to train oneself to score defects with a high degree of repeatability, and for each new assemblage repeatability of scores should be tested. Goodman and Rose (1990) advocate repeat scoring every tenth skeleton. The difficulties in reliably defining what is to be scored as a defect mean that it is very difficult to compare the results of different writers, as what may be counted as a hypoplasia by one may be disregarded by another.

It may be that different tooth types differ in their susceptibilities to hypoplasia formation. Studies of both recent and archaeological material (Goodman and Armelagos 1985; Goodman and Rose 1990), indicate that in man anterior teeth generally show more hypoplastic lines than the molars and pre-molars. Many osteoarchaeologists concentrate on the anterior teeth alone when recording hypoplasias. It may also be that different parts of a particular tooth show differing vulnerabilities to hypoplasia formation—Goodman and Armelagos (1985) found that regardless of the fact that different tooth crowns were forming at different times in an individual's life, defects were generally more common on the middle third of the tooth enamel, suggesting greater susceptibility of the middle part of the crown to defect formation.

There is some evidence (e.g. Suckling *et al.* 1986) to suggest that the depth and breadth of a hypoplastic line varies with the severity and duration of the insult which caused it. This suggests that it might be useful to record the dimensions of defects in ancient skeletons. However, there are difficulties in measuring these reliably, so this has only rarely been attempted (e.g. Duray 1996).

Since tooth crowns grow in a fairly regular manner, age at formation can in theory be estimated from the location of a defect with respect to a fixed landmark such as the cemento-enamel junction. Several schemes (e.g. Goodman *et al.* 1980: Figure 1) have been published purporting to show the relationship between location of a defect and age at formation. However, a recent reconsideration (Skinner and Goodman 1992) has shown that they are not very accurate.

Many population studies of hypoplasias in the permanent dentition in archaeological material confine themselves to adult skeletons. There are a number of reasons for this. In adults, formation of the dentition is complete, so all individuals will have had a similar period of years in which potentially to acquire defects. All teeth will have erupted into the mouth, facilitating observation for enamel defects. Since sex can be determined in adult skeletons, recording hypoplasias offers a way in which gender-specific health patterns in childhood can be studied (although care is required here as males and females have inherently unequal resistance to growth disruptions). It also offers the opportunity to investigate any associations between childhood health and subsequent longevity.

## Causes of Dental Enamel Hypoplasias

Knowledge of the sorts of disease and dietary deficiencies which can cause dental enamel hypoplasias comes both from experimental work on animals and from studies of human populations. This has shown that a wide range of specific causes can lead to dental enamel defects, including fevers, gut parasites, diarrhoea, rickets, scurvy, measles, allergic reactions, whooping cough, pneumonia, vitamin deficiencies and general malnutrition (Sweeney *et al.* 1969; Pindborg 1970:138–210; Pindborg 1982). In individuals, it is often difficult to demonstrate any one-to-one correspondence between episodes of nutritional deficiency or disease and hypoplasia formation. However, much work exists showing a general association between increased nutritional or disease stress, and increased rates of dental enamel defects at the population level. For example, investigations on Guatemalan children by Sweeney *et al.* (1969), found that those with dental enamel hypoplasias showed nearly twice the rate of infectious disease as those without. Another study of Guatemalan children (Sweeney *et al.* 1971) showed an inverse correlation between frequency of dental enamel hypoplasias and nutritional status. Goodman *et al.* (1991) found that under-nourished children from a Mexican village who had been fed nutritional supplements to increase calorie and protein intakes showed a reduced rate of hypoplasias compared with those on un-supplemented diets.

Some studies have shown a direct association between dental enamel hypoplasias and socio-economic status. For example, Cyril Enwonwu studied children from a poor rural community in Nigeria. He found that 21 per cent of them showed enamel hypoplasias. However, among a ‘privileged’ group of 123 children of academic staff at Ibadan University and Teaching Hospital, none showed hypoplastic defects (Enwonwu 1973). In another study on Mexican children, Goodman *et al.* (1992) found that in a rural community offspring of families of low socio-economic status showed higher rates of dental enamel defects than did those of wealthier families. Indeed, referring to work conducted in the developing world, Sweeney *et al.* (1971) felt able to generalise that dental enamel defects are almost always limited to children of the lower socio-economic classes. However, other studies have failed to find any association between hypoplastic lines and socio-economic status. Investigations by Dummer *et al.* (1986) in Wales, and Dobney and Goodman (1991) in England, found no correlation between enamel defects and social class, and this was also the result of a study by Wilfrid Nation and colleagues of Californian children (Nation *et al.* 1987). Nation *et al.* contrasted their findings with those of Enwonwu in Nigeria. They pointed out that all their US children were of a fairly high socio-economic level, with fairly small differences between the groups studied. The socio-economic span between Enwonwu’s groups was much greater, and his poorer group were of very low socio-economic status. Nation and colleagues suggested that these factors might explain why they failed to obtain a correlation between social class and hypoplasias. These factors may likewise explain why this was also the finding from the other studies in the developed world, referred to above.

The above discussion would seem to imply that, in an earlier human group, a fairly high degree of social differentiation may be needed for any differences in dental enamel defects between status groups to occur. This would tend to militate against the finding of an association between inferred social status and hypoplasias in the relatively non-hierarchical societies which existed throughout most of the archaeological past. The literature seems to offer some support for this supposition. For example, Powell (1991) studied the prevalence of several health indicators, among them dental enamel defects, in a collection of skeletons from Moundville, Alabama, USA, dating to about AD 1050–1700. Burials were classified into three status groups on the basis of grave goods and location. Powell failed to find an association between status and dental enamel defects (or, indeed, any other of the health indicators she studied). I conducted a similar study on early Bronze Age (*c.* 2000 BC) material from Hainburg, Austria (Mays 1987). Social status, as inferred from grave goods, showed no association with dental enamel hypoplasias. The impression from these two studies is that (assuming that social status has reliably been inferred) differences in nutrition or disease did not exist between social ranks, or that any such

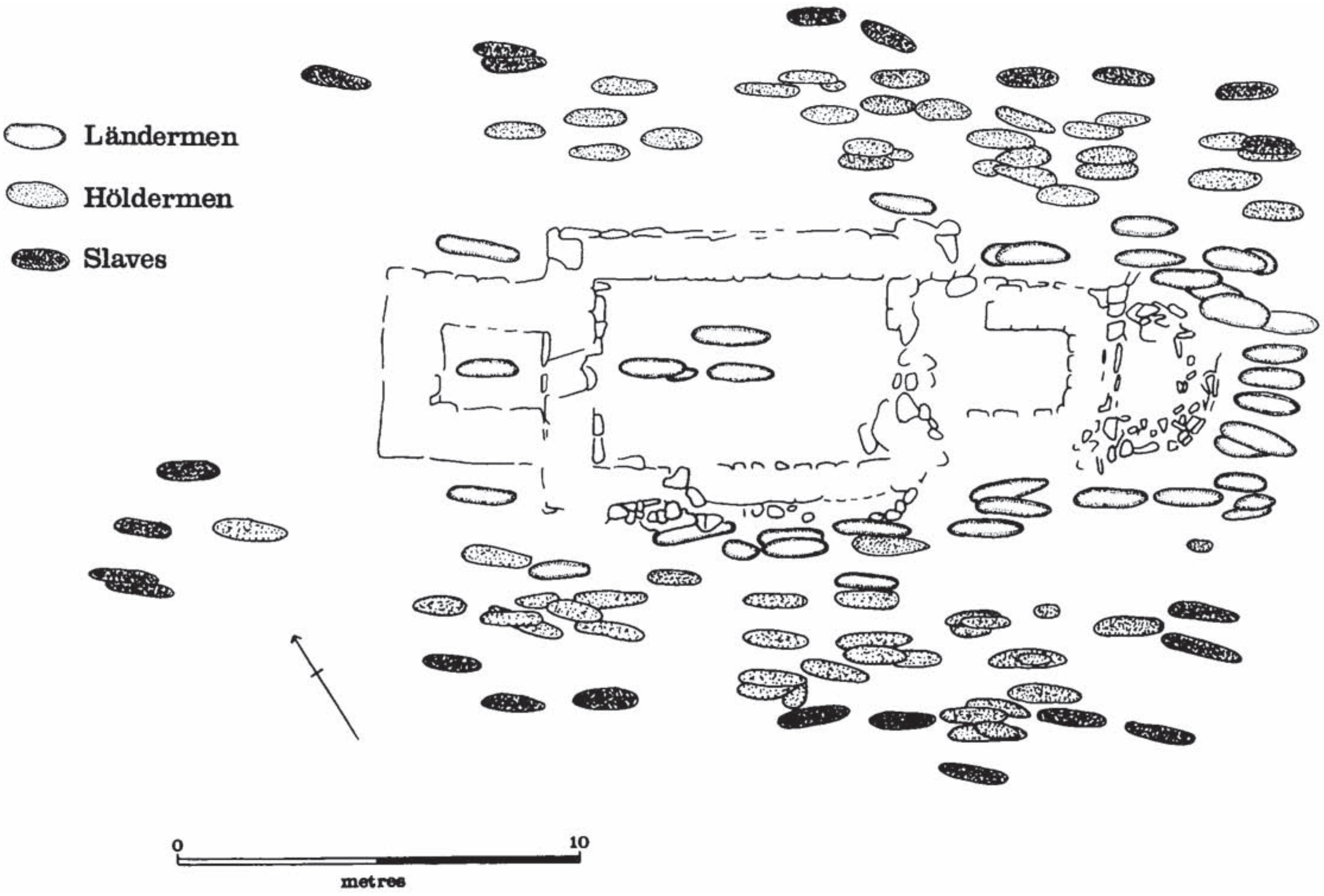


*Figure 7.7* The burials at Västerhus showing social status as inferred from the location of burial plots

*Source*: After Swärdstedt (1966: Map 1).

differences were too slight to be detected on the skeletons. A further possibility, suggested by Powell for her Moundville data, is that nutrition was adequate for all, the elite may just have been somewhat overfed, but not at the expense of others. All the Austrian skeletons which I scored for dental enamel defects were adults, as were most of those in Powell's study. The social status inferred for individuals at these sites was that obtaining at time of death. Both at Moundville and at Hainburg it seemed probable that social status was to a significant extent based upon achievements during life rather than solely ascribed at birth. Thus the social status inferred from the burial data may not correspond closely with that of the individual when he or she was a child. This may have acted to weaken any association which might have existed between archaeologically inferred social status and dental enamel hypoplasias.

The circumstances, then, under which we are perhaps most likely to find an association in archaeological material between dental enamel defects and social status in adult burials is when we are dealing with a society with marked social inequalities and when socio-economic status is to a great extent ascribed at birth. Social organisation of this nature existed in medieval Europe.

Swärdstedt (1966) studied dental enamel defects in a medieval assemblage from Västerhus, central Sweden. The burials come from in and around Västerhus church, and date from AD 1025–1375. Medieval Swedish society was strongly hierachical in nature, and ecclesiastical codes specified the location of a burial plot according to the social class of the deceased (see Gejvall 1960). Ländermen were the agents of the monarch or their deputies; the ecclesiastical codes state that they and their families were to be buried within the church or in its immediate vicinity. Höldermen held a lower position by birth than Ländermen, but were higher on the social scale than slaves or freed slaves. Höldermen and their families were to be buried a little further away from the church than Ländermen. Slaves and their kin were buried furthest away.

Swärdstedt used the location of the burials to classify the skeletons into the three status groups (Figure 7.7).

Of the 126 skeletons Swärdstedt scored for hypoplasias, 12 were aged 14–20 years, 64 were aged 20–40 years and the remaining 50 were over 40. Swärdstedt found that hypoplastic lines were generally less frequent in adults over 40 than they were in the younger age classes (Table 7.3). This suggests that those who experienced high frequencies of these defects in childhood had a reduced expectancy of life. She also found different frequencies of dental enamel hypoplasias in the three status groups (Table 7.3).

The data seem to show a higher frequency of dental enamel hypoplasias lower down the social scale. Statistical analysis of the data led Swärdstedt to infer that highly significant differences existed between the three status groups in terms of frequencies of enamel defects. Hypoplasias in an individual dentition cannot be taken as independent events for statistical purposes, so the levels of statistical significance may not be as high as Swärdstedt claims. Nevertheless, the differences between the three groups are striking, and would seem to imply that childhood health and diet were to some extent dependent on social class, those children born to families lower down the social scale experiencing poorer health.

The inverse association between age at death and hypoplasia frequency found in the Västerhus skeletons is also interesting. A similar result was obtained on US material by Goodman and Armelagos (1988). They suggested three possibilities to explain

*Table 7.3* Mean Number of Hypoplasias for Different Age Classes and Status Groups at Västerhus, Sweden

| *Age class* | *Ländermen* | *Höldermen* | *Slaves* |
|---|---|---|---|
| Juveniles (14–20 years old) | 2.00 | 1.50 | 3.71 |
| Young adults (20–40 years) | 0.73 | 1.83 | 2.83 |
| Mature adults (40+ years) | 0.21 | 0.47 | 1.00 |
| Weighted average | 0.65 | 1.25 | 2.19 |

*Source*: Data from Swärdstedt (1966: Table 56).

their results. The first was the ‘weaker constitution’ hypothesis—that individuals who fall ill in childhood continue to do so in adulthood due to some inherent low resistance to disease. The ‘biological damage’ hypothesis was that those who suffered wear and tear due to disease or nutritional deficiency during childhood may have been less likely to survive subsequent disease episodes. The last possibility was that those children who suffered growth disturbances did so because they were born of low ranking parents; they retained this low social status into adulthood and as a result continued to suffer more than their fair share of disease and poor nutrition, and hence early deaths. Regarding the Västerhus material it is difficult to argue for the first hypothesis to explain the age/hypoplasia association because if the presence of dental enamel defects were simply markers for individuals with inherently low disease resistance then it would be difficult to explain the inverse correlation between social class and hypoplasia frequency. Perhaps the Västerhus finding might be explained by a combination of the last two possibilities.

# 8

# TRACES OF INJURY ON THE SKELETON

Although injuries to soft tissues may occasionally leave traces in the bones (e.g. in the form of ossified blood clots), the most frequent form of injury seen on ancient skeletons is bone fractures. It is to these that this chapter is devoted.

## TYPES OF FRACTURES

Although fractures may occur as a result of repetitive stress (fatigue fractures), most are caused by sudden injury. Although fractures are infinitely variable in appearance most may, for convenience, be classified into a few groups based on the type of break (Figure 8.1).

The type of fracture may give a clue as to the nature of the injury that caused it. Bending force or a blow at right angles to the long axis of a bone may cause a transverse fracture (Figure 8.1a), twisting force may cause a spiral fracture (Figure 8.1b). An oblique fracture (Figure 8.1c) may be caused by a combination of bending, twisting and compressive forces. Application of greater force or a crushing injury may lead to bone fragmentation—a comminuted fracture (Figure 8.1d).

The above are all complete fractures—there is a complete break in the bone. In some instances the break may not extend right the way through the bone. Compression and greenstick fractures are examples of incomplete fractures. Compression fractures occur when trabecular bone is crumpled. A frequent site for this type of injury is the vertebral column: forced flexion of the spine may result in wedge-shaped crushing of a vertebral body by compression between its neighbours (Figure 8.1e). Greenstick fractures are characteristic of the bones of children. Children's bones are more springy and resilient than those of adults. A bending force which might result in a transverse break in an adult bone may in a child result in bending and incomplete fracturing, the greenstick fracture (Figure 8.1f). In archaeological material an additional type of injury, which is probably best classified as a fracture, is sometimes found: cuts due to slicing of bone by a sharp weapon; of this type of injury, more later.

## FRACTURE REPAIR

The healing of fractures in tubular bones may be divided into five stages (Figure 8.2).

1 Haematoma formation. Tearing of blood vessels in and around the broken ends results in a collection of blood (haematoma) at the fracture site. As a consequence of damage to minor blood vessels, bone within a few millimetres of the fracture site dies and is subsequently resorbed.
2 Cellular proliferation. Within eight hours of the injury, cells proliferate in the fracture area. This leads to formation of flexible, fibrous tissue which pushes aside the haematoma (which is slowly resorbed) and eventually bridges the break between the bone ends.

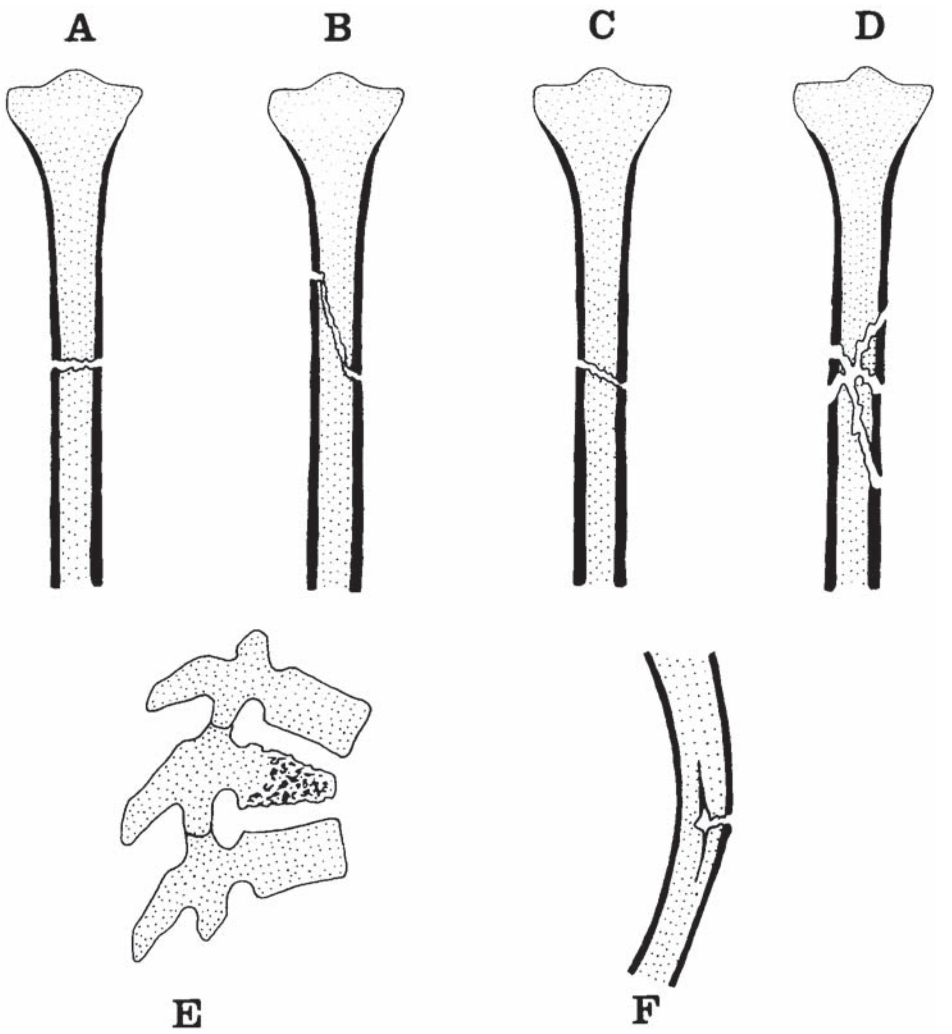
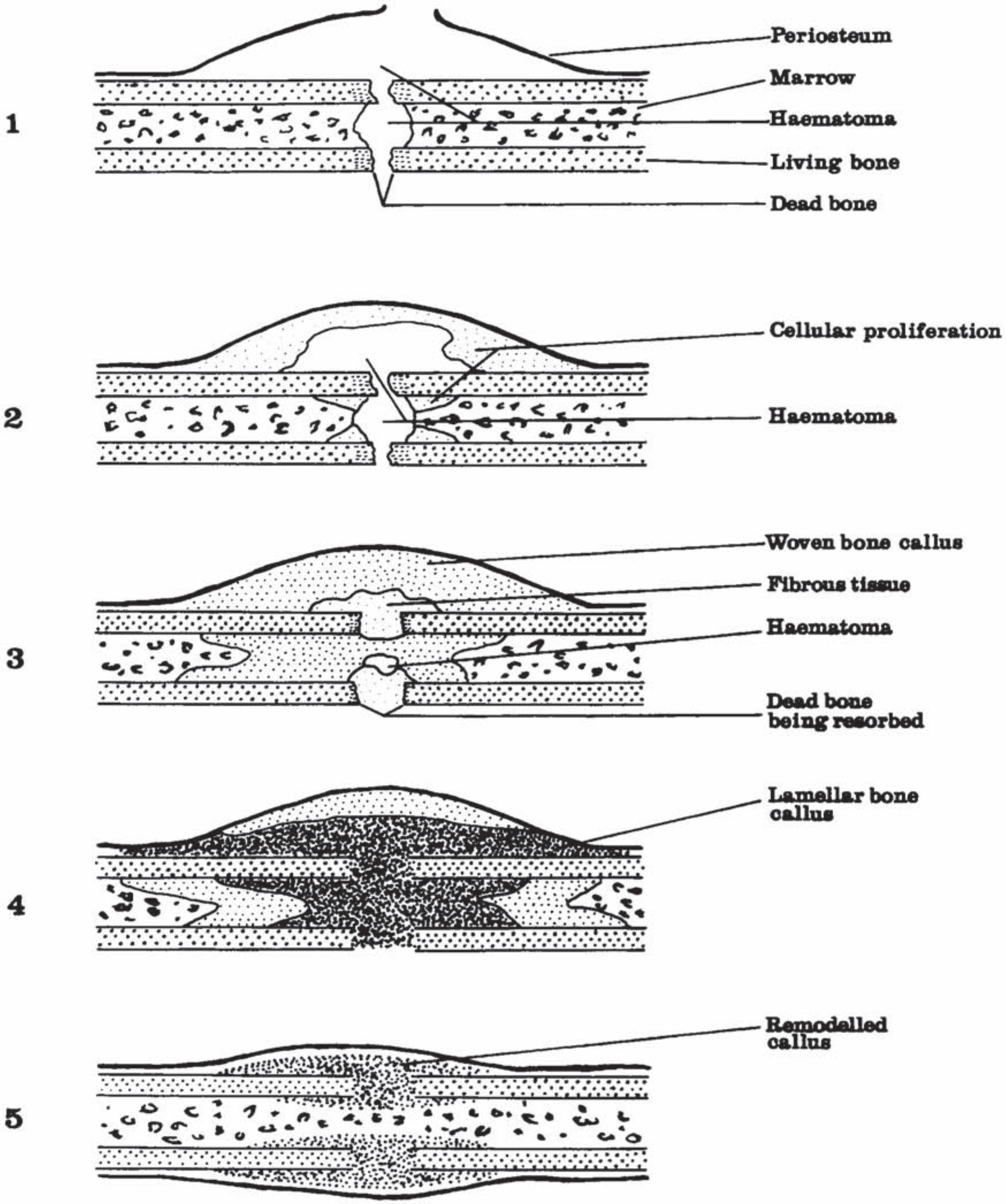


*Figure 8.1* Common types of fracture: (a) transverse fracture; (b) spiral fracture; (c) oblique fracture; (d) comminuted fracture; (e) compression fracture; (f) greenstick fracture
*Source*: Adapted from Adams and Hamblen (1992: Figure 3).

3 Callus formation. Osteoblasts lay down bone so that the fibrous union between the bone ends is replaced by immature, or woven bone. Osteoclasts remove dead bone from the fracture site. By the end of this stage the fracture is united by a rigid bridge of woven bone.

4 Consolidation. The activities of osteoblasts and osteoclasts gradually convert the woven bone callus into mature, or lamellar bone. By the end of this stage the fracture site is bridged by a strong cuff of bone.

5 Remodelling. The bulbous collar of bone surrounding the fracture site is gradually remodelled so that some buttresses of bone are removed and


Periosteum
Marrow
1
Haematoma
Living bone
Dead bone
Cellular proliferation
2
Haematoma
Woven bone callus
Fibrous tissue
Haematoma
3
Dead bone being resorbed
Lamellar bone callus
4
Remodelled callus
5

more bone is deposited where stresses are greatest. The medullary cavity reforms.

Repair of trabecular bone follows a similar pattern to the above. However, as there is no medullary cavity and there is normally a much broader area of contact between the broken fragments than is the case for a tubular bone, union can occur directly between the bone surfaces—it does not have to take place via internal and external callus.

The timing of fracture healing is highly variable. It is faster in children than in adults, and fractures in trabecular bone tend to heal more quickly than those in cortical bone. Among those factors which hinder fracture repair are inadequate immobilisation of the broken ends, infection at the fracture site and poor local blood supply. In a long-bone, under optimal healing conditions, fibrous tissue union between the bone ends occurs after about two weeks. The earliest new bone formation may occur as soon as five days after fracture but it is not until at least six weeks that the bone ends are united by woven bone callus. The replacement of the woven bone by lamellar bone during the consolidation phase is a gradual process extending over several months. The subsequent remodelling stage is even more protracted, occurring over a period of months or years—increased remodelling may be observable in long-bone fractures as much as 6–9 years after injury.

The above schedule is for optimal cases. At the other end of the scale, if factors hindering healing are severe enough, bony union may never occur. In such cases the bone ends may be united by flexible fibrous tissue, or alternatively a false joint, or pseudarthrosis, may form between them. In the latter case the bone ends are covered by cartilage and enclosed by a capsule containing synovial fluid, in imitation of a normal joint.

[The above account was taken from Resnick and Niwayama (1988:2766–2772), Revell (1986:203– 209), Adams and Hamblen (1992:3–18) and Apley and Solomon (1993:515–520).]

Fractures do not need treatment in order to heal; indeed, in nearly all cases fractures will unite whether they are splinted or not. After a complete fracture, the broken ends usually become displaced through the force of the injury or through muscular contraction, so if a fracture is left to heal unaided the bones may well unite in a poorly aligned position. However, even if a fracture in an ancient bone is found united in good alignment, it does not necessarily mean that the individual received treatment in the form of splinting for the injury. Studies on the bones of wild apes (Schultz 1967) show that many fractures heal with little deformity even without treatment.

## FRACTURES IN ANCIENT BONES

Breaks found in bones excavated from archaeological sites may have occurred:

(a) prior to death;
(b) at or around time of death (termed perimortal injuries);
(c) after burial, and may be divided into: (i) ancient breaks occurring whilst the bone is in the soil, and (ii) fresh breaks occurring during excavation or post-excavation processing.

Fractures which occurred some time before death are distinguished from those in categories (b) and (c) by the fact that they show bone production as part of the healing process. If the fracture was in the fairly early stages of healing when death intervened, woven bone callus will be present at the fracture site. Woven bone

*Figure 8.2* Stages in the healing of a fracture in a tubular bone: (1) haematoma formation; (2) cellular proliferation; (3) callus formation; (4) consolidation; (5) remodelling

*Source*: After Adams and Hamblen (1992: Figure 7).

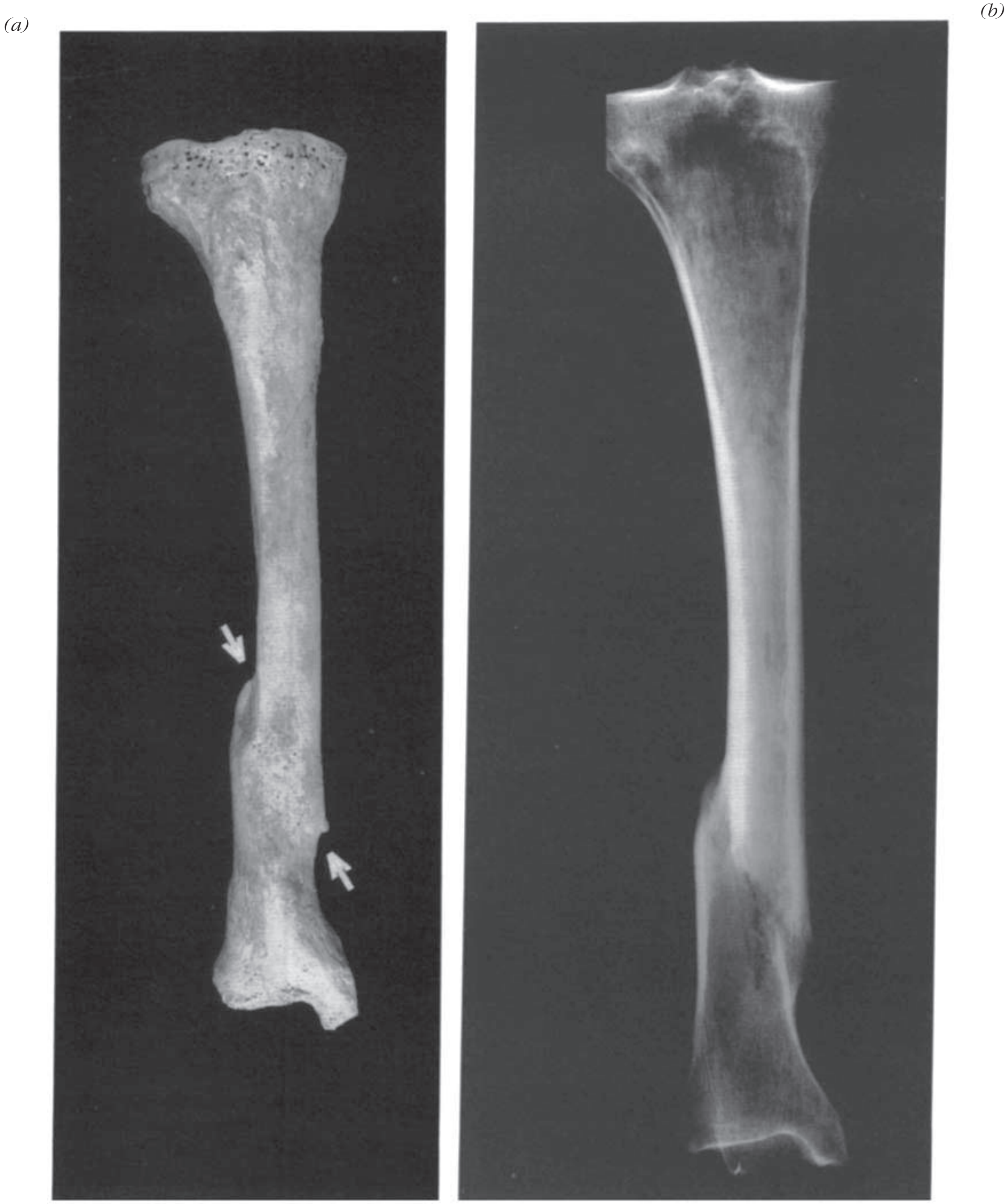


*Figure 8.3* (a) Anterior view of the right tibia of an adult showing a healed fracture in its distal third. The fracture site (arrowed) shows smooth, well-remodelled callus, (b) A radiograph of the same bone

has a distinctive appearance (see Figure 1.4) so fractures in the early stages of healing should be distinguishable from those which occurred long before death. In the latter, callus appears as a cuff of fairly smooth bone at the fracture site.

An example of a healed fracture in an archaeological specimen is shown in Figure 8.3. Looking first at Figure 8.3a, the bone at the fracture site has a fairly smooth, well-remodelled appearance, suggesting that the fracture occurred long before death. The appearance of the bone also suggests that the broken ends have united in less than perfect alignment—there appears to be some lateral displacement of the distal part. The radiograph (Figure 8.3b) shows that there has been some over-riding of the broken ends resulting in shortening of the bone. The radiograph also shows that it was a spiral fracture. Spiral fractures generally result from twisting forces so it was probably sustained as a result of a severely twisted ankle.

Breakage of bones may occur due to careless handling during or after excavation—this damage is relatively easy to identify as it results in 'fresh' breaks; that is, the broken surfaces are white and unweathered. Post-depositional breakage of bones often occurs due to pressure of overlying soil, freeze-thawing, changes in soil moisture content, etc. (Boddington 1987b). This means that human bones from archaeological sites often show breaks with weathering to the broken surfaces. This weathering indicates that they occurred in antiquity, but not whether they were perimortal or post-depositional events. Distinguishing fractures in categories (b) and (c)(i) is often very difficult, as in neither case do they show healing and both types will show weathered edges. Since post-depositional breaks in archaeological materials are so common, particularly in relatively fragile material like buried bone, the best course is to regard all such fractures as post-depositional unless there is compelling evidence that they do represent perimortal injuries.

One type of unhealed, perimortal injury which is readily distinguishable from post-depositional breaks is the blade injury, which occurs as a result of a blow from a sharp metal weapon such as a sword. When weapons such as these strike bone in a living individual (or, indeed, in a fresh corpse) they tend to slice rather than shatter it. This is due to the slight 'give' or resilience conferred on bone by its organic component. Blade injuries tend to be linear, without large irregularities to the line of the injury, their edges are generally well defined and clean, and the surfaces of the cut edges tend to be fairly flat and smooth and may show polishing (Brothwell 1971; Wenham 1989). By contrast, post-depositional breaks tend to be haphazard in orientation and have ragged, irregular edges because they generally occur long after burial when the organic component in the bone has decayed, rendering it brittle.

A blade injury on a medieval skull from Ipswich, England is shown in Figure 8.4. The skull is of an adult male, and the injury takes the form of a linear cut extending from the area of the left orbit (eye socket) diagonally across the left side of the skull, terminating in the area of the crown of the head. The two sides of the injury do not fit together well due to some distortion of the skull as a result of soil pressure as it lay in the ground. The cut surfaces are fairly flat and parts of them have a polished appearance (Figure 8.5). Had the individual survived the injury for any length of time, new bone would have begun to form at the fracture site and started to obliterate the honeycomb pattern of the trabecular bone on the cut surfaces. Figure 8.5 shows that this has not happened, the honeycomb structure is plainly visible with no signs of new bone formation. Indeed, the brain injury consequent upon the wound must have been so massive that death would have been instantaneous. The lack of fragmentation around the wound edges shows that the weapon used must have been very sharp indeed.

When unhealed blade injuries are examined under a microscope, their cut surfaces often show fine, parallel scratch marks. An experiment was undertaken at Leicester University, England to try and investigate the causes of these scratch marks (Wenham and Wakely 1988; Wenham 1989). Wakely and Wenham purchased fresh pigs' heads from their local butcher. They used

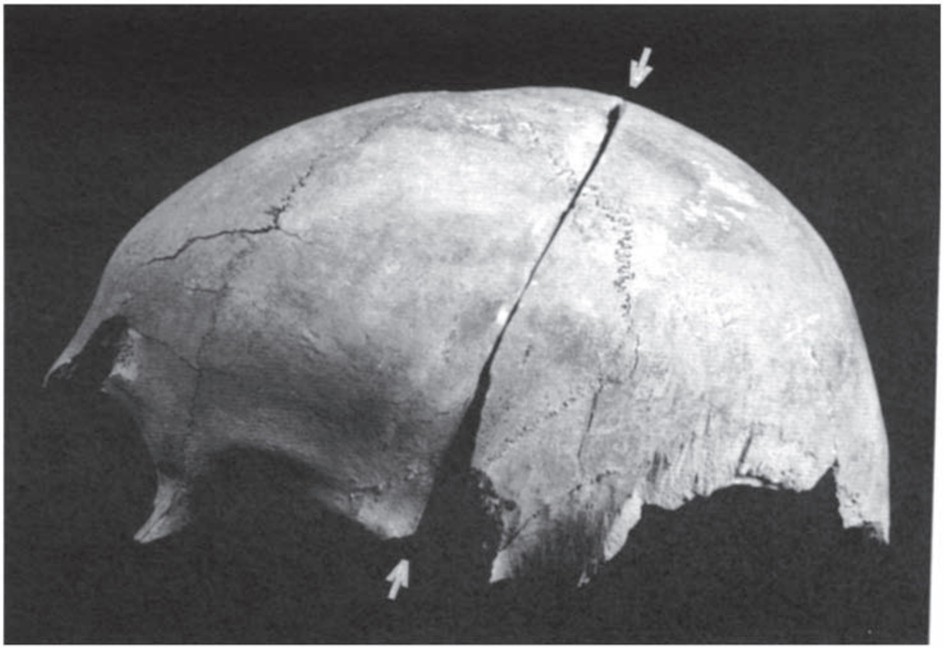


*Figure 8.4* The Ipswich skull showing an unhealed blade injury

replicas of medieval swords to strike the pigs' heads with blows whose trajectories were carefully recorded. The cut surfaces on the skulls were then examined microscopically and this showed that the fine, parallel scratches aligned with the passage of the blade through the bone. They appeared to be caused by minute irregularities on the blade's surface. Thus the orientation of these parallel scratches in archaeological specimens may be a guide to the trajectory of the blow which caused the injury.

Examination of the surfaces of the cut on the Ipswich skull under a low-powered microscope revealed fine, parallel scratch marks which were vertically orientated. This suggests that the injury was caused by a downward blow.

Sometimes perimortal and post-burial fractures can be distinguished in another type of injury: blunt injury to the skull. When the skull vault in a living individual (or in a fresh corpse) is struck by a blunt weapon or object, a depressed fracture tends to result, where fragments of the bone are driven inwards towards the brain. In such injuries the natural slight 'give' of fresh or living bone means that fragments tend to be bent inwards still attached to the skull. In some instances fracture lines may radiate away from the point of impact. Post-depositional breaks to the skull of a long-buried skeleton tend to shatter the vault and do not produce the inward pointing fragments which are characteristic of perimortal blunt injuries.

A blunt injury is illustrated on the skull of a medieval child from Wharram Percy, England. The child was about 5–6 years old at death. The injury is shown in Figures 8.6 and 8.7. The lesion is a depression situated on top of the head, just to the right of the midline (Figure 8.6). The skull is not perforated, but the bone on the external surface is pushed down about 5 mm below the surrounding surface. Looking at the inner side of the injury (Figure 8.7), it can be seen that some of the inner table of the skull has splintered away exposing the underlying trabecular bone. Some fragments remain attached and point inwards. There is

*Figure 8.5* The anterior part of the cut surface of the blade injury in the Ipswich skull. The orbit (eye-socket) is on the left in the photo. The fairly flat cut surface is smooth and has a polished appearance; this is most visible in the anterior part of the lesion, just above the orbit

no sign of healing, so the injury must have occurred at or around time of death.

With the weapon injury described in the Ipswichskull, there could be little doubt that it was caused by intentional violence, but in the case of the Wharram Percy child it is impossible to determine whether the cause was accident (for example a hard object falling on the head) or assault. If the latter, the nature of the wound suggests that the blow was probably delivered using a blunt weapon with a fairly small contact area (to produce the small diameter fracture). The posterior side of the wound slopes

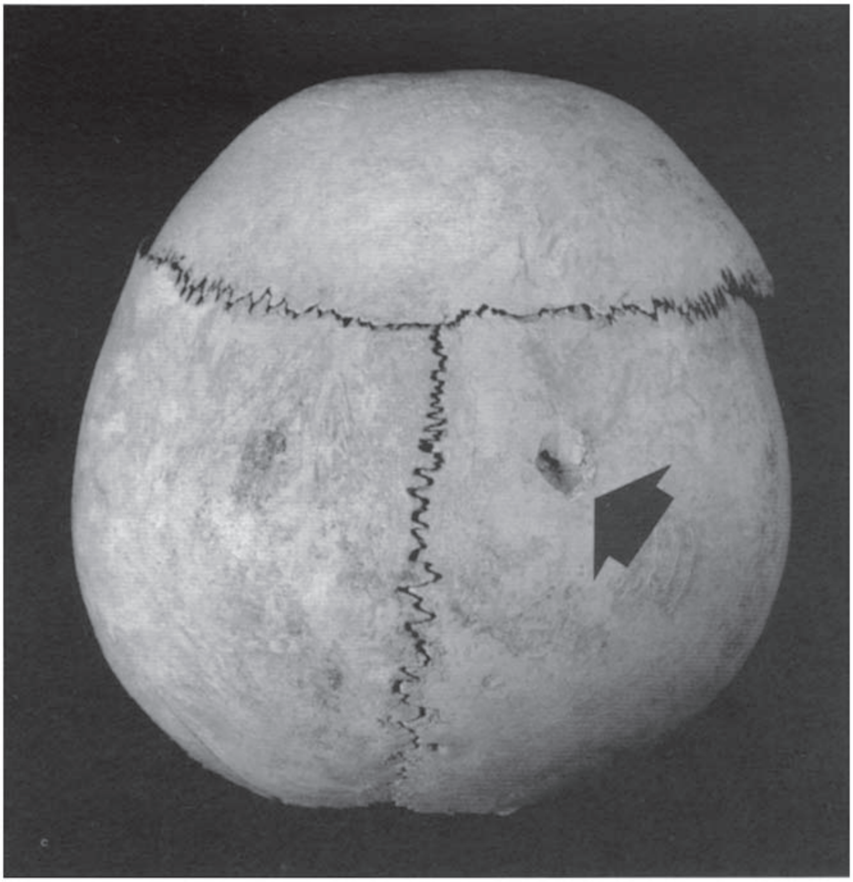


*Figure 8.6* Superior view of the Wharram Percy skull showing an unhealed blunt injury (arrowed)

more steeply and is deeper than the anterior side (Figure 8.6). This suggests that if it was the result of a blow with a hammer or similar instrument, it was delivered from behind the victim.

A further type of perimortal injury occasionally seen on more recent archaeological material is gunshot wounds. Entrance wounds are often approximately circular; exit wounds are often larger and more irregular in shape. As with blunt injuries, fracture lines may radiate from the point of impact. Unlike blunt injuries, holes due to gunshot wounds do not generally show adherent, inwardly directed fragments at their margins: the speed of the bullet means that bone fragments break away rather than bend (Berryman and Haun 1996). Unless the bullet is retained embedded in the bone, it is very difficult to distinguish gunshot wounds from post-depositional damage on simple visual examination of the remains. This point is illustrated by a study which has been conducted on one of the Spitalfields skulls (Cox *et al*. 1990).

In order not to bias the scientific results, all the data on the Spitalfields skeletons were recorded 'blind' —i.e. without reference to the coffin plates and other sources which provide biographical information about many of the interred individuals. When the biographical data was tied in with the skeletons, it was noted that one of the burials was of William Leschallas, who committed suicide in 1852 by

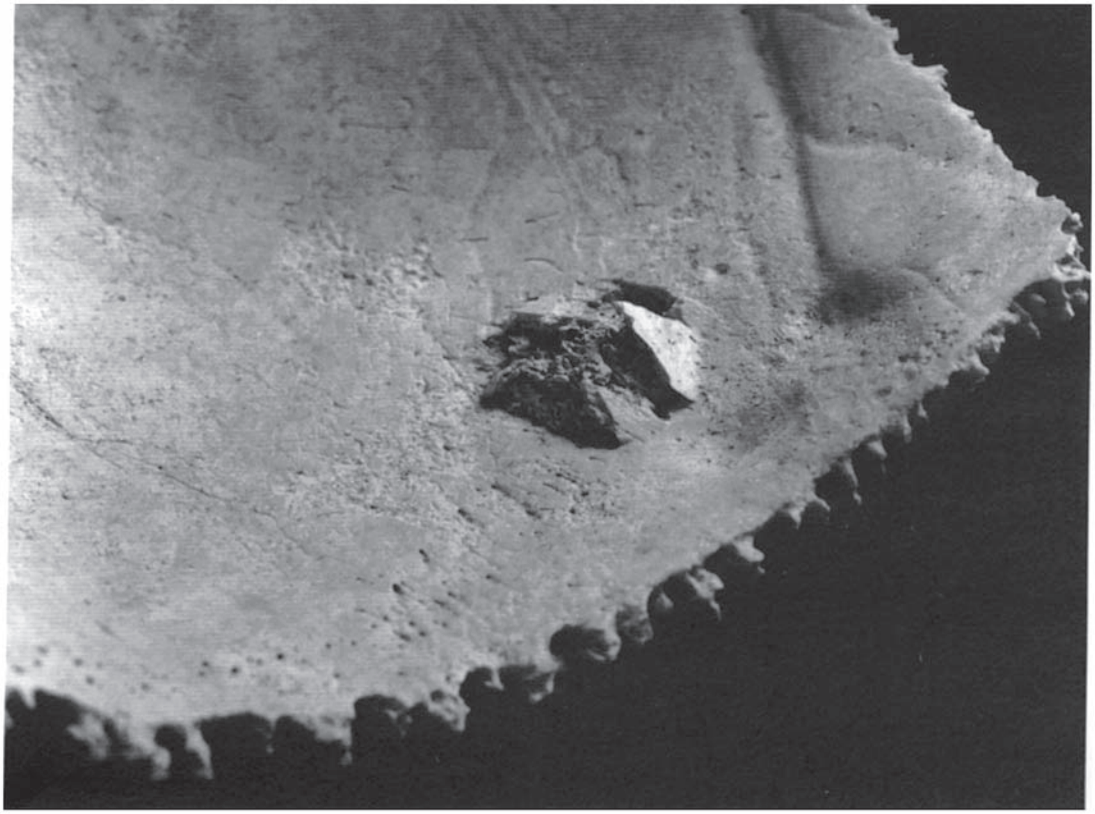


*Figure 8.7* The inner surface of the Wharram Percy skull at the site of the injury

shooting himself in the head with a pistol. The skull in question showed an approximately circular hole in the right temple (Figure 8.8) and a larger more ragged hole in the back of the skull. These holes looked typical of the sort of post-depositional damage customarily seen on archaeological remains, and indeed were accepted as such by several researchers who had previously examined the skull. When it was realised that the skull belonged to the suicide victim, a radiograph of it was examined and tiny opaque particles were found to be visible. These were lead fragments which had become embedded in the bone. This showed that the two holes were in fact entry and exit wounds from the gunshot. Because gunshot injuries are so difficult to distinguish from post-depositional defects on simple visual examination of the bones, radiography plays an important role in helping to make this distinction in archaeological material where gunshot wounds are suspected.

Other examples of gunshot injuries have sporadically been reported in archaeological remains post-dating the introduction of firearms (e.g. Irish *et al.* 1993; Bowman *et al.* 1992; Gill 1994). A recent publication by Willey and Scott (1996) discusses six skeletons showing unhealed gunshot wounds, excavated from the battle site at Little Bighorn, Montana, USA. The excavated remains were of members of General Custer's army, defeated here by a force of Plains Indians in 1876. Three of the six individuals showed gunshot wounds to the head, three had post-cranial lesions. One of these latter, excavated

*Figure 8.8* The right temple area of the skull of William Leschallas, excavated from the Spitalfields crypt, London. The orbit is visible on the right of the photograph, the ear canal towards the bottom left. The hole in the temple is the entry wound from the bullet which caused his death

*Source*: Reproduced from Cox *et al.* (1990: Figure 1).

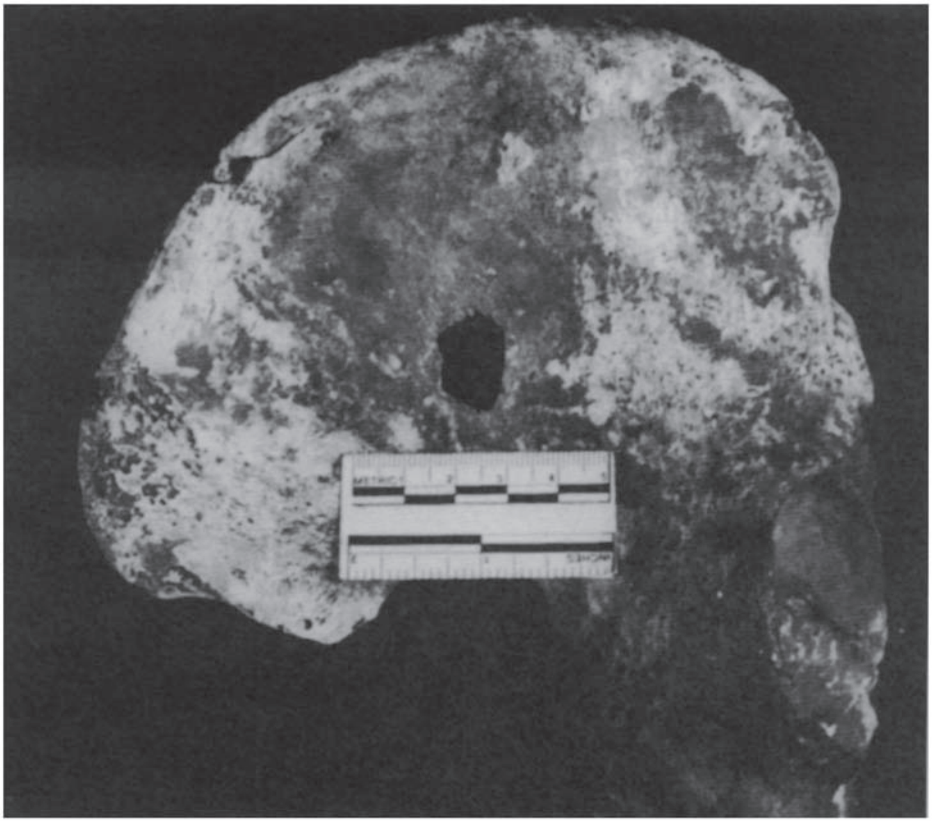


*Figure 8.9* The right pelvic bone from a skeleton recovered from the Little Bighorn battle site. The hole proved to be a gunshot wound
*Source*: Reproduced from Willey and Scott (1996: Figure 5).

from an area of the battlefield known as Weir Point, is illustrated in Figure 8.9. The appearance of the hole in the right pelvic bone is similar to post-depositional defects often seen on archaeological bones. However, on X-ray, Willey and Scott found lead fragments were visible at its margin, indicating that it was a gunshot wound. X-ray also revealed lead spatter on the adjacent part of the sacrum. They reasoned that the bullet must have entered the right hip from the rear and exited through the abdomen. The wound, together with other skeletal parameters, assisted in providing a personal identification for this skeleton. Contemporary accounts of the skirmish at Weir Point indicate that Farrier Vincent Charley was hit in the hips by a bullet, and his comrades were forced to abandon him in their retreat (Willey and Scott 1996:23).

Although, strictly speaking, in the cases above we cannot determine from the injuries themselves whether they were delivered to a living person or to a fresh corpse, common sense indicates that they were almost certainly inflicted on living individuals and hence were cause of death. However, with some perimortal injuries the situation is less clear.

In cemeteries in Britain dating from the fourth to the seventh centuries AD it is not uncommon to find a few decapitated burials (Figure 8.10). Decapitated burials can be distinguished from burials in which the skull has been moved by inadvertent disturbance to

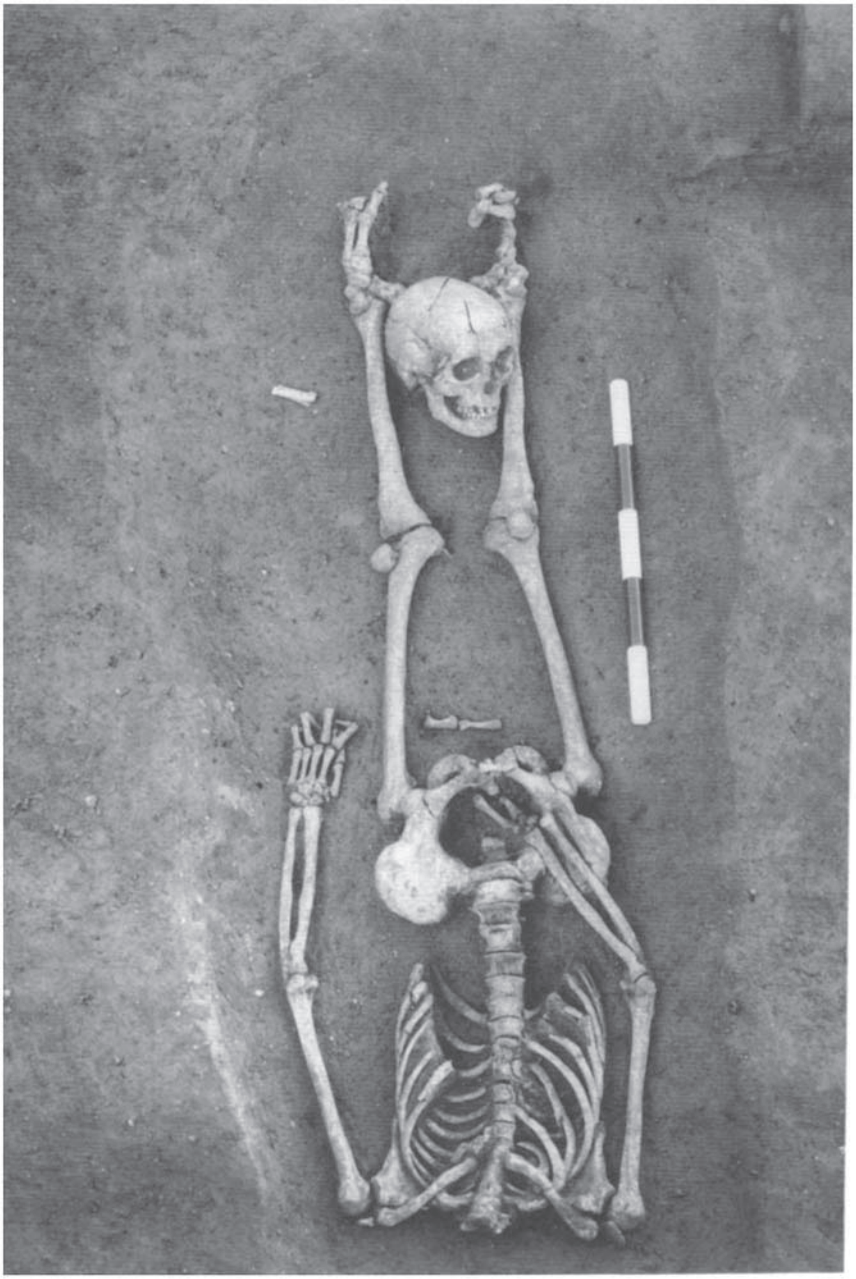


*Figure 8.10* A decapitated burial dating to the late fourth century AD from a cemetery excavated at Stanwick, England

a long-forgotten grave by the presence of cut or chop marks on the neck vertebrae and by the observation that the top few vertebrae are still articulated with the skull. Various explanations for these decapitated burials have been suggested, including executions of criminals or enemies, human sacrifices, mutilations to corpses to prevent ghosts walking and mutilations to dishonour the corpses of enemies (discussion in MacDonald 1979; Harman *et al.* 1981; Philpott 1991:77–89). The first two possibilities assume that the decapitation was cause of death, whereas the last two assume that it was inflicted upon a lifeless corpse. Although it is certain that they were perimortal injuries, in no instance is it possible to determine from the bones whether the decapitation was cause of death or inflicted after death. It is perhaps worth noting, however, that from decapitated skeletons which showed some cuts which failed to extend right through the vertebrae (indicating that several blows were required before the head was successfully severed) it seems that in most cases the blows were inflicted from the front (Harman *et al.* 1981:165). It was usual in executions by beheading in later periods in Britain to deliver the blow(s) to the back of the neck.

## ARCHAEOLOGICAL POPULATION STUDIES

Three studies of injuries in ancient populations are discussed below. The first deals with fracture patterns and their interpretation in a series of American Indian skeletons. The second deals with the types of fractures suffered by the elderly osteoporosis sufferers from Wharram Percy. Finally, an account is given of a classic study of blade injuries at a Swedish medieval battle cemetery.

### Fracture Patterns in a Native American Group

Fracture patterns in the long-bones of a large series of skeletons excavated from the Libben site, Ohio, USA have been studied by C.Owen Lovejoy and co-workers (Lovejoy and Heiple 1981; Mensforth and Lovejoy 1985). The Libben people were hunter-gatherers, and the site dates to about AD 800–1100.

At Libben, Lovejoy and co-workers found that there was no overall difference in frequency of long-bone fractures between the sexes, nor between bones on left and right sides of the body. Most fractures were firmly healed. The frequencies of fractures of the different long-bones ranged from a high of 5.8 per cent for the clavicle to a low of 0.7 per cent for the humerus (Figure 8.11).

Save for blade injuries, it is normally impossible in individual cases to be certain whether a fracture was due to accident or violence. There were no blade injuries on the Libben bones and indeed, for most instances where inferences could be made, the fractures seemed more likely to be due to accident. For example, in the most frequently injured long-bone, the clavicle, fractures were of the type most often caused by a fall onto an outstretched hand or onto the point of the shoulder. The next most commonly fractured long-bone at Libben was the radius. Most of the radius fractures occurred near the lower end and are of the type termed Colles' fractures, where the fracture is through the distal metaphysis of the bone. Colles' fractures are characteristically the result of a fall onto an outstretched hand.

The only fractures in the Libben long-bones for which a case can be made that they result from violence are two cases of midshaft fractures of the ulna. Although fractures to this area are often caused by accident (Smith 1996), they may also be a result of the forearm being raised to parry a blow from a staff or similar weapon aimed at the head. As a consequence they are sometimes termed parry fractures.

Lovejoy and co-workers attempted to study the distribution of fractures by age. Most of the fractures were firmly consolidated, indicating that they probably occurred long before death, but in individual cases it is clearly impossible to determine the age of the person when the injury occurred. Although the rate of bone remodelling in early childhood and infancy means that evidence for fractures occurring during early life may in time be obliterated from the

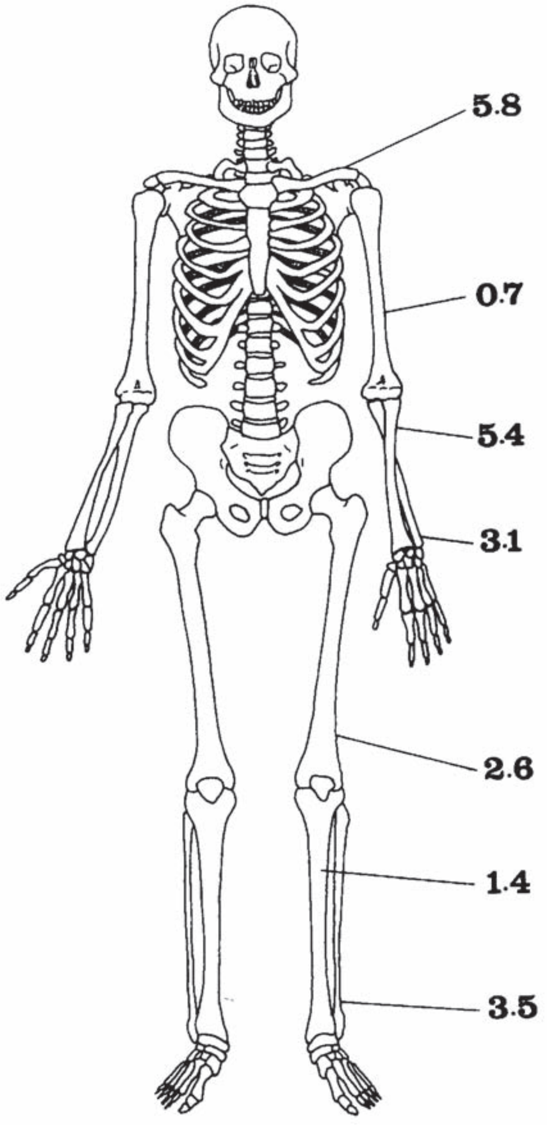


*Figure 8.11* The fracture rate of the Libben long-bones expressed as a percentage of each bone type examined (i.e. number of bones fractured divided by total number of each skeletal element examined, multiplied by 100). Left and right sides combined

*Source*: Figures from Lovejoy and Heiple (1981).

skeleton, in adults the fracture site usually remains evident throughout life (Adams and Hamblen 1992: 10–11). This means that to a large extent the skeleton bears a cumulative record of the fractures suffered during life. The older the individual, the more likely he or she is to show fractures. If risk of fracture is constant throughout life, a steady increase in the prevalence of fractures in successive age classes should occur, any deviation in this pattern should highlight any age groups at which risk of fracture is increased or decreased. At Libben fractures showed a steady accumulation with age (Mensforth and Lovejoy 1985:97), indicating that, overall, no particular age group was more at risk of fracture than any other. This would not be expected if warfare was a significant cause of fractures in this Native American group—a raised fracture rate would be expected in younger male adults if this were the case.

Lovejoy and Heiple (1981) found that in almost every case the fractures had healed in good alignment and there was generally little shortening of the injured bone. Although, as already discussed, untreated fractures may heal with little deformity, the consistent pattern of good alignment seen at Libben may well support Lovejoy and Heiple's contention that some sort of splinting or setting of fractures was practised.

The general picture then, is that fractures were not uncommon in the Libben people. However, this seemed to be a reflection of their physically strenuous life-style rather than a high level of inter-personal aggression. When fractures were sustained they may have been treated rather than left to heal unaided.

## Osteoporosis-Related Fractures in Medieval Wharram Percy

Fractures to bones weakened by disease are termed pathological fractures. One disease which leads to increased susceptibility to fractures is osteoporosis. As we saw in Chapter 6, the medieval women from Wharram Percy suffered from osteoporosis, the degree of bone loss following the menopause being similar to that experienced by women in modern Western populations. This seems to have predisposed them to fractures of the vertebral bodies and ribs (Figure 8.12), just as it does today. The Wharram Percy women, however, did not show the fractures of the hip and wrist often seen in modern sufferers from osteoporosis. This difference in fracture experience would have had an extremely important effect on the impact which osteoporosis would have had on the lives of the elderly in medieval times. Although vertebral compression fractures are painful, and may cause some deformity to the spine and loss of height, hip fractures (actually fractures of the upper part of the femur) have much more severe consequences: they often heal poorly and even today carry with them a high risk of death or disability (Miller 1978; Parker and Pryor 1993). The lack of them means that the consequences of osteoporosis would have been much less serious for the medieval people. It is worth considering why no hip fractures were detected at Wharram Percy.

In modern elderly, most deaths connected with hip fracture occur soon after the injury (Miller 1978). This might lead one to ask whether hip fractures occurring shortly before death may have been present at Wharram Percy but were overlooked due to the difficulty in distinguishing them from breaks occurring to the bones as they lay in the soil. This possibility prompted me to re-examine the Wharram Percy femurs. Most were intact and unbroken. For those few which did show breaks in the femoral neck area, the broken edges were in an unweathered state, indicating recent damage rather than perimortal injuries. It seems, then, that the lack of hip fractures at Wharram Percy is a real phenomenon. There are several possible reasons for the dearth of hip fractures, but perhaps the most likely is that people did not in general survive to be old enough for the frequency of hip fractures to be significant. In recent populations, the frequency of hip fractures only begins to rise markedly in women over about 75–80 years of age (Buhr and Cooke 1959). In Chapter 3 it was pointed out that it is very difficult to

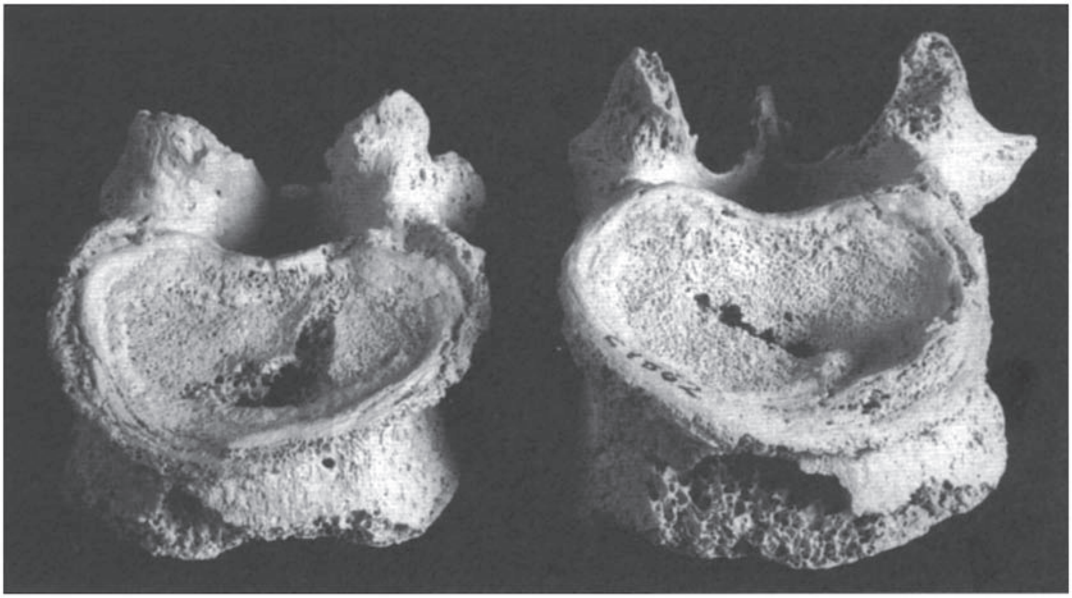


*Figure 8.12* Healed compression fractures of the bodies of two vertebrae of an elderly female from medieval Wharram Percy. The metacarpal cortical index (see Chapter 6) of this individual was two standard deviations below the young female adult mean

determine age at death from the skeleton in those over about 50 years, so it is difficult to infer the proportion of the Wharram Percy adults who were over about 75 years old when they died. However, if documentary data are anything to go by, it was low. Using the Inquisitions Post-Mortem (see Chapter 3), Russell (1937) found that only 4 per cent lived to over 75 years. Demographic differences between medieval and modern times may therefore lie behind the difference in fracture patterns. Another factor may be to do with the nature of falls suffered by the medieval as opposed to modern elderly. Although hip fractures in the elderly may occur spontaneously, most follow falls resulting in impact near the hip (Hayes *et al.* 1993). Absorbtion of energy on impact is likely to play an important part in determining whether or not falls onto the hip result in fracture. In our rural medieval group, when people fell they would generally have done so onto soft surfaces such as grass, bare earth or mud, rather than onto hard floors or pavements. These more yielding surfaces would help to dissipate the impact of a fall, reducing the likelihood of a fracture occurring.

Unlike those of the hip, wrist fractures are not mainly confined to the very elderly (Buhr and Cooke 1959), so demographic factors are not a likely explanation for their absence at Wharram Percy. Most wrist fractures follow falls onto an outstretched hand (Aloia 1993), so perhaps the lack of them at Wharram Percy has to do with falls, when they occurred, being onto yielding rather than hard surfaces.

## Weapon Injuries at a Medieval Battle Cemetery

In most archaeological assemblages, skeletons showing weapon injuries are few. However, a few battle cemetery sites have been excavated yielding large numbers of mutilated skeletons. One such site is Wisby, which lies on the Swedish island of Gotland in the Baltic Sea.

The Battle of Wisby took place in July 1361. The Danish Army invaded, and roundly defeated a hastily raised Swedish peasant levy to take the island for Denmark. Three mass-graves containing skeletons of the fallen were excavated in the earlier part of the twentieth century (Thordemann 1939). Bones from more than a thousand individuals were recovered. The battle injuries on these bones formed the subject of a pioneering osteoarchaeological study by the Swedish anatomist, Bo Inglemark (Inglemark 1939).

Wounds found on the Wisby skeletons included blade cuts, blunt injuries and arrow wounds. The blade injuries were inflicted with swords, with perhaps some axe wounds. Heavy swords were used at this time, although two-handed swords were rare. Bone injuries varied from superficial cuts, to bones which were completely severed. The wounds on the Wisby skeletons provide a vivid testament to the brutality of medieval warfare. Many skeletons bear severe multiple injuries (Figure 8.13), showing that the individuals had been felled and mutilated by a series of violent blows. They also illustrate the devastating effectiveness of medieval weaponry. For example, a number of individuals show severed limbs, and in one skeleton both lower legs had been severed by a single sword-slash. Some of the bodies had been cast into the grave pits still wearing their armour. It is clear that in many cases this gave insufficient protection from the Danish heavy weaponry. For example, some skeletons showed fatal cuts which penetrated clean through chain-mail.

Most of the cuts on the skeletons were directed from above, the natural arc of a slashing weapon like the medieval sword. The distribution of blade injuries to the skull and long-bones is shown in Figure 8.14. Many blows landed on the head. That the skull was frequently struck is of no surprise—the head is the natural target in hand-to-hand violence (Ström 1992). Inglemark observed an asymmetry in the distribution of the blade injuries on the skull. More blows fell on the left side, the left/right ratio of blade injuries to the skull was 1.6:1. The majority of people are right-handed, so in face-to-face combat an overarm blow with a weapon such as a sword would tend to fall on the upper left side of the victim's head. The lateral asymmetry was most pronounced in those skulls showing a single blade injury (left/right ratio 2.3:1), the distribution being much more even in those

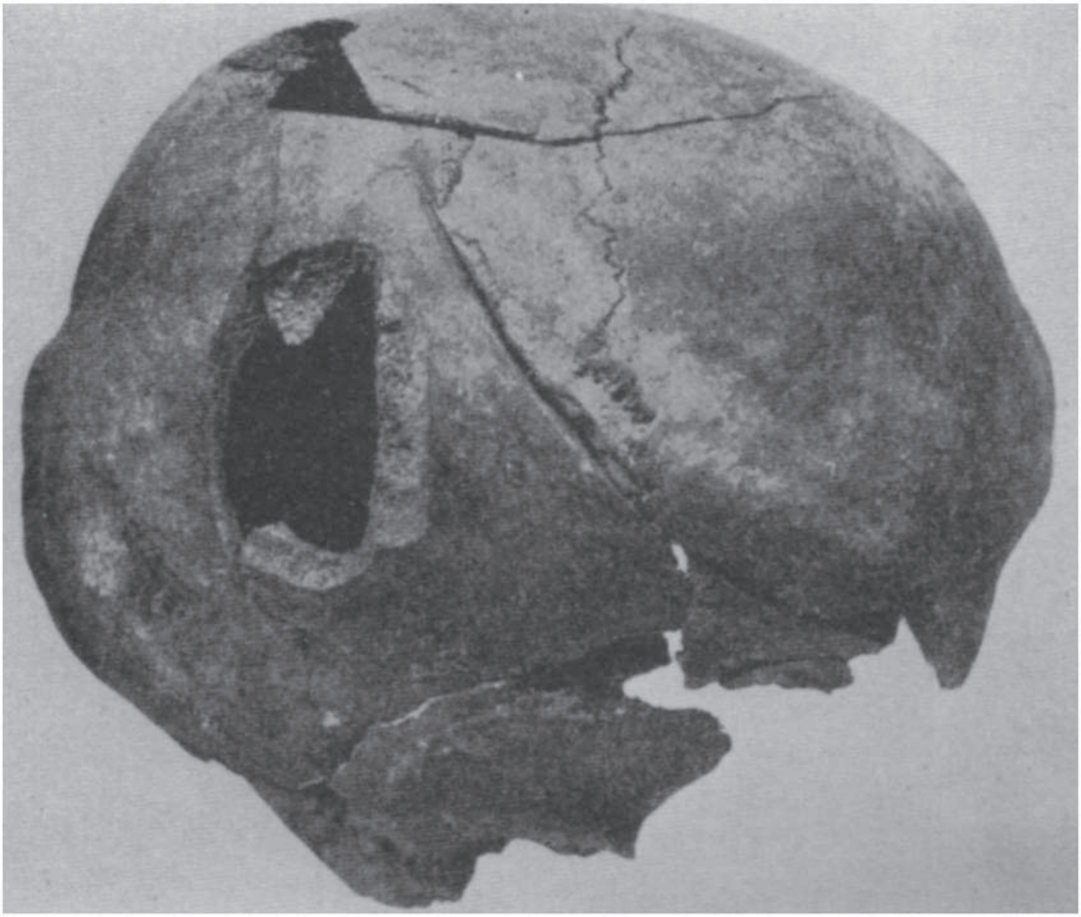


*Figure 8.13* A skull from Wisby showing several cuts in various directions
*Source*: Reproduced from Inglemark (1939: Figure 175).

showing multiple cuts (left/right ratio 1.2:1). Inglemark felt that this suggested that the single cuts were struck during face-to-face combat, whereas many of the multiple cuts probably came from blows aimed at fallen warriors.

Although most of the cranial injuries were found on the upper and front parts of the head, a significant minority (15 per cent) occurred on the occipital bone at the back of the skull. They occurred with similar frequency on left and right sides of the occipital bone. Inglemark felt that these too were likely to have been from blows directed at fallen opponents. The lower legs are not a naturally favoured target in inter-personal violence (Ström 1992), but in the Wisby skeletons a large proportion of cuts were found in this area. Inglemark attributed this to a number of factors. Shields would have provided some protection for the upper body, as would the body armour; however, the lower legs were lightly armoured if at all. Aiming at the lower legs may also have been a deliberate tactic. Blows here

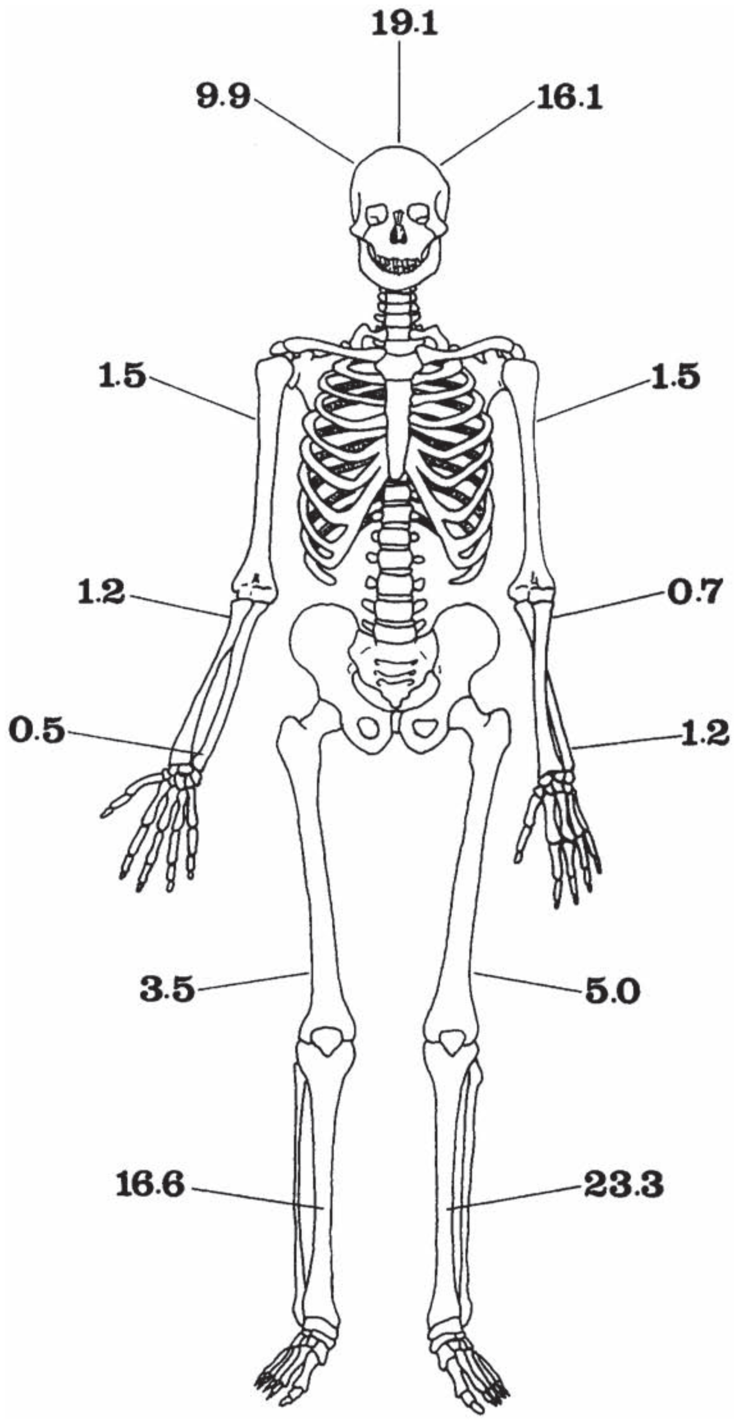

19.1
9.9
16.1
1.5
1.5
1.2
0.7
0.5
1.2
3.5
5.0
16.6
23.3

*Figure 8.14* The distribution of blade injuries according to skeletal element and side in the skull and long-bones from Wisby. Figures are percentages of a total of 404 cuts. The large number of skull wounds of indeterminate side is largely because many cuts were identified on skull fragments; in such circumstances it was frequently impossible to determine whether the injury lay mainly on the left or right side of the cranium

*Source*: From figures given in Inglemark (1939).

would have been difficult to parry and were probably aimed at scything down an opponent prior to administering the *coup de grâce.* Inglemark also points out that the tibia's superficial location means that it would be injured even by relatively light blows which, had they landed elsewhere on the body, might have stopped in overlying muscle.

The left—right asymmetry of injuries was less marked in the limb-bones than in the skull. Inglemark felt that an explanation was that although most blows were aimed at the left side of an opponent, some missed the left limb only to hit the medial (inner) side of the right instead. In support of this the left:right ratio of injuries on the lateral (outer) surface of the tibia was 2.07:1, whereas for the medial surface it was 0.69:1—i.e. more right bones than left were injured on the medial surface, consistent with blows aimed towards the left side of victims.

# 9

# CHEMICAL ANALYSIS OF BONE

The last few decades have seen an increasing interest in recovering information about ancient diets from chemical analysis of human bones. One important focus has been the analysis of the isotopic composition of bone, mainly of the collagen component. Other work has concentrated on the study of the chemical composition of the mineral part of bone, particularly in terms of trace elements.

## STABLE ISOTOPE ANALYSIS

Isotopes are atoms of an element with different masses. Most elements exist as mixtures of two or more isotopes. Isotopes may be radioactive (for example carbon-14), in which case they steadily decay, transmuting into other elements. Others are stable—that is, they are not radioactive and so do not change in abundance over time.

As was explained in Chapter 1, the main constituent of the organic part of bone is a protein, collagen. Collagen is composed of amino acids, compounds of carbon, hydrogen, oxygen, nitrogen and sulphur. Of these elements it is the stable isotopes of carbon and nitrogen which have to date received the most attention from the point of view of investigating ancient diets. Carbon occurs in two stable isotopes, of mass 12 and 13 (written as $^{12}C$ and $^{13}C$). The average relative abundances of these is about 98.9 per cent and 1.1 per cent respectively. Nitrogen also has two stable isotopes, $^{14}N$ and $^{15}N$, with relative abundances of approximately 99.6 per cent and 0.4 per cent. Stable isotope ratios of carbon and nitrogen are slightly different in different classes of foods. These differences are passed on to the bones of the consumer, so bone stable isotope ratios can potentially tell us about diet.

To analyse for stable isotopes, the collagen is extracted from the bone and purified. The resulting material is then burnt, and the gases produced are analysed using a mass spectrometer. This gives the relative abundance of the different isotopes present. A bone sample of 2 grams or less is all that is generally required.

Because differences in isotopic ratios in different parts of the natural environment, and in different foods, are small, stable isotope ratios are not normally written as simple ratios of one isotope to another, but as delta units. Delta units measure deviation in isotopic ratio from a particular standard. They are expressed in terms of parts per thousand (‘per mil’) using the symbol ‰, and calculated according to the formulae below:

$$\delta^{13}C = \left[\frac{(^{13}C/^{12}C)_{\text{Sample}}}{(^{13}C/^{12}C)_{\text{Standard}}} - 1\right] \times 1000$$

$$\delta^{15}N = \left[\frac{(^{15}N/^{14}N)_{\text{Sample}}}{(^{15}N/^{14}N)_{\text{Standard}}} - 1\right] \times 1000$$

The standard for carbon is a mineral called PD Belemnite (PDB); for nitrogen it is air. The majority of biological materials have less carbon-13 than the PDB standard, so most $\delta^{13}$C values are less than zero. Most biological samples have more nitrogen-15 than atmospheric nitrogen, so most $\delta^{15}$N values are greater than zero.

## Carbon Stable Isotopes in the Environment

Carbon stable isotope ratios in plants vary according to the photosynthetic pathway used by the plant to manufacture carbohydrates from atmospheric carbon dioxide. The two major pathways are known as the C3 and C4 mechanisms.

Most temperate zone vegetation uses the C3 pathway, so called because it involves the production of a three-carbon compound as its first step. The mean $\delta^{13}$C value for C3 plants clusters around –27 to –28‰(O'Leary 1988).

Some plants from tropical and sub-tropical areas, adapted to conditions of high temperature and high light intensity, use a photosynthetic pathway involving the creation of a four-carbon compound as the first step. C4 plants include important cultivated species such as maize, millet and sugar-cane. The $\delta^{13}$C values of C4 plants cluster around a mean of about—12 to—13‰ (O'Leary 1988).

Although the principal determinant of the $\delta^{13}$C value of a plant is the photosynthetic pathway used, factors affecting the precise figure include water and nutrient availability, light intensity and altitude (O'Leary 1981; Tieszen 1991). In addition, plants growing in dense forest understoreys may produce anomalously negative delta values due to uptake of carbon dioxide from rotting vegetation (Vogel 1978).

The difference in $\delta^{13}$C values between diet and the flesh of the consumer is small, less than 1‰ (Tieszen *et al.* 1983). This means that in a given environment, $\delta^{13}$C values of animal and plant foods are similar.

Since the Industrial Revolution, the burning of fossil fuels has made the delta value of atmospheric carbon dioxide about 1.5‰ more negative (Friedli *et al.* 1986). Because carbon in terrestrial food chains ultimately derives from atmospheric carbon dioxide, to estimate $\delta^{13}$C values for terrestrial foods in antiquity about 1.5‰ needs to be added to modern figures.

Carbon in marine environments derives from dissolved bicarbonate, which is enriched in C-13 compared with atmospheric carbon dioxide (Smith and Epstein 1971). Marine plants and plankton (which are mainly C3) therefore have less negative $\delta^{13}$C values than terrestrial C3 plants (Chisholm *et al.* 1982; Tan 1989). The flesh of marine mammals and fish has a delta value of about—17 to—18‰ (Chisholm *et al.* 1982).

## Nitrogen Stable Isotopes in the Environment

Most plants cannot obtain the nitrogen they need to form proteins and other compounds directly from the atmosphere, they take it up from the soil. Excep-tions are legumes, such as peas and beans, which can use atmospheric nitrogen as well as absorbing it from the soil. $\delta^{15}$N values for leguminous plants lie between 0 and +4‰, for other plants they are about + 5‰ (DeNiro and Hastorf 1985). Unlike carbon dioxide, the delta value for atmospheric nitrogen (which is by definition 0‰) appears to have remained unchanged from millions of years (DeNiro 1987), however $\delta^{15}$N in some soils has been reduced somewhat by the use of modern chemical fertilisers (DeNiro and Hastorf 1985).

Factors which affect the precise $\delta^{15}$N values of plants include temperature, altitude, rainfall, the salinity of the soil, and the application of natural fertilisers such as guano (Ambrose 1991). In animals, water stress may affect $\delta^{15}$N values. For example drought-adapted, desert-dwelling animals show anomalously high delta values (Schoeninger and DeNiro 1984), and archaeological human remains from arid areas often show higher $\delta^{15}$N values than do those from environments where water is more plentiful (Ambrose 1993).

Flesh has a $\delta^{15}$N value about 2–3‰ higher than diet (DeNiro and Epstein 1981). There is thus an increase in $\delta^{15}$N as one ascends a food chain. Although this difference is greater than is the case for carbon isotopes, it is still rather too small to allow nitrogen isotopes to be used for the investigation of meat:vegetable ratios in human diets (Spielmann *et al.* 1990).

Dissolved nitrates in seawater provide the major nitrogen source for marine food chains. They are enriched in $\delta^{15}N$ compared with atmospheric and soil nitrogen so that marine plants have higher $\delta^{15}N$ values than do terrestrial ones, and marine animals have higher delta values than do terrestrial species at corresponding positions in food chains (Schoeninger *et al.* 1983; Schoeninger and DeNiro 1984). Schoeninger and DeNiro (1984) found that marine fish had values of about +11 to + 16‰ and marine mammals +11 to +23‰. Shellfish $\delta^{15}N$ values may be somewhat lower than this—Sealy *et al.* (1987) quote values of about +7 to +8‰.

Approximate mean carbon and nitrogen stable isotope values for some major classes of food are shown in Figure 9.1. The figures are estimates of likely values obtaining in antiquity; that is, they are adjusted to take into account the effects of atmospheric pollution and the application of chemical fertilisers on modern values.

## Stable Isotope Ratios in Human Bone Collagen

The $\delta^{13}C$ value of human bone collagen is probably about 5‰ less negative than diet (Ambrose 1993). The $\delta^{15}N$ in collagen is about the same as that in flesh—about 2–3‰ greater than diet (DeNiro and Epstein 1981). Collagen turnover in adults is rather slow, requiring at least 10–30 years for complete replacement (discussion in Chisholm 1989). Collagen stable isotope data give a picture of diet aver-aged over the last few decades of an individual's life.

After burial, bone collagen is gradually broken down to large peptide units. These in turn degrade into their constituent amino acids, which are then leached out of bone (Lynch and Jeffries 1982). It is theoretically possible that these chemical reactions might lead to alterations in stable isotope ratios (Bada *et al.* 1989). Collagen has a specific amino acid composition. During post-depositional degradation (diagenesis) a collagen-like amino acid composition (implying the presence of intact collagen) persists until about 5 per cent of the original protein content remains. Below this figure, an amino acid composition which differs from that of collagen begins to predominate (Stafford *et al.* 1991). Masters (1987) compared carbon and nitrogen stable isotope ratios in bone which retained a collagen-like amino acid composition and bone which was so extensively degraded that it did not. Unlike specimens which did retain collagen-like amino-acid signatures, bones with non-collagenous amino-acid profiles showed anomalous carbon and nitrogen delta values.

One way of detecting bone which may have undergone diagenetic alteration in its stable isotope values is thus to analyse the protein part to determine whether it retains a collagen-like amino acid signature. Alternatively, analysis may be restricted to bone retaining about 5 per cent or more of its original protein (i.e. with an organic residue equal to or greater than about 1 per cent of the bone weight); in practice most bones from archaeological contexts in temperate zones satisfy this criterion.

## Stable Isotope Work on Archaeological Bones

The main thrust of carbon stable isotope studies has been to investigate the relative contribution of C3 and C4 plants to human diets, and to examine the relative use of marine as opposed to terrestrial food resources. The main application of nitrogen isotopes has been the investigation of the consumption of marine foods. A theoretical model showing the approximate $\delta^{13}C$ and $\delta^{15}N$ values expected of human bone collagen from ancient populations on C3, C4 and marine diets is shown in Figure 9–2.

Maize is a C4 plant, so its introduction into temperate regions with natural C3 vegetational cover can be studied using carbon stable isotope ratios. By the time of Columbus, maize had become the dominant staple crop of the Americas. It was cultivated from

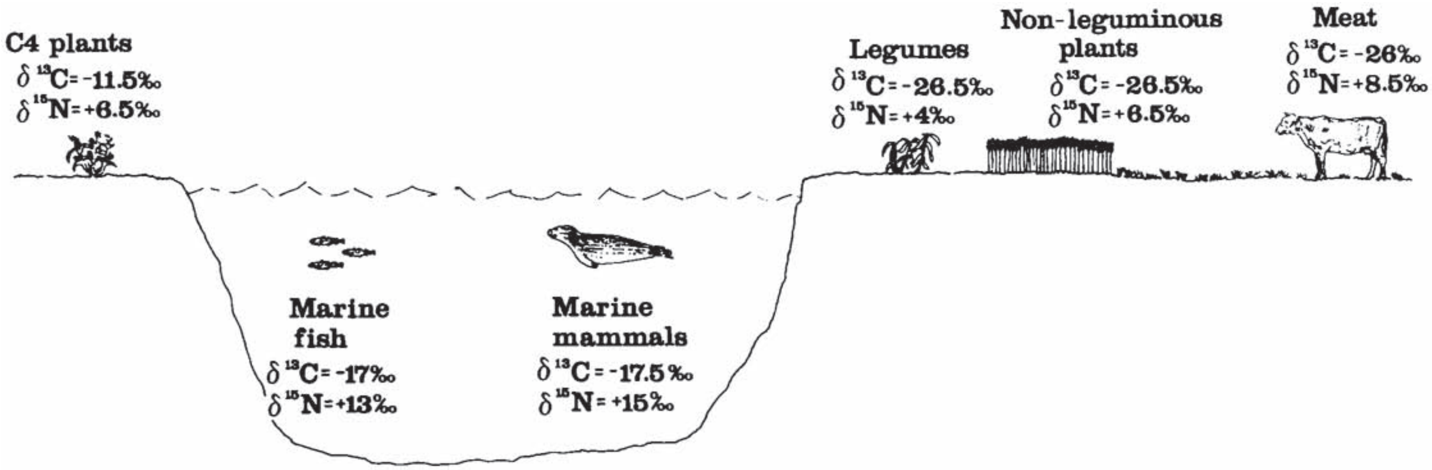


*Figure 9.1* Approximate mean stable isotope values for some major food classes. Values are estimates of those obtaining in antiquity—in other words they are adjusted to take into account the effects of fossil fuel burning and the application of chemical fertilisers on modern values. For sources see text

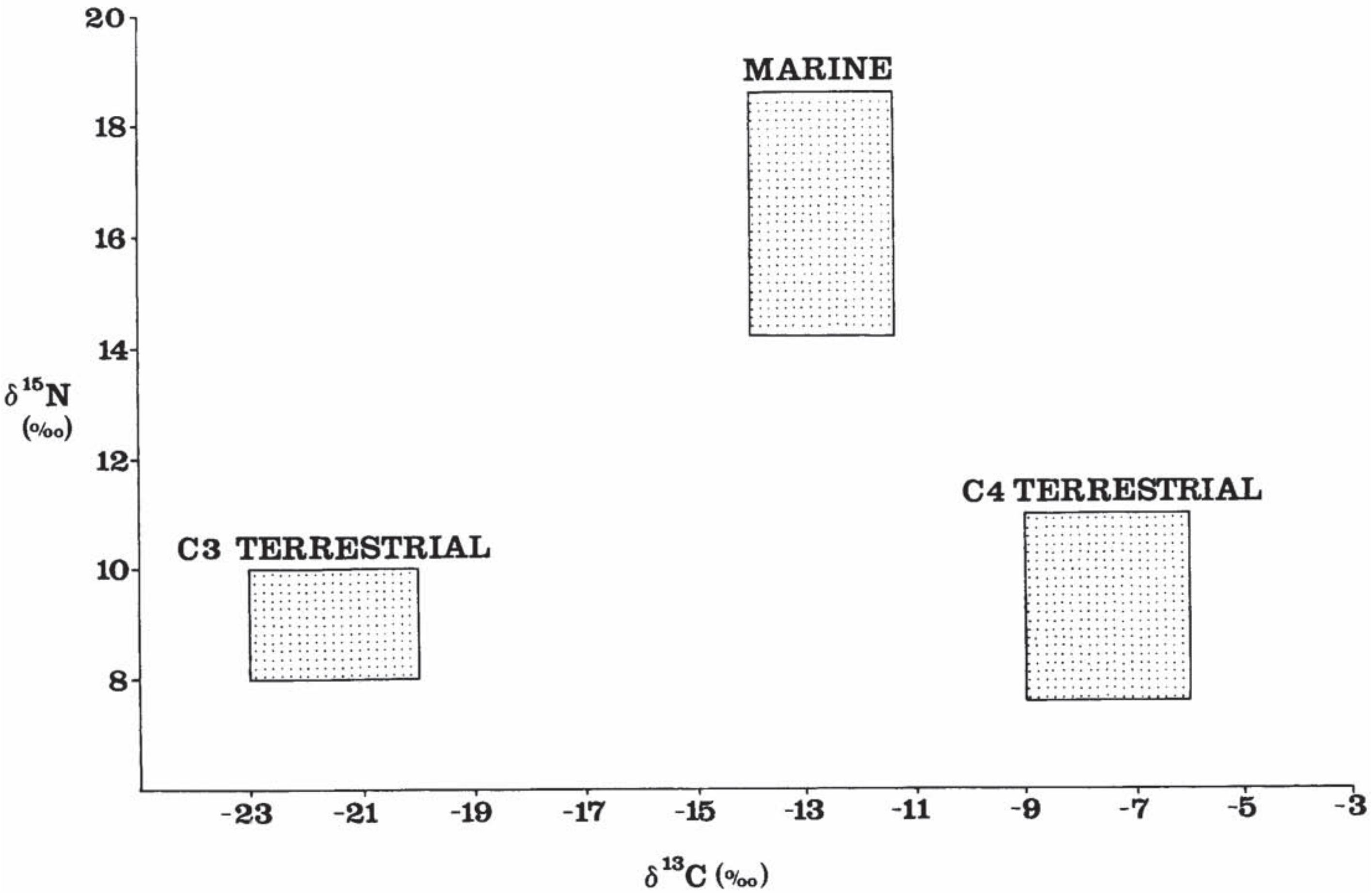


*Figure 9.2* Approximate human bone collagen stable isotope ratios expected for archaeological populations consuming pure C3, C4 and marine diets. Pure C3 diets are found in archaeological material from areas far from the coast with no C4 plants. Exclusively marine and, in particular, exclusively C4 diets are purely hypothetical

Argentina and Chile in the south, to Canada in the north (Galinat 1985). It was introduced into temperate North America as a cultigen from Mexico and Central America. In time it largely replaced existing subsistence strategies based on the cultivation of native plants and the hunting and gathering of wild resources (Nassaney 1987).

In the eastern US, maize cobs start to appear on settlement sites from about AD 200 onwards (Chapman and Crites 1987; Smith 1989). However, bone carbon stable isotope results indicate that maize did not form a significant part of human diets until many centuries after this, and furthermore it was taken up as a dietary staple in different regions of eastern North America at different times. For example, Schurr and Redmond (1991) demonstrate from analysis of bones from the Lake Erie Basin, Michigan, that maize was an important dietary component here by about AD 800. Stable isotope data show that maize intensification occurred rather later across the south-eastern US (Schwarcz and Schoeninger 1991), in many instances not until after about AD 1000 (e.g. Schoeninger *et al.* 1990).

As well as helping to build up an overview of the rise of maize cultivation in North America, carbon stable isotope data have also allowed local sequences of subsistence change to be constructed. For example, Lynott *et al.* (1986) studied material from sites in Missouri and Arkansas. An important aim was to investigate the relationship between the rise of maize-dominated agriculture and the emergence of 'Mississippian' cultural developments. These include increased social inequalities, increased population density, a change in settlement pattern from dispersed hamlets to fewer, larger villages, the appearance of ceremonial centres and various technological innovations (Smith 1986; Goldstein 1981). The advent of intensive maize agriculture has been widely viewed as enabling these developments (Lynott *et al.* 1986). Various components of this cultural package start to make their appearance in the middle Mississippi valley after about AD 700.

The results of Lynott and co-workers' stable isotope analyses are shown in Figure 9.3. From 3000 BC to AD 1000 the $\delta^{13}C$ values range from –19.9‰ to –21.7‰. Reference to Figure 9.2 shows that these values are consistent with a diet of terrestrial C3 foods. After AD 1000 there is a rise in carbon isotope ratios. Skeletons after this date give values ranging from –10.4‰ to –15.8‰. Although the complexities of human physiology mean that it is not easy to estimate the precise ratio of C3 to C4 foods in diets from $d^{13}C$ values, these figures indicate the rapid adoption of a significant C4 component in diets after about AD 1000. Lynott and co-workers interpret this as indicating that intensive maize agriculture began in the region at this time. Remains of maize cobs have been found on sites in the area dating as early as about AD 200 (Chapman and Crites 1987), and after about AD 800 there is an abrupt increase in the quantities of maize cobs found (Keegan and Butler 1987). The isotope data, however, show that there was no concomitant increase in maize consumption at this time. Smith (1989) has suggested that maize may have been mainly a ceremonial food prior to its adoption as a dietary staple.

The stable isotope data also facilitated a re-examination of the relationship between agricultural intensification and the rise of Mississippian culture in the region. Technological advances in pottery production, and in food processing and storage techniques, seem to coincide with the increase in the numbers of corn cobs recovered from settlement sites, but pre-date the large-scale consumption of maize (Smith 1986). On the other hand, aspects of the Mississippian cultural package such as the advent of a less dispersed settlement pattern and the construction of civic and ceremonial centres appear to coincide with the adoption of maize as a dietary staple. Hence some important aspects of Mississippian culture cannot be consequent upon the change to intensive maize agriculture—this transition occurred after the development of Mississippian culture had already begun.

Europe lacks the widespread introduction of a C4 cultigen to parallel the rise of maize agriculture in North America. Most carbon isotope work on European remains has therefore focused on investigation of the relative marine contribution to diets. An area of particular interest in this respect is dietary change

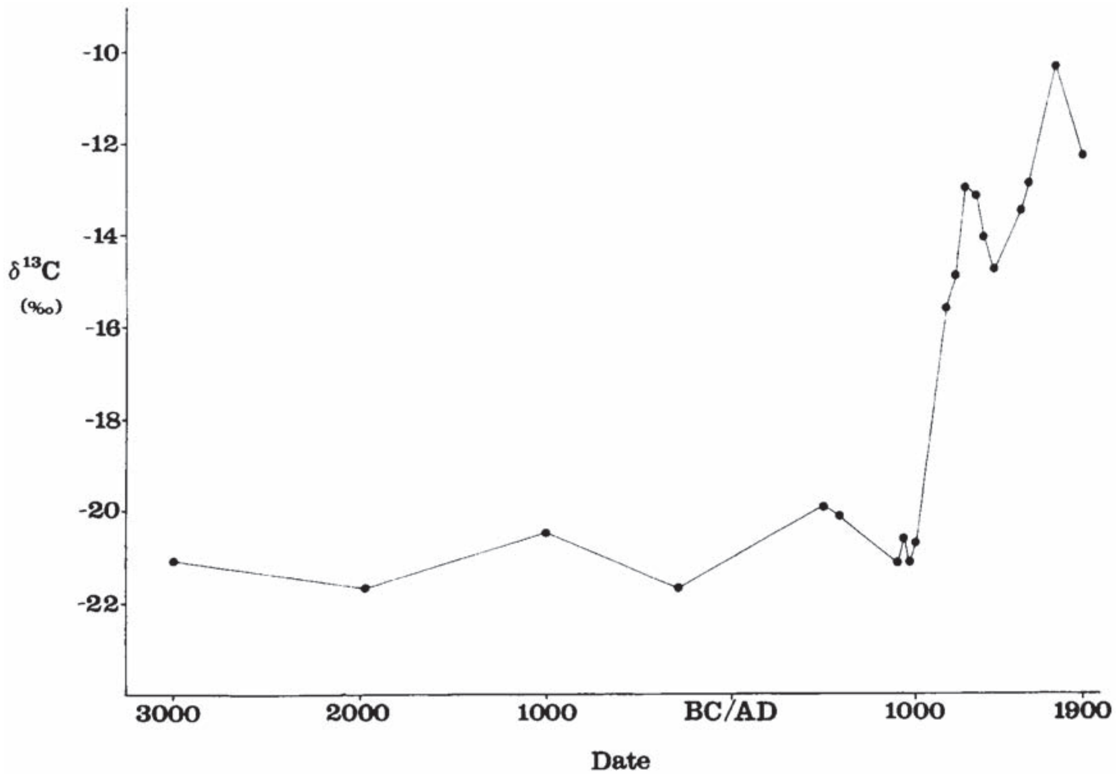


*Figure 9.3* Carbon stable isotope values for some burials from Missouri and Arkansas, USA
*Source*: From data in Lynott *et al.* (1986).

during the transition from Mesolithic hunter-gatherer-fisher cultures to the farming communities of the Neolithic. Henrik Tauber has studied this question using skeletons from Denmark (Tauber 1981, 1986). The results from Tauber's analysis of the bone collagen from Danish skeletons dating from the Mesolithic onwards are shown in Figure 9.4.

The carbon stable isotope values for the earlier Mesolithic skeletons (–17‰ to –20‰) indicate a mainly terrestrial diet. The earlier Mesolithic was a period in which sea levels were very much lower than they are today. The sites studied were some distance from the ancient coastline so it is not surprising that those buried there seem to have consumed diets dominated by terrestrial rather than marine foods.

The later Mesolithic bones all came from coastal sites. Their $\delta^{13}$C values range from about –12‰ to –16‰, suggestive of a predominantly marine diet. The heavy reliance on seafoods is consistent with finds from coastal settlements of the period. Abundant marine fish remains have been found when the use of sieving techniques allowed the recovery of these small bones. Most are of a type which could be caught close to the shore, using hooks or traps (Bødker Enghoff 1993).

With the adoption of agriculture in the Neolithic, a marked dietary change occurred: $\delta^{13}$C values from Neolithic and later sites cluster around –20‰, characteristic of a terrestrial C3 diet. Within the resolution of archaeological dating, the dietary transition seems to have been rapid, and the lack of intermediate delta values between the Mesolithic and Neolithic groupings also supports the notion of an

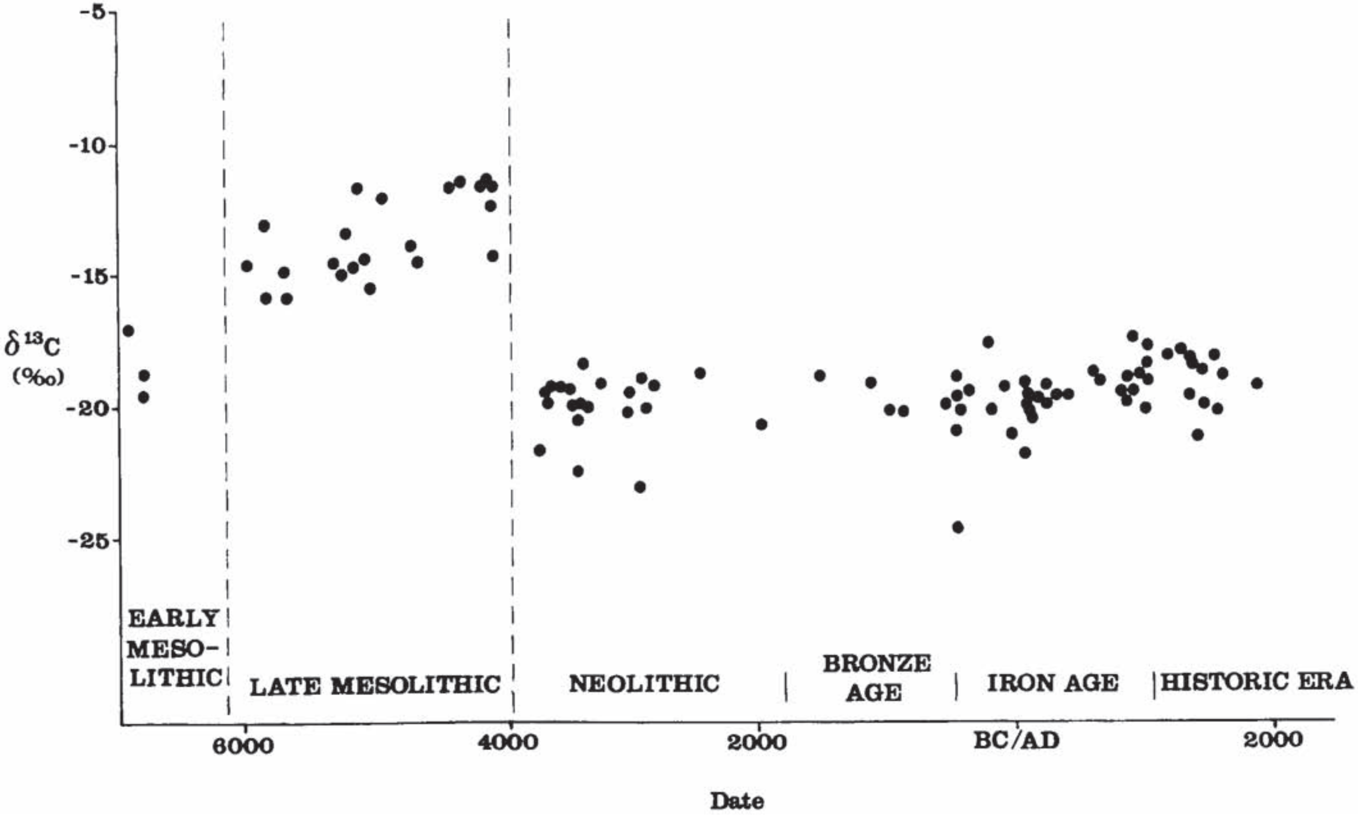


*Figure 9.4* Carbon stable isotope results from some skeletons from Denmark

*Source*: After Tauber (1986: Figure 3).

abrupt change. Artifactual evidence indicates that the Danish Mesolithic cultures were in contact with farming peoples to the south for more than six hundred years before the first evidence for agriculture in Denmark. Despite this, there is no evidence from the stable isotope data of a gradual adoption of food cultivation; the change in subsistence strategy, when it finally came, was precipitate. Most of the early Neolithic sites which Tauber studied were on or near the coast; it would seem that a fishery resource which had been successfully exploited for centuries was now largely abandoned. This is supported by the fish-bone evidence. In coastal sites whose occupation spans the Mesolithic—Neolithic transition, an abrupt shift has been observed between Mesolithic layers, which characteristically yield abundant fish remains, and Neolithic levels, which yield few if any (Bødker Enghoff 1989, 1991). An abrupt change in material culture has also been observed at these sites—Andersen (1989, 1991) states that the shift in technological materials from those associated with Mesolithic life-ways to those of Neolithic type occurred within a hundred years or less. It would seem then, that with the dawning of the Neolithic Age in Denmark, the old ways were quickly extinguished by the new.

The dietary studies discussed above used stable isotopes of carbon alone, as they dealt with instances in which variation in carbon delta values could be interpreted solely in terms of C3 versus C4, or marine versus terrestrial foods. When both C4 resources and marine foods may potentially form part of diets, nitrogen isotopes can be used to help discern whether variation in the carbon values reflects marine/terrestrial or C3/C4 components.

Murray and Schoeninger (1988) used stable isotope data to investigate diet at an Iron Age (450– 300 BC) cemetery at Magdalenska Gora, Slovenia. The $\delta^{13}$C values for these skeletons ranged from –13.0‰ to –17.2‰, with a mean of –14.4‰. The natural vegetational cover in temperate Europe is C3, but these values are markedly less negative than expected for a human population consuming C3 terrestrial foods (Figure 9.2). One possible explanation is that there was a significant marine component in the diet, even though the site lies over 80 km from the sea. Another possibility is that some hitherto unsuspected C4 food was being consumed. Nitrogen isotope determinations were conducted; these gave $\delta^{15}$N values ranging from 8.7‰ to 10.6‰, with a mean of 9.6‰. Figure 9.2 shows that these values are indicative of terrestrial rather than marine diet.

The data suggest heavy consumption of a C4 food by the people of Magdalenska Gora. A literature search (Murray and Schoeninger 1988) suggested that this C4 plant was probably millet. This is a hardy cereal with a short growing season and a tolerance of poor soils, which would have enabled its cultivation in south—central Europe. Indeed, the first-century Greek geographer, Strabo, records the inhabitants of the south-eastern Alps (a region which includes Slovenia) as cultivators of millet.

## TRACE ELEMENT ANALYSIS

The hydroxyapatite of which bone mineral is composed is far from chemically pure; there are a host of other elements present in small quantities. The concentration of many of these is so low that they are termed 'trace elements'. The concentration of bone trace elements is such that they are quantified not in terms of percentage of bone weight, but rather in parts per million (ppm) —i.e. micrograms per gram of bone. Most analyses of the element composition of bone aimed at investigating ancient diets have focused on trace elements.

Bone trace elements have been used to address a variety of aspects of ancient diets. Those which are present naturally in different quantities in different classes of foods may potentially tell us something of dietary composition. Those not naturally present in foods, but introduced as contaminants, may give information on food preparation and storage practices.

For a trace element to be a potential dietary indicator, its level in bone in the living person should be a good indicator of that in diet. In addition, post-depositional changes in its concentration in buried bone should be sufficiently slight so that levels in archaeological bone are an adequate indication of those obtaining during life.

Some trace elements, such as zinc or iron, are essential nutrients. Levels of these elements in bodily tissues are tightly controlled by metabolic processes. This means that their levels in bone may not be good indicators of those in diet. For example, it appears from animal studies that increasing or decreasing dietary zinc results in little change in bone levels (discussion in Ezzo 1994). Essential trace elements are not good candidates for dietary indicators. Elements which do not fulfil a physiological function may present better prospects; their bone levels are not tightly controlled by metabolic processes, so they are more free to vary with dietary intake. Two trace elements with no physiological functions and which have been used to study ancient diets, are strontium and lead.

## Strontium

Strontium (Sr) is one of the few trace elements whose distribution in foodwebs has been extensively studied; this was as a result of concern over the effects of the radioactive isotope, strontium-90, produced by atmospheric nuclear tests in the 1950s. Strontium has similar chemical properties to calcium (Ca), the main constituent of bone mineral. Unlike strontium, calcium is an essential element in mammals, so, not surprisingly, mammals absorb less strontium than calcium from food and more strontium than calcium is excreted by the kidneys (Comar *et al.* 1957a, 1957b; MacDonald *et al.* 1957; Spencer *et al.* 1960). Almost all the body's strontium is located in the skeleton (Schroeder *et al.* 1972), and a firm relationship between dietary intake and bone strontium levels has been established (Comar *et al.* 1957a, 1957b; Elias *et al.* 1982; Price *et al.* 1986). The above suggests that the Sr/Ca ratio will tend to be lower in herbivore tissue than in the plants they consume, and that carnivores in turn should have lower Sr/Ca ratios than the herbivores upon which they prey. This expectation that Sr/Ca values should decrease as one ascends a food chain has been borne out by experimental work on living ecosystems (Elias *et al.* 1982; Comar 1966). Analysing human foodstuffs, Schroeder *et al.* (1972) confirm that, in very broad terms, vegetable foods contain more strontium than do meats.

Several factors complicate this simple picture. For example, different plant foods contain different strontium levels (Runia 1987a). Marine fish contain high levels of strontium, as do both freshwater and marine shellfish. In addition to dietary intake, bone strontium levels may also be affected by physiological factors. Studies using laboratory animals have shown that pregnancy and lactation may increase strontium levels in the maternal skeleton (Price *et al.* 1986; Hartsook and Hershberger 1973; Kostial *et al.* 1969). In this light it is interesting to note that archaeological studies have often found higher strontium levels in female skeletons. Despite these complicating factors, an important focus of archaeological bone strontium work has been the study of meat to vegetable ratios in ancient diets.

## Lead

Like strontium, lead has no physiological function, but unlike strontium it is actually harmful if ingested in significant quantities. It is thus classified as a toxic trace element.

In the absence of industrial pollution, lead levels in the environment are very low. Foods naturally only contain minute quantities, and such small amounts can be excreted so do not accumulate in the body. However, due to its scarcity in the natural environment, man has not evolved an excretory system which can eliminate lead when it is ingested in levels exceeding those found naturally. In such circumstances it is retained in the body, over 90 per cent of it in the skeleton (Schroeder and Tipton 1968). Lead turnover is very slow, so that bone levels will to all intents and purposes represent the total lifetime exposure of the person to lead (Aufderheide *et al.* 1988).

In antiquity, intake of lead was generally a result of contamination of food and drink from leaden eating and cooking utensils, food storage vessels, water pipes and aqueducts, although it may also have been absorbed through the skin or inhaled as dust or fumes during metalworking (Patterson *et al.* 1987; Aufderheide 1989).

## The Problem of Post-Depositional Changes in Trace Element Levels in Archaeological Bone

Despite the complexities of human physiology and diet, the most troublesome problem afflicting the study of ancient diets using bone trace elements is diagenesis—chemical changes occurring whilst the bones are in the soil. No element is immune to diagenetic change, although some seem more vulnerable than others. The possibility of diagenesis needs to be investigated whenever trace element analyses of archaeological human remains are carried out.

The initial studies using bone trace elements for dietary reconstruction were undertaken over twenty years ago. For a time, the pervasiveness of diagenetic change in trace element levels in archaeological bone was not appreciated. For example, in the 1970s and early 1980s it was commonplace to read in the literature that elements such as strontium were little affected by diagenesis over a wide range of soil conditions. Subsequent work has indicated that this is untrue (discussion in Radosevich 1993). From the mid-1980s onwards, the emphasis of bone trace element work has shifted away from dietary reconstruction towards attempting to understand diagenetic processes and their influence on the chemical composition of buried bone.

Diagenesis may be detected in a number of ways, including comparison of element levels in ancient and modern bones, comparison of levels in different parts of the skeleton, studying the distribution of elements with respect to the bone surface, comparison of levels in bone with those in surrounding soil, and studies of bone microstructure. Large differences in concentrations of an element between ancient and modern bones, differences in concentrations between different skeletal parts, concentration gradients between the surface of a bone and the interior, or the presence of microstructural damage (Figure 2.5) all suggest significant diagenesis. On the other hand, if patterning in trace element concentrations matches that expected in theory (e.g. human bone strontium levels intermediate between carnivore and herbivore bones from the same site, reflecting the omnivorous human diet) then this would tend to support the idea that lifetime patterns have not become obscured by diagenesis. Much recent work (e.g. papers in Sandford 1993) relies on using a combination of methods in order to build up an understanding of the extent of diagenesis in the particular assemblage under study.

Some steps can also be taken to minimise diagenesis by careful sample selection and pre-treatment. Most workers choose cortical rather than trabecular bone for analysis. This is because it presents less surface area for exchange of trace elements with the soil. Elements which are present in bone as contaminants from the soil often tend to concentrate on the outer surfaces, and those which tend to be lost to the soil often show lower concentrations along bone surfaces than in the interior. Thus removal of bone surfaces excludes those parts most likely to be affected by diagenetic changes.

The solubility of bone mineral affected by diagenesis may differ from that of unaffected bone. For example, if buried bone has incorporated fluoride ions from the soil then the affected parts of the bone mineral are less soluble than unaffected parts. More commonly, however, diagenetic bone mineral is more soluble than unaffected bone (this is the case, for example, if bone is contaminated by carbo-nate ions from the soil). In such cases it may be possible to wash out contaminated bone mineral. In practice this means repeated washing of the bones with weakly acidic solutions. The element levels in each wash solution are analysed in order to monitor the removal of any more soluble diagenetic bone mineral (Figure 9.5). This method is called solubility profiling (Sillen 1986; Sealy *et al.* 1991) and has been developed particularly in the context of the strontium work. Although it does not work in all cases, it may provide a method of reducing diagenetic contamination of bone.

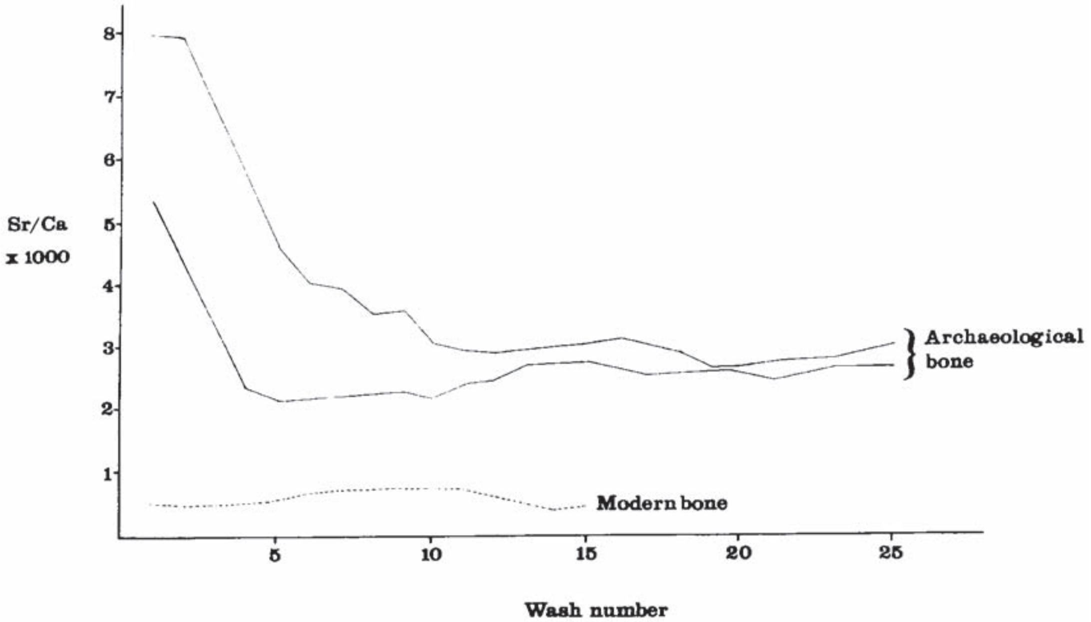


*Figure 9.5* Solubility profiles of two prehistoric skeletons from South Africa. Prior to treatment they showed very high Sr/Ca ratios. The values decreased after the first few washes, to stabilise after about wash 10. This suggests that the high strontium levels in the untreated bones were due to diagenesis, and that some or all the diagenetic mineral was removed by washing. The modern bone, which had never been buried, showed no release of strontium on washing
*Source*: After Sealy *et al.* (1991: Figure 3).

## Applications of Trace Element Analyses to the Study of Ancient Diets

A number of studies have been done on lead from bones from US colonial sites in order to study patterns of food contamination by this toxic element.

Aufderheide *et al.* (1981) looked at the lead content of bones from skeletons buried at the Clift's Plantation Site, Virginia, USA. Clift's Plantation was a prosperous tobacco farm, occupied during the period AD 1670–1730. The cemetery (Figure 9.6) yielded 16 burials: the northern part contained the graves of five members of the owner's family, the southern part 11 burials of the plantation's slave labour force. The mean bone lead concentration of the plantation owners was 185 ppm, that of the slaves 35 ppm. Although diagenesis was not expli-citly addressed in this study, Aufderheide *et al.* indicate that these lead concentrations are of the right order of magnitude to be representative of physiological levels. Furthermore, the lead levels in the bones of the slaves were found to increase with age at death, as expected with constant, long-term ingestion. It is difficult to see how this pattern, or the observed difference between the bones of the plantation owners and their slaves, could be artifacts of diagenesis; on the contrary, it seems likely that they represent *in vivo* patterns.

Historical evidence shows that vessels made of pewter, an alloy of tin and lead, were ubiquitous in colonial households. Ceramic assemblages from Clift's and contemporary sites show many lead-glazed storage, eating and drinking vessels. The bulk of food and drink consumed by planters and their families must have been in contact with lead containers at some point or other.

The slave labour force lived in separate quarters to the owner's family, so they would not have shared the same utensils. Archaeological evidence suggests that the

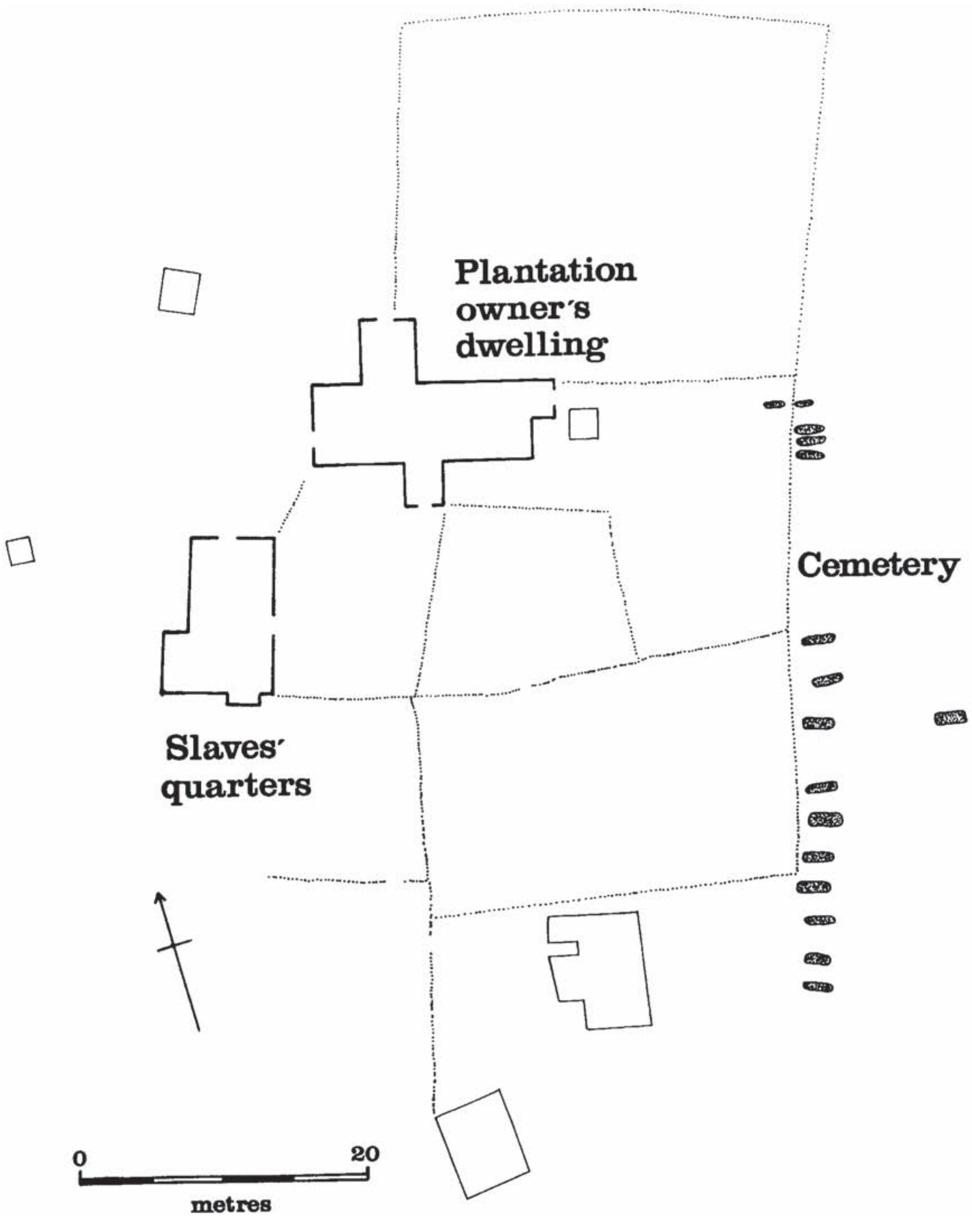


*Figure 9.6* Layout of the Clift's Plantation
*Source*: After Aufderheide *et al.* (1981: Figure 1).

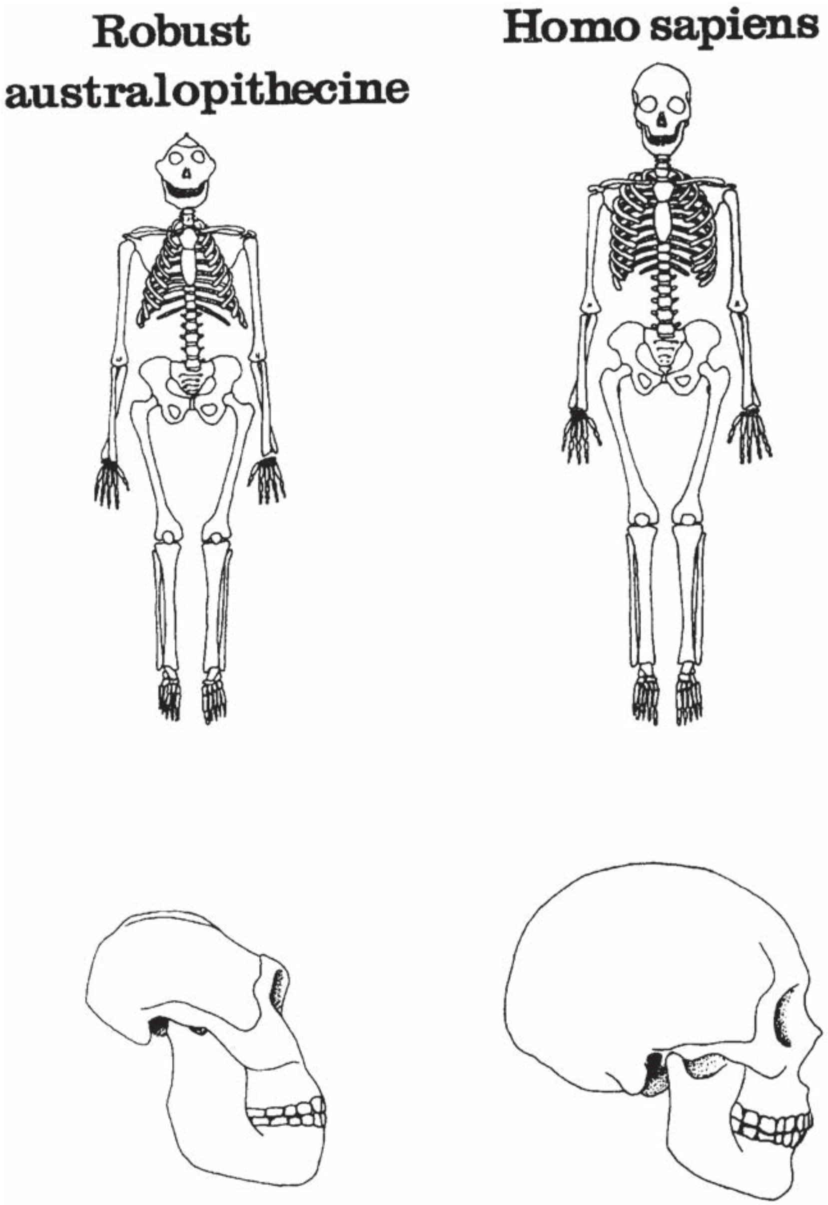


*Figure 9.7* Skeletal anatomy of the robust australopithecines, compared with *Homo sapiens* (modern man). Many of the body proportions of robust australopithecines, such as the funnel-shaped thoracic cage, are ape-like. The braincase is small, about half that of humans, and the jaws and teeth are massive, adapted to a diet including coarse plant foods

slaves used some lead-glazed earthenware vessels but much fewer than the owner's family, and there is no evidence for their using pewter vessels. That the slaves did not have access to luxury lead utensils meant that they showed a lower lead burden than the plantation owner's family.

In another study (Aufderheide *et al.* 1985) of bone lead at a US colonial site (the Catoctin Iron Furnace site, Maryland) the mean bone lead level of 16 slave burials was found to be 28.8 ppm. However within this group, the females showed a mean level three times greater than that of the males (40.3 ppm compared with 14.1 ppm). The sexes shared the same quarters, which were separate from those of the furnace owners. The results suggest that the women had access to a lead source which the men did not. Aufderheide and co-workers suggest that this indicates that these women probably worked as domestic servants in the furnace owner's living quarters where they would have had some access to food or drink contaminated by lead.

Bone strontium has recently been used to study diet in robust australopithecines. Robust australopithecines (Figure 9.7) are a type of early hominid who inhabited parts of Africa some 1–2 million years ago. In many respects they are intermediate between apes and humans; for example, they had small brains and were ape-like in many of their body proportions, but walked upright. From studies of their skulls and teeth many have suggested that these creatures were herbivores. Their robust jaws with large molars are well adapted to grinding tough, fibrous plant foods, and microscopic studies of tooth wear patterns appear to show that these sorts of foods were eaten. Andrew Sillen, of the University of Capetown, used bone strontium levels in order to re-examine austra-lopithecine diet (Sillen 1992).

Sillen studied bones from the Swartkrans cave site, in the South African Transvaal. In order to try and minimise any problems of diagenesis he selected only dense cortical bone samples for his analysis. He also used his solubility profiling technique to wash out contaminated bone mineral.

To test for diagenesis, Sillen analysed animal bones recovered from the Swartkrans site. He compared carnivore bones with those of prey species, and also compared bones of herbivores consuming different types of diets. His results are shown in Table 9.1.

*Table 9.1* Strontium:Calcium Ratios in Animal and Hominid Bones From Swartkrans, South Africa, Following Solubility Profiling

| *Species* | | *Sr/Ca × 1000* | |
|---|---|---|---|
| | *N* | *Mean* | *Standard deviation* |
| Hyaena | 1 | 0.22 | — |
| Leopard | 9 | 0.17 | 0.04 |
| Baboon | 10 | 0.35 | 0.11 |
| Kudu | 4 | 0.20 | 0.05 |
| Hare | 5 | 0.32 | 0.11 |
| Hyrax (*P. antiqua*) | 8 | 0.56 | 0.30 |
| Hyrax (*P. transvaalensis*) | 7 | 0.76 | 0.35 |
| *Australopithecus robustus* | 8 | 0.26 | 0.03 |

*Source*: Figures from Sillen (1992).

The carnivores (hyaena and leopard) show low Sr/Ca ratios; specifically, the leopard has a lower value than the baboon, one of its principal prey species. The leaf and grass eaters, the kudu (a type of ante-lope) and the hare, also show quite low Sr/Ca ratios, lower than those of the hyrax, whose diet includes substantial amounts of high fibre plant parts in addition to leaves. As we have seen, the low values for the carnivores is as expected. The patterning among the herbivores is also as expected. Many plant parts have high strontium:calcium ratios compared with leaves, and, in addition, fibre tends to bind calcium so that high fibre diets have relatively more available Sr/Ca than lower fibre ones. The patterning observed in the faunal Sr/Ca ratios supports the suggestion that they are indicative of *in vivo* levels.

The Sr/Ca ratio for the australopithecines is higher than that of the carnivores, but is relatively low compared with the other fauna. One explanation might be that they were leaf-browsers, but this is highly unlikely from the dental evidence. A better explanation, argues Sillen, is that they were omni-vores, not herbivores—their diets probably did include some meat.

# 10

# THE STUDY OF DNA FROM ANCIENT BONES

DNA contains the inherited genetic information which controls the structure, development and metabolism of the body. It is present in all cells, including the osteocytes, osteoblasts and osteoclasts of bone.

The first published report of successful retrieval of DNA from ancient human tissues was by Chinese scientists in 1980, when they recovered it from a rib cartilage from a 2,000-year-old mummy from Hunan province (Herrmann and Hummel 1994). By the late 1980s it had become clear that DNA could also be extracted from ancient bones (Hagelberg *et al.* 1989; Horai *et al.* 1989).

The genetic information in ancient DNA recovered from human skeletons may provide an additional means of studying relationships between populations and, on a smaller scale, relationships between groups or individuals in a particular cemetery. It may also provide an additional means of sexing ancient skeletons. In the realm of palaeopathology, it may help us to detect inherited diseases, and it may even be possible to diagnose infectious diseases from traces in the bones of DNA from infecting micro-organisms. However, work on ancient DNA is still in its infancy, so it is as yet unclear to what extent its potential will be realised.

## THE NATURE OF DNA

DNA (deoxyribonucleic acid) is a long, threadlike molecule. It is a polymer; that is, it is composed of a sequence of chemical sub-units, or monomers. In DNA these sub-units are called nucleotides, and they each consist of a sugar, a nitrogenous base and phosphoric acid. There are four different nucleotides; they differ according to which nitrogenous base they contain, either adenine, guanine, thymine or cytosine. The different nucleotides are referred to as A, G, T and C, according to their nitrogenous base. The structure of DNA is twin-stranded, the strands being joined by hydrogen bonds between pairs of bases on opposite nucleotides, adenine always bonds with thymine, guanine with cytosine. The nucleotide sequence on the two strands is thus complementary, the sequence of one determining that of the other. The two strands are not laid flat, but are wound around one another in the famous double helix pattern (Figure 10.1).

Most of a cell's DNA is located in the chromosomes, threadlike bodies which occur in the nucleus of a cell. The unit of biological information is the gene. Genes are segments of DNA, generally several thousands of nucleotides long, separated from one another by lengths of intergenic, or 'spacer' DNA (Figure 10.2). Man has 23 pairs of chromosomes, bearing 50,000 genes. The genetic information in a gene is conveyed by the specific sequence of nucleotides. Given the thousands of nucleotides typically present in a single gene, the number of possible sequences is practically infinite; so, therefore, is the range of information which can be carried.

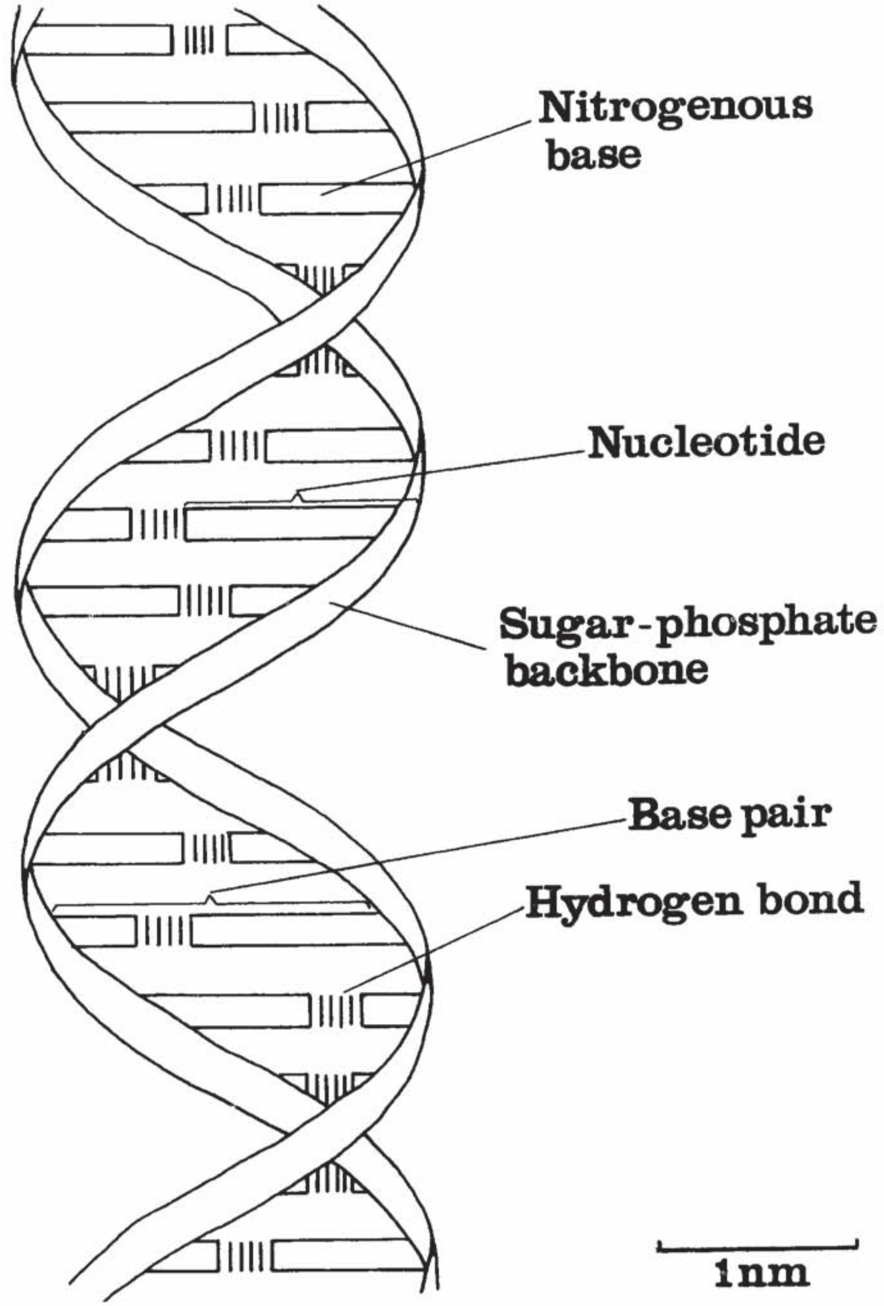


*Figure 10.1* The structure of DNA

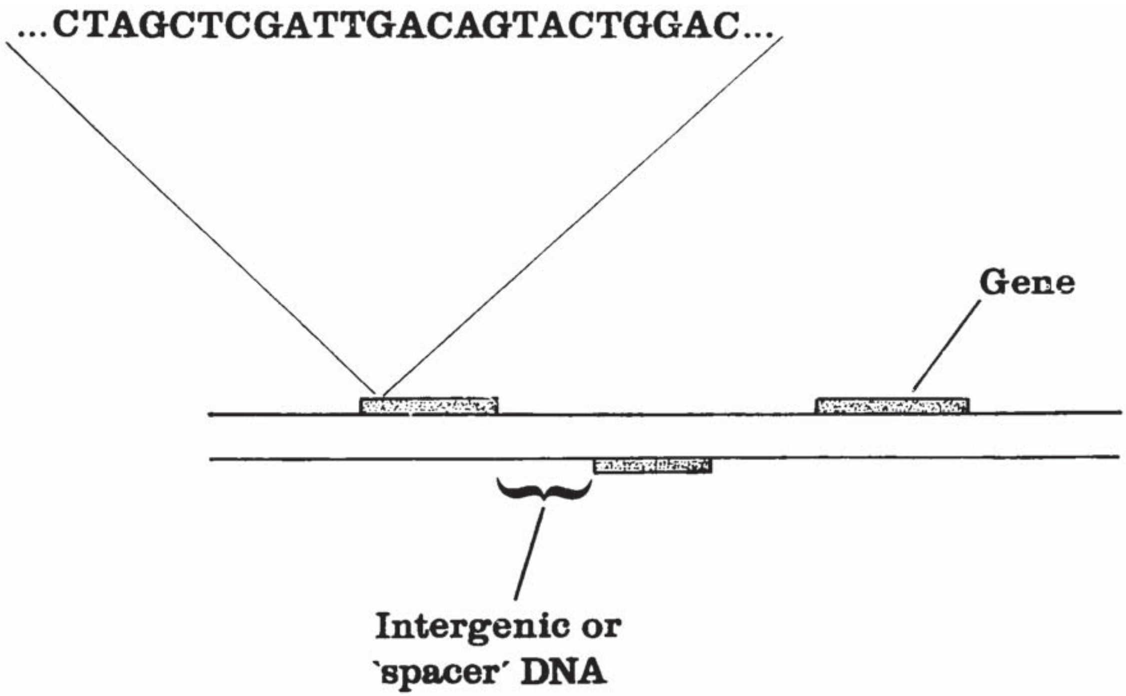


*Figure 10.2* DNA molecules bear genes, separated by intergenic or 'spacer' DNA

Although most DNA is located in the chromosomes, some is also present in the mitochondria. Mitochondria lie outside the nucleus and are the cell's energy-generation units. They each contain about a thousand identical copies of a DNA molecule much shorter than those in the chromosomes (16,569 nucleotides, as opposed to about 100 million nucleotides for chromosomal DNA). Chromo-somal DNA is inherited equally from both parents; mitochondrial DNA is inherited solely from the mother.

[The above information is taken from Brown (1992) and Brown and Brown (1992), to which the reader is referred for more information.]

## EXTRACTING AND AUTHENTICATING ANCIENT DNA

All components of the human body degrade after death, and DNA is no exception. In many archaeological specimens no detectable DNA remains. Even when some does survive it is highly fragmented—units with more than a few hundred nucleotides are rarely found. When it does survive in ancient bones, amounts are small, generally less than about 2 per cent of the levels found in fresh bone (Richards *et al.* 1995).

The small amount of DNA which typically survives in archaeological materials presented a major stumbling-block to the study of ancient DNA until the development of the polymerase chain reaction (PCR) technique in the mid-1980s (Mullis and Faloona 1987). This allows trace amounts of fragmented DNA to be amplified into quantities which can be studied. Primers are used to target regions of interest, which are then amplified using naturally occurring enzymes. Primers are short strands of syn-thetic DNA. Two primers are used whose nucleotide sequences correspond with sequences at the ends of the region of the ancient DNA molecule which is of interest. The primers attach themselves to these sites and the polymerase then produces a copy of the DNA sequence bounded by the primers. This process is repeated so that, if the amplification is successful, within a few hours the region of interest has been amplified into enough material to work with. When this has been achieved, the nucleotide sequence of the segment can be determined. With PCR, less than 1 gram of bone is all that is generally required for DNA work.

Because of the specificity of the PCR reaction, if the primers are correctly chosen it is unaffected by the large amounts of DNA from soil-dwelling micro-organisms inevitably present in buried bone (Francalacci 1995). However, it is theoretically possible for post-depositional degradation to cause problems in accurately determining the sequence of ancient DNA. Brown *et al.* (1996) point out that, since bases may become detached or modified during post-depositional chemical degradation, some potential does exist for misreading of the nucleotide sequences in ancient DNA. They state that as most ancient DNA sequences do make genetic sense this problem may not be very widespread, but more information on the chemical nature of ancient DNA is needed.

In general, mitochondrial rather than nuclear DNA is the focus of study in ancient bones. There are a number of reasons for this (Richards *et al.* 1993). Mitochondrial DNA is a relatively small and well-characterised molecule, and, unlike chromosomal DNA, it is present in as many identical copies, so that it is more readily amplified than single-copy nuclear DNA when DNA survival is poor. Mitochondrial DNA is highly variable, so that individuals are likely to differ from one another in some points in the nucleotide sequence unless closely related. The simple maternal inheritance mode makes it suitable for uncovering female-line genealogies.

The major technical problem when studying ancient DNA is contamination. Contamination with modern human DNA may potentially occur during excavation, in post-excavation processing, or within the laboratory. Any contaminative modern DNA is, unlike ancient DNA, undamaged, and will likely be present in far greater amounts. This means that any modern contamination will swamp the ancient DNA and hence it, rather than the ancient DNA, will tend to be amplified by the PCR. A number of precautions designed to prevent, detect and remove contamination have been formulated. Human skin cells, sweat and saliva are all good sources of DNA, so handling specimens will con-taminate them. Some writers have seriously suggested that excavators wear gloves and face-masks when excavating human remains which might in the future be needed for DNA work. Needless to say such precautions are highly impractical, particularly as during excavation it is rarely known whether DNA analysis will be carried out at all, let alone which skeletons will be targeted. A more realistic strategy is to remove contamination by chemical or physical pre-treatment of bone samples when they reach the laboratory. One pre-treatment technique is removal of bone surfaces. Richards *et al.* (1995) deliberately contaminated a piece of archaeological pig bone by handling it. The bone was divided into several fragments, one of which was subjected to surface removal by shot-blasting. On analysis, an untreated fragment gave only human DNA, showing that contaminative material was out-competing the endogenous pig DNA. The shot-blasted piece, however, yielded only pig DNA, indicating that the shot-blasting technique had been effective in removing the contamination. Flooding with bleach may be another useful anti-contamination measure, particularly for poorly preserved bone in which contaminants may have penetrated pores and fissures (ibid.).

In an effort to prevent contamination in the laboratory all materials are kept scrupulously clean, but there remains the danger of airborne contaminants. To detect contamination, it is normal laboratory procedure to process blanks (i.e. samples with all reagents except the ancient bone) alongside the bone samples. If DNA is found in these blank samples then this clearly indicates a problem in the laboratory. There are a number of other procedures for authenticating DNA results (Richards *et al.* 1995; Stoneking 1995), including analysing several differ-ent bones from the same skeleton or having a second laboratory analyse the remains independently.

## SOME FACTORS INFLUENCING DNA SURVIVAL IN ANCIENT BONE

DNA has been extracted from bones up to 25,000 years old (an Alaskan horse bone—Höss and Pääbo 1993), but its survival in ancient bone is often poor. Survival of DNA depends on local burial conditions. It may vary markedly between sites and even within a site. Shinoda and Kunisada (1994) studied bones from the cemetery of Kuma-Nishioda, Kyushu, Japan, dating to about 100 BC-AD 200. A 213 base-pair mitochondrial DNA sequence of interest could be amplified successfully in 55 out of 100 burials. The success rate differed between two parts of the site: in the main part of the cemetery DNA could be amplified from 61 per cent of burials, in another group of interments, located on a separate mound, the success rate was only 39 per cent. Differences in soil conditions were likely responsible for the difference in DNA survival. This inference was supported by the observation that gross bone preservation in the main cemetery was better than in the mound, although gross bone preservation is not necessarily always a good indicator of DNA survival (Faerman *et al.* 1995).

Chemical reactions are slower at lower temperatures, so one might expect material buried in colder environments to show better DNA survival than that from warmer climes. Looking at material from around the world, Hoss *et al.* (1996) found some evidence to support this idea, and Poinar *et al.* (1996) suggest that in warm climates such as Egypt, DNA survival may be limited to a few thousand years. Working on bone up to two thousand years old excavated from sites in temperate latitudes, Richards *et al.* (1995) used a number of primers to amplify DNA segments of between 149 and 359 base pairs in length, and were successful in about 50 per cent of samples.

## APPLICATIONS OF DNA ANALYSES TO ARCHAEOLOGICAL PROBLEMS

### Investigation of Genetic Relationships

Easter Island in the southern Pacific is one of the most isolated islands in the world (Figure 10.3). Despite its remote location, it has been inhabited since about the fourth century AD. The most widely known aspect of the culture of its prehistoric inhabitants is the spectacular monumental architecture they produced, particularly the immense stone sta-tues which stare broodingly out to sea.

Where the Easter Islanders came from has long been debated. There are two basic options: Polynesia to the west, or South America to the east. One of the most publicised theories on Easter Island origins is that of the Norwegian, Thor Heyerdahl. He argued for initial colonisation from South America, mainly on the basis of supposed similarities in material culture between ancient Easter Island and certain parts of prehistoric South America. In order to show that a voyage from South America to Polynesia could have been made in ancient times, simply using the prevailing winds, he set out from the Peruvian coast in a primitive balsa wood raft, the Kon Tiki. He successfully reached Polynesia (although he made landfall on Tuamotu, not Easter Island). This voyage helped bolster his theory and provide publicity for it.

Although Heyerdahl's views have been heavily publicised, few would now maintain that Easter Island was first settled from South America. On the contrary, careful study of evidence from linguistics, material culture and oral traditions clearly points to a Polynesian origin for the Easter Island people (summarised in Bahn and Flenley 1992:38– 68). The craniometric data also support this view. For example, Brace and Hunt (1990), in a study of various world populations, found that Easter Island crania clustered with other material from Polynesia, and were quite distinct from Peruvian and other crania from the Americas.

A team led by Erica Hagelberg used mitochondrial DNA extracted from some ancient Easter Island

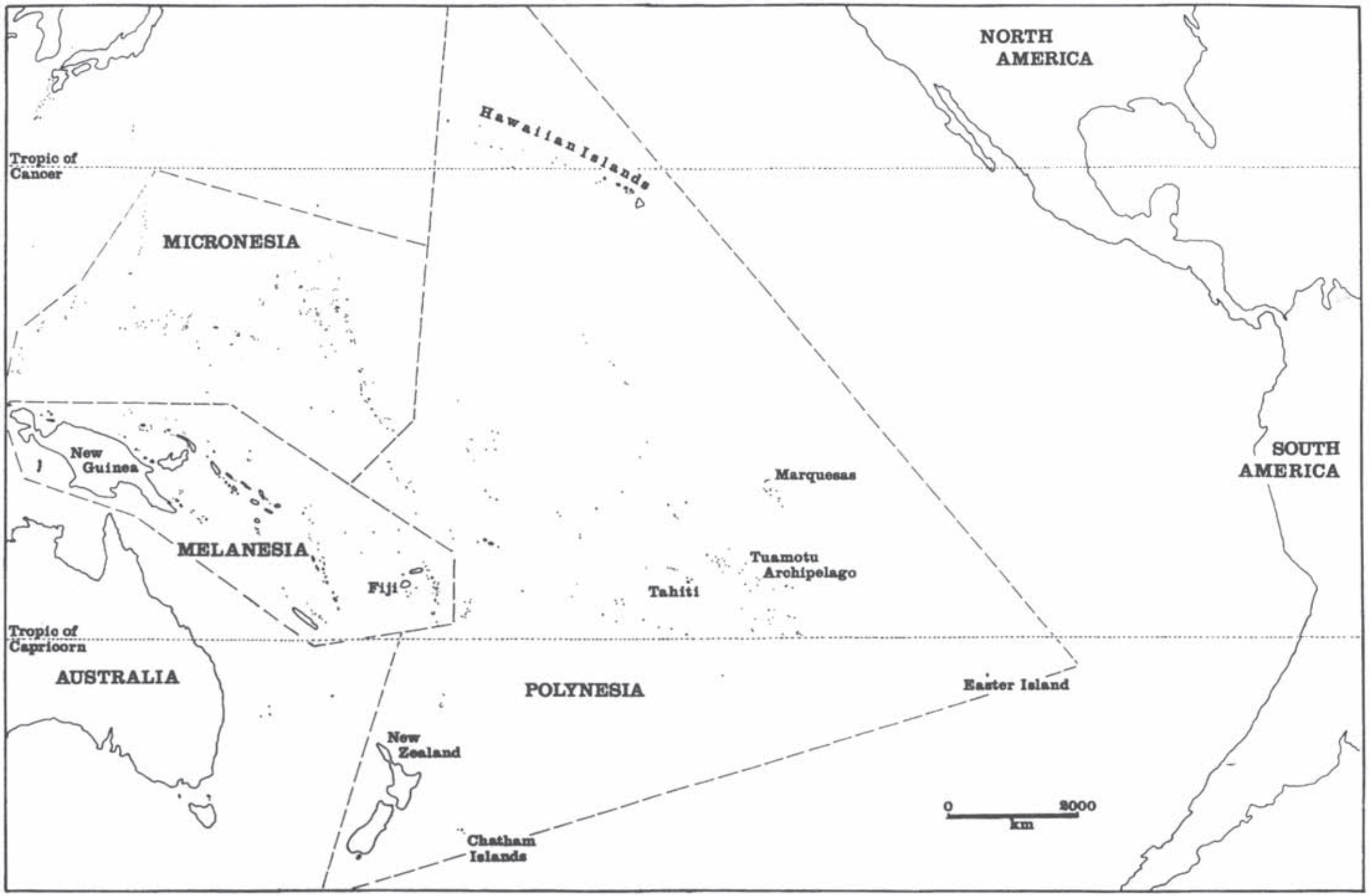


*Figure 10.3* The location of Easter Island in the Pacific

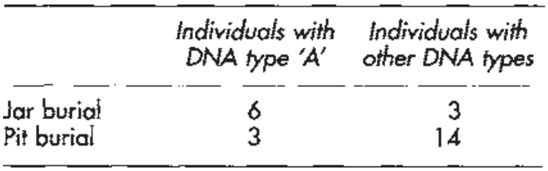
skeletons as a further source of evidence on the question of the origin of the island's inhabitants (Hagelberg *et al.* 1994). Polynesian populations characteristically show base substitutions (i.e. have different bases to those of a European reference sample) at three specific locations in one region of the DNA molecule. They also often show deletion of nine base-pairs in another part of their mitochondrial DNA. Hagelberg and associates looked at DNA from 12 skeletons and found that all carried the nine base-pair deletion and the three base substitution. Although the nine base-pair deletion is found in populations from other areas of the world, including the Americas, it does not occur there in conjunction with the three base substitutions like it does in Polynesia. The DNA evidence presented by Hagelberg and co-workers would seem to constitute yet another strand supporting the hypothesis of a Polynesian origin for the Easter Islanders.

In areas with more complex population histories and less divergent populations, any insights into migrations using ancient DNA are likely to be rather more hard-won. In order to use ancient DNA to study population history we need to ascer-tain that distinct and regular differences in mitochondrial DNA sequences do occur between the populations of interest. This requires comprehensive work on sequencing DNA from modern populations. Some of this background information is available from the literature, some has yet to be carried out. Richards *et al.* (1993), as one of their first steps in a project to study the degree of Germanic migration into Britain in the Early Saxon period following the end of Roman occupation, conducted a study of mitochondrial DNA from modern British and Germanic populations. This part of the study was done to investigate the extent of genetic differences between the populations and to identify potential population markers in the DNA which might then be usefully studied in ancient skeletons. They report very preliminary results from their project in their 1993 publication. They found that many modern British and German samples shared the same sequence for the region of mitochondrial DNA which they looked at. Most skeletons from British Early Saxon cemeteries also showed this sequence. Richards and colleagues point out that because the sequence occurs so widely it is uninformative concerning the population affiliation of the groups under study. A way forward was to look at additional region(s) of the DNA sequence in order to try and find areas which do differ in a regular way between modern British and Germanic populations. Some progress has been made in this direction (Richards *et al.* 1996), and in future perhaps this will assist in the study of earlier Germanic migrations into Britain using ancient DNA.

Looking at genetic relationships on a smaller scale, Hiroki Oota and his colleagues (Oota *et al.* 1995) analysed mitochondrial DNA in burials from a shell mound site, Takuta-Nishibun, in northern Kyushu, Japan. The burials here dated to between the first century BC and the first century AD, during the Yayoi cultural period. There were two different types of burial at the site. Most skeletons were found in simple earth graves, but some were buried placed in large earthenware jars. The resolution of the question of whether there was an association between burial style and genetic relationships was an important goal of their DNA work—due to poor skeletal preservation, little light could be shed on this from metric or non-metric studies of the bones. Looking at a 141-nucleotide segment, which they were able to amplify from 26 burials, they found 11 different sequences. There was indeed an association between DNA type and burial style. The most common single sequence was shared by most of the jar interments, but by few of those buried in the pits (Table 10.1).

Oota and co-investigators suggest that one interpretation of the results is that those using the different burial practices came from different communities or populations, perhaps separated in time (it was unclear at this site whether the jar and the earth grave burials were precisely contemporary). Another possibility is that the burial rite accorded to an individual depended on his or her kinship ties within the community—more specifically on maternal lineages (remembering that mitochondrial DNA is inherited only from the mother).

*Table 10.1* Association Between Mitochondrial DNA Type and Burial Style at Takuta-Nishibun, Kyushu, Japan



| | Individuals with DNA type 'A' | Individuals with other DNA types |
|---|---|---|
| Jar burial | 6 | 3 |
| Pit burial | 3 | 14 |

*Source*: Data from Oota *et al.* (1995: Table 4).

Interestingly, at the Kuma-Nishioda site referred to above (p. 201), which is of similar date, Shinoda and Kimisada (1994) also found an association between mitochondrial DNA markers and mode of burial. There was a difference in DNA type between burials in the main cemetery area and those in the mound, suggesting an individual's genetic background played a part in determining place of burial. So taken together these two sites suggest that during the Yayoi period in northern Kyushu, genetic relationships appear to have been an important consideration in determining burial treatment.

## Sex Determination

As we saw in Chapter 3, the sex of an individual depends on the chromosomes, females having two X sex chromosomes, males an X and a Y. Analysis of chromosomal DNA may thus offer an additional way of determining sex in instances where it is not clear from skeletal form. Indeed, what little work has been done on ancient remains has yielded fairly encouraging results.

The method of preference for determining sex from DNA in ancient bones is to study the amelogenin gene. This is a gene which has a role in con-trolling dental enamel development; both X and Y chromosomes carry copies which differ slightly in their nucleotide sequence. By targeting suitable areas, and amplifying them with PCR, we can infer the sex of the individual. For males we would expect to see products from both X and Y copies; for females we would expect only one, the X copy.

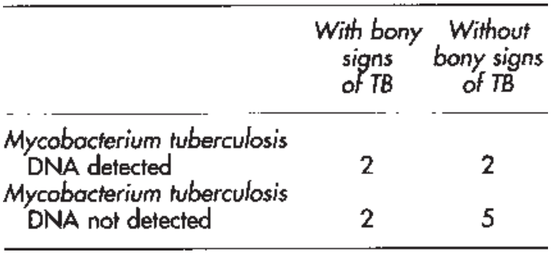
In order to investigate its utility in sex determination, Stone *et al.* (1996) amplified a small fragment of the amelogenin gene extracted from 20 archaeological skeletons. They were from a site in Illinois, USA, dating to about AD 1300. Each skeleton was a well preserved adult whose sex could be reliably inferred from skeletal form, thus providing a check on the DNA results. They found that in 19 cases the DNA sex tallied with the osteologically determined sex. Faerman *et al.* (1995) also looked at the amelogenin gene for sexing, although they used a somewhat different experimental protocol. Like Stone *et al.*, they were successful in determining sex in archaeological skeletons: six out of seven specimens were sexed correctly, in the remaining case sex could not be determined due to poor DNA survival.

Although DNA may be useful for sexing poorly preserved adult burials, its main potential would seem to be for sex determination in immature skeletons, as there are severe difficulties in doing this from skeletal form (see Chapter 3). For example, it would be interesting to determine the sex of those infants from Roman Britain who, in Chapter 3, I argued were probably victims of infanticide. In many societies, male children are more desired than females, so when infanticide is practised, often more female babies than males may be killed (Scrimshaw 1984). Interestingly, among adult burials from Roman sites in Britain, males generally outnumber females. There are a variety of possible explanations for this, but one wonders if it reflects female infanticide; this will remain speculative until Roman perinatal infant skeletons can be sexed.

## Ancient DNA and Palaeopathology

As well as analysing human DNA from ancient bones, some workers have tried to study ancient disease by looking for traces of DNA which may have been left in the bones by infecting micro-organisms which were present in the body at time of death. There are a number of pitfalls with this approach (Hummel and Herrmann 1995). Any DNA from infectious agents will be present in minute quantities, even compared with residues of

*Table 10.2* Samples Subjected by Spiegelman and Lemma to Analysis for *Mycobacterium tuberculosis*



| | *With bony signs of TB* | *Without bony signs of TB* |
|---|---|---|
| *Mycobacterium tuberculosis* DNA detected | 2 | 2 |
| *Mycobacterium tuberculosis* DNA not detected | 2 | 5 |

*Source*: Results from Spiegelman and Lemma (1993: Table 1).

the individual's own DNA. Secondly, there exists the potential for the production of false positive results, as some disease producing types (e.g. the bacterium responsible for tuberculosis) are closely related to soil-dwelling bacteria. Nevertheless, some pilot studies have reported the isolation of bacterial DNA from archaeological bone.

Spiegelman and Lemma (1993) attempted to detect DNA from *Mycobacterium tuberculosis* in 11 bone samples from around the world. They chose four which showed bony signs of tuberculosis; seven which did not were used as controls. Their results are summarised in Table 10.2.

If *Mycobacterium tuberculosis* DNA survives fairly regularly, and the methodology used to detect it is reliable, then one would expect an association between positive results for the bacterial DNA and bony signs of the disease. However, any such association would be expected to be fairly weak. Cases showing bony tuberculosis but which were negative for DNA may be those in which the bacterial DNA failed to survive, and they may also be those in which the diagnosis of tuberculosis from the bone was in error (the difficulties of reliably identifying disease from ancient bones were discussed in Chapter 6). Perhaps individuals with no bony signs of tuberculosis but which were positive for the bacterial DNA had tuberculosis but the skeleton was not involved—bone is typically involved in only 5–7 per cent of cases of tuberculosis. It is therefore rather difficult to know whether the results in Table 10.2 provide any support for the notion that the DNA results are reliable.

## Prospects for the Future of Ancient DNA Studies

When a new technique is introduced, particularly a high-tech, high profile technique like analysis of ancient DNA, there is generally an initial flush of enthusiasm for the new method. We are still very much in this stage regarding the DNA work, and this makes it very difficult to predict its eventual impact on archaeology. Nevertheless, it is likely that some of the factors discussed below will be important in helping determine this.

In a recent review of work on ancient human DNA, Mark Stoneking complains that so far very few studies have been directed at tackling general archaeological questions (Stoneking 1995). On one level he is right to castigate researchers on this point: if DNA work is ever to make a serious contribution to archaeology it must be orientated towards important archaeological questions. Looking at the published literature, most work to date has consisted of pilot studies and methodological work to do with technical aspects of extracting and authenticating ancient DNA, or else has looked at its degradation in the burial environment. There is a contrast here between the way in which DNA work is being introduced into archaeology and the introduction of another scientific technique, trace element analysis, which at the time was also seen as a major breakthrough. Bone trace element analysis was introduced into archaeology in the 1970s, and right from the beginning it was applied to archaeological problems concerned with ancient diets. As we saw in Chapter 9, failure to take fully into account from the outset basic issues such as the physiological behaviour and, particularly, diagenesis, of the elements concerned, meant that many of the early inferences from trace element results have proved to be unreliable. One hopes that by first tackling the technical and diagenetic aspects of ancient DNA we are laying firm foundations upon which reliable archaeological inferences can in future be built.

One important factor in the eventual impact of DNA work is of course the frequency with which amplifiable DNA survives in archaeological bone. Another is cost. DNA analysis is expensive. Given the way in which most archaeology is funded, new techniques which make the most impact tend to be those which are inexpensive to apply. For an expensive, high-tech method to be widely used, it needs to be of fundamental importance. Thus carbon-14 dating is one of the few high-tech scientific techniques that has become routine. It is difficult to see DNA analysis becoming routinely applied to site-based work—the sheer expense of doing the technique on large numbers of skeletons means this is not realistic. It is more likely that DNA work will be mainly restricted to research situations in which specific questions are being tackled. So, for example, it might be useful to employ DNA sex determination in a research project aimed at detecting female infanticide, but not as a routine sexing method for immature skeletons whenever these are encountered.

Although analysis of ancient human DNA is not the miracle technique that some have claimed, it will probably become established as an additional method in the armoury of the researcher in osteoarchaeology, alongside the more traditional techniques discussed in the other chapters of this book. One is more sceptical over the contribution which will be made to palaeopathology by the study of DNA from residues of infecting micro-organisms. In theory, the potential of this work is very great. Few of the diseases to which mankind is heir actually leave traces on the bone. If we could identify micro-organism DNA then this would enable the identification of a host of new diseases in ancient remains, and, given sufficient resources, would enable us to infer cause of death in many cases. However, very little is yet known about the survival of micro-organism DNA in archaeological bones, and, despite the protestations of some workers, one does worry about the production of false positive results due to the activities of soil-dwelling micro-organisms (although analysis of soil samples as well as bones will help control for this—Baron *et al.* 1996). Without being specific, Roberts and Manchester (1995) indicate that a number of question-able reports have already entered the literature. Given the newness of this particular technique, though, it is probably best to keep an open mind and see what develops.

# 11

# CREMATED BONE

The previous chapters have dealt exclusively with inhumation burials; however, cremation was practised in many periods and in many parts of the world. This chapter discusses cremated human remains and the information which can be gained from their study.

## THE PROCESS OF CREMATION

Our understanding of the process of cremation has been aided by studies conducted in modern crematoria. The following description is based upon one such study (Evans 1963). When a corpse is exposed to fire, initially there is scorching and burning of the skin and hair. About 60 per cent of body-weight is water. This is driven off by the heat early on in the cremation process, and as a result muscles and tendons may contract, giving rise to visible movements of the extremities (although tales of muscle contrac-tions causing corpses suddenly to sit up in the furnace are apocryphal!). There may be swelling of the abdomen due to gaseous expansion within, before the skin and muscles split. As cremation progresses, destruction of overlying soft tissues causes parts of the skeleton to be revealed. Eventually all soft parts are destroyed (the ligaments and brain tissue are often the last to go) leaving only the bones.

The bones are not destroyed on heating, but changes to their structure and composition do occur. On heating, the moisture is driven off and the organic component (chiefly collagen) combusted, leaving only the mineral portion. The bones also fragment and become distorted, and some shrinkage occurs. Although the bone is very fragmented, fragment size is not nearly as small as that in the ‘ashes’ (actually burnt bone fragments) from modern crematoria. In modern cremation procedures, the bone fragments are ground up in a special machine after burning, hence their rather gritty consistency.

The fragmentation and distortion suffered by the bone during cremation are probably due to rapid water loss. The shrinkage may be associated with the structural changes which occur to the bone mineral (hydroxyapatite). These structural alterations take the form of changes in crystallinity. High crystallinity denotes large crystal size and absence of structural defects in a mineral, qualities which tend to be found together (discussion in Sillen 1989). In living bone, the crystals of bone mineral are very small, but on heating an increase in crystallinity is observed. The American anthropologist Pat Shipman and her co-workers (Shipman *et al.* 1984) heated modern bone samples in a furnace and studied the changes in crystal structure using X-ray diffraction. The temperature of heating for individual samples ranged from 185°C to 940°C. The results are shown in Figure 11.1. Up to about 525°C there is a gradual increase in crystal size, indicated by the narrowing and sharpening of the peaks in the diffraction pattern. Between 525 and 645°C there appears to be a fairly abrupt transition to a much more highly crys-talline

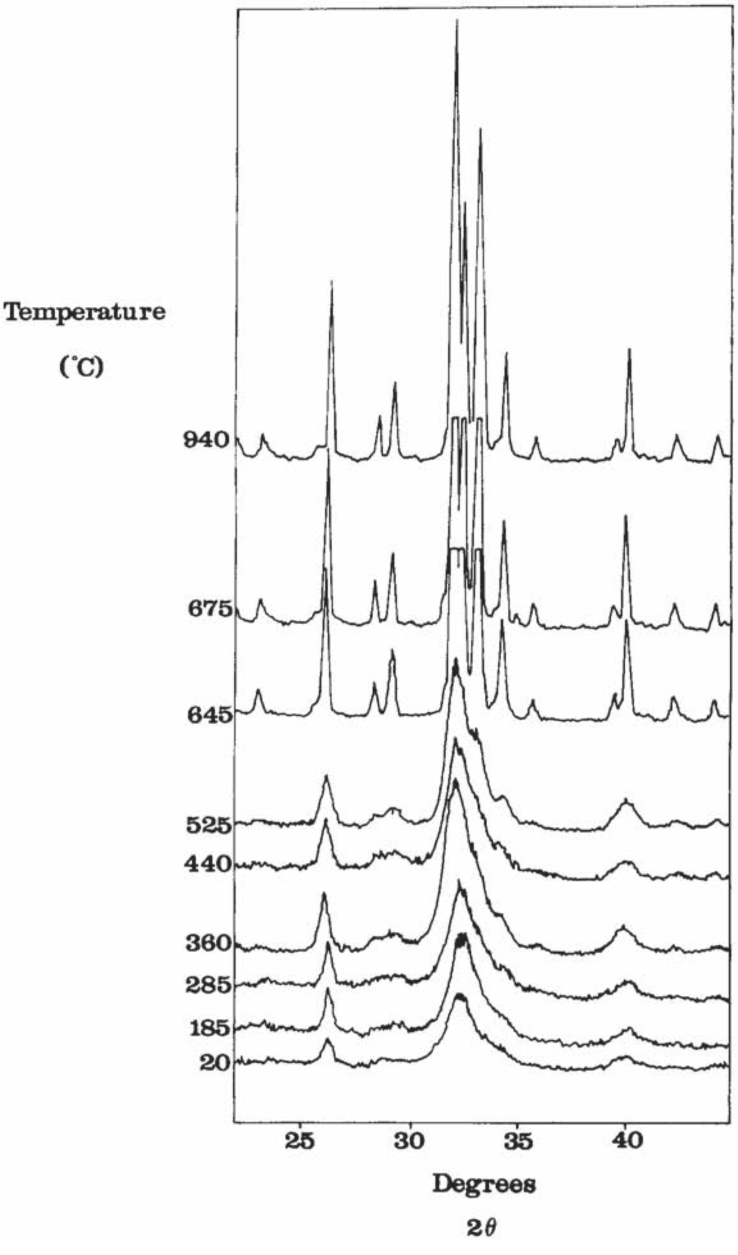


*Figure 11.1* X-ray diffraction patterns from goat bones heated to different temperatures obtained by Shipman *et al.* (1984). A slight sharpening of the peaks (indicating increasing crystal size) with heating is displayed at temperatures up to and including 525°C. There is a major change in the pattern at 645°C and above, with much narrower, sharper peaks. This shows a transition to a structure with increased crystallinity

*Source*: Redrawn from Shipman *et al.* (1984: Figure 7).

*Note*: The flattened tops of some of the peaks in the 645°C and 675°C samples are due to truncation of the pen trace.

structure with a larger individual crystal size. Little further change occurs above 645°C.

## SURVIVAL OF CREMATED BONE IN THE SOIL

It has long been noted (e.g. de Jong 1926) that cremated bone tends to survive better in the soil than unburnt bone. Cremated bone also has greater mechanical strength than unburnt archaeological bone. By apparent contrast, observations made on experimentally burnt bone (Stiner *et al.* 1995), and on bone from modern crematoria (Dokladal 1970; Wahl 1982), have shown that after burning the fragments are very fragile and prone to further breakage. Stiner *et al.* (1995) found that the degree of fragility increased with the thoroughness of firing.

The reasons why bone is very fragile immediately after burning, yet archaeological cremated bone has a fairly high mechanical strength and is very resistant to destruction in the soil, are unclear, but a few points are worth bearing in mind. Wahl (1982) stated that cremated bone regains strength after firing due to uptake of water. Posner (1969) has shown that hydroxyapatite, the chief constituent of bone mineral, converts to another mineral, beta-tricalcium phosphate, when exposed to temperatures above about 800°C. On cooling there is a rapid re-reaction back to hydroxyapatite on the uptake of moisture from air or soil (Herrmann and Grupe 1988). Perhaps this reversion to hydroxyapatite of large crystal size is to some extent responsible for the regaining of strength on uptake of water which Wahl (1982) has noted for fired bone.

In archaeological contexts, unburnt bone is subject to decomposition by micro-organisms which attack the organic component and in so doing release acidic by-products which dissolve the mineral part (see Chapter 2). Thoroughly fired bone lacks an organic component, so is not attractive to micro-organisms. This may play a part in aiding its survival in the soil. Cremated bone also appears to be more resistant to dissolution in acidic soils than is unburnt bone. The reasons for this are unclear, but are presumably connected with the structural changes to the mineral part, consequent on heating.

## RECOVERY OF CREMATED BONE IN THE FIELD

Given that bone from archaeological cremations generally consists of small fragments, recovery of the remains by hand is likely to result in loss of significant quantities of material. The usual procedure to recover the bone is wet-sieving—that is, to wash the contents of the cremation urn or pit through a series of sieves of different mesh sizes with water. Mesh sizes and the number of sieves used vary between different workers, but I generally use two sieves, of 4 mm and 2 mm mesh.

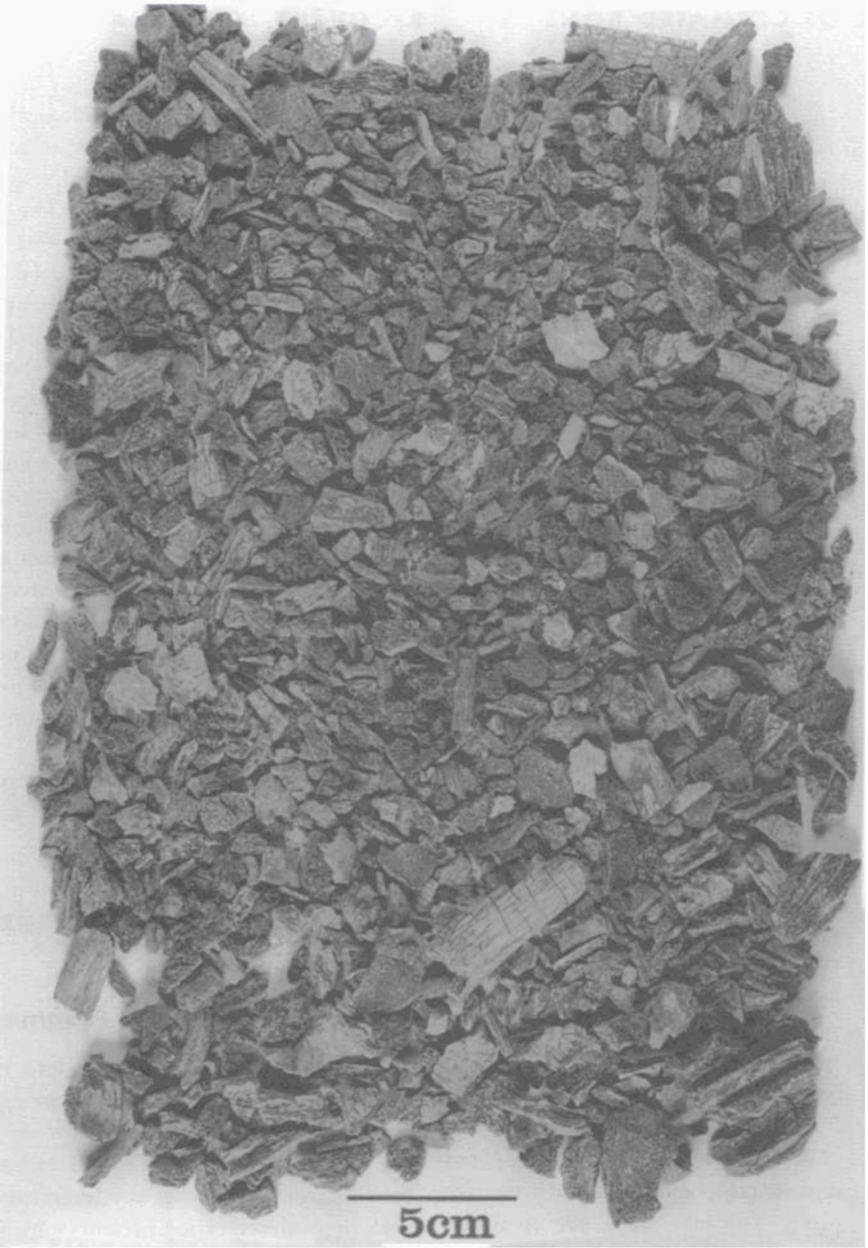
After sieving, the bone fragments are picked out by hand. It would be very tedious and time-con-suming to sort material from the smaller mesh sizes in this way. In fact few bone fragments from fractions retained by mesh sizes less than about 4 mm are identifiable. In my two-sieve system I only sort the material from the 4 mm mesh, but the material from the 2 mm mesh is retained for study so that it can be scanned for any diagnostic fragments. Material recovered from a cremation urn using this method is shown in Figure 11.2.

When the bone has been sieved, sorted, and left to dry, it is ready for specialist examination.

## THE ARCHAEOLOGICAL STUDY OF CREMATED BONE

### Identification of Bone Fragments

Even in material from the 4 mm sieve, fragment size is generally fairly small, often on average about 1–2 cm, although occasional fragments up to about 10 cm long may be present. The small size and distorted nature of most of the fragments means that even their identification presents a major challenge. To a great


5cm

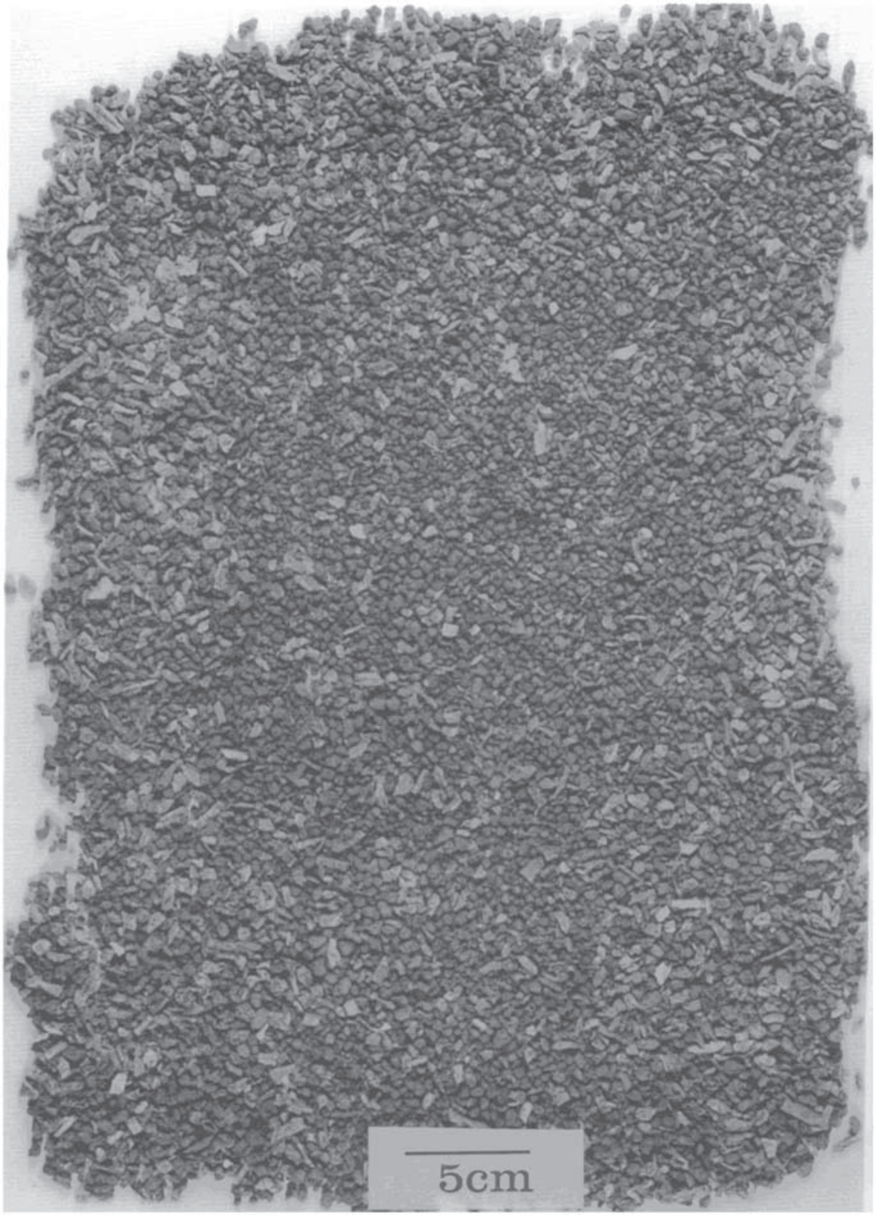
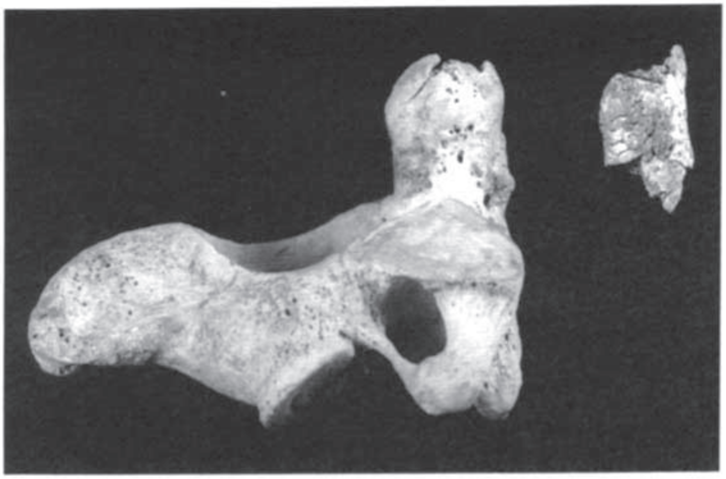
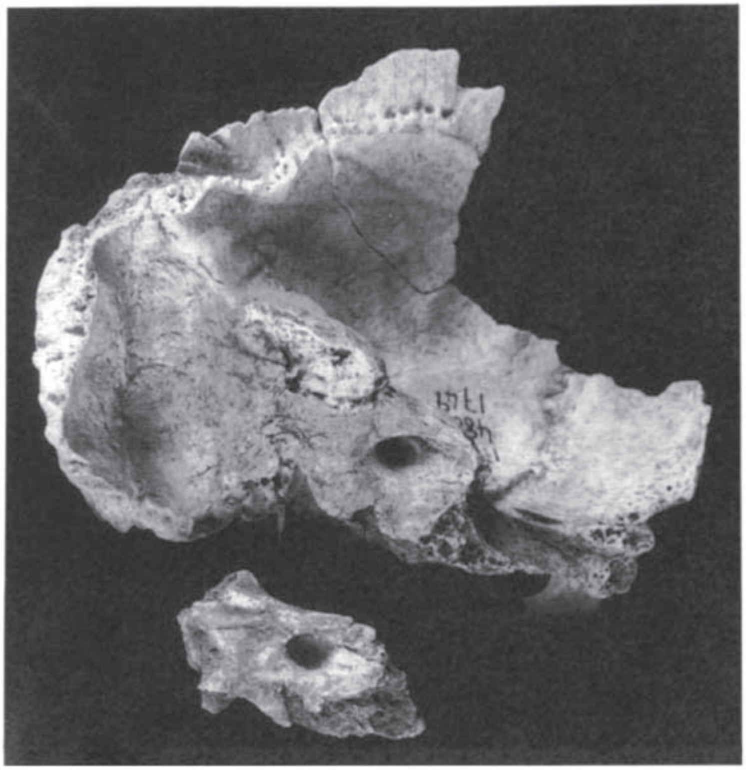


*Figure 11.2* Bone from a cremation burial after sieving. Bone sorted from the material retained by the 4 mm mesh is shown on the opposite page. The material shown on this page is the residue from the 2 mm mesh: it has not been sorted

*(a)*



*(c)*



(b)

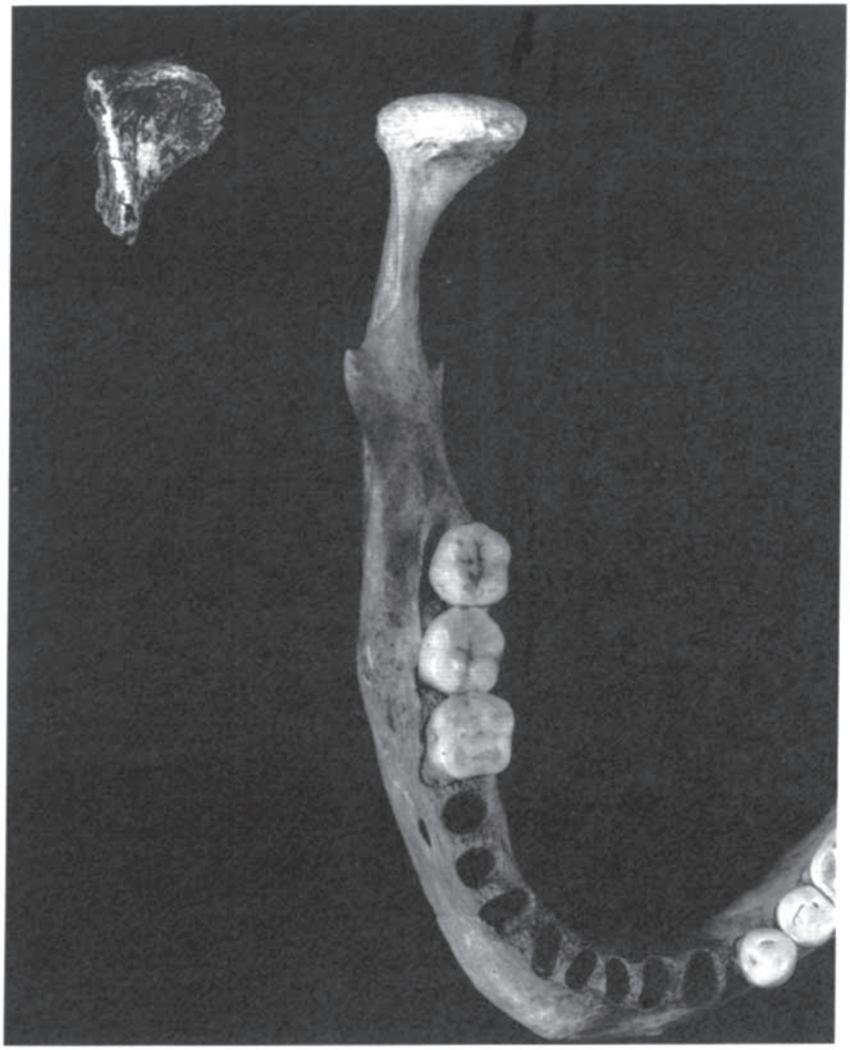


*Figure 11.3* Commonly occurring fragments in cremation burials: (a) the odontoid process of an axis vertebra; (b) a mandibular condyle; (c) the petrous part of a temporal bone. Unburnt bones are shown next to each cremated specimen to illustrate where the cremated fragments come from

extent, the proportion of material which can be identified is dependent upon fragment size. However, other factors also play a part. Pieces from some parts of the skeleton are easier to identify than others. Very small bones such as terminal phalanges, sesamoids and carpals often survive cremation with-out fragmenting. They are thus easier to identify than the larger bones which shatter into many pieces. There are also differences between the larger bones in terms of 'identifiability'. For example, even when very small, skull vault fragments are quite distinctive. By contrast, it may be impossible to determine from which particular arm or leg bone even quite large long-bone fragments come. A factor which assists in identification of cremated bone fragments is that, when subject to heat, bones do not shatter in a completely random way. Fracture patterns are influenced by bone anatomy (Gejvall 1969). The seasoned observer gets used to seeing similar fragments in cremation after cremation, and tends to be on the look-out for them. Commonly occurring fragments include the odontoid process of the axis vertebra, the mandibular condyles and the petrous part of the temporal bone at the base of the skull (Figure 11.3).

Although many writers divide their identified fragments into broad categories such as skull, axial skeleton and upper and lower limbs, more precise identification of as many fragments as is practicable is important. We cannot assume that a cremation burial contains the remains of only one person. Any duplication of skeletal elements indicates the presence of more than one individual.

In most cremations a substantial portion of the bone cannot be identified to skeletal element, or even, in many cases, to broader categories such as axial skeleton etc. This severely limits the data which can be obtained from them.

Careful examination of the bones may also reveal that not all are human. Burnt animal bones have been found in cremations from Britain and some parts of continental Europe. These seem, in different cases, to have represented food offerings, sacrifices, or parts of hides or furs in which the corpse may have been wrapped before burning (Bond 1994; Zikmundova 1961; Wahl and Kokabi 1988).

## Estimation of Age at Death

During cremation, tooth crowns tend to shatter due to the differing thermal properties of the enamel and dentine components (Dokladal 1970). However, crowns of teeth which were unerupted at time of death may survive intact. In some child burials then, dental development can be used as an age indicator.

In cremated remains of immature skeletons, fragments of unfused epiphyses may be noted. However, difficulties in identification to specific skeletal element hamper the use of epiphysial fusion as an ageing technique. In instances where dental development cannot be used for ageing immature remains, one is often reduced to using the fragments to gain an impression of the general size of the bones, and using this to give a very approximate indication of age at death.

It was argued in Chapter 3 that the best way of estimating age at death in adult remains is dental wear. The destruction of tooth crowns means that this is not a viable method for most cremation burials. Many of the other parts of the skeleton which have been used as indicators of age at death (Figure 3.12) tend to survive poorly in the cremation process. For example, in the large assemblage of cremated bone from Spong Hill, England (sixth-seventh century AD), in only 4 per cent of cases did the pubic symphysis survive (McKinley 1994).

The relative ease with which skull vault fragments can be picked out facilitates the use of cranial suture closure over other methods of ageing adult cremated remains. The uncertain reliability of this method has already been referred to in Chapter 3, and in cremations its use is complicated as, with a bone fragment, it is often difficult to identify which part of a suture one is dealing with. This is important, as published ageing schemes rely on scoring closure at different sites in the various skull vault sutures (Key *et al.* 1994; Masset 1989). Nevertheless, some idea of the general state of suture closure can often be gained. On occasions, signs of joint degeneration may be visible, in the form of pitting or porosis of the joint surfaces or lipping at the joint margins. In modern populations such changes are not common before middle age. If we can assume that the same was true in antiquity then they may be used, to some extent at least, as auxiliary age indicators. However, the safest course is often to classify fully mature material (i.e. with adult-sized bones and no evidence of unfused epiphyses) simply as adult and not to attempt any finer age distinctions.

## Determination of Sex

The highly fragmented and distorted nature of cremated bone makes it very difficult to gain an impression of bone shape. This makes the use of the sexing criteria outlined in Chapter 3 problematic. Sometimes though, by happy chance, diagnostic areas survive, often parts of the skull such as the nuchal crest area or the brow ridge. If such fragments are not available, sex may have to be determined from the general size and robusticity of the skeleton, as inferred from the bone fragments, although it must be borne in mind that in a population which was generally of heavy build an excess of males may be identified; the opposite is likely to be true in groups of slender build. An additional complication in sex determination is the shrinkage suffered by bone during cremation. Milan Dokladal has conducted experimental work to investigate bone shrinkage during cremation (Dokladal 1971). He cut a series of modern cadavers in half lengthwise. He burnt one half of each corpse in a crematorium oven. The other halves, which acted as controls, were not burnt, but the flesh was removed in order that the bones might be measured. He found that shrinkage on burning varied in different parts of the skeleton and in different dimensions of the same bone, but in general a shrinkage of up to 15 per cent was found. Shipman *et al.* (1984), heating bone samples, produced similar results, although Hummel and Schutkowski (1986), also heating bone samples rather than fleshed corpses, reported bone shrinkage of up to 30 per cent. It is important to take at least a subjective account of bone shrinkage when attempting to gain an impression of the general size and robusticity of the skeleton from cremated remains. Dokladal (1971) has drawn attention to the reported preponderance of females in cremation cemeteries excavated in central Europe. He suggests that this imbalance may be more apparent than real because the shrinkage of skeletal elements on burning may have given earlier workers the impression that skeletal size was rather smaller than would have been the case.

Unsurprisingly, in view of the problems discussed above, sex can usually only be determined in a fairly modest proportion of burials. For example, Ann Stirland examined a large series of first century AD cremation burials from St Albans, England (Stirland 1989). In only 37 per cent of the adults could any determination of sex (however tentative) be made, and in only 25 per cent could sex be assigned with any certainty.

## The Study of Normal and Pathological Skeletal Variation

The nature of the material means that measurement studies play little part in the analysis of cremated bone. Although non-metric variants and disease-related changes may sporadically be noted, little useful data on the frequencies of these features can be obtained.

## Chemical Analyses

In cremations where combustion of the organic component is incomplete, sufficient collagen may remain for stable isotope ratios to be determined. However DeNiro *et al.* (1985) have demonstrated that heating may cause shifts in carbon and nitrogen stable isotope ratios; they conclude that dietary inferences should not be made from stable isotope analyses of burnt bone.

Some work has been done on trace element composition of cremated bone from the point of view of investigating ancient diets (e.g. Runia 1987b). However, it has been shown (Grupe and Hummel 1991) that burning may result in unpredictable changes in the levels of many elements, making the interpretation of results even more problematic than it is for unburnt bone.

Brown *et al.* (1995) claim to have extracted DNA from archaeological cremated bone, but further work is needed to determine whether this is generally feasible.

## THE VALUE OF STUDYING CREMATED BONE

Given the discussion above, the reader may well be wondering whether it is worth studying cremated bone at all. There are, however, a number of compelling reasons why cremations from archaeological sites should be studied. Firstly, for many periods cremation is the sole archaeologically visible burial practice. Unless we confront the difficulties in studying cremated bone we will be unable to learn anything from human remains when this is so, as it is for example in the late Bronze Age in much of Europe. In many archaeological cultures both inhumation and cremation burial seem to have been practised—as they are in most nations today (Davies 1982). For example, during the middle Bronze Age of central Europe cremation gradually ousted inhumation as the dominant burial type, but for a long period both rituals were practised side by side (Müller-Karpe 1980:213). In such instances we cannot assume that data from inhumation burials is representative of the whole population.

As has been discussed, cremated bone is more resistant to destruction in the soil than is unburnt bone. Indeed, at some sites and in some areas only cremated bone survives. In the British early Saxon period, both cremation and inhumation were practised. The Spong Hill site already referred to was in fact a mixed inhumation and cremation cemetery. Although substantial amounts of burnt bone were present in the cremation burials, survival of bone from the inhumations was negligible (Putnam 1984).

Another important reason for studying cremation burials is that much may be learnt of ancient funerary practices. Indeed, due in great part to the limitations on the data which can be obtained on other aspects, much work has concentrated on this. The following sections discuss how we can estimate the temperature of firing and what can be learnt about burial practices from studying the weights of bone present in ancient cremations.

## ANCIENT CREMATION PRACTICES

### Temperature of Firing

Many writers have tried to estimate the temperatures reached in ancient cremation pyres. One of the pioneers in this respect was the British worker, Calvin Wells. He studied early Saxon (approximately sixth—seventh century) cremation burials from Illington, Norfolk, in the 1950s (although, in an example of publication which was tardy even by archaeological standards, the site report containing his bone work was, through no fault of his own, not published until 1993, some 37 years after he had completed it and 15 years after his death!). Many of the cremations contained glass beads as grave goods. These had clearly accompanied the corpse on the pyre, as they had been affected by heat. Most had suffered partial melting, although in no case had they been completely liquefied. Wells (1993) re-heated some of the beads, and found that they started to melt at about 850°C and were completely liquefied by about 940°C. He inferred, therefore, that cremation temperature must have been somewhere between these two figures.

Unfortunately, most cremation burials do not have remains of partly melted grave goods from which pyre temperature can be estimated, so this must be inferred from the bones themselves. In order to investigate some of the changes occurring to bone on heating, a number of studies, such as the one already referred to by Shipman *et al.* (1984), have been conducted involving heating modern bone samples to a range of temperatures. This sort of work provides a baseline for estimating firing temperature in ancient cremations. A number of aspects have been investigated from this point of view, including X-ray diffraction patterns (see pp. 207–208), bone colour, microscopic appearance, and even the sound the fragments make when tapped!

*Table 11.1* Colours Observed After Heating of Fresh Goat Bone

| *My results* | | *Shipman et al.'s (1984) results* | |
|---|---|---|---|
| *Temperature (°C)* | *Colour* | *Temperature (°C)* | *Colours* |
| 185 | Red/orange | Under 285 | White or yellow |
| 285 | Dark brown/black | 285–525 | Red/brown, red/yellow, dark grey/brown or dark grey |
| 360 | Black | | |
| 440 | Grey/brown | 525–645 | Black, blue or red/yellow |
| 525 | Grey/brown (lighter than that observed at 440°C) | 645–940 | White, light grey or light blue/grey |
| 645–1200 | White, some pale yellow | 940 | White, some grey or red/yellow |

In order to investigate, among other things, how bone colour changes with temperature, I examined a series of modern animal bone samples which a colleague had heated in a furnace. The maximum temperature for individual specimens ranged from 185–1200°C. The colours observed after heating are shown in Table 11.1. I was by no means the first to conduct this sort of experiment; many others have looked at colour changes in heated bone (e.g. Binford 1963; Wahl 1982; Shipman *et al.* 1984; Nicholson 1993). The results of Shipman *et al.* (1984) are included in Table 11.1 for comparison.

All the studies of bone colour cited above found a similar basic pattern of dark reds and browns at low firing temperatures, giving way to a charred black appearance and then progressively lightening again with increasing temperature so that ultimately the fragments are white. However, there are many differences between studies with respect to the particular colours seen and the specific temperatures at which they occur. Table 11.1 shows a number of discrepancies between Shipman *et al.*'s results and mine. For example, none of my samples showed blue colouration. As well as being noted by Shipman, bluish fragments are commonly seen in archaeological cremations. Unlike Shipman, I observed no further colour change above 645°C.

In my heating experiment I tried to match the published methods of Shipman *et al.* (1984) as closely as I could. Both experiments used the same temperature increments (although Shipman's maximum temperature was only 940°C). In both experiments, bone samples were heated in a muffle furnace for four hours before the furnace was switched off and allowed to cool. Given the similarity in our experimental procedures it is surprising that our results should deviate as they do. Although there is a degree of subjectivity in recording colour, this is hardly sufficient to account for the differences. The causes of the discrepancies are unknown; however, the very fact they exist shows that factors other than maximum temperature attained and duration of heating must exert some influence on bone colour.

I studied a series of over four hundred cremation burials of sixth—seventh century AD date from Mucking, Essex (Mays 1992a). One of the aims of this work was to investigate firing temperatures. The colour of the bone fragments was generally white. This suggests that they had been exposed to a temperature in excess of about 650°C. The X-ray diffraction pattern (Figure 11.4) is consistent with this. Within a particular burial, the firing tended to be fairly even, with few poorly burnt fragments. Some cremations contained glass which had been melted. Presumably this came from objects which were on the corpse as part of the funeral clothing or were placed in the pyre with it as offerings. Unlike the Illington cases described by Calvin Wells, the glass adhering to the Mucking bone fragments had come from objects which had completely melted in the heat of the pyre, the deposits having the appearance of blobs of sticky liquid (Figure 11.5). Chemical analysis of this glass (Finney 1996) showed that its composition was typical of Anglo-

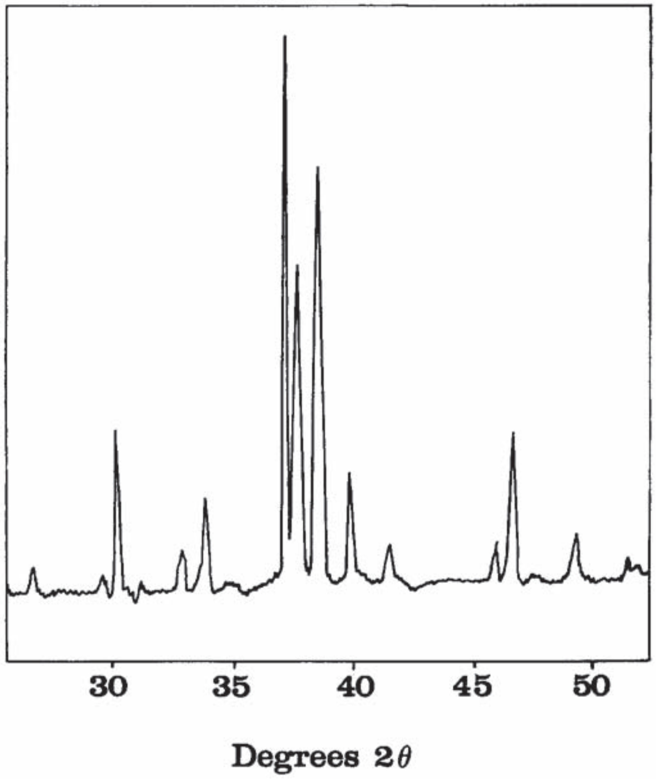


*Figure 11.4* X-ray diffraction pattern from a skull fragment from a Mucking cremation. The fragment was white in colour, suggesting exposure to a temperate in excess of about 650°C. The sharp peaks on the X-ray diffraction spectrum are consistent with this (compare with Figure 11.1)

*Note*: The peaks in this spectrum occur at slightly different diffraction angles (26) than those in Figure 11.1; this is because radiation of a different wavelength was used to produce this spectrum—the overall pattern is unaffected.

Saxon soda-glass used to make beads. In the light of Calvin Wells's work at Illington, the state of the Mucking glass suggests temperatures in excess of about 940°C. Splashes of molten bronze were also present on some bone fragments. Copper melts at 1084°C, although the melting point of bronze, a copper-tin alloy, would be somewhat lower than this, probably about 900–1000°C (Brandes 1983).

In some of the Mucking burials, fragments of a yellow-brown material with a glistening, irregular surface were recovered with the bones. A similar 'clinker' was noted by Calvin Wells in his examination of the Illington cremations back in the 1950s (Wells 1993). On the basis of an experiment in which he placed a plait of human hair beneath a corpse in a modern crematorium (Wells I960), Wells concluded that this material derived from burnt hair. However, later work on archaeological clinker (Henderson *et al.* 1987), involving techniques including X-ray diffraction and scanning elec-tron microscopy, showed that Wells was wrong. The clinker appears to be a result of the combination of silica in the soil with material from the pyre during combustion. Henderson and co-workers indicate that temperatures in excess

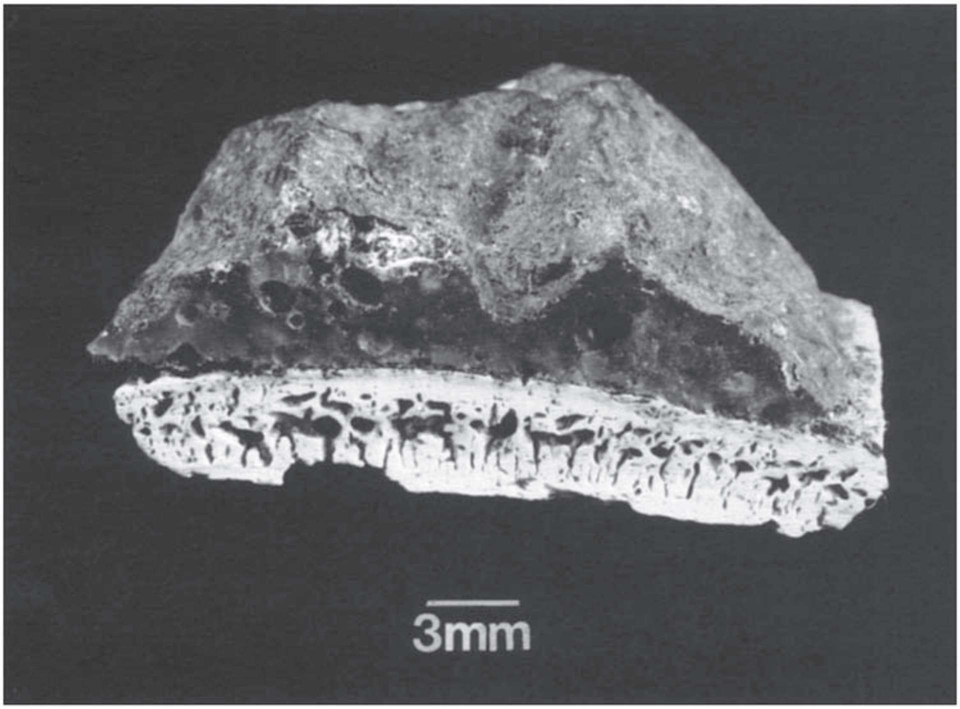


*Figure 11.5* A section through a skull fragment from one of the Mucking cremations showing a fused mass of glass on its outer surface

of about 900°C are likely to be necessary to produce clinker. Taken together, then, the observations on the Mucking cremations suggest that the temperature attained in the cremation pyres was in excess of about 950°C.

With respect to temperature attained and thoroughness of firing, the Mucking cremations are similar to those from modern crematoria. This degree of firing is not unusual for archaeological remains. For example, Wahl (1982), working in Mainz, Germany, has remarked on the general similarity in appearance between ancient cremations and bone fragments recovered from a furnace at a modern crematorium, and comments on the high efficiency of firing that this implies for cremations carried out in ancient times.

That high temperatures were routinely reached in ancient cremations should not surprise us. In a series of experimental wood camp-fires, Stiner *et al.* (1995) recorded temperatures of 900–1000°C using a thermocouple. Of course, whether the corpse itself reaches the maximum temperature of the fire depends upon duration of heating. In experiments involving the cremation of dead dogs, Buikstra and Swegle (unpublished work, cited in Shipman *et al.* 1984) showed that the bones did not reach the maximum temperature of the fire in less than two hours. If an archaeological cremation burial is poorly fired it may be because the duration of the pyre blaze was too short, rather than because the temperature attained by the pyre was too low.

Another factor which may influence firing temperature is the amount of fat in the body. McKinley (1994), in observations on a modern British crematorium, noted that when the furnace reaches about 800°C, the fat in the body ignites; thereafter the

*Table 11.2* Ash Weight of the Human Skeleton

| *Age group* | *Mean weight (grams)* |
|---|---|
| 0–6 months | 54 |
| 6 months–3 years | 185 |
| 3–13 years | 661 |
| 13–25 years | 2,191 |
| Adult | 1,919 (males 2,288 [range 1,534–3,605], females 1,550 [range 952–2,278]) |

*Source*: Figures calculated from Trotter and Hixon (1974); adult ranges estimated from their Figure 1.

gas jets can be switched off, because the body continues to burn in its own fat. When body fats ignite, they may burn very fiercely; Henderson *et al.* (1987) indicate that temperatures in excess of 1000°C may be attained. Consistent with this, Wells (1960), in observations at a modern crematorium, noted that a fat body tends to burn better than a thin one. In an archaeological cremation then, bony parts covered by abundant fat may reach higher temperatures than those surrounded by less fat. It is frequently reported for ancient cremations that the bones of the hands and feet are less well fired than other parts of the skeleton. This has often been taken as an indication of the position of the body on the pyre—that the hands and feet were near the pyre edges or even sticking out from a pyre that was built too small. However, we might expect these parts often to be more poorly fired regardless of the body's initial position on the pyre because of the lack of fat deposits in the extremities. Small bones may also tend to fall more readily to cooler parts of the pyre as the body disintegrates.

## Burial Practices

Trotter and Hixon (1974) studied the weight of the human skeleton. One aspect they report is ash-weight (Table 11.2). This is the weight of the mineral part of the skeleton and indicates the weight of bone which might be expected from a thoroughly cremated corpse.

The figures in Table 11.2 are similar to bone yields reported from the burning of corpses in modern crematoria; for example, Malinowski and Porawski (1969) give average figures of 2004 g and 1540 g for weights of bone obtained from male and female adult corpses. As can be seen from the adult figures, bone weights can vary widely between individuals. The weight of the skeleton depends upon a number of factors, including height and general body build. Bone mass also falls with individual age in older adults, particularly females.

In archaeological burials it is rare to find cremations containing the full amount of bone expected from a cremated corpse (McKinley 1993), even where there is no evidence for loss of bone through post-depositional disturbance of the burial. The phenomenon of 'missing' bone from cremation burials was apparent at a Romano-British (second century AD) burial site at Godmanchester, England (Mays 1993b). Some of the burials had suffered damage due to deep ploughing of the site in recent times, but many remained undamaged. Twenty-eight undamaged urns contained the remains of only one adult individual each. The bone, which generally had a white, well-fired appearance, was recovered from the earth fills of the pots by sieving through a stack of sieves of 4 mm, 2 mm, and 0.5 mm mesh. Only the residue from the 4 mm sieve was sorted. The mean weight of bone from these burials was 777 g (Figure 11.6). This is a little over one-third of the bone that might be expected if each burial contained the complete remains from a cremated body.

One possibility in explaining the relative lack of

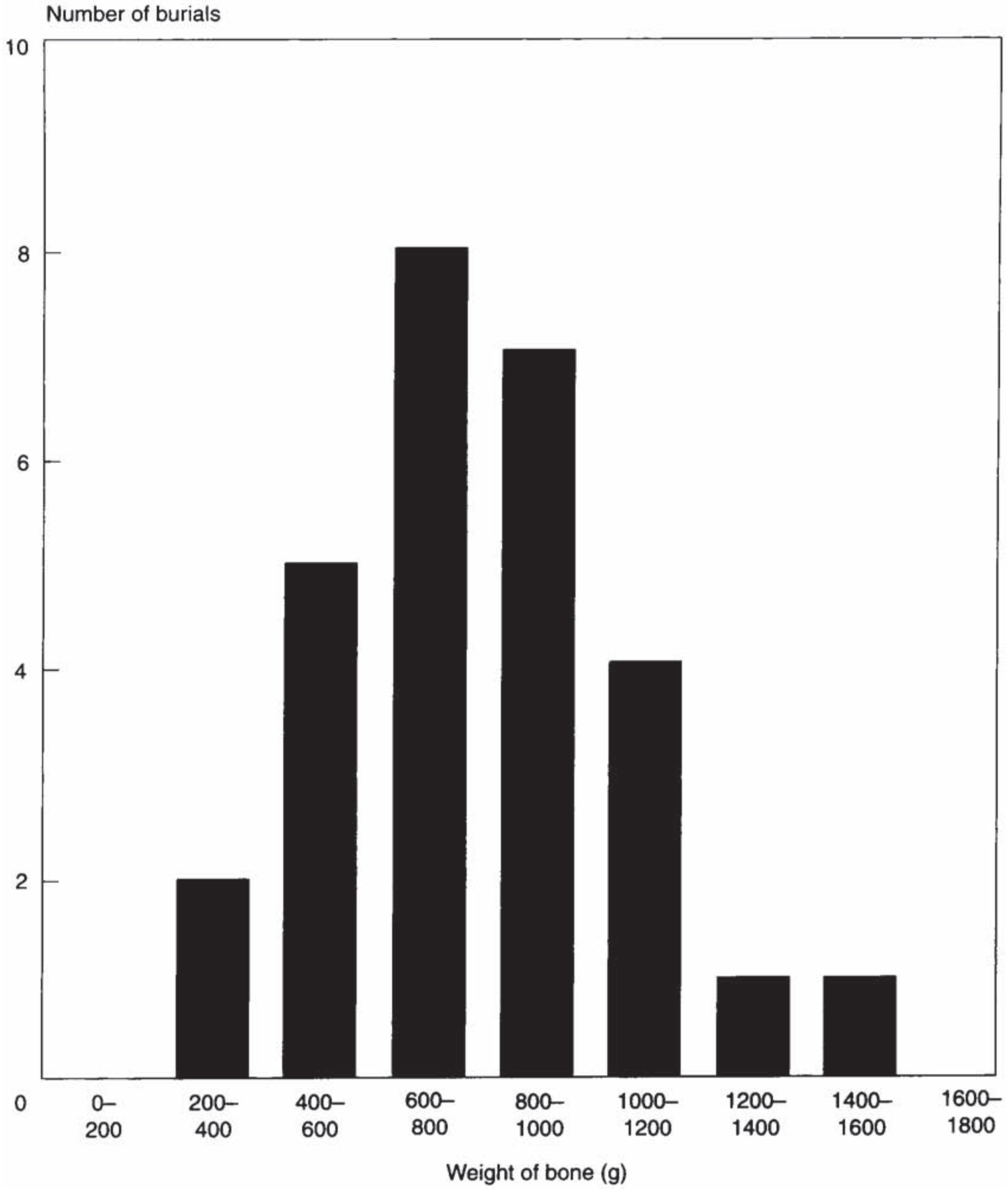


*Figure 11.6* The distribution of bone weights from the adult cremation burials from Godmanchester

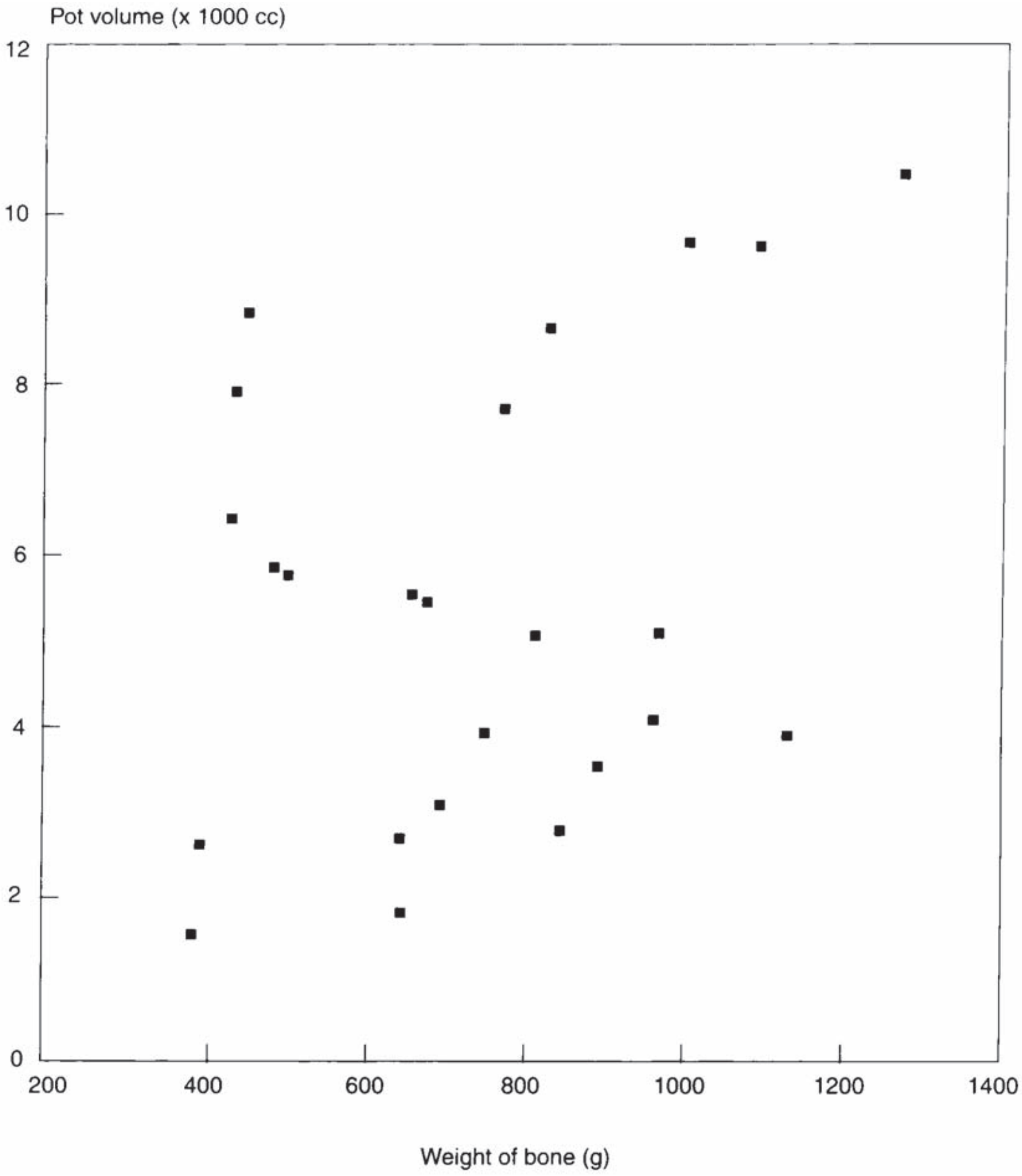


*Figure 11.7* Pot volume versus the weight of bone recovered from adult Godmanchester cremations

bone initially appeared to be that the shortfall might be made up by the bone in the unsorted (and hence unweighed) fractions retained by the mesh sizes 2 mm and under. However, scanning these residues showed that in fact they contained little bone. Even if these fractions had been sorted and the bone fragments weighed they would have added little to the overall bone weights. It might also be suggested that some trabecular bone may have crumbled to dust and hence been lost, but, against this, many trabecular bone fragments were in fact present, and in any case trabecular bone makes a fairly modest contribution to the overall weight of the skeleton compared with the much denser cortical bone. These two factors certainly cannot account for the 'missing' bone.

It might be argued that destruction of much cremated bone had taken place whilst the burials lay in the soil. As already discussed, cremated bone is markedly more resistant to destruction in the soil than is unburnt bone. In addition to the cremations, there were also a few Romano-British inhumations at Godmanchester. Although preservation of bone in the inhumations was fairly good, many bones showed superficial soil erosion. By contrast, there was no surface erosion visible on the cremated bone. It seems unlikely that there were substantial losses of cremated bone when the less resistant unburnt bone survived well and the fragments of cremated bone which were present showed no evidence of eroded surfaces.

There was no evidence for burning of the soil in the area that the cremation urns were buried; the pyres must have been outside the excavated area. A likely source for most of the bone loss is during collection of remains from the pyre in antiquity prior to burial.

Some cremations contained fragments of charcoal, but amounts were generally small. This suggests that bone was picked out from the pyre for burial fairly carefully. If bone and other materials were simply picked up haphazardly and put in an urn we would expect a lot more charcoal. If we are right in our inference that bone was carefully collected, why are the burials so short on bone? One possibility seemed to be that the limiting factor was the capacity of the pot. However, in most cases the pots do not seem to have been filled: the amount of bone found in them was very much less than they could have held, even allowing for some post-depositional settling and fragmentation of the bone. It is possible that some uncombusted pieces of wood and soft tissue survived the pyre and were placed in the urns but have since decayed. Although this possibility cannot be completely excluded, the presence of such material would seem at odds with the thorough firing of most of the bone fragments and the apparent care with which they were collected.

Even if it is accepted that the pots were unlikely ever to have been completely filled with bone, it could be argued that the size of pot might still have been an influence on the amount of bone collected, the tendency being to collect a larger amount of bone for a larger pot. To test this hypothesis, I investigated whether there was a relationship between quantity of bone and vessel volume (the sizes of the pots varied quite markedly). No evidence of any such relationship was found (Figure 11.7): vessel volume did not seem to have influenced the amount of bone collected.

The amount of bone in the pots shows that it must have been an important part of funerary practices to collect a substantial quantity of bone from the pyre for burial, a token amount was clearly not acceptable. Equally, however, it cannot have been important to try and collect all the bone. It is possible that many smaller fragments of bone may have been inadvertently overlooked when the bone was picked out of the pyre for burial in antiquity. However, practical experiments by Piontek (1976) show that bone fragments are quite easy to spot and retrieve from pyre remains, even by the inexper-ienced, and in the Godmanchester urns quite small fragments were indeed present. It may be, rather, that a certain quantity (perhaps about 750–1000 g) appeared to those involved in the funerary rituals at Godmanchester to be a sufficient or appropriate amount to collect and bury. The fairly marked central tendency in the distribution of bone weights (Figure 11.6) would appear to support this—if there was no set notion of what constituted a seemly amount for burial we might expect a more random spread of bone weights.

Although the above account provides a plausible way of accounting for the distribution of bone weights at Godmanchester, it is an interpretation which must remain tentative, not least because of the relatively small number of burials upon which it is based. Nevertheless it does, together with the earlier discussion, serve to illustrate the sort of information concerning ancient funerary practices potentially available from the study of cremated bone from archaeological sites.

# BIBLIOGRAPHY

Aaron, J.E., Rogers, J. & Kanis, J.A. (1992). Paleohistology of Pagets Disease in Two Medieval Skeletons. *American Journal of Physical Anthropology* 89: 325–331.

Acsadi, G. & Nemeskeri, J. (1970). *History of Human Lifespan and Mortality*. Akademiai Kiado, Budapest.

Adams, J.C. & Hamblen, D.L. (1992). *Outline of Fractures* (10th edition). Churchill Livingstone, London.

Adams, W.Y., van Gerven, D.P. & Levy, R.S. (1978). The Retreat from Migrationism. *Annual Review of Anthropology* 7: 483–532.

Aiello, L. & Molleson, T. (1993). Are Microscopic Ageing Techniques More Accurate than Macroscopic Ageing Techniques? *Journal of Archaeological Science* 20: 689–704.

Aloia, J.F. (1993). *A Colour Atlas of Osteoporosis*. Wolfe, London.

Aloia, J.F., Vaswani, A.N., Yeh, J.K., Ross, P., Ellis, K. & Cohn, S.H. (1983). Determinants of Bone Mass in Postmenopausal Women. *Archives of Internal Medicine* 143: 1700–1704.

Ambrose, S.H. (1991). Effects of Diet, Climate and Physiology on Nitrogen Isotope Abundances in Terrestrial Foodwebs. *Journal of Archaeological Science* 18: 293–317.

Ambrose, S.H. (1993). Isotopic Analysis of Palaeodiets: Methodological and Interpretative Considerations, pp. 59–130 in M.K. Sandford (ed.) *Investigations of Ancient Human Tissue*. Gordon & Breach, Reading.

Andersen, S.H. (1989). Norsminde. A 'Køkkenmødding' with Late Mesolithic and Early Neolithic Occupation. *Journal of Danish Archaeology* 8: 13–40.

Andersen, S.H. (1991). Bjørnsholm. A Stratified Køkkenmødding on the Central Limfjord, North Jutland. *Journal of Danish Archaeology* 10: 59–96.

Anderson, A. (1987). Recent Developments in Japanese Prehistory: A Review. *Antiquity* 61: 270–281.

Anderson, D.L., Thompson, G.W. & Popovich, F. (1976). Age of Attainment of Mineralisation Stages of the Permanent Dentition. *Journal of Forensic Sciences* 21: 191–200.

Anderson, T., Arcini, C., Anda, S., Tangerud, A. & Robertsen, T. (1986). Suspected Endemic Syphilis (Treponarid) in Sixteenth Century Norway. *Medical History* 30: 341–350.

Angel, J.L. (1969). The Bases of Paleodemography. *American Journal of Physical Anthropology* 30: 427–438.

Angel, J.L. (1982). A New Measure of Growth Efficiency: Skull Base Height. *American Journal of Physical Anthropology* 59: 297–305.

Angel, J.L., & Olney, L.M. (1981). Skull Base Height and Pelvic Inlet Depth From Prehistoric to Modern Times. *American Journal of Physical Anthropology* 54: 197.

Apley, A.G., & Solomon, L. (1993). *Apley's System of Orthopaedics and Fractures* (7th edition). Butterworth Heinemann, Oxford.

Armelagos, G.J., Jacobs, K.H. & Martin, D.L. (1981). Death and Demography in Prehistoric Sudanese Nubia, pp. 33–57 in S.C. Humphreys & H.King (eds) *Mortality and Immortality*. Academic Press, London.

Ashbee, P. (1966). The Fussell's Lodge Long Barrow Excavations 1957. *Archaeologia* 100: 1–80.

Atkinson, R.J.C. (1965). Wayland's Smithy. *Antiquity* 39: 126–133.

Aufderheide, A.C. (1989). Chemical Analysis of Skeletal Remains, pp. 237–260 in M.Y.Iscan & K.A.R.Kennedy (eds) *Reconstruction of Life From the Skeleton*. Liss, New York.

Aufderheide, A.C., Angel, J.L., Kelley, J.O., Outlaw, A.C., Outlaw, M.A., Rapp, G. & Wittmers, L.E. (1985). Lead in Bone III. Prediction of Social Correlates from Skeletal Lead Content in Four Colonial American Populations (Catoctin Furnace, College Landing, Governor's Land and Irene Mound). *American Journal of Physical Anthropology* 66: 353–361.

Aufderheide, A.C., Neiman, F.D., Wittmers, L.E., & Rapp, G. (1981). Lead in Bone II: Skeletal Lead Content as an Indicator of Lifetime Lead Ingestion and the Social Correlates in an Archaeological Population. *American Journal of Physical Anthropology* 55: 285–291.

Aufderheide, A.C., Wittmers, L.E., Rapp, G. & Wallgren, J. (1988). Anthropological Applications of Lead Analyses. *American Anthropologist* 90: 931–936.

Axelsson, G. & Hedegard, B. (1981). Torus Mandibularis Among Icelanders. *American Journal of Physical Anthropology* 54: 383–389.

Bada, J.L., Schoeninger, M.J. & Schimmelmann, A. (1989). Isotopic Fractionation During Peptide Bond Hydrolysis. *Geochimica et Cosmochimica Acta* 53: 3337–3341.

Bagchi, K. & Bose, A.K. (1962). Effect of Low Nutrient Intake During Pregnancy on Obstetrical Performance and Offspring. *American Journal of Clinical Nutrition* 11: 586–592.

Bahn, P. & Flenley, J. (1992). *Easter Island, Earth Island.* Thames & Hudson, London.

Baker, B.J. & Armelagos, G.J. (1988). The Origin and Antiquity of Syphilis. *Current Anthropology* 29: 703–737.

Barbujani, G., Pilastro, A., De Domenico, S. & Renfrew, C. (1994). Genetic Variation in North Africa and Eurasia: Neolithic Demic Diffusion vs. Palaeolithic Colonisation. *American Journal of Physical Anthropology* 95: 137–154.

Barker, H., Hughes, M.J., Oddy, W.A. & Werner, A.E. (1975). Report on Phosphate Analysis Carried Out in Connection with the Cenotaph Problem, pp. 550–572 in R.L.S. Bruce-Mitford (ed.) *The Sutton Hoo Ship Burial* (Volume 1). British Museum, London.

Baron, H., Hummel, S. & Herrmann, B. (1996). *Mycobacterium tuberculosis* Complex DNA in Ancient Human Bones. *Journal of Archaeological Science* 23: 667–671.

Baud, C.-A. & Kramer, C. (1991). Soft Tissue Calcifications in Paleopathology, pp. 87–89 in D.J.Ortner & A.C.Aufderheide (eds) *Human Paleopathology, Current Syntheses and Future Options.* Smithsonian Institution Press, Washington.

Beals, K.L. (1972). Head Form and Climatic Stress. *American Journal of Physical Anthropology* 37: 85–92.

Beals, K.L., Smith, C.L. & Dodd, S.M. (1983). Climate and the Evolution of Brachycephalisation. *American Journal of Physical Anthropology* 62: 425–437.

Becker, M.J. (1994). Etruscan Gold Dental Appliances: Origins and Functions as Indicated by an Example From Valsiarosa, Italy. *Journal of Palaeopathology* 6: 69–92.

Becks, H., Jensen, A.L. & Millar, C.B. (1944). Rampant Dental Caries: Prevention and Prognosis; A Five Year Clinical Survey. *Journal of the American Dental Association* 31: 1189.

Bedford, M.E., Russell, K.F., Lovejoy, C.O., Meindl, R.S., Simpson, S.W. & Stuart-Macadam, P.L. (1993). Test of the Multifactorial Ageing Method Using Skeletons With Known Agesat-Death From the Grant Collection. *American Journal of Physical Anthropology* 91: 287–297.

Bennett, J.M. (1987). *Women in the Mediaeval English Countryside.* Oxford University Press, Oxford.

Bennike, P. (1985). *Palaeopathology of Danish Skeletons.* Akademisk Forlag, Copenhagen.

Bennion, E. (1986). *Antique Dental Instruments.* Sotheby's, London.

Beresford, M. & Hurst, J. (1990). *Wharram Percy.* Batsford, English Heritage, London.

Berry, A.C. (1975). Factors Affecting the Incidence of NonMetrical Skeletal Variants. Journal of Anatomy 120: 519–535.

Berry, A.C. (1978). Anthropological and Family Studies on Minor Variants of the Dental Crown, pp. 81–98 in P.M. Butler & K.A.Joysey (eds) *Development, Function and Evolution of the Teeth.* Academic Press, London.

Berry, A.C. & Berry, R.J. (1967). Epigenetic Variation in the Human Cranium. *Journal of Anatomy* 101: 361–379.

Berry, R.J. (1968). The Biology of Non-Metric Variation in Mice and Men, pp. 103–133 in D.R. Brothwell (ed.) *The Skeletal Biology of Earlier Human Populations.* Pergamon Press, London.

Berry, R.J. (1979). Genes and Skeletons Ancient and Modern. *Journal of Human Evolution* 8: 669–677.

Berry, R.J. & Searle, A.G. (1963). Epigenetic Polymorphism in the Rodent Skeleton. *Proceedings of the Zoological Society of London* 140: 577–615.

Berryman, H.E. & Haun, S.J. (1996). Applying Forensic Techniques to Interpret Cranial Fracture Patterns in an Archaeological Specimen. *International Journal of Osteoarchaeology* 6: 2–9.

Bethell, P.H. & Carver, M.O.H. (1987). Detection and Enhancement of Decayed Inhumations at Sutton Hoo, pp. 10–21 in A. Boddington, A.N.Garland & R.C.Janaway (eds) *Death, Decay and Reconstruction.* Manchester University Press, Manchester.

Bibby, B.G. & Mundorff, S.A. (1975). Enamel Demineralisation by Snack Foods. *Journal of Dental Research* 54: 461–470.

Binford, L. (1963). An Analysis of Cremations From Three Michigan Sites. *Wisconsin Archaeologist* 44: 98–110.

Blondiaux, J. & Alduc le Bagousse, A. (1994). Une Treponematose du Bas-Empire Romain En Normande?, pp. 99–100 in O. Dutour, G. Palfi, J. Berato & J.-P. Brun (eds) *L'Origine de la Syphilis En Europe, Avant ou Apres 1493?.* Editions Errance, Centre Archeologiques du Var.

Bloom, W. & Fawcett, D.W. (1986). *A Textbook of Histology* (11th edition). W.B.Saunders, Philadelphia.

Bocquet-Appel, J.-P. (1984). Biological Evolution and History in 19th Century Portugal, pp. 289–321 in G.N. van Vark & W.W.Howells (eds) *Multivariate Statistical Techniques in Physical Anthropology.* Reidel, Groningen.

Boddington, A. (1987a). From Bones to Population: The Problem of Numbers, pp. 180–197 in A.Boddington, A.N.Garland & R.C.Janaway (eds) *Death, Decay and Reconstruction.* Manchester University Press, Manchester.

Boddington, A. (1987b). Chaos, Disturbance and Decay in an Anglo-Saxon Cemetery, pp. 27–42 in A.Boddington, A.N. Garland & R.C. Janaway (eds) *Death, Decay and Reconstruction.* Manchester University Press, Manchester.

Bødker Enghoff, I. (1989). Fishing from the Stone Age Settlement Norsminde. *Journal of Danish Archaeology* 8: 41–50.

Bødker Enghoff, I. (1991). Mesolithic Eel Fishing at Bjørnsholm, Denmark, Spiced with Exotic Species. *Journal of Danish Archaeology* 10: 105–118.

Bødker Enghoff, I. (1993). Coastal Fishing, p. 69 in S.Hvass & B. Storgaard (eds) *Digging Into the Past. 25 Years of Archaeology In Denmark.* Aarhus University Press, Aarhus.

Bökönyi, S. (1978). The Vertebrate Fauna of Vlasac, pp. 35–65 in D.Srejovic & Z.Letica (eds) *Vlasac: A Mesolithic Settlement in the Iron Gates.* Serbian Academy of Sciences, Belgrade.

Bond, J. (1994). The Cremated Animal Bone, pp. 92–100 & 123–135 in J.McKinley *Spong Hill: Part VIII The Cremations.* East Anglian Archaeology Report No. 69.

Bondioli, L., Corruccini, R.S. & Macchiarelli, R. (1986). Familial Segregation in the Iron Age Community of Alfedena, Abruzzo, Italy, Based on Osteodontal Trait Analysis. *American Journal of Physical Anthropology* 71: 393–400.

Borovansky, L. & Hnevkovsky, O. (1929). Growth of the Body and Process of Ossification in Prague Boys from 4 to 19 Years. *Anthropologie (Prague)* 7: 169–208.

Boucher, B.J. (1957). Sex Differences in the Foetal Pelvis. *American Journal of Physical Anthropology* 15: 581–600.

Bowman, J.E., MacLaughlin, S.M. & Scheuer, J.L. (1992). Burial of an Early 19th Century Suicide in the Crypt of St Bride's Church, Fleet Street. *International Journal of Osteoarchaeology* 2: 91–94.

Brabant, H. (1967). Palaeostomatology, pp. 538–550 in D.R. Brothwell & A.T.Sandison (eds) *Diseases in Antiquity*. Charles C.Thomas, Springfield.

Brace, C.L. (1964). The Probable Mutation Effect. *American Naturalist* 98: 453–455.

Brace, C.L., Brace, M.L. & Leonard, W.R. (1989). Reflections on the Face of Japan: A Multivariate Craniofacial and Odonto metric Perspective. *American Journal of Physical Anthropology* 78: 93–113.

Brace, C.L. & Hunt, K.D. (1990). A Nonracial Cranial Perspective on Human Variation: A(ustralia) to Z(uni). *American Journal of Physical Anthropology* 82: 341–360.

Brace, C.L. & Nagai, M. (1982). Japanese Tooth Size: Past and Present. *American Journal of Physical Anthropology* 59: 399–411.

Brace, C.L., Rosenberg, K.R. & Hunt, K.D. (1987). Gradual Change in Human Tooth Size in the Late Pleistocene and Post Pleistocene. *Evolution* 41: 705–720.

Brace, C.L., Smith, S.L. & Hunt, K.D. (1991). What Big Teeth You Had Grandma! Human Tooth Size Past and Present, pp. 33–57 in M.A.Kelley & C.S.Larsen (eds) *Advances in Dental Anthropology*. Wiley-Liss, Chichester.

Brandes, E.A. (1983). *Smithell's Metals Reference Book* (6th edition). Butterworth, Oxford.

Brodie, N. (1994). *The Neolithic—Bronze Age Transition in Britain*. British Archaeological Reports, British Series, No. 238. Tempus Reparatum, Oxford.

Brooks, S. & Suchey, J.M. (1990). Skeletal Age Determination Based on the Os Pubis: A Comparison of the AcsadiNemeskeri and Suchey–Brooks Methods. *Human Evolution* 5: 227–238.

Brothwell, D.R. (1963a). *Digging Up Bones* (1st edition). Oxford University Press/British Museum (Natural History), Oxford.

Brothwell, D.R. (1963b). The Macroscopic Dental Pathology of Some Earlier Human Populations, pp. 271–287 in D.R.Brothwell (ed.) *Dental Anthropology*. Pergamon, Oxford.

Brothwell, D.R. (1971). Forensic Aspects of the So-Called Neolithic Skeleton Q1 From Maiden Castle, Dorset. *World Archaeology* 3: 233–241.

Brothwell, D.R. (1972). *Digging Up Bones* (2nd edition). Oxford University Press/British Museum (Natural History), Oxford.

Brothwell, D.R. (1981). *Digging Up Bones* (3rd edition). Oxford University Press/British Museum (Natural History), Oxford.

Brothwell, D.R. & Blake, M.L. (1966). The Human Remains From Fussell's Lodge Long Barrow: Their Morphology, Discontinuous Traits and Pathology. *Archaeologia* 100: 48–63.

Brothwell, D.R. & Cullen, R. ([1969] 1991). Wayland's Smithy, Oxfordshire: The Human Bone. *Proceedings of the Prehistoric Society* 57: 72–80.

Brothwell, D.R. & Krzanowski, W, (1974). Evidence of Biological Differences Between Early British Populations From Neolithic to Mediaeval Times, as Revealed by Eleven Commonly Available Cranial Vault Measurements. *Journal of Archaeological Science* 1: 249–260.

Brothwell, D.R. & Powers, R. (1968). Congenital Malformations of the Skeleton in Earlier Man, pp. 173–203 in D.R.Brothwell (ed.) *The Skeletal Biology of Earlier Human Populations*. Pergamon, Oxford.

Brown, K.A., O'Donoghue, K. & Brown, T.A. (1995). DNA in Cremated Bones from an Early Bronze Age Cemetery Cairn. *International Journal of Osteoarchaeology* 5: 181–187.

Brown, T.A. (1992). *Genetics, A Molecular Approach*. Chapman & Hall, London.

Brown, T.A. & Brown, K.A. (1992). Ancient DNA and the Archaeologist. *Antiquity* 66: 10–23.

Brown, T.A., O'Donoghue, K. & Brown, K.A. (1996). Chemical Structure of DNA in Bone from Overton Down, pp. 199–200 in M.Bell, P.J.Fowler & S.W.Hillson (eds) *The Experimental Earthwork Project 1960–1992*. CBA Research Report 100, Council for British Archaeology, York.

Budinoff, L.C. & Tague, R.G. (1990). Anatomical and Developmental Bases for the Ventral Arc of the Human Pubis. *American Journal of Physical Anthropology* 82: 73–79.

Buhr, A.J. & Cooke, A.M. (1959). Fracture Patterns. *The Lancet* 1: 531–536.

Buikstra, J.E. (1972). Techniques for Coping with the Age Regressive Nature of Non-Metric Traits. *American Journal of Physical Anthropology* 37: 431–432.

Bunyard, M.W. (1972). Effects of High Sucrose Cariogenic diets with Varied Protein-Calorie Levels on the Bones and Teeth of the Rat. *Calcified Tissue Research* 8: 217–227.

Burgess, C. & Shennan, S. (1976). The Beaker Phenomenon: Some Suggestions, pp. 309–331 in C.Burgess & R.Miket (eds) *Settlement and Economy in the 3rd and 2nd Millenia BC*. British Archaeological Reports, British Series, No. 33. Tempus Reparatum, Oxford.

Calcagno, J.M. & Gibson, K.R. (1988). Human Dental Reduction: Natural Selection or Probable Mutation Effect. *American Journal of Physical Anthropology* 77: 505–517.

Campbell, J.C. (1986). Foreword, pp. xi-xii in R.J.Pearson, G.L. Barnes & K.L.Hutterer (eds) *Windows on the Japanese Past: Studies in Archaeology and Prehistory*. Center for Japanese Studies, Ann Arbor.

Carlson, D.S. & van Gerven, D.P. (1977). Masticatory Function and Post-Pleistocene Evolution in Nubia. *American Journal of Physical Anthropology* 46: 495–506.

Carlson, D.S. & van Gerven, D.P. (1979). Diffusion, Biological Determinism and Biocultural Adaptation in the Nubian Corridor. *American Anthropologist* 81: 561–580.

Chapman, J. & Crites, G.D. (1987). Evidence for Early Maize (*Zea mays*) from the Icehouse Bottom Site, Tennessee. *American Antiquity* 52: 352–354.

Charles, D.K., Condon, K., Cheverud, J.M. & Buikstra, J.E. (1989). Estimating Age at Death from Growth Layer Groups in Cementum, pp. 277–301 in M.Y.Iscan (ed.) *Age Markers in the Human Skeleton*. Charles C.Thomas, Springfield.

Childe, A.M. (1995). Towards an Understanding of the Microbial Decomposition of Archaeological Bone in the Burial Environment. *Journal of Archaeological Science* 22: 165–174.

Childe, A.M. & Pollard, A.M. (1992). A Review of the Applications of Immunochemistry to Archaeological Bone. *Journal of Archaeological Science* 19: 39–47.

Chisholm, B.S. (1989). Variation in Diet Reconstructions Based on Stable Carbon Isotopic Evidence, pp. 10–37 in T.D.Price (ed.) *The Chemistry of Prehistoric Human Bone*. Cambridge University Press, Cambridge.

Chisholm, B.S., Nelson, D.E. & Schwarcz, H.P. (1982). Stable

Carbon Isotope Ratios as a Measure of Marine Versus Terrestrial Protein in Ancient Diets. *Science* 216: 1131–1132.

Clarke, N.G. & Hirsch, R.S. (1991). Physiological, Pulpal and Periodontal Factors Influencing Alveolar Bone, pp. 241–266 in M.A.Kelley & C.S.Larsen (eds) *Advances in Dental Anthropology*. Wiley-Liss, Chichester.

Clay, R.M. (1909). *The Mediaeval Hospitals of England*. Methuen, London.

Cohen, B. & Bowen, W.H. (1966). Dental Caries in Experimental Monkeys. *British Dental Journal* 121: 269–276.

Comar, C.L. (1966). Movement of Fallout Radionuclides Through the Biosphere and Man. *Health Physics* 12: 175–206.

Comar, C.L., Russell, R.S. & Wasserman, R.H. (1957a). Strontium–Calcium Movement from Soil to Man. *Science* 126: 485–492.

Comar, C.L., Wasserman, R.H., Ullberg, S. & Andrews, G.A. (1957b). Strontium Metabolism and Strontium–Calcium Discrimination in Man. *Proceedings of the Society for Experimental Biology and Medicine* 95: 386–391.

Cook, D.C. (1981). Mortality, Age Structure and Status in the Interpretation of Stress Indicators in Prehistoric Skeletons: A Dental Example from the Lower Illinois Valley, pp. 133–144 in R.Chapman, I.Kinnes & K.Randsborg (eds) *The Archaeology of Death*. Cambridge University Press, Cambridge.

Corbett, M.E. & Moore, W.J. (1976). Distribution of Dental Caries in Ancient British Populations: IV The 19th Century. *Caries Research* 10: 401–414.

Corruccini, R.S. (1974). An Examination of the Meaning of Cranial Discrete Traits for Human Skeletal Biological Studies. *American Journal of Physical Anthropology* 59: 443–459.

Corruccini, R.S. & Beecher, R.M. (1982). Occlusal Variation Related to Soft Diet in a Non-Human Primate. *Science* 218: 74–75.

Cox, M. (1989). *The Human Bones From Ancaster*. AML Report 93/89. English Heritage, London.

Cox, M., Molleson, T. & Waldron, T. (1990). Preconception and Perception: The Lessons of a 19th Century Suicide. *Journal of Archaeological Science* 17: 573–581.

Crelin, E.H. (1969). The Development of the Bony Pelvis and its Changes During Pregnancy and Parturition. *Transactions of the New York Academy of Sciences* 31: 1049–1058.

Croft, P., Coggon, D., Cruddas, M. & Cooper, C. (1992). Osteoarthritis of the Hip: An Occupational Disease in Farmers. *British Medical Journal* 304: 1269–1272.

Crosby, A.W. (1969). The Early History of Syphilis: A Reappraisal. *American Anthropologist* 71: 218–227.

Dahinten, S.L. & Pucciarelli, H.M. (1983). Effects of Protein-Calorie Malnutrition During Suckling and Post-Weaning Periods on Discontinuous Cranial Traits in Rats. *American Journal of Physical Anthropology* 60: 425–430.

Dahinten, S.L. & Pucciarelli, H.M. (1986). Variations in Sexual Dimorphism in the Skulls of Rats Subjected to Malnutrition, Castration and Treatment with Gonadal Hormones. *American Journal of Physical Anthropology* 71: 63–67.

Davies, A. (1932). A Re-Survey of the Morphology of the Nose in Relation to Climate. *Journal of the Royal Anthropological Institute* 62: 337–359.

Davies, M.R.R. (1982). *The Law of Burial, Cremation and Exhumation* (5th edition). Shaw, London.

Dawes, J.D. & Magilton, J.R. (1980). *The Cemetery of St Helen-on-the-Walls, Aldwark*. The Archaeology of York 12/1. Council for British Archaeology, York.

De Jong, W.F. (1926). La Substance Mineral dans les Os. *Receuil des Traveaux Chimiques de Pays-Bas* 45, No. 6.

Demirjian, A. (1978). Dentition, pp. 413–444 in F.Falkner & J.M.Tanner (eds) *Human Growth*. Plenum, London.

DeNiro, M.J. (1987). Stable Isotopy and Archaeology. *American Scientist* 75: 182–191.

DeNiro, M.J. & Epstein, S. (1981). Influence of Diet on the Distribution of Nitrogen Isotopes in Animals. *Geochimica et Cosmochimica Acta* 45: 341–351.

DeNiro, M.J. & Hastorf, C.A. (1985). Alteration of $^{15}$N/$^{14}$N and $^{13}$C/$^{12}$C Ratios of Plant Matter During the Initial Stages of Diagenesis: Studies Utilizing Archaeological Specimens from Peru. *Geochimica et Cosmochimica Acta* 49: 97–115.

DeNiro, M.J., Schoeninger, M.J. & Hastorf, C.A. (1985). Effect of Heating on Stable Carbon and Nitrogen Isotope Ratios of Bone Collagen. *Journal of Archaeological Science* 12: 1–7.

Deol, M.S. & Truslove, G.M. (1957). Genetical Studies on the Skeleton of the Mouse. XX. Maternal Physiology and Variation in the Skeleton of C57BL Mice. *Journal of Genetics* 55: 288–312.

Dequeker, J. (1976). Quantitative Radiology: Radiogrammetry of Cortical Bone. *British Journal of Radiology* 49: 912–920.

Dickson, J.H. (1978). Bronze Age Mead. *Antiquity* 52: 108–113.

Dieppe, P. & Rogers, J.M. (1989). Skeletal Palaeopathology of Rheumatic Disorders, pp. 8–15 in D.A.McCarty (ed.) *Arthritis and Allied Conditions: A Textbook of Rheumatology* (11th edition). Lea & Febiger, Philadelphia.

Dingwall, E.J. (1931). *Artificial Cranial Deformation: A Contribution to the Study of Ethnic Mutilations*. Bale & Danielsson, London.

Dobney, K. & Goodman, A.H. (1991). Epidemiological Studies of Dental Enamel Hypoplasias in Mexico and Bradford: Their Relevance to Archaeological Skeletal Studies, pp. 81–100 in H. Bush & M.Zvelebil (eds) *Health in Past Societies*. British Archaeological Reports (International Series) No. 567. Tempus Reparatum, Oxford.

Dodo, Y. & Ishida, H. (1990). Population History of Japan as Viewed from Cranial Non-Metric Variation. *Journal of the Anthropological Society of Nippon* 98: 269–287.

Dokladal, M. (1970). Ergebnisse Experimenteller Verbrennungen zur Feststellung von Form- und Grössenveränderung von Menschenknochen unter dem Einfluss von Hohen Temperaturen. *Anthropologie (Brno)* 8(2): 3–17.

Dokladal, M. (1971). A Further Contribution to the Morphology of Burned Human Bones, pp. 561–568 in V.Novotny (ed.) *Proceedings of the Anthropological Congress Dedicated to Ales Hrdlicka in Prague and Humpolec, 1969*. Czechoslovak Academy of Science, Prague.

Donaldson, C.L., Hulley, S.B., Vogel, J.M., Hatter, R.S., Buyers, J.H. & McMillar, D.E. (1970). Effect of Prolonged Bed Rest on Bone Mineral. *Metabolism, Clinical & Experimental* 19: 1071–1084.

Dreizen, S., Snodgrasse, R.M., Webb-Peploe, H. & Spies, T.D. (1957). The Effect of Prolonged Nutritive Failure on Epiphysial Fusion in the Human Hand Skeleton. *American Journal of Roentgenology* 78: 461–470.

Dreizen, S. & Spies, T.D. (1948). Further Studies on the Association

Between the Products of Protein Putrefaction and Dental Caries Activity. *Journal of Dental Research* 27: 305–315.

Dummer, P.M.H., Kingdon, A. & Kingdon, R. (1986). Prevalence of Enamel Developmental Defects in a Group of 11- and 12-year-old Children in South Wales. *Community Dentistry and Oral Epidemiology* 14: 119–122.

Duray, S.M. (1996). Dental Indicators of Stress and Reduced Age at Death in Prehistoric Native Americans. *American Journal of Physical Anthropology* 99: 275–286.

Dutour, O., Panuel, M., Palfi, G. & Berato, J. (1994). Diagnostic Differentiel des Lesions Observees sur le Foetus 'Christobal', pp. 139–146 in O.Dutour, G.Palfi, J.Berato & J.-P.Brun (eds) *L'Origine de la Syphilis En Europe, Avant ou Apres 1493?*. Editions Errance, Centre Archeologiques du Var.

Edwards, N.T. (1975). The Effects of Temperature and Moisture on Carbon Dioxide Evolution in a Mixed Deciduous Forest Floor. *Soil Science Society of America Proceedings* 39: 361–365.

Elias, R.W., Hirao, Y. & Patterson, C.C. (1982). The Circumvention of the Natural Biopurification of Calcium Along Nutrient Pathways by Atmospheric Inputs of Industrial Lead. *Geochimica et Cosmochimica Acta* 46: 2561–2580.

El-Najjar, M.Y., Lozoff, B. & Ryan, D.J. (1975). The Paleoepidemiology of Porotic Hyperostosis in the American Southwest: Radiological and Ecological Considerations. *American Journal of Roentgenology* 125: 918–924.

El-Najjar, M.Y., Ryan, D.J., Turner, C.G. & Lozoff, B. (1976). The Etiology of Porotic Hyperostosis Among the Prehistoric and Historic Anasazi Indians of the Southwestern United States. *American Journal of Physical Anthropology* 44: 477–488.

Enwonwu, C.O. (1973). Influence of Socio-Economic Conditions on Dental Development in Nigerian Children. *Archives of Oral Biology* 18: 95–107.

Enwonwu, C.O. (1974). Socio-Economic Factors in Caries Prevalence and Frequency in Nigerians. *Caries Research* 8: 155–171.

Evans, C. (1988). Monuments and Analogy: The Interpretation of Causewayed Enclosures, pp. 47–73 in C.Burgess, P.Topping, C.Mordant & M.Maddison (eds) *Enclosures and Defences in the Neolithic of Western Europe*. British Archaeological Reports, International Series, No. 403(i), British Archaeological Reports, Oxford.

Evans, J.G. (1975). *The Environment of Early Man in the British Isles*. Elek, London.

Evans, J.G. (1978). *An Introduction to Environmental Archaeology*. Elek, London.

Evans, W.E.D. (1963). *The Chemistry of Death*. Charles C.Thomas, Springfield.

Eveleth, P.B. & Tanner, J.M. (1990). *Worldwide Variation in Human Growth* (2nd edition). Cambridge University Press, Cambridge.

Ezzo, J.A. (1994). Putting the 'Chemistry' Back into Archaeological Bone Chemistry Analysis: Modelling Potential Palaeodietary Indicators. *Journal of Anthropological Archaeology* 13: 1–34.

Faerman, M., Filon, D., Kahila, G., Greenblatt, C.L., Smith, P. & Oppenheim, A. (1995). Sex Identification of Archaeological Human Remains Based on Amplification of the X and Y Amelogenin Alleles. *Gene* 167: 327–332.

Fazekas, I.G. & Kosa, F. (1978). *Forensic Foetal Osteology*. Akademiai Kiado, Budapest.

Feldesman, M.R. (1992). Femur/Stature Ratio and Estimates of Stature in Children. *American Journal of Physical Anthropology* 87: 447–459.

Field, R.K. (1965). Worcestershire Peasant Buildings, Household Goods and Farming Equipment in the Later Middle Ages. *Mediaeval Archaeology* 9: 105–145.

Finnegan, M. (1978). Non-Metric Variation of the Infracranial *Skeleton*. *Journal of Anatomy* 125: 23–37.

Finney, T. (1996). *Investigation of a Skull Fragment from Cremation 704, Mucking, Essex*. AML Report 1/96. English Heritage, London.

Flecker, H. (1942). Time of Appearance and Fusion of Ossification Centres as Observed by Roentgenographic Methods. *American Journal of Roentgenology* 47: 97–159.

Fornaciari, G., Mallegni, F., Bertini, D. & Nuti, V. (1981). Cribra Orbitalia and Elemental Iron in the Punics of Carthage. *Ossa* 8: 63–77.

Francalacci, P. (1995). DNA Recovery from Ancient Tissues: Problems and Perspectives. *Human Evolution* 10: 81–91.

Franciscus, R.G. & Long, J.C. (1991). Variation in Human Nasal Height and Breadth. *American Journal of Physical Anthropology* 85: 419–427.

Frayer, D.W. (1988). Auditory Exostoses and Evidence for Fishing at Vlasac. *Current Anthropology* 29: 346–349.

Frayer, D.W. (1989). Oral Pathologies in the European Upper Palaeolithic and Mesolithic, pp. 255–281 in I.Hershkovitz (ed.) *People and Culture in Change*. British Archaeological Report (International Series) No. 508. Tempus Reparatum, Oxford.

Friedli, H., Lotscher, H., Oescheger, H., Siegenthaler, U. & Stauffer, B. (1986). Ice Core Record of the $^{13}$C/$^{12}$C Ratio of Atmospheric CO$_2$ in the Past Two Centuries. *Nature* 324: 237–238.

Galinat, W.C. (1985). Domestication and Diffusion of Maize, pp. 245–278 in R.Ford (ed.) *Prehistoric Food Production in North America*. Museum of Anthropology, University of Michigan.

Gardner, W.U. & Pfeiffer, C.A. (1943). Influence of Estrogens and Androgens on the Skeletal System. *Physiological Reviews* 23: 139–165.

Garland, A.N. & Janaway, R.C. (1989). The Taphonomy of Inhumation Burials, pp. 15–37 in C.Roberts, F.Lee & J. Bintliff (eds) *Burial Archaeology Current Research, Methods and Developments*. British Archaeological Reports, British Series, No. 211. British Archaeological Reports, Oxford.

Garn, S.M., Lewis, A.B. & Bonne, B. (1962). Third Molar Formation and Its Developmental Course. *The Angle Orthodontist* 32: 270–279.

Garn, S.M., Osborne, R.H. & McCabe, K.D. (1979). The Effect of Prenatal Factors on Crown Dimensions. *American Journal of Physical Anthropology* 51: 665–678.

Gejvall, N.-G. (1960). *Westerhus: Mediaeval Population and Church in the Light of Skeletal Remains*. Hakak Ohlsson, Lund.

Gejvall, N.-G. (1969). Cremations, pp. 468–479 in D.R.Brothwell & E.Higgs (eds) *Science in Archaeology*. Thames & Hudson, London.

Gilbert, B.M. & McKern, T.W. (1973). A Method For Ageing the Female Os Pubis. *American Journal of Physical Anthropology* 38: 31–38.

Giles, E. & Elliot, O. (1963). Sex Determination by Discriminant Function Analysis of Crania. *American Journal of Physical Anthropology* 21: 53–68.

Gill, G.W. (1994). Skeletal Injuries of Pioneers, pp. 159–172 in D.W.Owsley & R.L.Jantz (eds) *Skeletal Biology in the Great Plains*. Smithsonian Institution Press, Washington.

Goldberg, P.J.P. (1986). Female Labour, Service and Marriage in the Late Mediaeval Urban North. *Northern History* 22: 18–38.

Goldstein, L. (1981). One Dimensional Archaeology and Multidimensional People: Spatial Organisation and Mortuary Analysis, pp. 53–70 in R.Chapman, I.Kinnes & K.Randsborg (eds) *The Archaeology of Death*. Cambridge University Press, Cambridge.

Goodman, A.H. & Armelagos, G.J. (1985). Factors Affecting the Distribution of Enamel Hypoplasias Within the Human Permanent Dentition. *American Journal of Physical Anthropology* 68: 479–493.

Goodman, A.H. & Armelagos, G.J. (1988). Childhood Stress and Decreased Longevity in a Prehistoric Population. *American Anthropologist* 90: 936–944.

Goodman, A.H., Armelagos, G.J. & Rose, J.C. (1980). Enamel Hypoplasias as Indicators of Stress in Three Prehistoric Populations from Illinois. *Human Biology* 52: 512–528.

Goodman, A.H., Martinez, C. & Chavez, A. (1991). Nutritional Supplementation and the Development of Linear Enamel Hypoplasias in Children from Tezontepan, Mexico. *American Journal of Clinical Nutrition* 53: 773–781.

Goodman, A.H., Pelto, G.H., Allen, L.H. & Chavez, A. (1992). Socioeconomic and Anthropometric Correlates of Linear Enamel Hypoplasia in Children From Solis, Mexico, pp. 373–380 in A.H.Goodman & L.L.Capasso (eds) *Recent Contributions to the Study of Enamel Developmental Defects*. Journal of Palaeopathology Monographic Publication No. 2, Chieti.

Goodman, A.H. & Rose, J.C. (1990). Assessment of Systemic Physiological Perturbations from Dental Enamel Hypoplasias and Associated Histological Structures. *Yearbook of Physical Anthropology* 33: 59–110.

Goose, D.H. (1962). Reduction of Palate Size in Modern Populations. *Archives of Oral Biology* 7: 343–350.

Gordon, C.G. & Buikstra, J.E. (1981). Soil pH, Bone Preservation and Sampling Bias at Mortuary Sites. *American Antiquity* 46: 566–571.

Gorecki, P.P. (1979). Disposal of Human Remains in the New Guinea Highlands. *Archaeology & Physical Anthropology in Oceania* 14: 107–117.

Gray, H. (1988). *Gray's Anatomy* (Revised American, from the 15th English edition). Galley Press, Leicester.

Grayson, D.K. (1979). On the Quantification of Vertebrate Archaeofaunas. *Advances in Archaeological Method and Theory* 2: 199–237.

Green, C.J.S., Paterson, M. & Biek, L. (1981). A Roman Coffin Burial from Crown Buildings, Dorchester with Particular Reference to the Head of Well-Preserved Hair. *Proceedings of the Dorset Natural History and Archaeological Society* 103: 67–100.

Greulich, W.W. & Pyle, S.I. (1950). *Radiographic Atlas of Skeletal Development of the Hand and Wrist*. Stanford University Press, Stanford.

Grewel, M.S. (1962). The Development of an Inherited Tooth Defect in the Mouse. *Journal of Embryology & Experimental Morphology* 10: 202–211.

Grüneberg, H. (1951). The Genetics of a Tooth Defect in the Mouse. *Proceedings of the Royal Society of London, Series B* 138: 437–451.

Grüneberg, H. (1952). Genetical Studies on the Skeleton of the Mouse IV. Quasi-Continuous Variations. *Journal of Genetics* 51: 95–114.

Grüneberg, H. (1963). *The Pathology of Development*. Blackwell, Oxford.

Grupe, G. (1988). Impact of the Choice of Bone Samples on Trace Element Data in Excavated Human Skeletons. *Journal of Archaeological Science* 15: 123–129.

Grupe, G. & Hummel, S. (1991). Trace Element Studies on Experimentally Cremated Bone. 1. Alteration of the Chemical Composition at High Temperatures. *Journal of Archaeological Science* 18: 177–186.

Gugliardo, M.F. (1982). Tooth Crown Size Differences Between Age Groups: A Possible New Indicator of Stress in Skeletal Samples. *American Journal of Physical Anthropology* 58: 383–389.

Gustafson, G. & Koch, G. (1974). Age Estimation Up to 16 Years of Age Based on Dental Development. *Odontologisk Revy* 25: 297–306.

Hackett, C.J. (1976). *Diagnostic Criteria of Syphilis, Yaws and Treponarid (Treponematoses) and of Some Other Disease in Dry Bones*. Springer, Berlin.

Hackett, C.J. (1981). Microscopic Focal Destruction (Tunnels) in Exhumed Bone. *Medicine, Science and the Law* 21: 243–265.

Hackett, C.J. (1983). Problems in the Palaeopathology of the Human Treponematoses, pp. 106–128 in G.D.Hart (ed.) *Disease in Ancient Man*. Clarke-Irwin, Toronto.

Hadler, N.M., Gillings, D.B., Imbus, H.R., Levitin, P.M., Makuc, D., Utsinger, P.O., Yount, W.J., Slusser, D. & Moskovitz, N. (1978). Hand Structure and Function in an Industrial Setting. *Arthritis & Rheumatism* 21: 210–220.

Hagelberg, E., Quevedo, S., Turbon, D. & Clegg, J.B. (1994). DNA from Ancient Easter Islanders. *Nature* 369: 25–26.

Hagelberg, E., Sykes, B. & Hedges, R. (1989). Ancient Bone DNA Amplified. *Nature* 342: 485.

Hager, L. (1996). Sex Differences in the Sciatic Notch of Great Apes and Modern Humans. *American Journal of Physical Anthropology* 99: 287–300.

Hanihara, T. (1992). Negritos, Australian Aborigines, and the 'Proto-Sundadont' Dental Pattern: The Basic Populations in East Asia, V. *American Journal of Physical Anthropology* 88: 183–196.

Hanihara, T. (1993). Population Prehistory of East Asia and the Pacific as Viewed From Craniofacial Morphology: The Basic Populations in East Asia, VII. *American Journal of Physical Anthropology* 91: 173–187.

Hanson, D.B. & Buikstra, J.E. (1987). Histomorphological Alteration in Buried Human Bone from the Lower Illinois Valley: Implications for Palaeodietary Research. *Journal of Archaeological Science* 14: 549–563.

Harman, M., Molleson, T.I. & Price, J.L. (1981). Burials, Bodies and Beheadings in Romano-British and Anglo-Saxon Cemeteries. *Bulletin of the British Museum of Natural History* 35: 145–188.

Harrison, R.J. (1980). *The Beaker Folk*. Thames & Hudson, London.

Hartsook, E.W. & Hershberger, T.V. (1973). Strontium-Calcium Discrimination During Placental Transfer and Foetal Uptake in Rats. *Proceedings of the Society for Experimental Biology and Medicine* 143: 343–349.

Hauser, G. & De Stefano, G.F. (1989). *Epigentic Variants of the Human Skull.* E.Schweizerbart'sche, Stuttgart.

Hayes, W.C., Myers, E.R., Morris, J.N., Gerhart, T.N., Yett, H.S. & Lipsitz, L.A. (1993). Impact Near the Hip Dominates Fracture Risk in Elderly Nursing Home Residents Who Fall. *Calcified Tissue International* 52: 192–198.

Henderson, J., Janaway, R. & Richards, J. (1987). A Curious Clinker. *Journal of Archaeological Science* 14: 353–365.

Hengen, O.P. (1971). Cribra Orbitalia: Pathogenesis and Probable Aetiology. *Homo* 22: 57–76.

Herrmann, B. & Grupe, G. (1988). Trace Element Content in Prehistoric Cremated Human Remains, pp. 91–101 in G. Grupe & B.Herrmann (eds) *Trace Elements in Environmental History.* Springer, Berlin.

Herrmann, B. & Hummel, S. (1994). Introduction, pp. 1–16 in B.Herrmann & S.Hummel (eds) *Ancient DNA.* Springer, Berlin.

Herrmann, B. & Newesley, H. (1982). Dekompositionsvorgänge des Knochens unter langer Liegerzeit. 1. die mineralische Phase. *Anthropologischer Anzeiger* 40: 19–31.

Higuchi, T. (1986). Relationships Between Japan and Asia in Ancient Times: Introductory Comments, pp. 121–125 in R.J. Pearson, G.L.Barnes & K.L.Hutterer (eds) *Windows on the Japanese Past: Studies in Archaeology and Prehistory.* Center for Japanese Studies, Ann Arbor.

Hillson, S. (1986). *Teeth.* Cambridge University Press, Cambridge.

Hillson, S. (1992). Dental Enamel Growth, Perikymata and Hypoplasia in Ancient Tooth Crowns. *Journal of the Royal Society of Medicine* 85: 460–466.

Holcomb, R.C. (1935). The Antiquity of Syphilis. *Medical Life* 42: 275–325.

Horai, S., Hayasaka, K., Murayama, K., Wate, N., Koike, H. & Nakai, N. (1989). DNA Amplification from Ancient Human Skeletal Remains and their Sequence Analysis. *Proceedings of the Japanese Academy, Series B* 65: 229–233.

Höss, M., Jaruga, P., Zastawny, T.H., Dizdaroglu, M. & Pääbo, S. (1996). DNA Damage and DNA Sequence Retrieval from Ancient Tissues. *Nucleic Acids Research* 24: 1304–1307.

Höss, M. & Pääbo, S. (1993). DNA Extraction From Pleistocene Bones by a Silica-Based Purification Method. *Nucleic Acids Research* 21: 3913–3914.

Howells, W.W. (1969). Criteria for Selection of Osteometric Dimensions. *American Journal of Physical Anthropology* 30: 451–458.

Howells, W.W. (1973). *Cranial Variation in Man. A Study by Multivariate Analysis of Patterns of Difference Among Recent Human Populations.* Papers of the Peabody Museum, No. 67, Harvard University Press, Cambridge.

Huard, P. & Montagne, M. (1950). Le Squelette Humain et L'attitude Accroupie. *Bulletin de la Societe des Etudes Indochinoises* 25: 401–426.

Hummel, S. & Herrmann, B. (1995). aDNA Analysis in Palaeopathology: Mini-Review and Prospects. *Palaeopathology Newsletter* 91: 6–9.

Hummel, S. & Schutkowski, H. (1986). Das Verhalten von Knochengewebe unter dem Einfluss höherer Temperaturen. Bedeutung für die Leichenbranddiagnose. *Zeitschrift für Morphologie und Anthropologie* 77: 1–9.

Inglemark, B. (1939). The Skeletons, pp. 149–205 in B. Thordemann (ed.) *Armour from the Battle of Wisby, 1361.* Vitterhets Historic och Antikvitets Akademien, Stockholm.

Irish, J.D., Pereira da Silva, M.A. & Cussenot, O. (1993). Hard Tissue Regeneration of a Gunshot Wound in a Historic North African Skull: A Palaeopathological Perspective. *Journal of Palaeopathology* 5: 135–141.

Iscan, M.Y., Loth, S.R. & Wright, R.K. (1984). Metamorphosis at the Sternal Rib End: A New Method to Estimate Age at Death in White Males. *American Journal of Physical Anthropology* 65: 147–156.

Iscan, M.Y., Loth, S.R. & Wright, R.K. (1985). Age Estimation from the Rib by Phase Analysis: White Females. *Journal of Forensic Sciences* 30: 853–863.

Jackson, R. (1988). *Doctors and Diseases in the Roman Empire.* British Museum Press, London.

Janaway, R.C. (1987). The Preservation of Organic Materials in Association with Metal Artifacts Deposited in Inhumation Graves, pp. 127–148 in A.Boddington, A.N.Garland & R.C.Janaway (eds) *Death, Decay and Reconstruction.* Manchester University Press, Manchester.

Jee, W. (1988). Bone, in L.Weiss (ed.) *Cell and Tissue Biology* (6th edition). Urban & Schwartzenberg, Baltimore.

Jones, H.H., Priest, J.D., Hayes, W.C., Tichenor, C.C. & Nagel, D.A. (1977). Humeral Hypertrophy in Response to Exercise. *Journal of Bone and Joint Surgery* 59A: 204–208.

Julkunen, H., Heinonen, O.P. & Pyorala, K. (1971). Hyperostosis of the Spine in an Adult Population. *Annals of the Rheumatic Diseases* 30: 605–612.

Kagawa, M. (1973). Primitive Agriculture in Japan: Latest Jomon Agricultural Society and Means of Production. *Asian Perspectives* 16: 1–15.

Kanaseki, H. (1986). The Evidence for Social Change Between the Early and Middle Yayoi, pp. 317–333 in R.J.Pearson, G.L. Barnes & K.L.Hutterer (eds) *Windows on the Japanese Past: Studies in Archaeology and Prehistory.* Center for Japanese Studies, Ann Arbor.

Katz, D. & Suchey, J.M. (1986). Age Determination of the Male Os Pubis. *American Journal of Physical Anthropology* 69: 427–435.

Keegan, W.F. & Butler, B.M. (1987). The Microeconomic Logic of Horticultural Intensification in the Eastern Woodlands, pp. 109–127 in W.F.Keegan (ed.) *Emergent Horticultural Communities of the Eastern Woodlands.* Center for Archaeological Investigations, Occasional Paper No. 7, Carbondale.

Keeley, H. (n.d.). Wharram Percy, Yorkshire, Soil Report. Manuscript on file at AML, English Heritage.

Keiley, F. (1989). On-Site Recovery of Human Bones. Paper presented at the one-day meeting of the Palaeopathology Society (British Section), May.

Kelley, M.A., Levesque, D.R. & Weidl, E. (1991). Contrasting Patterns of Dental Disease in Five Early Northern Chilean Groups, pp. 203–213 in M.A.Kelley & C.S.Larsen (eds) *Advances in Dental Anthropology.* Wiley-Liss, Chichester.

Kelley, M.A. & Micozzi, M.S. (1984). Rib Lesions in Chronic Pulmonary Tuberculosis. *American Journal of Physical Anthropology* 65: 381–386.

Kennedy, G.E. (1986). The Relationship Between Auditory Exostoses and Cold Water: A Latitudinal Analysis. *American Journal of Physical Anthropology* 71: 401–415.

Kennedy, K.A.R. (1989). Skeletal Markers of Occupational Stress, pp. 129–160 in M.Y.Iscan & K.A.R.Kennedy (eds) *Reconstruction of Life From the Skeleton*. Liss, New York.

Kent, S. (1986). The Influence of Sedentism and Aggregation on Porotic Hyperostosis and Anaemia: A Case Study. *Man* 21: 605–636.

Kent, S. & Dunn, D. (1996). Anaemia and the Transition of Nomadic Hunter-Gatherers to a Sedentary Life-Style: Follow-Up Study of a Kalahari Community. *American Journal of Physical Anthropology* 99: 455–472.

Kent, S., Weinberg, E.D. & Stuart-Macadam, P. (1994). The Etiology of the Anaemia of Chronic Disease and Infection . *Journal of Clinical Epidemiology* 47: 23–33.

Key, C.A., Aiello, L.C. & Molleson, T. (1994). Cranial Suture Closure and its Implications for Age Estimation. *International Journal of Osteoarhaeology* 4: 193–207.

Kieser, J.A., Preston, C.B. & Evans, W.G. (1983). Skeletal Age at Death: an Evaluation of the Miles Method of Ageing. *Journal of Archaeological Science* 10: 9–12.

Kinnes, I. (1992). *Non-Megalithic Long Barrows and Allied Structures in the British Neolithic.* British Museum Occasional Paper No. 52. British Museum, London.

Kobyliansky, E. (1983). Changes in Cephalic Morphology of Israelis Due to Migration. *Journal of Human Evolution* 12: 779–786.

Kohn, L.A.P. (1991). The Role of Genetics in Craniofacial Morphology and Growth. *Annual Review of Anthropology* 20: 261–278.

Kostial, K., Gruden, N. & Durakovic, A. (1969). Intestinal Absorbtion of Calcium-47 and Strontium-85 in Lactating Rats. *Calcified Tissue Research* 4: 13–19.

Kozintsev, A. (1990). Ainu, Japanese, Their Ancestors and Neighbours. *Journal of the Anthropological Society of Nippon* 98: 247–267.

Kroeber, A.L. (1927). Disposal of the Dead. *American Anthropologist* 29: 308–315.

Lambert, J.B., Simpson, S.V., Weiner, S.G. & Buikstra, J.E. (1985). Induced Metal Ion Exchange in Excavated Human Bone. *Journal of Archaeological Science* 12: 85–92.

Lambert, J.B., Vlasak, S.M., Thometz, A.C. & Buikstra, J.E. (1982). A Comparative Study of the Chemical Analysis of Ribs and Femurs in Woodland Populations. *American Journal of Physical Anthropology* 59: 289–294.

Langer, W.L. (1974). Infanticide: A Historical Survey. *History of Childhood Quarterly* 1(3): 353–365.

Larsen, C.S., Shavit, R. & Griffen, M.C. (1991). Dental Caries Evidence for Dietary Change: An Archaeological Context, pp. 179–202 in M.A.Kelley & C.S.Larsen (eds) *Advances in Dental Anthropology*. Wiley-Liss, Chichester.

Levesque, G.-Y., Demirjian, A. & Tanguay, R. (1981). Sexual Dimorphism in the Development, Emergence and Agenesis of the Mandibular Third Molar. *Journal of Dental Research* 60: 1735–1741.

Lewis, A.B. & Garn, S.M. (1960). The Relationship Between Tooth Formation and Other Maturational Factors. *The Angle Orthodontist* 30: 70–77.

Libby, W.F. (1955). *Radiocarbon Dating* (2nd edition). University of Chicago Press, Chicago.

Lindsay, W.L. (1979). *Chemical Equilibria in Soils*. Wiley, New York.

Liversage, H.M. (1994). Accuracy of Age Estimation from Developing Teeth of a Population of Known Age (0 to 5.4 years). *International Journal of Osteoarhaeology* 4: 37–45.

Lovejoy, C.O. & Heiple, K.G. (1981). The Analysis of Fractures in Skeletal Populations with an Example from the Libben Site, Ottowa County, Ohio. *American Journal of Physical Anthropology* 55: 529–541.

Lovejoy, C.O., Meindl, R.S., Pryzbeck, T.R. & Mensforth, R.P. (1985a). Chronological Metamorphosis of the Auricular Surface of the Ilium: A New Method of Determining Adult Age at Death. *American Journal of Physical Anthropology* 68: 15–28.

Lovejoy, C.O., Meindl, R.S., Mensforth, R.P. & Barton, T.J. (1985b). Multifactorial Determination of Skeletal Age at Death: A Method and Blind Tests of its Accuracy. *American Journal of Physical Anthropology* 68: 1–14.

Lucy, D., Pollard, A.M. & Roberts, C.A. (1995). A Comparison of Three Dental Techniques for Estimating Age at Death in Humans. *Journal of Archaeological Science* 22: 417–428.

Lynch, B.M. & Jefferies, R.W. (1982). A Comparative Analysis of Nitrogen Content of Bone as a Means of Establishing a Relative Temporal Ordination of Prehistoric Burials. *Journal of Archaeological Science* 9: 381–390.

Lynott, M.J., Boutton, T.W., Price, J.E. & Nelson, D.E. (1986). Stable Carbon Isotope Evidence for Maize Agriculture in Southeast Missouri and Northeast Arkansas. *American Antiquity* 51: 51–65.

MacDonald, J.L. (1979). Religion, pp. 406–433 in G.Clarke (ed.) *The Roman Cemetery at Lankhills*. Clarendon, Oxford.

MacDonald, N.S., Noyes, P. & Lorick, P.C. (1957). Discrimination of Calcium and Strontium by the Kidney. *American Journal of Physiology* 188: 131–136.

McGrath, J.W., Cheverud, J.M. & Buikstra, J.E. (1984). Genetic Correlations Between Sides and Heritability of Asymmetry for Non-Metric Traits in Rhesus Macaques on Cayo Santiago. *American Journal of Physical Anthropology* 64: 401–411.

McKern, T.W. & Stewart, T.D. (1957). *Skeletal Age Changes in Young American Males*. Quartermaster Research and Development Command, Natick.

McKinley, J.I. (1993). Bone Fragment Size and Weights of Bone from Modern British Cremations and the Implications for the Interpretation of Archaeological Cremations. *International Journal of Osteoarchaeology* 3: 283–287.

McKinley, J.I. (1994). *Spong Hill. Part VIII, The Cremations.* East Anglian Archaeology Report No. 69.

Mainfort, R.C. (1985). Wealth, Space and Status in a Historic Indian Cemetery. *American Antiquity* 50: 555–579.

Malinowski, A. & Porawski, R. (1969). Identificationsmöglichkeiten menschlicher Brandknochen mit besonderer Berucksichtigung ihres Gewichters. *Zacchia* 5: 392–410.

Manchester, K. (1983a). *The Archaeology of Disease.* Bradford University Press, Bradford.

Manchester, K. (1983b). Secondary Cancer in an Anglo-Saxon Female. *Journal of Archaeological Science* 10: 475–482.

Mann, R.W. & Murphy, S.P. (1990). *Regional Atlas of Bone Disease.* Charles C.Thomas, Springfield.

Mant, A.K. (1987). Knowledge Acquired from Post-War Exhumations, pp. 65–78 in A.Boddington, A.N.Garland & R.C. Janaway (eds) *Death, Decay and Reconstruction*. Manchester University Press, Manchester.

Marchiafava, V., Bonucci, L. & Ascenzi, A. (1974). Fungal Osteoclasia: A Model of Dead Bone Resorption. *Calcified Tissue Research* 14: 195–210.

Maresh, M.M. (1955). Linear Growth of the Long Bones of the Extremities from Infancy Through Adolescence. *American Journal of Diseases in Children* 89: 725–742.

Marshall, T.K. (1976). Changes After Death, pp. 78–100 in F.E. Camps (ed.) *Gradwohl's Legal Medicine* (3rd edition). John Wright, Bristol.

Martin, R. (1928). *Lehrbuch der Anthropologie in Systematischer Darstellung*. Fischer, Jena.

Masset, C. (1989). Age Estimation on the Basis of Cranial Sutures, pp. 71–103 in M.Y.Iscan (ed.) *Age Markers in the Human Skeleton*. Charles C.Thomas, Springfield.

Masters, P.M. (1987). Preferential Preservation of Non-Collagenous Protein During Bone Diagenesis: Implications for Chronometric and Stable Isotope Measurements. *Geochimica et Cosmochimica Acta* 51: 3209–3214.

Mays, S.A. (1987). Social Organisation and Social Change in the Early and Middle Bronze Age of Central Europe: A Study Using Human Skeletal Remains. Ph. D. Thesis , University of Southampton.

Mays, S.A. (1989). *The Anglo-Saxon Human Bone from School Street, Ipswich, Suffolk*. AML Report 115/89. English Heritage, London.

Mays, S.A. (1991). *The Mediaeval Burials from the Blackfriars Friary, School Street, Ipswich, Suffolk*. AML Report 16/91. English Heritage, London.

Mays, S.A. (1992a). *Anglo-Saxon Human Remains from Mucking, Essex*. AML Report 18/92. English Heritage, London.

Mays, S. (1992b). Taphonomic Factors in a Human Skeletal Assemblage. *Circaea* 9: 54–58.

Mays, S. (1993a). Infanticide in Roman Britain. *Antiquity* 67: 883–888.

Mays, S. (1993b). *The Human Bone from Godmanchester, Cambridgeshire (1988–92 Excavations)*. AML Report 39/93. English Heritage, London.

Mays, S. (1995a). Killing the Unwanted Child. *British Archaeology* 2: 8–9.

Mays, S. (1995b). The Relationship Between Harris Lines and Other Aspects of Skeletal Development in Adults and Juveniles. *Journal of Archaeological Science* 22: 511–520.

Mays, S.A. (1996). Age-Dependent Cortical Bone Loss in a Mediaeval Population. *International Journal of Osteoarchaeology* 6: 144–154.

Mays, S. (forthcoming). The Radiography of Human Skeletal Remains, in M.Corfield (ed.) *The Radiography of Archaeological Materials*. English Heritage, London.

Mays, S., de la Rua, C. & Molleson, T. (1995). Molar Crown Height as a Means of Evaluating Existing Wear Scales for Estimating Age at Death in Human Skeletal Remains. *Journal of Archaeological Science* 22: 659–670.

Meadow, R.H. (1980). Animal Bones: Problems for the Archaeologist Together With Some Possible Solutions. *Paleorient* 6: 65–77.

Meindl, R.S., Lovejoy, C.O., Mensforth, R.P. & Carlos, L.D. (1985). Accuracy and Direction of Error in the Sexing of the Skeleton. *American Journal of Physical Anthropology* 68: 79–85.

Mensforth, R.P. & Lovejoy, C.O. (1985). Anatomical, Physiological and Epidemiological Correlates of the Aging Process: A Confirmation of Multifactorial Age Determination in the Libben Skeletal Population. *American Journal of Physical Anthropology* 68: 87–106.

Mensforth, R.P., Lovejoy, C.O., Lallo, J.W. & Armelagos, G.J. (1978). The Role of Constitutional Factors, Diet and Infectious Disease in the Etiology of Porotic Hyperostosis and Periosteal Reactions in Prehistoric Infants and Children. *Medical Anthropology* 2(1): 1–59.

Mercer, R.J. (1980). *Hambledon Hill: A Neolithic Landscape*. Edinburgh University Press, Edinburgh.

Mercer, R.J. (1988). Hambledon Hill, Dorset, England, pp. 89– 106 in C.Burgess, P.Topping, C.Mordant & M.Maddison (eds) *Enclosures and Defences in the Neolithic of Western Europe*. British Archaeological Reports, International Series, No. 403(i). Tempus Reparatum, Oxford.

Miles, A.E.W. (1963). The Dentition in the Assessment of Individual Age in Skeletal Material, pp. 191–209 in D.R. Brothwell (ed.) *Dental Anthropology*. Pergamon, Oxford.

Miller, C.W. (1978). Survival and Ambulation Following Hip *Fracture*. *Journal of Bone and Joint Surgery* 60A: 930–934.

Molleson, T. (1991). Demographic Implications of the Age Structure of Early English Cemetery Samples. *Actes des Journees Anthropologiques* 5: 113–121.

Molleson, T. (1993). The Human Remains, pp. 142–214 in D.E. Farwell & T.I.Molleson, *Excavations at Poundbury 1966–80. Volume II: The Cemeteries*. Dorset Natural History & Archaeology Society Monograph Series Number 11. Dorset Natural History and Archaeology Society, Dorchester.

Molleson, T. (1995). Rates of Ageing in the Eighteenth Century, pp. 199–222 in S.Saunders & A.Herring (eds) *Grave Reflections*. Canadian Scholars' Press, Toronto.

Molleson, T. (n.d.). Unpublished data on non-metric traits at Spitalfields, London.

Molleson, T. & Cox, M. (1993). *The Spitalfields Project. Volume 2: The Anthropology*. CBA Research Report 86. Council for British Archaeology, York.

Moore, W.J. & Corbett, M.E. (1975). Distribution of Dental Caries in Ancient British Populations: III. The 17th Century. *Caries Research* 9: 163–175.

Moore, W.J. & Corbett, M.E. (1978). Dental Caries Experience in Man, pp. 3–19 in N.H.Rowe (ed.) *Diet, Nutrition and Dental Caries*. University of Michigan School of Dentistry & the Dental Research Institute, Chicago.

Moore, W.J., Lavelle, C.L.B. & Spence, T.F. (1968). Changes in the Size and Shape of the Human Mandible in Britain. *British Dental Journal* 125: 163–169.

Morant, G.M. (1950). Secular Changes in the Heights of British People. *Proceedings of the Royal Society of London* 137B: 443–452.

Mörmann, J.E. & Mühlemann, H.R. (1981). Oral Starch Degradation and its Influence on Acid Production in Human Dental Plaque. *Caries Research* 15: 166–175.

Morris, A.G. & Rodgers, A.L. (1989). A Probable Case of Prehistoric

Kidney Stone Disease from the Northern Cape Province, South Africa. *American Journal of Physical Anthropology* 79: 521–527.

Müller-Karpe, H. (1980). *Handbuch der Vorgeschichte. IV: Bronzezeit*. C.H.Beck, Munich.

Mullis, K.B. & Faloona, F.A. (1987). Specific Synthesis of DNA in-vitro via a Polymerase-Catalysed Chain Reaction. *Methods in Enzymology* 155: 335–350.

Murray, M.L. & Schoeninger, M.J. (1988). Diet, Status and Complex Social Structure in Iron Age Central Europe: Some Contributions of Bone Chemistry, pp. 155–176 in D.B.Gibson & M.N.Geselowitz (eds) *Tribe and Polity in Late Prehistoric Europe*. Plenum, New York.

Musher, D.M. (1990). Biology of Treponema Pallidum, pp. 205– 211 in K.K.Holmes, P.-A.Mardh, P.F.Sparling & P.J. Wiesner (eds) *Sexually Transmitted Diseases* (2nd edition). McGraw-Hill, London.

Nakahashi, T. (1993). Temporal Craniometric Changes from the Jomon to the Modern Period in Western Japan. *American Journal of Physical Anthropology* 90: 409–425.

Nassaney, M.S. (1987). On the Causes and Consequences of Subsistence Intensification in the Mississippi Alluvial Valley, pp. 129–150 in W.F.Keegan (ed.) *Emergent Horticultural Economies of the Eastern Woodlands*. Center for Archaeological Investigations, Occasional Paper No. 7, Carbondale.

Nation, W.A., Matsson, L. & Peterson, J.E. (1987). Developmental Enamel Defects of the Primary Dentition in a Group of Californian Children. *Journal of Dentistry for Children* 4: 330–334.

Nelson, B.K., DeNiro, M.J., Schoeninger, M.J., & De Paulo, D.J. (1986). Effects of Diagenesis on Strontium, Carbon, Nitrogen and Oxygen Concentration and Isotopic Composition of Bone. *Geochimica et Cosmochimica Acta* 50: 1941–1949.

Nemeskeri, J., Harsanyi, L. & Acsadi, G. (1960). Methoden zur Diagnose der Lebensalters von Skelettfunden. *Anthropologischer Anzieger* 24: 70–95.

Newbrunn, E. (1982). Sugar and Dental Caries: A Review of Human Studies. *Science* 217: 418–423.

Newman, M.T. (1953). The Application of Ecological Rules to the Racial Anthropology of the Aboriginal New World. *American Anthropologist* 55: 311–327.

Nicholson, R. (1993). A Morphological Investigation of Burnt Animal Bone and an Evaluation of its Utility in Archaeology. *Journal of Archaeological Science* 20: 411–428.

Nowell, G.W. (1978). An Evaluation of the Miles Method of Ageing Using the Tepe Hissar Dental Sample. *American Journal of Physical Anthropology* 49: 271–267.

O'Leary, M.H. (1981). Carbon Isotope Fractionation in Plants. *Phytochemistry* 20: 553–567.

O'Leary, M.H. (1988). Carbon Isotopes in Photosynthesis. *BioScienc*e 38: 328–336.

Oota, H., Saitou, N., Matsushita, T. & Ueda, S. (1995). A Genetic Study of 2,000 Year Old Human Remains from Japan Using Mitochondrial DNA Sequences. *American Journal of Physical Anthropology* 98: 133–145.

O'Rahilly, R. (1953). A Survey of Carpal and Tarsal Anomalies. *Journal of Bone & Joint Surgery* 35A: 626–642.

Oranje, P., Noriskin, N. & Osborn, T.W.B. (1935). The Effect of Diet Upon Dental Caries in the South African Bantu. *South African Journal of Medical Sciences* 1: 57–62.

Ortner, D.J. (1991). Theoretical and Methodological Issues in Paleopathology, pp. 5–11 in D.J.Ortner & A.C.Aufderheide (eds) *Human Paleopathology, Current Syntheses and Future Options*. Smithsonian Institution Press, Washington.

Ortner, D.J. & Putschar, W.G.J. (1985*). Identification of Pathological Conditions in Human Skeletal Remains*. Smithsonian Institution Press, Washington.

Ortner, D.J., Tuross, N. & Stix, A.I. (1992). New Approaches to the Study of Disease in Archaeological New World Populations. *Human Biology* 64: 337–360.

Ossenberg, N.S. (1976). Within and Between Race Distances in Population Studies Based on Discrete Traits of the Human Skull. *American Journal of Physical Anthropology* 45: 701–716.

Palfi, G., Dutour, O., Borreani, M., Brun, J.-P. & Berato, J. (1992). Pre-Columbian Congenital Syphilis from the Late Antiquity in France. *International Journal of Osteoarchaeology* 2: 245–261.

Parise Badoni, F. & Ruggeri Giove, M. (1980). *Alfedena. La Necropoli di Campo Consolino. Scavi 1974– 79*. Soprintendenza Archeologica dell'Abruzzo, Chieti.

Parker, M.J. & Pryor, G.A. (1993). Mortality and Morbidity After Hip Fractures. *British Medical Journal* 307: 1248–1250.

Patterson, C.C., Shirahata, H. & Ericson, J.E. (1987). Lead in Ancient Human Bones and its Relevance to Historical Developments and Social Problems with Lead. *Science of the Total Environment* 61: 167–200.

Payne, S. (1972). Partial Recovery and Sample Bias: The Results of Some Sieving Experiments, pp. 49–64 in E.S.Higgs (ed.) *Papers in Economic Prehistory*. Cambridge University Press, Cambridge.

Pearson, G.W., Pilcher, J.R., Baillie, M.G.L., Corbett, D.M. & Qua, F. (1986). High Precision C-14 Measurement of Irish Oaks to Show the Natural C-14 Variations from AD 1840– 5210 BC. *Radiocarbon* 28: 911–934.

Pearson, R.J. (1986). Prehistory, Culture History and Society: Introduction, pp. 181–184 in R.J.Pearson, G.L.Barnes & K.L.Hutterer (eds) *Windows on the Japanese Past: Studies in Archaeology and Prehistory*. Center for Japanese Studies, Ann Arbor.

Pedersen, P.O. (1947). Dental Investigations of Greenland Eskimos. *Proceedings of the Royal Society of Medicine* 40: 726–732.

Perizonius, W.R.K. (1979). Non-Metric Cranial Traits: Symmetry and Side Difference. *Proceedings of the Koninklijke Nederlandse Akademie van Wettenschappen, Series C* 82: 91–112.

Perzigian, A.J. (1976). The Dentition of the Indian Knoll Skeletal Population: Odontometrics and Cusp Number. *American Journal of Physical Anthropology* 44: 113–121.

Phenice, T.W. (1969). A Newly Developed Visual Method of Sexing the Os Pubis. *American Journal of Physical Anthropology* 30: 297–302.

Philpott, R. (1991). *Burial Practices in Roman Britain*. British Archaeological Reports, British Series, No. 219. Tempus Reparatum, Oxford.

Piggott, S. (1962). *The West Kennet Long Barrow Excavations 1955–56*. HMSO, London.

Pindborg, J.J. (1970). *Pathology of the Dental Hard Tissues*. Munksgaard, Copenhagen.

Pindborg, J.J. (1982). Aetiology of Developmental Enamel Defects not Related to Fluorosis. *International Dental Journal* 32: 123–134.

Piontek, J. (1976). The Process of Cremation and its Influence on the Morphology of Bones in the Light of Results from Experimental Research. *Archaeologica Polski* 21: 254–280.

Pitrusewsky, M. (1972). Application of Distance Statistics to Anthroposcopic Data, and the Comparison of Results with those Using Discrete Traits of the Skull. *Archaeology & Physical Anthropology in Oceania* 6: 21–33.

Poinar, H.N., Höss, M., Bada, J.L. & Pääbo, S. (1996). Amino Acid Racemisation and the Preservation of Ancient DNA. *Science* 272: 864–866.

Posner, A.S. (1969). Crystal Chemistry of Bone Mineral. *Physiological Reviews* 49: 760–792.

Powell, M.L. (1991). Ranked Status and Health in the Mississippian Chiefdom at Moundville, pp. 22–51 in M.L.Powell, P.S. Bridges & A.M.Wagner-Mires (eds) *What Mean These Bones? Studies in Southeastern Bioarchaeology*. University of Alabama Press, Tuscaloosa.

Price, T.D., Swick, R.W. & Chase, E.P. (1986). Bone Chemistry and Prehistoric Diet: Strontium Studies of Laboratory Rats. *American Journal of Physical Anthropology* 70: 365–375.

Putnam, G. (1984). The Human Bones, pp. 15–17 in C. Hills, K. Penn & R.Rickett (eds) *The Anglo-Saxon Cemetery at Spong Hill, North Elmham Part III: Catalogue of Inhumations*. East Anglian Archaeology Report No. 21, Norfolk Archaeological Unit, Norwich.

Pyle, S.I. & Hoerr, N.L. (1955). *Radiographic Atlas of Skeletal Development of the Knee*. Charles C.Thomas, Springfield.

Radin, E.L., Paul, I.L. & Rose, R.M. (1980). Osteoarthrosis as a Final Common Pathway, pp. 84–89 in G.Nuki (ed.) *The Aetiopathogenesis of Osteoarthrosis*. Pitman Medical, London.

Radosevich, S.C. (1993). The Six Deadly Sins of Trace Element Analysis: A Case of Wishful Thinking in Science, pp. 269–332 in M.K.Sandford (ed.) *Investigations of Ancient Human Tissue*. Gordon & Breach, Reading.

Rao, P.D.P. (1966). Squatting Facets on the Talus and Tibia in Australian Aborigines. *Archaeology & Physical Anthropology in Oceania* 1: 51–56.

Reichs, K.J. (1989). Treponematosis: A Possible Case from the Late Prehistoric of North Carolina. *American Journal of Physical Anthropology* 79: 289–303.

Reinhard, K.J. (1988). The Ecology of Prehistoric Parasitism on the Colorado Plains. *American Journal of Physical Anthropology* 77: 355–366.

Reinhard, K.J. (1992). Patterns of Diet, Parasitism and Anaemia in Prehistoric West North America, pp. 219–258 in P. StuartMacadam & S.Kent (eds) *Diet, Demography and Disease: Changing Perspectives on Anaemia*. Aldine, New York.

Renfrew, C. (1973). *Before Civilisation*. Penguin, Harmondsworth.

Renfrew, C. (1992). Archaeology, Genetics and Linguistic Diversity. *Man* 27: 445–478.

Resnick, D. & Niwayama, G. (1988). *Diagnosis of Bone and Joint Disorders* (2nd edition). W.B.Saunders, London.

Revell, P.A. (1986). *Pathology of Bone*. Springer, Berlin.

Reynolds, E.L. (1947). The Bony Pelvis in Prepubertal Childhood. *American Journal of Physical Anthropology* 5: 165–200.

Richards, L.C. & Miller, S.L.J. (1991). Relationships Between Age and Dental Attrition in Australian Aboriginals. *American Journal of Physical Anthropology* 84: 159–164.

Richards, M., Smalley, K., Sykes, B. & Hedges, R. (1993). Archaeology and Genetics: Analysing DNA from Skeletal Remains. *World Archaeology* 25: 18–28.

Richards, M.B., Sykes, B.C. & Hedges, R.E.M. (1995). Authenticating DNA Extracted from Ancient Skeletal Remains. *Journal of Archaeological Science* 22: 291–299.

Richards, M., Corte-Real, H., Forster, P., Macauley, V., Wilkinson-Herbots, H., Demaine, A., Papiha, S., Hedges, R., Bandelt, H.-J. & Sykes, B. (1996). Paleolithic and Neolithic Lineages in the European Mitochondrial Gene Pool. *American Journal of Human Genetics* 59: 185–203.

Rightmire, G.P. (1976). Metric Versus Discrete Traits in African Skulls, pp. 383–407 in E.Giles & J.S. Friedlaender (eds) *The Measures of Man: Methodologies in Biological Anthropology*. Peabody Press, New York.

Roberts, C. (1994). Treponematosis in Gloucester, England: A Theoretical and Practical Approach to the Precolumbian Theory, pp. 101–108 in O.Dutour, G.Palfi, J.Berato & J.-P, Brun (eds) *L'Origine de la Syphilis En Europe, Avant ou Apres 1493?*. Editions Errance, Centre Archeologiques du Var.

Roberts, C. & Manchester, K. (1995). *The Archaeology of Disease* (2nd edition). Alan Sutton, Stroud.

Roberts, C. & Wakely, J. (1992). Microscopical Findings Associated with the Diagnosis of Osteoporosis in Palaeopathology. *International Journal of Osteoarchaeology* 2: 23–30.

Rogers, J. (1989). Palaeorheumatology, p. 289 in C.Roberts, F. Lee and J.Bintliff (eds) *Burial Archaeology*. British Archaeological Reports, British Series, No. 211. British Archaeological Reports, Oxford.

Rogers, J., Waldron, T., Dieppe, P. & Watt, I. (1987). Arthropathies in Palaeopathology: The Basis of Classification According to Most Probable Cause. *Journal of Archaeological Science* 14: 179–193.

Rösing, F.W. (1982). Discreta des Menschlichen Skeletts—ein Critischer Uberblick. *Homo* 33: 100–125.

Rösing, F.W. & Schwidetzky, I. (1984). Comparative Statistical Studies on the Physical Anthropology of the Late Mediaeval Period (AD 1000–1500). *Journal of Human Evolution* 13: 325–329.

Rothschild, B.M. (1992). Advances in Detecting Disease in Earlier Human Populations, pp. 131–151 in S.R.Saunders & M.A.Katzenberg (eds) *Skeletal Biology of Past Peoples: Research Methods*. Wiley-Liss, Chichester.

Runia, L.T. (1987a). Strontium and Calcium Distribution in Plants: Effect on Palaeodietary Studies. *Journal of Archaeological Science* 14: 599–608.

Runia, L.T. (1987b). *The Chemical Analysis of Prehistoric Bones*. British Archaeological Reports, International Series, No. 363. Tempus Reparatum, Oxford.

Russell, F. (1900). Studies in Cranial Variation. *American Naturalist* 34: 737–745.

Russell, J.C. (1937). Length of Life in England 1250–1348. *Human Biology* 9: 528–541.

Russell, J.C. (1948). *British Medieval Population*. University of New Mexico Press, Albuquerque.

Salzano, F.M., Callegari, J., Franco, M.H.L.P., Hutz, M.H., Weimer, R.S.S. & da Rocha, F.J. (1980). The Caingang Revisited: Blood Genetics and Anthropometry. *American Journal of Physical Anthropology* 53: 513–524.

Sandford, M.K. (ed.) (1993) *Investigations of Ancient Human Tissue.* Gordon & Breach, Reading.

Sandford, M.K. & Kissling, G.E. (1993). Chemical Analysis of Human Hair: Anthropological Applications, pp. 131–166 in M.K.Sandford (ed.) *Investigations of Ancient Human Tissue.* Gordon & Breach, Reading.

Saunders, S.R. (1989). Nonmetric Skeletal Variation, pp. 95–108 in M.Y.Iscan & K.A.R. Kennedy (eds) *Reconstruction of Life From the Skeleton.* Alan Liss, New York.

Saunders, S.R. (1992). Subadult Skeletons and Growth Related Studies, pp. 1–20 in S.R.Saunders & M.A.Katzenberg (eds) *Skeletal Biology of Past Peoples: Research Methods.* Wiley-Liss, Chichester.

Saunders, S.R., Fitzgerald, C., Rogers, T., Dudar, C. & McKillop, H. (1992). A Test of Several Methods of Skeletal Age Estimation Using a Documented Archaeological Sample. *Canadian Society of Forensic Science Journal* 25: 97–117.

Saunders, S.R. & Hoppa, R.D. (1993). Growth Deficit in Survivors and Non-Survivors: Biological Mortality Bias in Subadult Skeletal Samples. *Yearbook of Physical Anthropology* 36: 127–151.

Saunders, S.R. & Popovich, F. (1978). A Familial Study of Two Skeletal Variants: Atlas Bridging and Clinoid Bridging. *American Journal of Physical Anthropology* 49: 193–204.

Scheuer, J.L., Musgrave, J.H. & Evans, S.P. (1980). Estimation of Late Foetal and Perinatal Age from Limb Bone Lengths by Linear and Logarithmic Regression. *Annals of Human Biology* 7: 257–265.

Schoeninger, M.J. & DeNiro, M.J. (1984). Nitrogen and Carbon Isotopic Composition of Bone Collagen from Marine and Terrestrial Animals. *Geochimica et Cosmochimica Acta* 48: 625–639.

Schoeninger, M.J., DeNiro, M.J. & Tauber, H. (1983). Stable Nitrogen Isotope Ratios of Bone Collagen Reflect Marine and Terrestrial Components of Prehistoric Diet. *Science* 220: 1381–1383.

Schoeninger, M.J., van der Merwe, N.J., Moore, K., Lee-Thorpe, J. & Larsen, C.S. (1990). Decrease in Diet Quality Between Prehistoric and Contact Periods, pp. 78–93 in C.S.Larsen (ed.) *The Archaeology of Mission Santa Catalina De Guale: 2. Biocultural Interpretations of a Population in Transition.* Anthropological Papers of the American Museum of Natural History No. 68. American Museum of Natural History, New York.

Schroeder, H.A. & Tipton, I.H. (1968). The Human Body Burden of Lead. *Archives of Environmental Health* 17: 965–978.

Schroeder, H.A., Tipton, I.H. & Nason, A.P. (1972). Trace Metals in Man: Strontium and Barium. *Journal of the Chronic Diseases* 25: 491–517.

Schultz, A.H. (1967). Notes on Diseases and Healed Fractures of Wild Apes, pp. 47–55 in D.R.Brothwell & A.T.Sandison (eds) *Diseases in Antiquity.* Charles C.Thomas, Springfield.

Schurr, M.R. & Redmond, B.G. (1991). Stable Isotope Analysis of Incipient Maize Horticulturalists from the Gard 2 Site. *Mid-continental Journal of Archaeology* 16: 69–84.

Schwarcz, H.P. & Schoeninger, M.J. (1991). Stable Isotope Analyses in Human Nutritional Ecology. *Yearbook of Physical Anthropology* 34; 283–321.

Scott, J.H. (1957). Muscle Growth and Function in Relation to Skeletal Morphology. *American Journal of Physical Anthropology* 15: 197–234.

Scrimshaw, S.C.M. (1984). Infanticide in Human Populations: Societal and Individual Concerns, pp. 439–462 in G.Hausfeter & S.B.Hardy (eds) *Infanticide.* Aldine, Hawthorne.

Sealy, J.C., van der Merwe, N.J., Lee-Thorpe, J.A. & Lanham, J.L. (1987). Nitrogen Isotopic Ecology in Southern Africa: Implications for Environmental and Dietary Tracing. *Geochimica et Cosmochimica Acta* 51: 2707–2717.

Sealy, J.C., van der Merwe, N.J., Sillen, A., Kruger, F.J. & Krueger, H.W. (1991). $^{87}$Sr/$^{86}$Sr as a Dietary Indicator in Modern and Archaeological Bone. *Journal of Archaeological Science* 18: 399–416.

Searle, A.G. (1954). Genetical Studies on the Skeleton of the Mouse XI. The Influence of Diet on Variation Within Pure Lines. *Journal of Genetics* 52: 413–424.

Self, S.G. & Leamy, L. (1978). Heritability of Quasi-Continuous Skeletal Traits in a Randombred Population of House Mice. *Genetics* 88: 109–120.

Shafer, W.G., Hine, M.K. & Levy, B.M. (1983). *A Textbook of Oral Pathology* (4th edition). W.B.Saunders, London.

Shaw, J.H. (1954). The Effect of Carbohydrate-Free and Carbohydrate-Low Diets on the Incidence of Dental Caries in White *Rats. Journal of Nutrition* 53: 151–162.

Shinoda, K. & Kunisada, T. (1994). Analysis of Ancient Japanese Society Through Mitochondrial DNA Sequencing *International Journal of Osteoarchaeology* 4: 291–297.

Shipman, P., Foster, G. & Schoeninger, M. (1984). Burnt Bones and Teeth: An Experimental Study of Colour, Morphology, Crystal Structure and Shrinkage. *Journal of Archaeological Science* 11: 307–325.

Sillen, A. (1986). Biogenic and Diagenetic Sr/Ca in Plio- Pleistocene Fossils of the Omo Shungura Formation. *Paleobiology* 12: 311–323.

Sillen, A. (1989). Diagenesis of the Inorganic Phase of Cortical Bone, pp. 211–229 in T.D.Price (ed.) *The Chemistry of Prehistoric Human Bone.* Cambridge University Press, Cambridge.

Sillen, A. (1992). Strontium-Calcium Ratios (Sr/Ca) of *Australopithicus Robustus* and Associated Fauna From Swartkrans. *Journal of Human Evolution* 23: 495–516.

Simpson, S.W., Hutchinson, D.L. & Larsen, C.S. (1990). Coping with Stress: Tooth Size, Dental Defects and Age at Death, pp. 66–77 in C.S.Larsen (ed.) *The Archaeology of the Mission Santa Catalina de Guale: 2. Biocultural Interpretations of a Population in Transition.* Anthropological Papers of the American Museum of Natural History No. 68. American Museum of Natural History, New York.

Singh, I. (1959). Squatting Facets on the Talus and Tibia in Indians. *Journal of Anatomy* 93: 540–550.

Sjøvold, T. (1984). A Report on the Heritability of Some Cranial Measurements and Non-Metric Traits, pp. 223–246 in G.N. van Vark (ed.) *Multivariate Statistical Methods in Physical Anthropology.* Reidel, Groningen.

Sjøvold, T. (1987). Decorated Skulls from Hallstatt, Austria: The Development of a Research Project, pp. 5–21 in G.Burenhult, A.Carlsson, A.Hyenstrand & T.Sjøvold (eds) *Theoretical Approaches to Artifacts, Settlement and Society.* British Archaeological Reports, International Series, No. 366. British Archaeological Reports, Oxford.

Skinner, M. & Goodman, A.H. (1992). Anthropological Uses of

Developmental Defects of Enamel, pp. 153–174 in S.R.Saunders & A.M.Katzenberg (eds) *Skeletal Biology of Past Peoples: Research Methods*. Wiley-Liss, Chichester.

Smith, B.D. (1986). The Archaeology of the Southeastern United States from Dalton to De Soto. *Advances in World Archaeology* 5: 1–92.

Smith, B.D. (1989). Origins of Agriculture in Eastern North America. *Science* 246: 1566–1571.

Smith, B.H. (1991). Standards of Human Tooth Formation and Dental Age Assessment, pp. 143–168 in M.A.Kelley & C.S. Larsen (eds) *Advances in Dental Anthropology*. Wiley-Liss, Chichester.

Smith, B.N. & Epstein, S. (1971). Two Categories of $^{13}C/^{12}C$ Ratios for Higher Plants. *Plant Physiology* 47: 380–384.

Smith, I.F. (1965). *Windmill Hill and Avebury*. Clarendon, Oxford.

Smith, M.O. (1996). 'Parry' Fractures and Female-Directed Interpersonal Violence: Implications for the Late Archaic Period of West Tennessee. *International Journal of Osteoarchaeology* 6: 84–91.

Snow, C.E. (1948). Indian Knoll Skeletons of Site Oh 2, Ohio County, Kentucky. *University of Kentucky Reports in Anthropology* 4: 371–554.

Sparling, P.F. (1990). Natural History of Syphilis, pp. 213–219in K.K.Holmes, P.-A.Mardh, P.P.Sparling & P.J.Wiesner (eds) *Sexually Transmitted Diseases* (2nd edition). McGraw-Hill, London.

Spencer, H., Li, M., Samachson, J. & Laszlo, D. (1960). Metabolism of Strontium-85 and Calcium-45 in Man. *Metabolism* 9: 916–925.

Spiegelman, M. & Lemma, E. (1993). The Use of Polymerase Chain Reaction (PCR) to Detect *Mycobacterium tuberculosis* in Ancient Skeletons. *International Journal of Osteoarchaeology* 3: 137–143.

Spielman, R.S. & Smouse, P.E. (1976). Multivariate Classification of Human Populations I. Allocation of Yanomama Indians to Villages. *American Journal of Human Genetics* 28: 317–331.

Spielmann, K.A., Schoeninger, M.J. & Moore, K. (1990). Plains-Pueblo Interdependence and Human Diet at Pecos Pueblo, New Mexico. *American Antiquity* 55: 745–765.

Stafford, T.W., Hare, P.E., Currie, L., Jull, A.J.T. & Donahue, D.J. (1991). Accelerator Radiocarbon Dating at the Molecular Level. *Journal of Archaeological Science* 18: 35–72.

Steinbock, R.T. (1976). *Paleopathological Diagnosis and Interpretation*. Charles C.Thomas, Springfield.

Stermer Beyer-Olsen, E.M. & Risnes, S. (1994). Radiographic Analysis of Dental Development Used in Age Determination of Infant and Juvenile Skulls from a Mediaeval Archaeological Site in Norway. *International Journal of Osteoarchaeology* 4 299–303.

Stevenson, P.H. (1924). Age Order of Epiphyseal Union in Man. *American Journal of Physical Anthropology* 7: 53–93.

Stewart, T.D. (1954). Sex Determination in the Skeleton by Guess and by Measurement. *American Journal of Physical Anthropology* 12: 385–392.

Stiner, M.C., Kuhn, S.L., Weiner, S. & Bar-Yosuf, O. (1995). Differential Burning, Recrystallisation and Fragmentation of Archaeological Bone. *Journal of Archaeological Science* 22: 223–237.

Stirland, A. (1989). The Cremations from the Iron Age Cemetery, pp. 240–244 in I.M.Stead & V.Rigby (eds) *Verulamium, The King Harry Lane Site*. English Heritage, London.

Stirland, A. (1994). Evidence for Precolumbian Treponematosis in Mediaeval Europe, pp. 109–115 in O.Dutour, G.Palfi, J. Berato & J.-P.Brun (eds) *L'Origine de la Syphilis En Europe, Avant ou Apres 1493?*. Editions Errance, Centre Archeologiques du Var.

Stone, A.C., Milner, G.R., Pääbo, S. & Stoneking, M. (1996). Sex Determination of Ancient Human Skeletons Using DNA. *American Journal of Physical Anthropology* 99: 231–238.

Stoneking, M. (1995). Ancient DNA: How Do You Know When You Have It and What Can You Do With It? *American Journal of Human Genetics* 57: 1259–1262.

Stout, S.D. (1992). Methods of Determining Age at Death Using Bone Microstructure, pp. 21–35 in S.R.Saunders & M.A. Katzenberg (eds) *Skeletal Biology of Past Peoples: Research Methods*. Wiley-Liss, Chichester.

Ström, C. (1992). Injuries Due to Violent Crimes. *Medicine, Science and the Law* 32: 123–132.

Stuart-Macadam, P. (1985). Porotic Hyperostosis: Representative of a Childhood Condition. *American Journal of Physical Anthropology* 66: 391–398.

Stuart-Macadam, P. (1987). Porotic Hyperostosis: New Evidence to Support the Anemia Theory. *American Journal of Physical Anthropology* 74: 521–526.

Stuart-Macadam, P. (1989a). Nutritional Deficiency Diseases: A Survey of Scurvy, Rickets and Iron Deficiency Anemia, pp. 201–222 in M.Y.Iscan & K.A.R.Kennedy (eds) *Reconstruction of Life From the Skeleton*. Alan Liss, New York.

Stuart-Macadam, P. (1989b). Porotic Hyperostosis: Relationship Between Otbital and Vault Lesions. *American Journal of Physical Anthropology* 80: 187–193.

Stuart-Macadam, P. (1992). Porotic Hyperostosis: A New Perspective. *American Journal of Physical Anthropology* 87: 39–47.

Suchey, J.M., Wiseley, D.V. & Katz, D. (1988). *Instructions for the Suchey–Brooks System for Age Determination of the Female Os Pubis*. Instructional Materials Accompanying Female Pubic Symphyseal Models of the Suchey-Brooks System. Distributed by France Casting (Diane France 2190 West Drake Road, Suite 259, Fort Collins CO 80526).

Suckling, G., Elliott, D.C. & Thurley, D.C. (1986). The Macroscopic Appearance and Associated Histological Changes in the Enamel Organ of Hypoplastic Lesions of Sheep Incisor Teeth Resulting from Induced Parasitism. *Archives of Oral Biology* 31: 427–439.

Suzuki, H. (1969). Microevolutional Changes in the Japanese Population from the Prehistoric Age to the Present Day. *Journal of the Faculty of Science, University of Tokyo, Section 5 (Anthropology)* 3: 279–309.

Suzuki, M. & Sakai, T. (1960). Familial Study of Torus Palatinus and Torus Mandibularis. *American Journal of Physical Anthropology* 18: 263–272.

Swärdstedt, T. (1966). *Odontological Aspects of a Mediaeval Population in the Province of Jamtland/Mid Sweden*. Tiden-Barnangen, Stockholm.

Swartz, M.N. (1990). Neurosyphilis, pp. 231–246 in K.K. Holmes, P.-A.Mardh, P.P.Sparling & P.J.Wiesner (eds) *Sexually Transmitted Diseases* (2nd edition). McGraw-Hill, London.

Sweeney, E.A., Cabera, J., Urrutia, J. & Mata, L. (1969). Factors Associated with Linear Hypoplasia of Human Deciduous Incisors. *Journal of Dental Research* 48: 1275–1279.

Sweeney, E.A., Saffir, A.J. & de Leon, R. (1971). Linear Hypoplasia of Deciduous Incisor Teeth in Malnourished Children. *American Journal of Clinical Nutrition* 24: 29–31.

Tague, R.G. (1995). Variation in Pelvic Size Between Males and Females in Nonhuman Anthropoids. *American Journal of Physical Anthropology* 97: 213–233.

Tan, F.C. (1989). Stable Carbon Isotopes in Dissolved Inorganic Carbon in Marine and Estuarine Environments, pp. 171–217 in P.Fritz & J.C.Fontes (eds) *Handbook of Environmental Isotope Geochemistry. Volume 3: The Marine Environment*. Elsevier, Oxford.

Tanner, J.M. (1981). *A History of the Study of Human Growth*. Cambridge University Press, Cambridge.

Tanner, J.M. (1989). *Foetus into Man* (2nd edition). Castlemead, Ware.

Tanner, J.M., Whitehouse, R.H. & Takaishi, M. (1966). Standards from Birth to Maturity for Height, Weight, Height Velocity and Weight Velocity; British Children 1965. *Archives of Disease in Childhood* 41: 454–471; 613–635.

Tattersall, I. (1968). Multivariate Analysis of Some Mediaeval British Cranial Series. *Man* 3: 284–292.

Tauber, H. (1981). $^{13}$C Evidence for Dietary Habits of Prehistoric Man in Denmark. *Nature* 292: 332–333.

Tauber, H. (1986). Analysis of Stable Isotopes in Prehistoric Populations, pp. 31–38 in B. Herrmann (ed.) *Innovative Trends in Prehistoric Anthropology*. Mitteilungen der Beliner Gesellschaft Für Anthropologie, Ethnologie und Urgeschichte, Band 7.

Thomas, J. (1987). Relations of Production and Social Change in the Neolithic of North-west Europe. *Man* 22: 405–430.

Thomas, J. (1988). The Social Significance of Cotswold-Severn Burial Practices. *Man* 23: 540–559.

Thomas, J. and Whittle, A. (1986). Anatomy of a Tomb—West Kennet Revisited. *Oxford Journal of Archaeology* 5: 129–156.

Thordemann, B. (1939) *Armour from the Battle of Wisby, 1361*. Vitterhets Historie och Antikvitets Akademien, Stockholm.

Thorpe, I.J. (1984). Ritual, Power and Ideology: A Reconstruction of Earlier Neolithic Rituals in Wessex, pp. 41–60 in R. Bradley and J.Gardiner (eds) *Neolithic Studies: A Review of Some Current Research*. British Archaeological Reports, British Series, No. 133. British Archaeological Reports, Oxford.

Thorpe, I.J. & Richards, C. (1984). The Decline of Ritual Authority and the Introduction of Beakers into Britain, pp. 67–84 in R.Bradley and J.Gardiner (eds) *Neolithic Studies: A Review of Some Current Research*. British Archaeological Reports, British Series, No. 133. British Archaeological Reports, Oxford.

Thorson, J. & Hägg, U. (1991). The Accuracy and Precision of the Third Mandibular Molar as an Indicator of Chronological Age. *Swedish Dental Journal* 15: 15–22.

Thurnam, J.T. (1863). On the Principal Forms of Ancient British and Gaulish Skulls. *Memoirs of the Anthropological Society of London* 1: 120–168.

Tieszen, L.L. (1991). Natural Variation in the Carbon Isotope Values of Plants: Implications for Archaeology, Ecology and Palaeoecology. *Journal of Archaeological Science* 18: 227–248.

Tieszen, L.L., Boutton, T.W., Tesdahl, K.G. & Slade, N.A. (1983). Fractionation and Turnover of Stable Carbon Isotopes in Animal Tissues: Implications for Delta $^{13}$C Analysis of Diet. *Oecologia* 57: 32–37.

Tinsley, H.M. (1981). The Bronze Age, pp. 210–249 in I.G. Simmonds & M.J.Tooley (eds) *The Environment in British Prehistory*. Duckworth, London.

Todd, T.W. (1920). Age Changes in the Pubic Bone. I. The Male White Pubis. *American Journal of Physical Anthropology* 3: 285–339.

Tomenchuk, J. and Mayhall, J.T. (1979). A Correlation of Tooth Wear and Age Among Modern Iglooik Eskimos. *American Journal of Physical Anthropology* 51: 67–78.

Tonge, C.H. & McCance, R.A. (1965). Severe Undernutrition in Growing and Adult Animals. 15. The Mouth, Jaws and Teeth of Pigs. *British Journal of Nutrition* 19: 361–372.

Torgersen, J.H. (1951a). The Developmental Genetics and Evolutionary Meaning of the Metopic Suture. *American Journal of Physical Anthropology* 9: 193–205.

Torgersen, J.H. (1951b). Hereditary Factors in the Sutural Patterns of the Skull. *Acta Radiologica* 36: 374–382.

Torgersen, J.H. (1954). The Occiput, the Posterior Cranial Fossa and the Cerebellum, pp. 396–418 in J.Jansen & A.Brodal (eds) *Aspects of Cerebellar Anatomy*. Gundersen, Oslo.

Trinkaus, E. (1975). Squatting Among the Neanderthals: A Problem in the Behavioral Interpretation of Skeletal Morphology. *Journal of Archaeological Science* 2: 327–351.

Trotter, M. & Gleser, G.C. (1952). Estimation of Stature from Long-Bones of American Whites and Negroes. *American Journal of Physical Anthropology* 10: 463–514.

Trotter, M. & Gleser, G.C. (1958). A Re-evaluation of Estimation of Stature Based on Measurements of Stature Taken During Life and Long-Bones After Death. *American Journal of Physical Anthropology* 16: 79–123.

Trotter, M. & Hixon, B.B. (1974). Sequential Changes in Weight, Density and Percentage Ash Weight of Human Skeletons from an Early Foetal Period Through to Old Age. *Anatomical Record* 179: 1–18.

Tsude, H. (1995). Archaeological Theory in Japan, pp. 298–311 in P.J.Ucko (ed.) *Theory in Archaeology, A World Perspective*. Routledge, London.

Turner, C.G. (1979). Dental Anthropological Indications of Agriculture Among the Jomon People of Central Japan. *American Journal of Physical Anthropology* 51: 619–636.

Turner, C.G., Nichol, C.R. & Scott, G.R. (1991). Scoring Procedures for Key Morphological Traits of the Permanent Dentition, pp. 13–31 in M.A.Kelley & C.S.Larsen (eds) *Advances in Dental Anthropology*. Wiley-Liss, Chichester.

Ucko, P.J. (1969). Ethnography and Archaeological Interpretation of Funerary Remains. *World Archaeology* 1: 262–280.

Uesugi, Y., Taguchi, O., Noumura, T. & Iguchi, T. (1992). Effects of Sex Steroids on the Development of Sexual Dimorphism in Mouse Innominate Bone. *The Anatomical Record* 234: 541–548.

Ullrich, H. (1972). *Das Aunjetitzer Graberfeld von Grossbrembach. Erster Teil: Anthropologische Untersuchungen zur Frage nach Entstehung und Verwandtschaft der thuringischen, bomischen und mahrischen Aunjetitzer.* Hermann Bolaus, Weimar.

Vecchi, F., Coppa, A. & Priori, R. (1987). Morphological Distance Between Four Ethnic Groups in Southern Mexico. *Rivista di Antropologia (Roma)* 65: 223–234.

Virtama, P. & Helela, T. (1969). Radiographic Measurements of Cortical Bone. Variations in a Normal Population Between 1 and 90 Years of Age. *Acta Radiologica* Supplementum 293.

Vogel, J.C. (1978). Recycling of Carbon in a Forest Environment. *Oecologia Plantarum* 13: 89–94.

Von Endt, D.W. & Ortner, D.J. (1982). Amino Acid Analysis of Bone from a Possible Case of Iron Deficiency Anaemia from the American Southwest. *American Journal of Physical Anthropology* 59: 377–385.

Von Endt, D.W. & Ortner, D.J. (1984). Experimental Effects of Bone Size and Temperature on Bone Diagenesis. *Journal of Archaeological Science* 11: 247–253.

Wahl, J. (1982). Leichenbranduntersuchungen: Ein Uberblick über die Bearbeitungs- und Aussagemoglichkeiten von Brandgräbern. Praehistorische Zeitschrift 57: 1–125.

Wahl, J. & Kokabi, M. (1988). Tierknochen, pp. 225–284 in J. Wahl & M.Kokabi (eds) *Das römische Gräberfeld von Stettfeld I.* Konrad Theiss, Stuttgart.

Walker, P.L. & Hewlett, B.S. (1990). Dental Health, Diet and Social Status Among Central African Foragers and Farmers. *American Anthropologist* 92: 383–398.

Watson, A.A. (1989). *Forensic Medicine. A Handbook for Professionals.* Gower, Aldershot.

Watson, J.P. (1967). A Termite Mound in an Iron Age Burial Ground in Rhodesia. *Journal of Ecology* 55: 663–669.

Webb, P.A.O. & Suchey, J.M. (1985). Epiphyseal Union of the Anterior Iliac Crest and Medial Clavicle in a Modern Multiracial Sample of American Males and Females. *American Journal of Physical Anthropology* 68: 457–466.

Weiss, K.M. (1973). *Demographic Models for Anthropology.* Memoirs of the Society for American Archaeology No. 27.

Weiss, L. (1988) *Cell and Tissue Biology* (6th edition). Urban & Schwartzenberg, Baltimore.

Wells, C. (1960). A Study of Cremation. *Antiquity* 34: 29–37.

Wells, C. (1967). Pseudopathology, pp. 5–19 in D.R.Brothwell & A.T.Sandison (eds) *Diseases in Antiquity.* Charles C.Thomas, Springfield.

Wells, C. (1993). Human Remains, pp. 100–107 in A.Davison, B.Green & W.Milligan (eds) *Illington: A Study of a Breckland Parish and its Anglo-Saxon Cemetery.* East Anglian Archaeology Report No. 63.

Wells, C. & Dallas, C. (1976). Romano-British Pathology. *Antiquity* 50: 53–55.

Wells, L.H. (1962). Report on the Inhumation Burials from the West Kennet Barrow, in S.Piggott, *The West Kennet Long Barrow Excavations 1955–56.* HMSO, London.

Wenham, S. (1989). Anatomical Interpretations of Anglo-Saxon Weapon Injuries, pp. 123–139 in S.C.Hawkes (ed.) *Weapons and Warfare in Anglo-Saxon England.* Oxford University Committee for Archaeology Monograph 21, Oxford.

Wenham, S. & Wakely, J. (1988). *Microscopic Features of Blade Injuries to Bone Surfaces in Six Anglo-Saxon Burials From Eccles, Kent.* Poster presented at the Burial Archaeology Conference, Bradford, May.

White, T.D. (1990). *Human Osteology.* Academic Press, London.

Whittle, A., Brothwell, D., Cullen, R., Gardner, N. & Kerney, M.P. (1991). Wayland's Smithy, Oxfordshire: Excavations at the Neolithic Tomb in 1962–63 by R.J.C.Atkinson and S. Piggott. *Proceedings of the Prehistoric Society* 57: 61–101.

Willcox, R.R. (1972). The Treponemal Evolution. *Transactions of the St Johns Dermatological Society* 58; 21–37.

Willey, P. & Hofman, J.L. (1994). Interproximal Grooves, Toothaches, and Purple Coneflowers, pp. 147–157 in D.W.Owsley & R.L.Jantz (eds) *Skeletal Biology in the Great Plains.* Smithsonian Institution Press, Washington.

Willey, P. & Scott, D.D. (1996). 'The Bullets Buzzed Like Bees': Gunshot Wounds in Skeletons From the Battle of Little Bighorn. *International Journal of Osteoarchaeology* 6: 15–27.

Wilson, J.D., George, F.W. & Griffin, J.E. (1981). The Hormonal Control of Sexual Development. *Science* 211: 1278–1284.

Wolpoff, M.H. (1968). Climatic Influence on the Skeletal Nasal Aperture. *American Journal of Physical Anthropology* 29: 405–424.

Workshop of European Anthropologists (1980). Recommendations for Age and Sex Diagnoses of Skeletons. *Journal of Human Evolution* 9: 517–549.

Zikmundova, E. (1961). Tierreste aus Lausitzer Brandgrabern im gebeit nordwestbomens. *Monumenta Archaeologica* 8: 291–293.

Zimmerman, M.R. & Kelley, M.A. (1982). *Atlas of Human Paleopathology.* Praeger, New York.

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